The Response Of Nuthatches (*Sitta* Spp.) To Restorative Treatments In Ponderosa Pine Ecosystems Of Northeastern Oregon

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Abstract

*Ponderosa pine (*Pinus ponderosa*) forests in western North America are in need of restoration due to the impacts of fire suppression. The effects of different restorative treatments on avian species should be determined before these treatments are widely applied. Of the common resident passerines in ponderosa pine forests, three species are nuthatches (*Sitta*). These nuthatches have similar ecological niches to each other but different life history traits. The objectives of this research were to determine differences among treatments in: abundance and foraging behavior of Pygmy (*Sitta pygmaea*), White-breasted (*S. carolinensis*), and Red-breasted (*S. canadensis*) Nuthatches, and daily nest success of Pygmy and Red-breasted Nuthatches. Structural characteristics of trees used for foraging and nesting were also documented. Thinning (‘thin’), prescribed burning (‘burn’), thinning followed by burning (‘thin and burn’) and ‘control’ areas were used. Pygmy Nuthatches were observed more often in ‘thin and burn’ areas than in ‘thin’ or ‘burn’ areas. White-breasted Nuthatches were encountered more often in ‘thin and burn’ units than ‘control’ units. The abundance of each species of nuthatch in treatment areas did not seem to be dictated by tree structural characteristics alone. Red-breasted Nuthatches spent more time foraging on trees in ‘thin and burn’ areas than in ‘thin’ or ‘control’ areas, but this difference was not due to tree structure. Red-breasted Nuthatches foraged upon Douglas-fir (*Pseudotsuga menziesii*) more than it was randomly available, and used trees for foraging that were larger and had less live crown than trees not used. White-breasted Nuthatches foraged on trees that were larger and had less live crown than average. Pygmy Nuthatches were more likely to forage on trees that were large in diameter. Models using structure and microhabitat of nest trees performed poorly at predicting the success of nests of Pygmy and Red-breasted Nuthatches. The number of nests of Red-breasted Nuthatches was different among treatments, with fewer nests within ‘thin and burn’ treatments than expected. The* *number of snags available for nesting was also different among treatment types, with 'burn' units having more and 'thin and burn' units having fewer snags than expected. More snags surrounded nest trees of Red-breasted Nuthatches, and snags used for nests had less canopy cover than snags not used. Snags used for nesting by Pygmy Nuthatches were larger in diameter than snags that were not used. The restorative treatment that combined thinning and burning appeared to improve habitat suitability for both White-breasted and Pygmy Nuthatches, while Red-breasted Nuthatches appear to be resilient to treatment type.*

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Kerry Farris gave me my first wildlife job, trapping small mammals in Sequoia National Park. Next, she gave me my first bird job, at the Hungry Bob study site in Oregon. Then, she encouraged me to apply to UNBC in pursuit of a master's degree, and helped me write my entrance proposal. After all that, she has become a good friend. She continues to be a constant source of encouragement and inspiration. Thanks for everything, Kerry. And I hope to see you in Bend real soon!

While working with small mammals in Sequoia National Park, I became more and more fascinated with the birds that I heard all around me. They were made more mysterious by the fact that you could rarely see them in the tall trees, except as silhouettes against the sky. Adam Patterson took me out into the forest one day, after unrelenting requests, and began to teach me the art of identifying birds by their songs and calls. The first bird I learned from him was the Red-breasted Nuthatch. My hunger for knowledge of all things birdy has been insatiable since then, but the Red-breasted Nuthatch still embodies that original sense of fascination and discovery from Sequoia National Park.

To the people that had to learn to deal with my obsession for small bark-gleaning birds day after day in the field: Regina Wasson, Colin Talbert, Evan Rehm, Tami Brunk, Rob Spaul, and Brian Bielfelt, thanks. Also, to Jennifer Kapp, who helped me gather my data and perhaps even developed a nuthatch fixation herself, if just for the summer, thanks for all of your hard work, accurate data, and all the fun we had with our 'nuthatch humor'. You really got me through the frustrations that we shared in an 'off' year for nuthatches at Hungry Bob, mostly with humor, as we entertained ideas about the new species of ground-nesting nuthatch we must have discovered in the summer of 2004.

Thanks to my parents. Throughout my life, they both encouraged me to do whatever I thought would make me happy. Even when that involved horse training, and especially when I decided to give up equine for avian. I hope you know that this path has truly made me the happiest I've ever been.

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1. General Introduction

1.1. The Recent History of Ponderosa Pine Forests within Western North America

Ponderosa pine (*Pinus ponderosa*) occurs within the western portion of the United States and Canada (Fig. 1.1). Historically, frequent fires maintained stands of large, widely spaced trees on dry, mid-elevation slopes. Since European settlement of western North America, and especially since 1910, fires were excluded from most of these forests. Forests affected by fire exclusion were more dense and uniform in their stem dispersion (Mast et al. 1999) with fewer large old trees and more small young trees (Swetnam 1990, Mast et al. 1999). Currently, ponderosa pine forests have higher mortality of old-growth trees, more stems of shade-tolerant species such as Douglas-fir (*Pseudotsuga menziesii*) and true firs (*Abies* spp.), less diversity within the understory, and more fire-fuels than their pre-settlement counterparts (Swezy and Agee 1991, Covington and Moore 1992, Mutch et al. 1993, Agee and Maruoka 1994, Harrod et al. 1998). These changes in forest composition and structure shifted the fire regime from frequent understory fires to infrequent, crowning wildfires to which ponderosa pine and the organisms associated with them have not adapted (Agee 1996).

Between 1991 and 2001, approximately 200,000 ha of habitat historically dominated by ponderosa pine within the Malheur, Umatilla, and Wallowa-Whitman National Forests of Oregon and Washington was destroyed by wildfire (J. McIver, Forest Ecologist, USGS, Pers. comm., 2003). There are an estimated 1.2 million ha of ponderosa pine forest in the Blue Mountains of Oregon and Washington that need restoration treatment (Caraher et al. 1992). Within the western portion of the United States, an additional 28 million ha of forest is in need of restoration (Schmidt et al. 2002, Brown et al. 2004).

Figure 1.1: Distribution of Ponderosa Pine within North America. Dark grey areas represent forests containing ponderosa pine. Reproduced for use within this thesis with permission from the United States Geological Survey.

Mechanical thinning and prescribed burning are the most common methods of restoring fire-suppressed forests to their historic conditions (Agee and Maruoka 1994, Hayes et al. 1997, Ottmar and Sandberg 2001). These treatments have both been responsible for decreasing fire intensity after they were applied to ponderosa pine forests (Pearson et al. 1972, Pollet and Omi 2002). Restoration methods will vary according to the extent of deviation from reference (historic) conditions, and other factors such as economic interests and climate change (Moore et al. 1999). As early as the 1930s, research suggested that the exclusion of fire from forests was detrimental to avian species (Stoddard 1931). However, the effects of various restorative treatments within ponderosa pine forests on biological aspects of ecosystem function, such as avian foraging and nesting dynamics, are poorly understood.

1.2. Nuthatches and Other Primary Cavity-excavating Birds are Important to Maintain within Ponderosa Pine Ecosystems

Three species of nuthatch (*Sittidae*) are present within the Blue Mountains of Oregon: White-breasted (*Sitta carolinensis*), Red-breasted (*S. canadensis*), and Pygmy Nuthatch (*S. pygmaea*). Each has a different association with ponderosa pine, and each has slightly different foraging and nesting requirements. The Pygmy Nuthatch occurs only in western North America, and roughly only where mature ponderosa pine and Jeffrey pine (*Pinus jeffreyi*) forests occur (Fig. 1.2; Diem and Zeveloff 1980, Szaro and Balda 1982, Balda et al. 1983, Bock and Fleck 1995, Csuti et al. 1997, Gardali et al. 1999, Kingery and Ghalambor 2001). Though more restricted in their habitat than other western North American nuthatches, Pygmy Nuthatches are the most diverse in their placement of nests (McEllin 1979). They excavate their nests or use natural cavities more often than they use nest-sites that were excavated by other species (McEllin 1979, Brawn 1987).

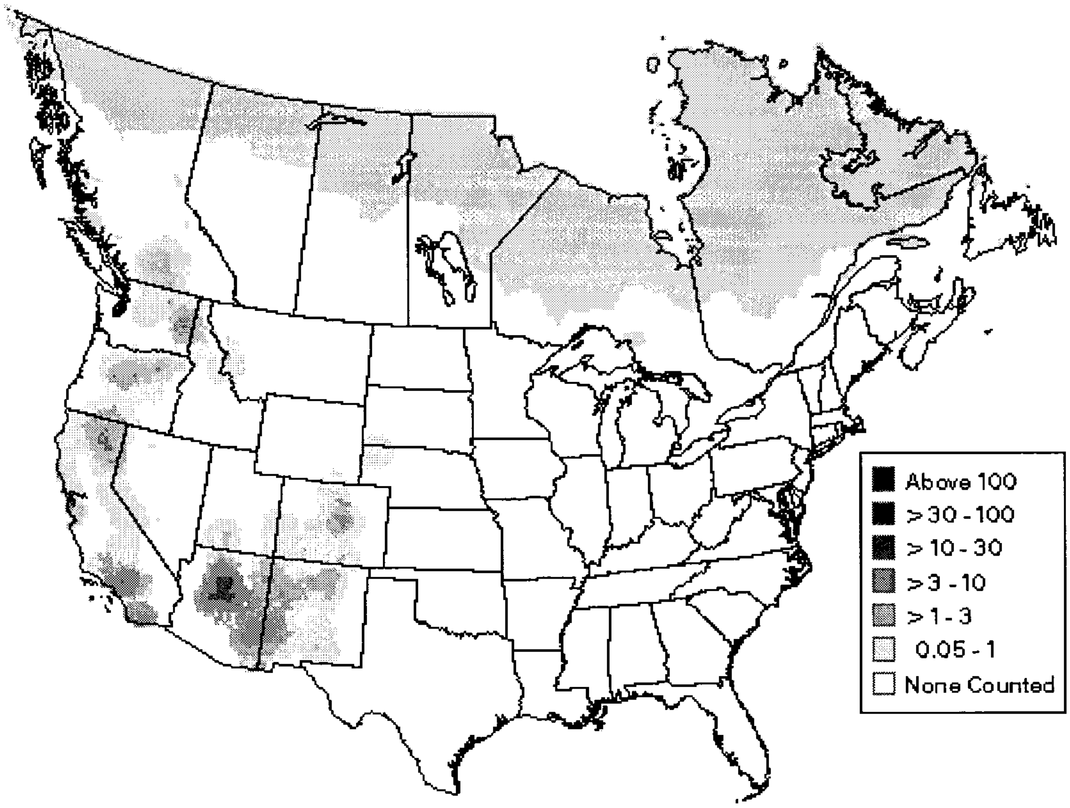

Figure 1.2: Average number of Pygmy Nuthatches counted per survey route between 1994 and 2003 within North America. From the Breeding Bird Survey, Sauer et al. 2005. The uniform grey area to the north was not surveyed.

The Pygmy nuthatch is considered an excellent indicator of the health of the avian community within ponderosa pine ecosystems because of its reliance on mature, heterogeneous stands (Diem and Zeveloff 1980, Szaro and Balda 1982). Pygmy Nuthatches may have developed fire-dependent foraging or nesting strategies owing to their near exclusive residence within ponderosa pine ecosystems (Kingery and Ghalambor 2001). There is a general belief that the Breeding Bird Survey (BBS) fails to effectively quantify Pygmy Nuthatch populations (Sauer et al. 1999, Altman and Bart 2001). The BBS is a major tool used to detect trends of decline in many bird species. For this reason, the Pygmy Nuthatch is listed as a sensitive species in the Blue Mountains of Oregon based on the decrease of mature ponderosa pine forest in those areas (USDA Forest Service 1996; Oregon Department of Fish and Wildlife 1997, US Fish and Wildlife Service 2002). It also appears on conservation watch lists in Colorado (Webb 1985), Idaho (Idaho BLM 2003), Montana (Clark et al. 1989), and Wyoming (Clark et al. 1989, Luce et al. 1997). Wisdom et al. (2000) recommend restoring the dominance of ponderosa pine where it has been taken over by Douglas-fir and true firs, in order to protect populations of Pygmy Nuthatch from further habitat loss.

White-breasted Nuthatches are also closely associated with ponderosa pine. However, they breed in good abundance within oak-dominated (*Quercus* spp.) stands as well as mixed-conifer stands where either pine or oak are available (Fig. 1.3; Bent 1964, Garrett and Dunn 1981, Root 1988, Matthysen 1998). White-breasted Nuthatches have been known to nest more often in natural cavities than excavated cavities in ponderosa pine (Brawn and Balda 1988a, McEllin 1979), and have only rarely been known to excavate their own nests (Bent 1964). Red-breasted and White-breasted Nuthatch populations appear to be increasing within the western United States and Canada. Most of this increase is due to both

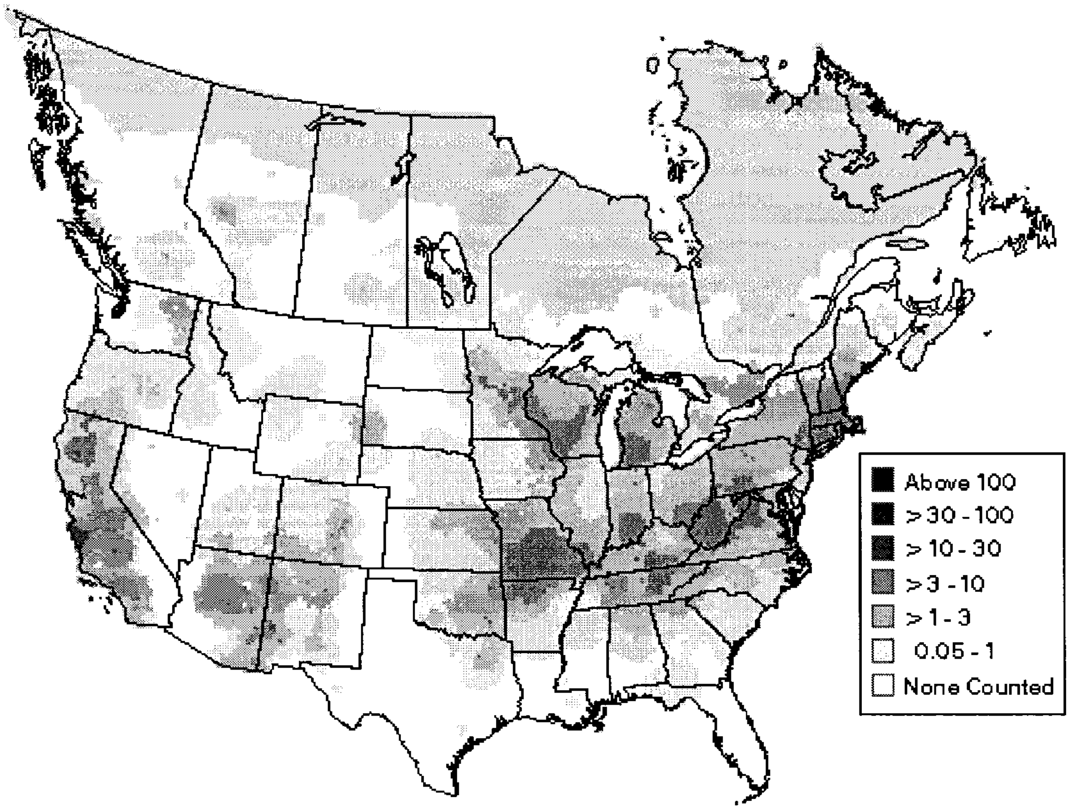

Figure 1.3: Average number of White-breasted Nuthatches counted per survey route between 1994 and 2003 within North America. From the Breeding Bird Survey, Sauer et al. 2005. The uniform grey area to the north was not surveyed.

species extending their ranges northward (DeSante and George 1994, Root and Weckstein 1994). This general increase in population size has masked the general trend of both species to decline within specific ecosystems, such as Douglas-fir in the northwest and ponderosa pine in the southwest (Hejl 1994), particularly in California, Colorado, and Oregon (Ghalambor and Martin 1999).

Red-breasted Nuthatches are habitat generalists. They are present in most forests within western North America (Fig. 1.4), including populated areas (Rohila and Marzluff 2002) and forest patches (McIntyre 1995). They tend to prefer mixed forests with a fir, Douglas-fir, or spruce (*Picea* spp.) component (Ghalambor and Martin 1999, Hobson and Bayne 2000). Red-breasted Nuthatches will most often excavate their own cavity; however, they will also nest in boxes, woodpecker cavities, and natural cavities (Ghalambor and Martin 1999, Aitken et al. 2002). Red-breasted Nuthatches tend to be more common within old-growth stands than either mature or young forest (Mannan et al. 1980, Carey et al. 1991, Hannon 2000).

The number of species dependent upon tree cavities best illustrates the value of cavities. Of all usurped nests reported in the literature, almost 91% were either cavity or enclosed nests (review in Lindell 1996). Cavity-excavating birds such as nuthatches provide nesting and roosting habitat for over 60 other bird and mammal species in the Pacific Northwest region of the United States (Thomas et al. 1979, Brown 1985). Over 25% of forest-dwelling mammals in the Pacific Northwest use cavities for nesting or resting (Bunnell et al. 1999). Each excavating species tends to create cavities with different qualities (i.e. depth, entrance width, volume, height on bole, distance to forest edge, decay type and extent). Therefore, the diversity of cavity-excavators can influence the diversity of

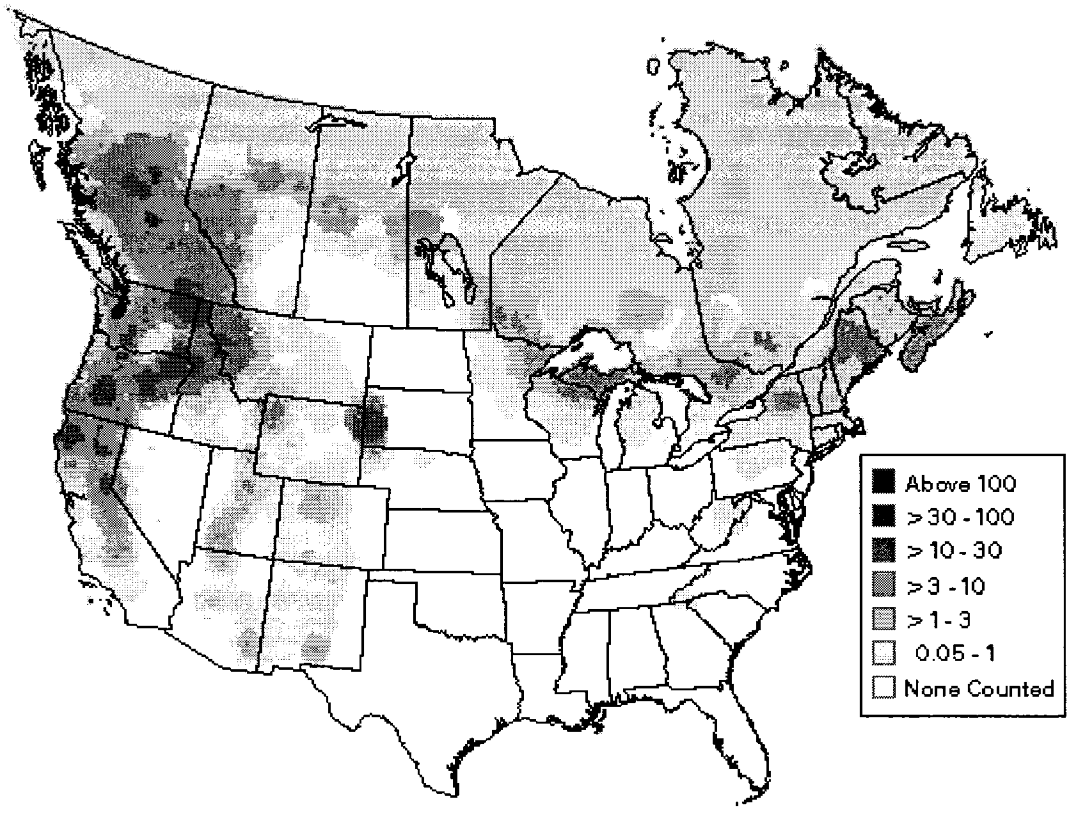

Figure 1.4: Average number of Red-breasted Nuthatches counted per survey route between 1994 and 2003 within North America. From the Breeding Bird Survey, Sauer et al. 2005. The uniform grey area to the north was not surveyed.

secondary cavity-nesters in an ecosystem (Brawn and Balda 1988a). Nuthatches, especially the Red-breasted Nuthatch, might be underestimated as cavity-creators. Within the boreal forests of British Columbia, cavities created by Red-breasted Nuthatches were used more often than those of any other excavating bird except Three-toed Woodpeckers (*Picoides tridactylus*, Aitken et al. 2002). Nuthatches have the potential to be more abundant in dry ponderosa pine forest types because they occupy much smaller territories than woodpeckers. However, nuthatches are weaker cavity-excavators and require more decay in their nesting substrate in comparison to woodpeckers, and may also prefer different microhabitat structural characteristics for nesting and foraging (Steeger and Hitchcock 1998).

A diversity of insectivorous bird species help to reduce insect populations (Bruns 1960, Holmes 1990, Torgersen et al. 1990, Machmer and Steeger 1995, Steeger and Hitchcock 1998, Murakami and Nakano 2000), and lessen the impact of insect epidemics (Korol 1985, Otvos 1979). Red-breasted and Pygmy Nuthatches reduce populations of adult western (*Dendroctonus brevicomis*) and mountain (*D. ponderosae*) pine beetles by up to 26% during outbreaks (Stallcup 1963, Otvos 1979). Red-breasted Nuthatches are also important predators of Douglas-fir tussock moth (*Orgyia pseudotsugata*), as well as jack pine budworm (*Choristoneura pinus*) and eastern spruce budworm (*C. fumiferana*; Mattson et al. 1968, Crawford et al. 1983). Leaf bugs (*Pseudococcid* spp.) are preyed upon by Pygmy Nuthatches (Bent 1964, Stallcup 1963, Anderson 1976, Otvos and Stark 1985, and Campbell et al. 1988). White-breasted nuthatches prey upon gypsy moths (*Lymantria dispar*) and tent caterpillars (*Malacosoma* spp.). All three western nuthatches also prey upon weevils (*Sitophilus* spp.), spruce budworm *(Choristoneura spp.)*, wood-boring beetles (*Cerambycidae* spp. and *Buprestidae* spp.; Bent 1964, Stallcup 1963, Anderson 1976, and Campbell et al. 1988), and larch casebearer (*Coleophora laricella*; Sloan and Coppel 1968). Nuthatches prey upon insects that are more likely to be missed by other bark foragers; they are the only species that forage while traveling down the trunk of the tree. Nuthatches forage upon trees that are heavily used by woodpeckers, looking opportunistically for any larval bark beetle or other insects that have been exposed by foraging woodpeckers (Kroll and Fleet 1979, Otvos 1979).

Although all three species of nuthatches found within western North America have similar foraging techniques and selection of food items (Anderson 1976), they differ enough in the placement of foraging effort on trees that they can all co-exist in the same forest (Stallcup 1968). Red-breasted Nuthatches distribute their foraging effort evenly upon trees (Stallcup 1968, Airola and Barrett 1985, Carey et al. 1991). Pygmy Nuthatches spend a large proportion of their time foraging on the distal ends of branches among the buds and terminal foliage at the tops of trees (Stallcup 1968, Bock 1969, Szaro and Balda 1979, Airola and Barrett 1985, Stone et al. 1999). White-breasted Nuthatches forage most often on the bole and proximal portions of branches in the middle and lower portions of trees (Stallcup 1968, Bock 1969, Szaro and Balda 1979).

Trunk-foraging species such as nuthatches may play an important role in snag cycling within ponderosa pine ecosystems (Farris et al. 2004). There was a positive correlation between the amount of foraging by woodpeckers and the amount of decay in snags of ponderosa pine within central Oregon (Farris et al. 2004). One reason for this is that woodpeckers may pass decay fungi from tree to tree with their bills (Farris et al. 2004). Of birds that had their beaks sampled for presence of wood-decaying fungi, all cavity-nesting species tested positive. Hairy (*Picoides villosus*), White-headed (*P. albolarvatus*), and Black-backed (*P. arcticus*) Woodpeckers had detection frequencies ranging from 0.50 to

0.57. Red-breasted Nuthatches had a detection frequency of 0.80 (Farris et al. 2004). Although this has not been investigated, nuthatches may also serve as vectors for transmission of these fungi.

In addition to supplying tree cavities and decreasing population sizes of forest insect pests, nuthatches may provide important cues for migrant birds returning from wintering grounds, according to the heterospecific attraction hypothesis (Monkkonen et al. 1997). When resident birds were experimentally eliminated from islands in northeastern Minnesota, some migrant populations were less abundant. Also, some migrant birds were more abundant on islands where resident bird populations had been increased, when compared to islands where resident bird populations had not been manipulated (Monkkonen et al. 1997).

1.3. Previous Research on the Effects of Restoration Treatments on Cavity-nesting Birds

1.3.1. Silvicultural Thinning

The effects of forest thinning on cavity-excavating birds are most dramatic when the treatment reduces the number of snags available for excavation. If nest-site availability is a limiting factor within a forest, a reduction in snag numbers may cause a decreased density of cavity-nesters the following season, regardless of other effects of the treatment (Chambers et al. 1999). White-breasted Nuthatches may be more resilient than other cavity nesters to a decrease in snag density because of their tendency to use natural cavities (McPeek et al. 1987, Brawn and Balda 1988b, Waters et al. 1990, Pravosudov and Grubb 1993, Bock and Fleck 1995). However, thinning stands increases the vigor of remaining trees, reducing decay in live stems and so reducing the creation of some types of natural cavities (Filip et al. 1995). As a result of these effects, birds may use nest trees with less desirable microhabitat characteristics, because they will have few choices for nest-sites within their territories

(Tobalske 1992). An alteration of nest-site microhabitat can affect the nest microclimate, predation rates, and nestling provisioning (Easton and Martin 2002). One simple way to counteract this management effect is to add nest boxes to treated areas. The addition of nest boxes in ponderosa pine forests of Colorado and northern Arizona increased densities of Pygmy, Red-breasted, and White-breasted Nuthatches (Brawn 1987, Bock and Fleck 1995).

The effects of thinning on foraging behavior of bark-gleaning birds are difficult to quantify. Birds can vary their foraging behavior and prey selection among years (Szaro et al. 1990), months (Hejl and Verner 1990), stages of the breeding cycle (Sakai and Noon 1990, Kelly and Wood 1996, Dobbs and Martin 1998), and even with time of day (Kleintjes and Dahlsten 1995, Kelly and Wood 1996). There can also be a difference in the foraging behavior based on sex (Grubb and Woodrey 1990, Hanowski and Niemi 1990, Kleintjes and Dahlsten 1995, Sodhi and Paszkowski 1995, Kelly and Wood 1996), age, and dominance status (Grubb and Woodrey 1990) of birds.

Avian population monitoring is often used as a tool to infer the quality of foraging habitat. However, studies have shown that all foraging and nesting guilds can have mixed responses to forest management (Saab and Powell 2005). Bark-foraging birds were detected more frequently within thinned than unthinned forests of Washington (Artman 2002) and the Oregon Coast Range (Hagar et al. 1996). Cavity-nesting birds were detected more frequently in thinned units than ‘control’ units in the Sierra Nevada range of California (Siegel and DeSante 2003). In Brazil, Aleixo (1999) reported that bark gleaners preferred to forage within intact forest rather than selectively logged forest. Pygmy Nuthatches were less abundant in partially logged than unlogged forests of ponderosa pine (Hejl 1994). Red-breasted Nuthatches, along with all other cavity-nesters studied, declined in thinned areas on

Vancouver Island, British Columbia (Beese and Bryant 1999). Red-breasted Nuthatches showed no preference between 'control' units and units with various degrees of silvicultural thinning in Douglas-fir forests of Oregon (Hagar 1999) or ponderosa pine forests in northeastern Wyoming (Anderson and Crompton 2002). Although the response of birds appears mixed, the responses tended to be stronger with increasing severity of thinning disturbance in the studies that tested for this effect (Beese and Bryant 1999, Chambers et al. 1999).

There is often a correlation between population density of nuthatches and vegetation characteristics that may be affected by thinning. The density of White-breasted Nuthatches was negatively correlated with foliage volume in eastern hemlock (*Tsuga canadensis*; Tingley et al. 2002) and oak/hickory (*Carya* spp.) forests (Showalter and Whitmore 2002). White-breasted Nuthatches tend to prefer nest sites with a greater percentage of canopy closure than found on average (Beier et al.2000). Canopy cover affected the abundance of Red-breasted Nuthatches within Idaho, with a greater abundance of birds within stands with greater canopy closure (Medin 1985). Alternatively, Pygmy Nuthatches were found only in forests with less than 70% canopy closure (Balda et al. 1983, Csuti et al. 1997, Kingery and Ghalambor 2001). Brown-headed Nuthatches (*Sitta pusilla*, a morphologically similar species to Pygmy Nuthatch) were negatively affected by increasing canopy cover in forests composed of Loblolly pine (*Pinus taeda*) in Florida (Lohr et al. 2002).

Source and sink dynamics, especially in the case of an attractive sink, make it difficult to conclude that there is no difference in habitat quality between two sites that exhibit the same densities of birds (Delibes et al. 2001). Sources and sinks can be differentiated by measuring fecundity. Attractive sinks are habitats which are superficially attractive to birds, but which provide poor nesting or foraging resources. Birds in source habitats usually have higher fecundity than birds in sink habitats. The entire group of cavity-nesting birds present within Sierran mixed conifer stands had significantly more nests, and more successful nests, in thinned than unthinned units (Siegel and DeSante 2003). Examining the number of young fledged from nests uses a finer scale than simply quantifying successful versus unsuccessful nesting attempts. Red-naped Sapsuckers (*Sphyrapicus nuchalis*) did not fledge a significantly different number of young from nests in thinned or control units (Tobalske 1992).

1.3.2. Understory Burning

The effects of habitat burning on birds have been extensively documented. In one of the earliest reports, Edwards and Ellis (1969) recorded the arrival of Mourning Doves (*Zenaida macroura*), quail (*Callipepla* spp.), and an American Woodcock (*Scolopax minor*) to the site of a grassland fire while it was still burning. A review of the literature shows mixed effects of burning on birds within all foraging and nesting guilds; however, most studies reported either positive response or no response of cavity-nesters and bark-insectivores to stand-replacing burns (Saab and Powell 2005). Cavity-nesting birds tend to increase in abundance after prescribed fire (Bunnell 1995, King et al. 1998, Dieni and Anderson 1999, White et al. 1999); however, research suggests that the response is limited to the year after the burn (Bock and Bock 1983, Dieni and Anderson 1999, Huff and Smith 2000). Cavity-nesting species generally increase as snag density increases, and most burning treatments create snags (Showalter and Whitmore 2002). However, the amount of decay needed to allow the excavation of a nest depends upon the strength of the excavator, but generally snags accumulate cavities as they decay (Swallow et al. 1986). It took 25 years for most ponderosa pine and Douglas-fir to reach decay classes that were most frequently excavated, and most cavity-bearing snags were found on burns over 20 years old (Lehmkuhl et al. 2003). The response of birds to prescribed burning tends to intensify with increasing burn area (Dieni and Anderson 1999).

1.3.3. Restorative Treatments

No published studies have documented the effects of restorative treatments on western North American nuthatches. Restorative treatments in pine have increased the abundance of Brown-headed Nuthatches in southeastern North America (Conner et al. 2002), and increased the fecundity of Western Bluebirds (*Sialia mexicana*; Germaine and Germaine 2002). When studied as a group, however, birds tend to respond in a species-specific way to thinning and burning treatments that are applied in a restorative context. Hannon (2000) found that no foraging or nesting guild responded to restorative treatments consistently. Instead, one species was more abundant in burned stands, two species were more abundant in thinned stands, two species were more abundant in both treatments, and four species were found in the same abundance in treated and control stands. Birds within ponderosa pine forests may not respond to restoration consistently across foraging or nesting guilds. Because restoration treatments are needed on a landscape scale within ponderosa pine forests of western North America, it is important to investigate the effects of treatments on avian species.

Few studies have focused on the habitat requirements of species in the nuthatch family in western North America (but see Sydeman 1989, Adams and Morrison 1993, Steeger and Hitchcock 1998). Even fewer studies have documented restorative-type disturbance on nuthatches (but see Wilson and Watts 1999). Research needs to be conducted to determine how restorative treatments affect nuthatches, before such treatments are widely used by land managers (Block et al. 2001).

1.4. Hungry Bob Study Site and Restorative Treatments

1.4.1. Hungry Bob

The 'Hungry Bob' research units were located within the Wallowa-Whitman National Forest in the Blue Mountains of northeastern Oregon (45° 37' N, 117° 15' W; Fig. 1.5). Ponderosa pine and interior Douglas-fir predominated, with western larch (*Larix occidentalis*) and lodgepole pine (*Pinus contorta*) found less commonly. Grand fir (*Abies grandis*), and western juniper (*Juniperus occidentalis*) were rarely present. The understory of the area was typically dominated by snowberry (*Symphoricarpos albus*) and pine grass (*Calamagrostis rubescens*). Study units were located mostly on ridge tops above steep valleys, with a range in elevation of 1113 to 1388 m.

The history of the site included fire suppression over the last century, selective harvesting from 1910 to 1996, and prescribed burning in some areas over the last 20 years (J. McIver, Forester, USDA Forest Service, pers. comm. 2003). The Blue Mountains of northeastern Oregon historically received ground fires on an average interval of 10 years, but the actual frequency ranged from 3 to 30 years (Agee 1993). These low-severity fires burned 400,000 acres or more in an average year until the 100% fire suppression initiative in 1906 (Hall 1980, Wickman 1992, Agee and Maruoka 1994, Bailey and Covington 2002). Forests in the Blue Mountains were experiencing extensive insect infestation, more frequent high-severity fires, and increased incidence of disease as a result of the change in the natural fire regime in the area, combined with other forest management decisions (Filip et al. 1996,

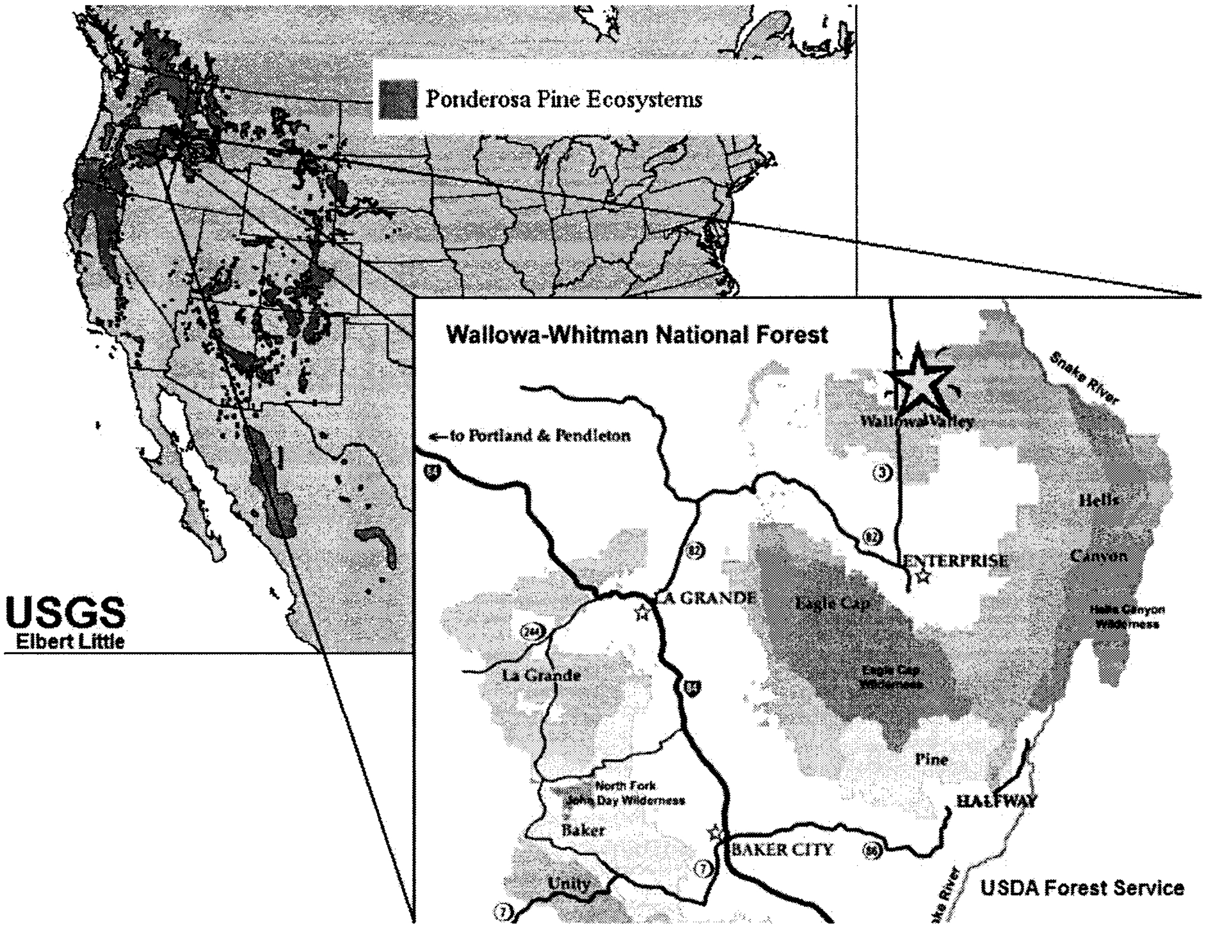

Figure 1.5: Hungry Bob location within northeastern Oregon (United States Geological Survey and United States Department of Agriculture Forest Service).

Jaindl et al. 1996). Dwarf mistletoes (*Arceuthobium douglasii, A. laricis, A. campylopodum, and A. americanum*), indian paint fungus (*Echinodontium tinctorium*), Douglas-fir tussock moth, larch casebearer, western and mountain pine beetle, and Douglas-fir beetle (*Dendroctonus pseudotsugae*) were among the forest health problems present in the Hungry Bob study area (Filip et al. 1996).

1.4.2. Restorative Treatments

The research units and treatments were established by scientists from the Pacific Northwest Research Station and Oregon State University. This interdisciplinary research project was funded by the United States government through both the Fire/Fire Surrogate Study and the Wallowa-Whitman National Forest Service. The study units were designed to include four treatments (prescribed burning only -'burn', mechanical thinning only -'thin', mechanical thinning followed by prescribed burning -'thin and burn', and no treatment - 'control') with four replicates of each treatment. Thus, a total of 16 experimental units were established in December of 1997. The treatment units ranged in size from 6.8 to 32 ha, with an average size of 17 ha. Study units of this size are large enough for several pairs of nuthatches to occupy, and also small enough to have replicates within the same forest type (Enoksson and Nilsson 1983, Brown 1985, Chambers et al. 1999). The treatment units were designed with an irregular shape because of patchy forestation and also to avoid areas that had recently (within the last 20 years) been thinned or burned. Reference markers were set in a grid with permanent rebar ('burn' and 'thin and burn') or wooden stakes ('thin' and 'control') 50 m apart to aid in orientation within the stands while collecting data.

Mechanical thinning on the 'thin' and 'thin and burn' study units was performed in the summer and fall of 1998 with the use of a single-grip harvester and forwarders. Slash was left on the sites, but the trees were removed and sold to recuperate the expense of the treatment (J. McIver, Forester, USDA Forest Service, pers. comm. 2003). Prescribed burning on the 'burn' and 'thin/burn' units was accomplished in the fall of 2000. Large woody debris was removed from around veteran ponderosa pines, but the forest floor was not raked away from the base of the trees (J. McIver, Forester, USDA Forest Service, pers. comm. 2003). Standing dead trees were intentionally left on all treatment units. The restorative treatments were performed with the desire to protect 80% of the stand from a wildfire that may occur under weather conditions that would normally produce unacceptable risk of a crown fire (within the 80th percentile, determined by an average of 15 years of data at the closest fire weather station; Weatherspoon 2000). To achieve this goal, a desired future condition (DFC) was established for all treated stands. The DFC was set to require a basal area of trees close to 16 m^2/ha, while retaining dominant and co-dominant crown classes (especially trees greater than 53 cm dbh) and also creating an irregular spacing of individual trees to simulate natural distribution (Weatherspoon 2000). To attain a stand structure that most closely approximated that found within mature ponderosa pine stands, large (>50 cm dbh) old (>150 years) dominant trees were protected by removing all competing conifers within a 9 m radius (Weatherspoon 2000).

1.5. Thesis Objectives: Determining the Effects of Restorative Treatments on Nuthatches

Cavity-nesting and bark-foraging birds are sensitive to landscape-level changes in forest structure (Dickson et al. 1983, Angelstam and Mikusinski 1994). This thesis aims to determine whether cavity-nesting and bark-foraging birds may be sensitive to changes in forest structure on a smaller scale. Occupancy of an area has been linked to fecundity and food availability and thus to habitat quality for avifauna (Enoksson and Nilsson 1983, Sergio and Newton 2003). For this reason, many studies concerned with documenting the effects of forest management practices on avian species have focused on species abundance, as measured by distance-sampling or encounter rates (Bock and Lynch 1970, Beese and Bryant 1999, Artman et al. 2001, Gram et al. 2003). Within this thesis, the number of birds encountered per observation period was compared among treatments.

The density of territories within an area has been linked to fecundity and food availability and thus to habitat quality for avifauna (Enoksson and Nilsson 1983, Sergio and Newton 2003). Within this thesis, the number of nuthatch nests within each treatment and each year unit was compared among treatment types. While measurements of abundance do address the ability of the habitat to provide the birds with the basics of survival, they fail to address the finer details of habitat quality that may affect nesting success and foraging patterns. One of the areas that requires further research is the effect of fire upon nesting success (Saab and Powell 2005). Modeling daily nest survival using methods that allow nest success to vary over time have been underutilized but may be much more effective than traditional methods (Dinsmore et al. 2002). Daily survival of nests of Red-breasted Nuthatches was analyzed within this thesis using an information theoretic approach.

Research that leads to better understanding the underlying causes of abundance and nest-survival differences among different habitats is also needed (Saab and Powell 2005). Quantifying and comparing foraging patterns among species and among treatment units can reveal differences in niche partitioning as well as functional responses of foraging birds among habitats with different attributes. The rate of travel for foraging birds has been shown to be inversely proportional to resource abundance, including food and cover (Morrison et al. 1987). In Lesser Spotted Woodpeckers (*Dendrocopos minor*), a positive correlation between length of time of substrate use and food availability was reported (Olsson et al. 2001). In this thesis, the amount of time that nuthatches stayed on individual trees while foraging was compared among treatments. The number of seconds nuthatches spent foraging upon trees was compared to the structural characteristics of the trees within this thesis.

Foraging effort was positively correlated to predation risk in Eurasian Blackbirds (*Turdus merula*; Post and Götmark 2006). Therefore, a difference in the proportion of time spent foraging among treatments might indicate foraging success differences among treatments. This was compared among species and treatments for nuthatches within this thesis. A difference in the use of foraging zones depending upon the treatment type would indicate a difference in prey abundance or quality within different areas of the trees and an adaptation by the nuthatches to this variation in food resources (Block 1990).

In summary, the objectives of this study were to: 1) determine whether restorative treatments in ponderosa pine influence the density of foraging Pygmy, White-breasted, or Red-breasted Nuthatches; 2) determine whether restorative treatments in ponderosa pine influence the foraging behavior of nuthatches; 3) describe the structural characteristics of trees used for foraging by nuthatches; 4) determine whether restorative treatments in ponderosa pine influence the density or daily survival of nests of nuthatches; 5) report on the nest-site characteristics of nuthatches within northeastern Oregon. This information was used to determine which restorative treatments, if any, were most beneficial for nuthatches within ponderosa pine forests of northeastern Oregon. It will also add to the general knowledge base of life history characteristics of western North American nuthatch species.

2. The effects of restorative treatments in ponderosa pine (*Pinus ponderosa*) on the foraging ecology of nuthatches (*Sitta* spp.) in northeastern Oregon

2.1. Abstract

*Fire exclusion and other forest management practices have shifted the fire regime of ponderosa pine (*Pinus ponderosa*) ecosystems from frequent understory fires to infrequent, crowning wildfires to which the organisms associated with them have not adapted. Mechanical thinning and prescribed burning are the most common methods of restoring forests to their historic conditions; however, their effects on biological aspects of ecosystem function, such as avian foraging dynamics, are poorly understood. These effects need to be researched as part of a careful evaluation of different restorative treatments before they are widely used. Restorative treatments ('thin', 'burn', 'thin and burn', and 'control') were applied to ponderosa pine forests within northeastern Oregon. The foraging behavior of White-breasted (*Sitta carolinensis*), Red-breasted (*S. canadensis*), and Pygmy (*S. pygmaea*) Nuthatches was determined using the focal animal sampling technique. White-breasted and Pygmy Nuthatches were encountered most frequently within 'thin and burn' treatment units. This abundance difference among treatments did not appear to be due entirely to characteristics of the trees found in each treatment. Red-breasted Nuthatches altered the amount of time spent on individual trees among treatment types, but not among trees with different structural attributes. Structure differed between trees used for foraging and those not used for each species of nuthatch. The birds did not alter their use of zones of the trees or the amount of time they spent in non-foraging behavior among treatments. The results suggest that thinning alone may be less beneficial to nuthatches than burning alone or thinning combined with burning. Further research on foraging behavior that incorporates greater complexity may better explain the variations in foraging patterns found in this study.*

2.2. Introduction

A century of fire suppression initiatives within western North America have contributed to the loss of ponderosa pine ecosystems (Allen et al. 2002, Brown et al. 2004). Increased fire-return intervals within these forests have allowed greater tree recruitment and retention, have increased the proportion of shade-tolerant species such as Douglas-fir (*Pseudotsuga menziesii*) and true firs (*Abies* spp.), and have also increased fire-fuels (Swezy and Agee 1991, Covington and Moore 1992, Mutch et al. 1993, Agee and Maruoka 1994, Harrod et al. 1998). These changes in forest composition and structure have contributed to an increase in crowning wildfires within ponderosa pine (Agee 1996). Between 1991 and 2001, approximately 500,000 acres of ponderosa pine within northeastern Oregon was destroyed by wildfire (J. McIver, Forest Ecologist, USGS, pers., comm., 2003). An estimated 3 million acres of forest within Oregon and Washington are in need of restoration (Caraher et al. 1992). Mechanical thinning and prescribed burning are the most common methods of restoring fire-suppressed forests to their historic conditions (Agee and Maruoka 1994, Hayes et al. 1997, Ottmar and Sandberg 2001), and have both been responsible for decreasing fire intensity when they are applied to ponderosa pine forests (Pearson et al. 1972, Pollet and Omi 2002). Cavity-nesting and bark-foraging birds are sensitive to landscape-level changes in forest structure (Dickson et al. 1983, Angelstam and Mikusinski 1994); therefore, the effects of restorative treatments on these birds need to be researched before they are widely used by land managers (Block et al. 2001).

Three species of cavity-excavator present within the Blue Mountains of Oregon are nuthatches (*Sitta*): White-breasted, Red-breasted, and Pygmy. Nuthatches, especially the Pygmy Nuthatch, may have developed fire-dependent foraging techniques owing to their residence within ponderosa pine ecosystems, yet few studies have documented the effects of restorative treatments on the foraging ecology of nuthatches.

The objectives of this study were as follows: 1) to determine whether nuthatches were encountered more frequently among treatments as a measure of species use and as an estimate of species abundance; 2) to determine whether the amount of time spent foraging on each tree varied among treatments or with structural characteristics of the trees; 3) report on the structural characteristics of trees foraged on by nuthatches within different restorative treatments; and 4) to determine whether the proportion of time birds spent foraging as opposed to other activities such as territory defense differed among treatments. General foraging behavior was used as an indication of where food resources were most abundant, detectable, and desirable within different treatments.

2.3. Methods

2.3.1. Study Site

The 'Hungry Bob' research units were located within the Wallowa-Whitman National Forest in the Blue Mountains of northeastern Oregon (45° 37' N, 117° 15' W). For a detailed description, please see section 1.4.

2.3.2. Treatments and Study Units

The study units were designed to include four treatments (prescribed burning only - 'burn', mechanical thinning only -'thin', mechanical thinning followed by prescribed burning -'thin and burn', and no treatment - 'control') with four replicates of each treatment. For a detailed description, refer to section 1.4.

2.3.3. Foraging Ecology

2.3.3.1. Foraging Behavior

Quantifying food abundance for generalist insectivores such as nuthatches requires a wide range of arthropod sampling techniques, which are time-consuming and expensive (Raphael and Maurer 1990, Wolda 1990). Quantification of food items taken by birds through the use of stomach content analysis, forced regurgitation, flushing, or ligatures were impractical for this study because of mortality, increased handling, and limited access to nuthatch nests. Quantification of prey items by direct observation was not attempted because of the subtle nature of gleaning attacks, which results in a bias towards large prey items (Robinson and Holmes 1982, Rundle 1982, Rosenberg and Cooper 1990). Therefore, observations of foraging behavior were performed using the focal animal technique (Martin and Bateson 1986), and were modified from those used by Weikel and Hayes (1999). Adult nuthatches were followed as they were encountered during a structured walk of each unit between sunrise and 14:00 hrs (Weikel and Hayes 1999). Foraging data were collected for two years between April 20th and July 30th, 2003 and 2004. During the observation periods, a hand-held voice recorder was used to document the behavior of nuthatches, with a focus on foraging behavior. The foraging observation period proceeded following these steps:

1) The research unit was walked for two hours following the sequentially numbered plot markers, alternating the sequence of plots on each visit.

2) When a nuthatch was encountered, the observation period clock was paused, and the bird was followed to the next tree to which it flew.

3) The amount of time (in seconds) spent in each behavior (Table 2.1) while upon the substrate as well as the bird's position upon the substrate (Fig. 2.1.) was recorded.

4) The tree was marked with a unique and removable tag.

Table 2.1. Classification of the behaviors of nuthatches (based on Remsen and Robinson 1990).

Behavioral Class	Activity	Detail of Activity
Search for Food	glean	search for food traveling on the bole of the tree
	probe	insert the bill into a crack or crevice
	peck	force the bill beneath the surface of the substrate
	scale/flake	peel off the surface of the substrate with the bill
Attack Food	capture	capture a food item while upon tree surface
	flycatch	capture food while flying or diving in the air
Food Handling	handle prey	to rub, jab, probe, or grasp food to prepare it for eating, or to take back to nestlings
Territory Defense	sing	series of calls while perching or foraging
	fight/chase	chase another bird from the area
	display	fluff feathers, flick wings, raise crest
	call	single notes, irregularly delivered
Other	preen	clean feathers while perched
	excavate	use bill to dig a nest cavity in soft wood
	mob	join conspecifics in the pursuit of a predator
	perch	sit in a stationary position, not actively gleaning

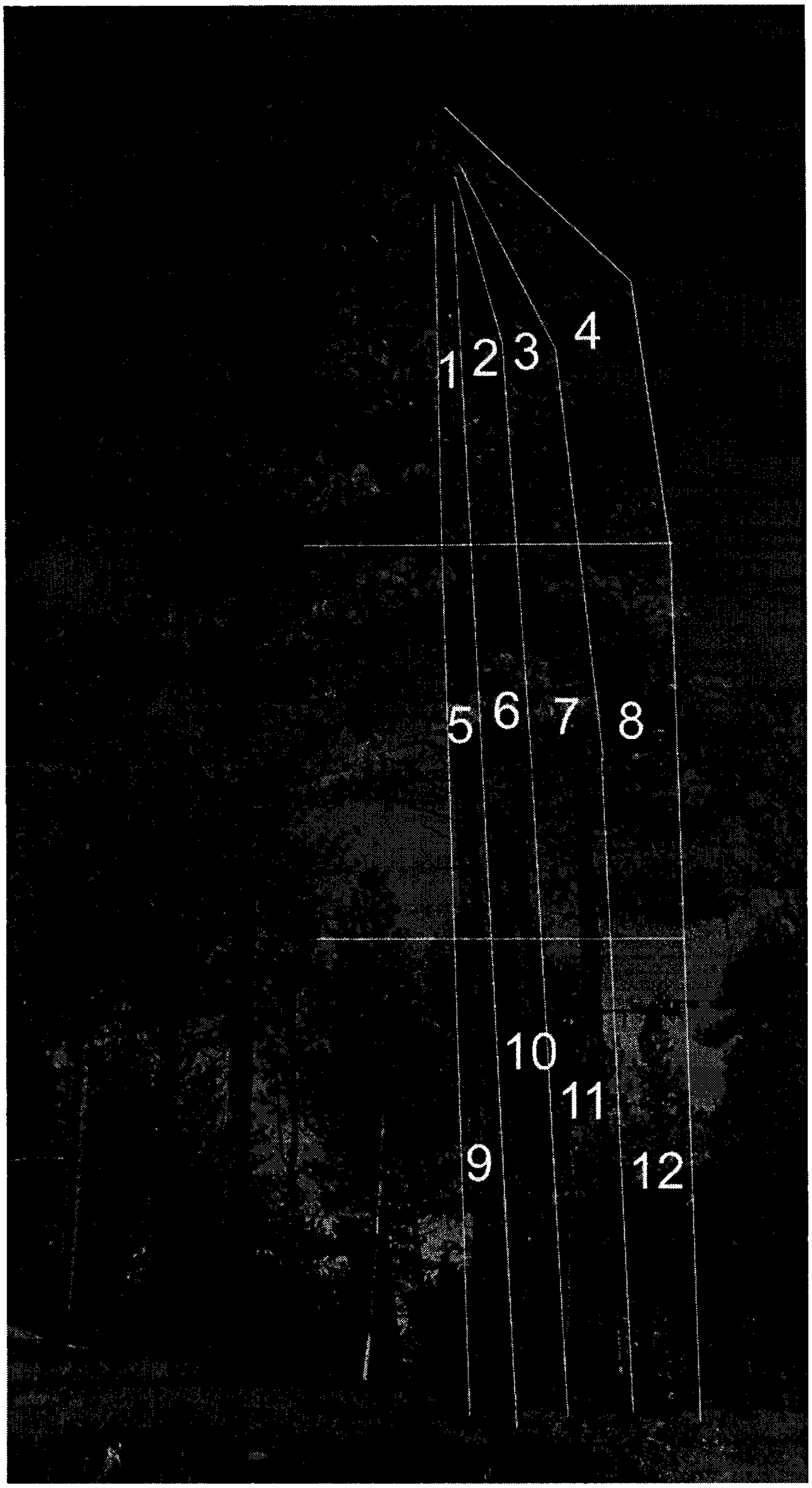

Figure 2.1: Foraging zones within a typical ponderosa pine on the Hungry Bob research units within northeastern Oregon.

5) Steps 3 and 4 were followed at each successive foraging substrate until the bird disappeared from view.

6) Once the bird was lost from view, the observer resumed the observation period clock and resumed walking the unit along the plot line until another nuthatch was encountered, or the observation period was over.

7) Tree structural and microhabitat measurements were taken from each tree that was foraged upon after the observation period.

8) The removable tag was replaced with a permanent mark on the bark of each tree.

(K.L. Farris, Ecologist, WCS, pers. comm. 2002)

No units were surveyed under weather conditions that might have affected the foraging patterns of birds, such as heavy rain, sleet, or snow. No units were surveyed under conditions that might have affected an observer's ability to follow a foraging individual, such as fog or high winds. Observation periods were staggered throughout the day to avoid bias due to daily foraging patterns, but ended no later than 14:00 hrs on any day (Adams and Morrison 1993, Weikel and Hayes 1999). Recording sequential observations helped to avoid biasing behavioral observations towards conspicuous or long-lasting behaviors (Morrison 1984, Noon and Block 1990). Nuthatches are generally tolerant to researchers in the field (Brokaw 1893, Jones 1930). However, to ensure that behaviors recorded were minimally influenced by observation, observers practiced watching nuthatches in the field prior to data collection each year. When the researcher was too close, the bird would flush from the tree, circle the bole of the tree, or freeze. No observer reported these behaviors by a foraging nuthatch except in response to interactions between other birds or predators. All attempts were made to keep track of the same foraging individual that was initially observed. If an individual was 'lost' at any point during the observation period, the observer would track a minimum of 100 m from the site before recording additional behavior data to avoid pseudoreplication.

2.3.3.2. Structural Characteristics of Trees Used for Foraging

Once the observation period ended, structural data were collected from each tree that had been foraged upon. Variables recorded were: (1) diameter at breast height; (2) height category of the tree (Table 2.2); (3) % of crown connected to the canopy; (4) % of the height of the bole with live branches; (5) species of tree; and (6) average depth of the furrows in the bark. The depth of bark furrows was estimated as described by Weikel and Hayes (1999). Four measurements were recorded of the deepest furrow of the bark within each quadrant of the bole of the tree, and then averaged. Structural measurements were also taken from an equal number of trees that were not foraged upon during any foraging observation, as determined by the permanent markers placed upon the bark of foraged trees.

2.3.4. Analysis

2.3.4.1. Use of Treatment Units by Birds

To determine whether nuthatches were encountered at different rates within different treatment types, the number of nuthatches observed foraging within each treatment unit during each observation period was compared using a Kruskal-Wallis test. ANOVAs were not used for these comparisons because the data were non-normal. Data consisted of many 0's, especially for Pygmy and White-breasted Nuthatches. This should not deter the use of a Kruskal-Wallis test (Conver 1999). Analyses were separated by bird species, resulting in three tests. Tests were run in MINITAB (Version 14, 2003; Tabachnick and Fidell 2000). Post-hoc multiple comparisons were done using the methods described in Siegel and

Table 2.2. Height categories recorded from each tree foraged upon by nuthatches.

Height Category	Height of Tree (m)
1	<11
2	11-15
3	16-20
4	21-25
5	>26

Castellan (1988). The alpha level for each test was set at 0.05.

2.3.4.2. Differing Use of Trees Among Treatment Types

The number of seconds that birds foraged upon each tree was compared among treatments using a Kruskal-Wallis non-parametric test. Behavioral data consisted of 23 observations of Pygmy Nuthatches, 109 observations of Red-breasted Nuthatches, and 64 observations of White-breasted Nuthatches. Each observation was the average number of seconds that a nuthatch was observed foraging upon each tree. Up to eight trees were recorded per observation of a nuthatch. Only trees with complete observations were considered. A complete observation occurred when the observer was able to see the bird land on the tree and was able to collect behavioral data from the bird until it flew from the tree. Because of limited samples, data were pooled between years and treatment units, but separated by bird species. Due to unequal sample sizes and non-normal data, ANOVA was not used for this analysis.

Structural characteristics of trees used for foraging by Red-breasted and White-breasted Nuthatches were compared with the number of seconds that birds foraged upon them using mixed linear models. Models could not be fitted for Pygmy Nuthatches due to small sample sizes. Fixed factors within the models included: tree species, treatment, and height categories. Bird I.D. was used as a random factor because up to eight trees foraged by the same bird were included in the analysis. Red-breasted Nuthatches are generalist foragers (Stallcup 1968), so models were designed to compare bole characteristics, crown characteristics, and a combination of bole and crown measurements. White-breasted Nuthatches are trunk foragers (Stallcup 1968), so models were designed to compare different aspects of tree size as well as the proportion of the bole that was not covered by live crown.

Candidate models were compared using Akaike's Information Criterion adapted for small sample sizes (AICc, Hurvich and Tsai 1989; Tables 2.3 and 2.4; Burnham and Anderson 2002). This was undertaken to determine whether structural characteristics or treatment type influenced the amount of time birds stayed on individual trees (Adams and Morrison 1993). Only trees with complete observations were included in the analysis.

Structural characteristics of trees that were foraged upon by nuthatches were compared with the structure of non-foraged trees with binomial logistic regressions using an information theoretic approach (Rodewald and Smith 1998, Steeger and Hitchcock 1998, Weikel and Hayes 1999, Anderson and Crompton 2002). Candidate models were developed based on what the literature has shown affects the use of trees by nuthatches for foraging (Table 2.5). For example, Pygmy Nuthatches often forage within the canopy (Stallcup 1968), so models were designed to compare tree size as well as canopy characteristics. Candidate models were compared using Akaike's Information Criterion adapted for small sample sizes (AICc, Hurvich and Tsai 1989, Burnham and Anderson 2002). Predictive ability of the models were assessed using receiver operating characteristic (ROC) scores (Zweig and Campbell 1993). Models with ROC scores exceeding 0.70 were considered useful models (Swets 1988, Manel et al. 2001). In order to avoid correlation between variables included within each model, Principle Components Analysis (PCA) was used (Lawley and Maxwell 1962). Three PCAs were used for each species of Nuthatch. One was used to combine diameter, height, and depth of furrows. This component ,'tree size', accounted 76.70% of the variation in the data for Red-breasted Nuthatches, 77.46% for Pygmy Nuthatches, and 82.10% for White-breasted Nuthatches. One PCA was used to combine diameter and furrow

Table 2.3. Candidate models to predict the number of seconds that Red-breasted Nuthatches foraged upon each tree using treatment and tree structure.

Variable	Model	1	2	3	4	5	6	7	8	9	10
Treatment			X		X	X		X		X	
Height			X	X				X	X		
Diameter			X	X		X	X			X	X
Furrow Depth			X	X		X	X			X	X
Canopy Connections			X	X				X	X	X	X
Crown Ratio			X	X				X	X	X	X

Table 2.4. Candidate models to predict the number of seconds that White-breasted Nuthatches foraged upon each tree using treatment and tree structure.

Variable	Model	1	2	3	4	5	6	7	8
Treatment			X		X	X		X	
Height			X	X				X	X
Diameter			X	X		X	X		
Furrow Depth			X	X		X	X		
Crown Ratio			X	X				X	X

Table 2.5. Candidate models to predict the structural characteristics of trees that nuthatches foraged upon.

Variable	Model	1	2	3	4	5	6	7	8	9	10	11	12	13
Tree Size			X	X									X	X
Tree Species				X		X		X		X		X	X	
Height									X	X				
Height + Diameter											X	X		
Diameter							X	X						
Diameter + Furrow					X	X								
Canopy Connections									X	X	X	X	X	X
Crown Ratio					X	X	X	X	X	X	X	X	X	X

depth. This component, ‘diameter/furrow depth’, accounted for 86.19% of the variation in the data for Red-breasted Nuthatches, 90.25% for Pygmy Nuthatches, and 89.17% for White-breasted Nuthatches. The last PCA was used to combine diameter and tree height. The resulting component, ‘diameter/height’ accounted for 85.81% of the variation in the data for Red-breasted Nuthatches, 82.93% for Pygmy Nuthatches, and 88.40% for White-breasted Nuthatches. The broken-stick method was used to evaluate the components produced by PCA (Frontier 1976, Jackson 1993). All variables were positively correlated with the components. Larger values of diameter, height, and furrow depth resulted in larger values of ‘tree size’, ‘diameter/furrow depth’, and diameter/height’.

Analyses were run using SPSS (Version 14, 2005) and MINITAB (Version 14, 2003). Post-hoc multiple comparisons for Kruskal-Wallis tests were performed using methods described in Siegel and Castellan (1988). The alpha level for each test was set at 0.05. Cases with standardized residuals >2.58 or <-2.58 and Cook’s distance of < 1 were eliminated as outliers within analyses.

2.3.4.3. Structural Differences Among Trees Within Each Treatment Unit

Structural characteristics of trees within each treatment unit were compared using data collected by the Pacific Northwest Research Station in LaGrande, OR and donated by Andy Youngblood (Research Forester). Diameter, height, crown ratio, canopy connections, furrow depth, and tree species composition were compared using Kruskal-Wallis H tests (SPSS Version 14, 2005). Multiple comparisons after Kruskal-Wallis were performed according to Siegel and Castellan (1988).

2.3.4.4. Behavior Differences Among Treatment Units

The proportion of observation time that each bird was documented in non-foraging behavior (singing, preening, perching, calling, aggressive territorial encounters, displaying, or excavating a cavity) was compared using a Kruskal-Wallis non-parametric test (Tabachnick and Fidell 2000). A nonparametric test was used because these data were not normally distributed, and sample sizes were unequal among treatment types. These analyses were undertaken to determine whether nuthatches differed in the proportion of time that they spent foraging among treatment types.

The number of seconds each bird was observed within each foraging zone (Fig. 2.1) was converted to the proportion of time each bird spent within each zone (Stallcup 1968). Transforming the data into continuous proportional data tended to create 1s and 0s. All 1s and all 0s within the data were converted in the following manner (Zar 1999): If x =1 then x was converted to 1-1/(4*seconds); If x=0 then x was converted to 1/(4*seconds). This method allowed the 0 value to approach 0 and the 1 value to approach 1 as the bird was watched a greater amount of time. At 400 seconds, the difference to 4 decimal places was 0.0006. At 10 seconds, the difference increased to 0.025. This reflected the fact that more zones were foraged depending upon how long the bird was watched in each tree. Comparisons were made among foraging zones along the horizontal and vertical axis (see Table 2.6). Zones 3, 7, and 11 were used as buffer areas between proximal and distal branch zones. For Pygmy Nuthatches, there were too few observations in ‘thin’ and ‘burn’ treatments to allow comparison. Only observations lasting longer than 10 seconds were used for the analysis (Morrison et al. 1987).

Table 2.6. Zone combinations used to compare foraging of nuthatches along horizontal and vertical axes.

Zones Combined	Variable	Axis of Comparison
1,5,9	bole zones	horizontal
2,6,10	proximal zones	horizontal
4,8,12	distal zones	horizontal
1,2,3,4	top zones	vertical
5,6,7,8	middle zones	vertical
9,10,11,12	bottom zones	vertical

Analyses were run using SPSS (Version 14, 2005 and MINITAB (Version 14, 2003; Tabachnick and Fidell 2000). Post-hoc multiple comparisons for Kruskal-Wallis tests were done using methods described in Siegel and Castellan (1988). The alpha level for each test was set at 0.05. Cases with standardized residuals >2.58 or <-2.58 and Cook's distance of < 1 were eliminated as outliers within analyses.

2.4. Results

All treatments were given equal observation time while searching for foraging nuthatches. For the purposes of analysis, all treatment units were pooled by treatment type. Due to differences in encounter rates between species and treatments, Pygmy Nuthatches were observed for a total of 123 minutes, Red-breasted Nuthatches were observed for 566 minutes, and White-breasted Nuthatches were observed for 416 minutes over the course of two breeding seasons (See Table 2.7). The behavioral data that resulted were used to analyze the similarity of foraging behavior and foraging location within trees between treatments.

All foraging observations of Pygmy Nuthatches and White-breasted Nuthatches in the 'control' treatment came from a single unit. One family group of cooperative nesters (4-5 birds) were the only Pygmy Nuthatches observed in this unit in both years of the study. More individuals of White-breasted Nuthatch were seen foraging within the 'control' unit than Pygmy Nuthatch. However, readers should interpret results obtained for Pygmy and White-breasted Nuthatches within this 'control' unit with caution.

2.4.1. Use of Treatment Units by Birds

The number of foraging birds encountered during each observation period was significantly different among treatments for both Pygmy Nuthatches (Kruskal-Wallis,

Table 2.7. Amount of time (minutes) birds were observed foraging within each treatment type. PYNU=Pygmy Nuthatch, RBNU=Red-breasted Nuthatch, and WBNU= White-breasted Nuthatch.

Bird Species	Treatment				
	Control	Thin	Burn	Thin and Burn	Total
PYNU	32	1	12	79	123
RBNU	160	99	151	158	566
WBNU	40	68	90	218	416
Total	230	168	253	455	1106

N=110, H=21.45, p<0.001; Fig. 2.2) and White-breasted Nuthatches (Kruskal-Wallis, N=110; H=10.43, p=0.015; Fig. 2.2). Post-hoc paired comparisons showed that Pygmy Nuthatches were observed significantly more often within 'thin and burn' treatments than within either 'thin' treatments or 'burn' treatments (p<0.05). White-breasted Nuthatches were encountered significantly more frequently in 'thin and burn' units than 'control' units (p<0.05). The number of foraging birds observed was not significantly different between treatments for Red-breasted Nuthatches (Kruskal-Wallis, N=110; H=5.77, p=0.123; Fig. 2.2). Results of the Kruskal-Wallis test comparing encounters of Pygmy Nuthatches within treatments must be interpreted with caution, as variances were not equal between groups for this species. Unequal variances tend to inflate Type I error rates in Kruskal-Wallis tests (Cribbie 2003).

2.4.2. Differing Use of Trees between Treatment Units

Red-breasted Nuthatches spent a significantly different amount of time upon trees between treatment types (Kruskal-Wallis, N=109, H=23.233, p<0.001; see Fig. 2.3). Multiple comparisons revealed that the birds spent less time on trees within 'control' treatments and 'thin' treatments than within 'thin and burn' or 'burn' treatments (p<0.05). The test was not significant for Pygmy Nuthatches (Mann-Whitney, N=23, U=41.0, p<0.341; see Fig. 2.3) or White-breasted Nuthatches (Kruskal-Wallis, N=64, H=3.537, p<0.316; see Fig. 2.3). A Mann-Whitney U test was used to compare data for Pygmy Nuthatches because sample size did not permit the analysis of trees within 'thin' or 'burn' treatments.

The amount of time that Red-breasted Nuthatches foraged upon trees was best predicted by a model that included only treatment type (Table 2.8). Treatment type was significant within the model at an alpha level <0.001 (Table 2.9; Fig 2.4). 'Thin and burn'

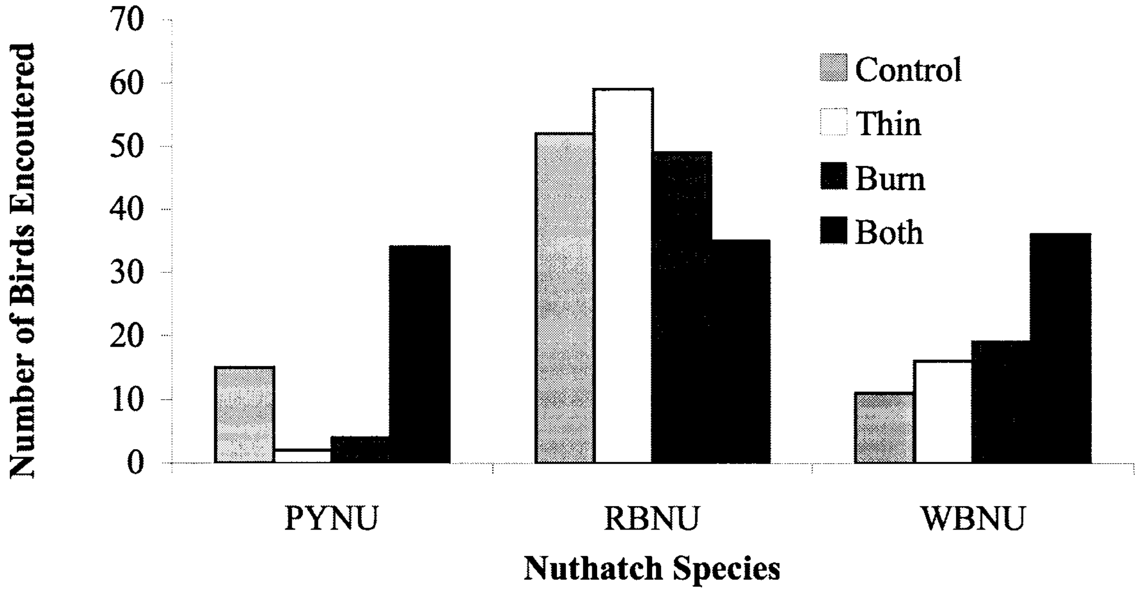

Figure 2.2: Number of nuthatches encountered within each treatment type. PYNU=Pygmy Nuthatch, RBNU=Red-breasted Nuthatch, and WBNU=White-breasted Nuthatch.

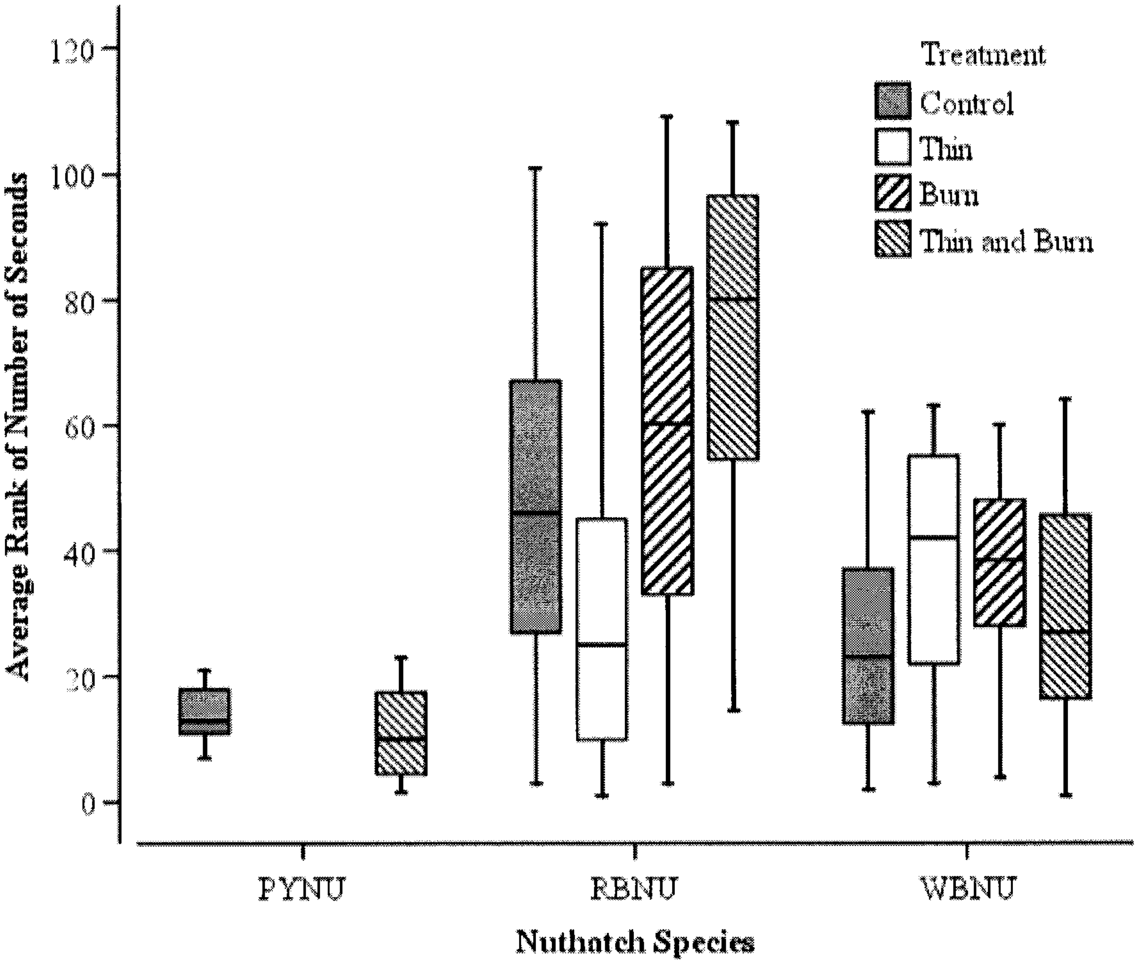

Figure 2.3: Mean rank of time (in seconds) each nuthatch species spent foraging upon each tree within each treatment type. PYNU=Pygmy Nuthatch, RBNU=Red-breasted Nuthatch, and WBNU=White-breasted Nuthatch. Lines represent medians, boxes represent the interquartile range of the data, and error bars represent ± 1 Standard Deviation.

Table 2.8. Comparison of models using the structural characteristics of trees to predict the length of time Red-breasted Nuthatches foraged upon them.

Model	Parameters Included	AICc	Δ AICc	Akaike Weight
4	treatment	611.967	0.000	0.835
7	canopy connections + crown ratio + height + treatment	615.272	3.305	0.160
5	furrow + dbh + treatment	622.612	10.645	0.004
6	furrow + dbh	636.902	12.935	0.000
9	canopy connections + crown ratio + dbh + furrow depth + treatment	625.282	13.315	0.001
2	(global) treatment + height + dbh + furrow depth + canopy connections + crown ratio	627.702	15.735	0.000
1	null	633.903	21.936	0.000
8	canopy connections + crown ratio + height	634.749	22.782	0.000
10	canopy connections + crown ratio + dbh + furrow depth	639.931	27.964	0.000
3	height + dbh + furrow depth + canopy connections + crown ratio	640.739	28.772	0.000

Table 2.9. Parameter estimates (PE), standard error (SE), *F*-value, *t*-value, and *p*-value of each variable within the best performing model using the structural characteristics of trees to predict the length of time Red-breasted Nuthatches foraged upon them.

Variable	PE	SE	*F*	*t*	*p*-value
Intercept	4.172	0.151	236.909	27.586	<0.001
Treatment			10.096		<0.001
'Control'	-0.751	0.198		-3.802	<0.001
'Thin'	-1.135	0.223		-5.095	<0.001
'Burn'	-0.350	0.213		-1.646	0.101
'Thin and Burn'	contrast				

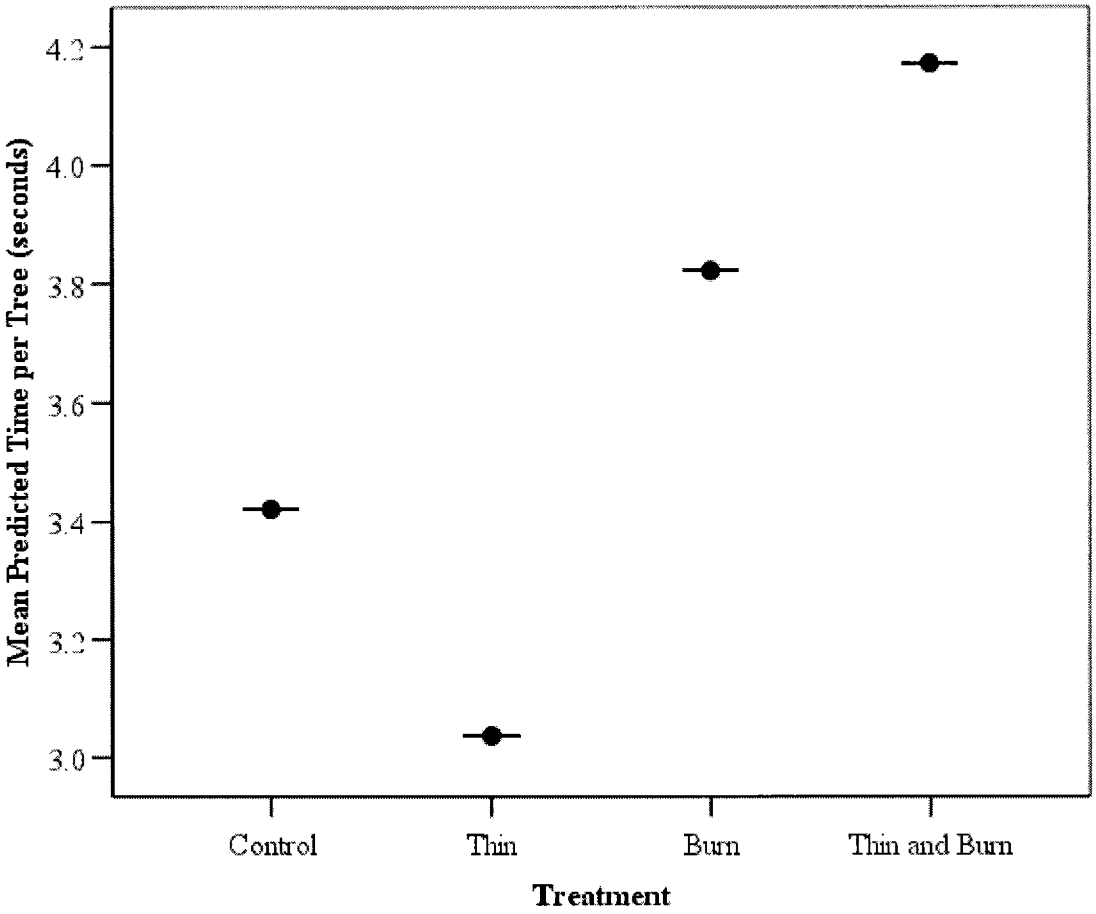

Figure 2.4: Mean amount of time (natural log of seconds) that Red-breasted Nuthatches were predicted to forage upon trees within each treatment.

was used as a contrast variable against which the rest of the treatments were compared. Parameter estimates shown in Table 2.8 are negative for 'control', 'thin', and 'burn', indicating that Red-breasted Nuthatches foraged upon trees in these treatments for a shorter amount of time than in 'thin and burn' treatment units.

The model best predicted the amount of time that White-breasted Nuthatches foraged upon trees included treatment type, which was not significant within the model at an alpha level <0.05 (Table 2.10 and Table 2.11).

Tree species preference could not be analyzed with logistic regression for Pygmy Nuthatches because the birds were recorded only twice upon Douglas-fir. The model that included diameter and crown ratio best predicted which trees Pygmy Nuthatches used for foraging (logistic regression, $\chi^2 = 42.169$, N=155, $p<0.001$; Table 2.12). The best-performing model had good predictive accuracy (ROC = 0.782). Pygmy Nuthatches foraged upon trees with a larger diameter than average (Table 2.13, Fig. 2.5).

Foraging of Red-breasted Nuthatches was best predicted by the model which included diameter/furrow depth, crown ratio, and tree species (logistic regression, $\chi^2 = 124.113$, N=718, $p<0.001$; Table 2.14). The model was a useful one for predicting the use of trees (ROC = 0.732). Trees that Red-breasted Nuthatches foraged upon had less live crown and were larger in diameter and furrow depth than trees that were not used for foraging. Red-breasted Nuthatches also foraged upon more Douglas-fir than was randomly available across the treatment units (Table 2.15).

Four models, one which contained height/diameter, canopy connections, and crown ratio (logistic regression, N=440, $\chi^2 = 43.453$, $p<0.001$), one which contained height/diameter, canopy connections, crown ratio, and tree species (logistic regression,

Table 2.10. Comparison of models using the structural characteristics of trees to predict the length of time White-breasted Nuthatches foraged upon them.

Model	Parameters Included	AICc	Δ AICc	Akaike Weight
4	treatment	361.936	0.000	0.7180
1	intercept	364.359	2.423	0.2137
7	height + crown ratio + treatment	367.775	5.879	0.0387
8	height + crown ratio	369.044	7.108	0.0205
2	(global) treatment + height + dbh + furrow depth + crown ratio	371.577	9.641	0.0058
5	dbh + furrow depth + treatment	373.540	11.604	0.0022
3	height + dbh + furrow depth + crown ratio	375.485	13.549	0.0008
6	dbh + furrow depth	377.900	15.964	0.0002

Table 2.11. Parameter estimates (PE), standard error (SE), F-value, t-value, and p-value of each variable within the best performing model using the structural characteristics of trees to predict the length of time White-breasted Nuthatches foraged upon them.

Variable	PE	SE	*F*	*t*	*p*-value
Intercept	4.001	0.142	1538.111	28.162	<0.001
Treatment			2.564		0.058
'Control'	-0.619	0.251		-2.462	0.015
'Thin'	0.092	0.284		0.324	0.746
'Burn'	0.002	0.229		0.011	0.992
'Thin and Burn'	contrast				

Table 2.12. Information criteria of candidate models used to predict the structural characteristics of trees foraged upon by Pygmy Nuthatches.

Model	Parameters Included	*p*-value	AICc	Δ AICc	Akaike Weight
6	diameter + crown ratio	<0.001	178.859	0.000	0.833
4	diameter/furrow depth + crown ratio	<0.001	182.217	3.358	0.155
2	tree size	<0.001	187.960	9.101	0.009
13	tree size + crown ratio + canopy connections	<0.001	190.741	11.882	0.002
10	height/diameter + canopy connections + crown ratio	<0.001	197.263	18.404	0.000
8	height + canopy connections + crown ratio	0.001	203.239	24.380	0.000
1	intercept	<0.001	216.895	38.036	0.000

Table 2.13. Parameter estimates (PE), standard error (SE), Wald value, and *p*-value of each variable within the best performing model using the structural characteristics of trees to predict foraging use by Pygmy Nuthatches.

Variable	PE	SE	Wald	*p*-value
Diameter	0.112	0.022	26.361	<0.001
Crown Ratio	0.004	0.011	0.116	<0.001

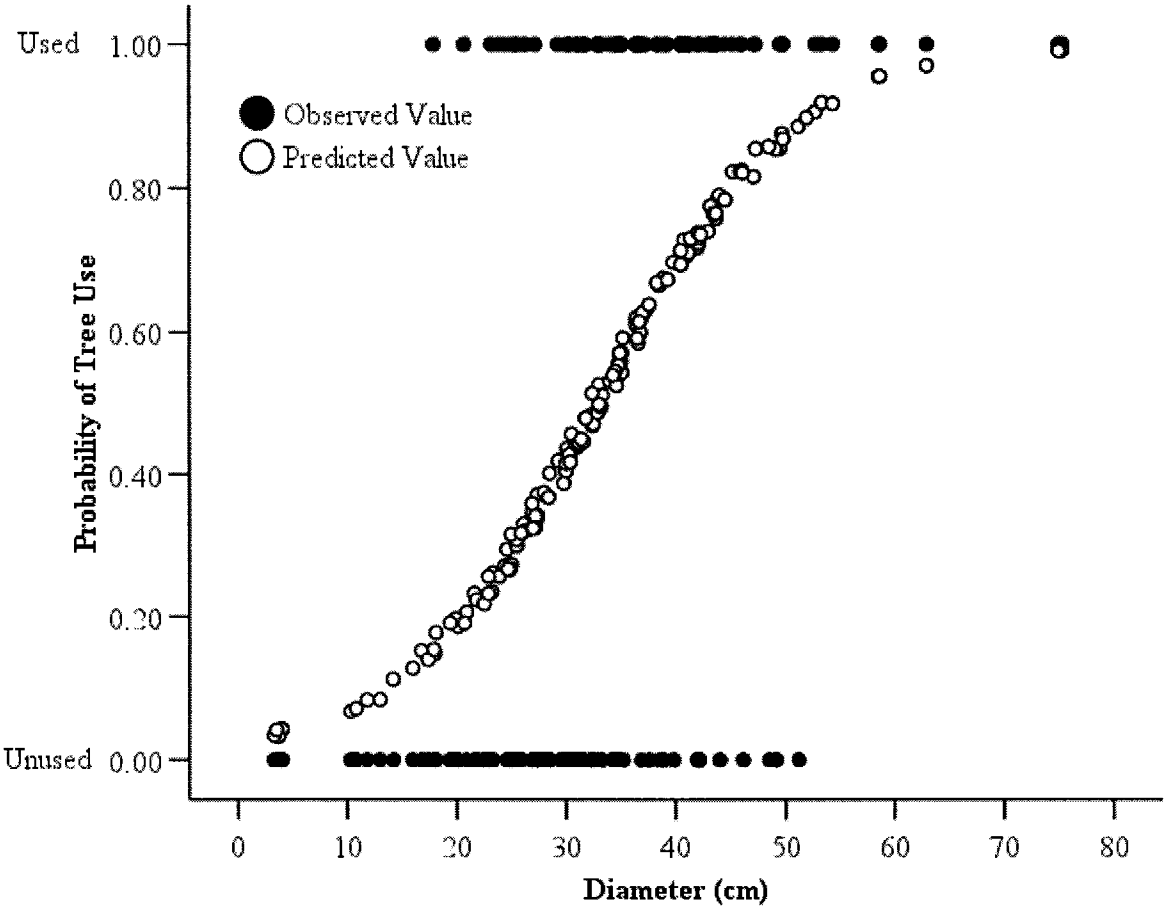

Figure 2.5: The probability that Pygmy Nuthatches would use a tree for foraging increased as the diameter (cm) of the tree increased.

Table 2.14. Information criteria of candidate models used to predict the structural characteristics of trees foraged upon by Red-breasted Nuthatches.

Model	Parameters Included	*p*-value	AICc	Δ AICc	Akaike Weight
5	diameter/furrow depth + crown ratio + tree species	<0.001	875.818	0.000	0.999
12	tree size + canopy connections + crown ratio + tree species	<0.001	890.446	14.628	0.001
11	height/diameter + canopy connections + crown ratio + tree species	<0.001	892.122	16.304	0.000
10	height/diameter + canopy connections + crown ratio	<0.001	897.689	21.871	0.000
9	height + canopy connections + crown ratio + tree species	<0.001	923.457	47.639	0.000
4	diameter/furrow depth + crown ratio	<0.001	924.724	48.906	0.000
13	tree size + canopy connections + crown ratio	<0.001	927.974	52.156	0.000
8	height + canopy connections + crown ratio	<0.001	939.626	63.808	0.000
7	diameter + crown ratio + tree species	<0.001	976.026	100.208	0.000
6	diameter + crown ratio	<0.001	997.082	121.264	0.000
3	tree size + tree species	<0.001	1001.765	125.947	0.000
2	tree size	<0.001	1043.467	167.649	0.000
1	intercept	1.000	1124.903	249.085	0.000

Table 2.15. Parameter estimates (PE), standard error (SE), Wald value, and *p*-value of each variable of each variable within the best performing model using the structural characteristics of trees to predict foraging use of Red-breasted Nuthatches.

Variable	PE	SE	Wald	*p*-value
Crown Ratio	-2.809	0.604	21.603	<0.001
Diameter/Furrow Depth	1.147	0.118	94.454	<0.001
Tree Species	1.555	0.227	46.758	<0.001

N=440, $\chi^2 = 44.528$, $p<0.001$), one which contained tree size, crown ratio, canopy cover, and tree species (logistic regression, N=395, $\chi^2 = 44.603$, $p<0.001$), and the model which included all predictors except tree species (logistic regression, N=395, $\chi^2 = 44.371$, $p<0.001$), were best at predicting tree use by White-breasted Nuthatches (Table 2.16). Both models had poor predictive accuracy (ROC = 0.672-0.676). White-breasted Nuthatches foraged upon trees that were larger, and with less live crown than trees that were not foraged upon (Table 2.17).

2.4.3. Structural Differences Among Trees Within Each Treatment Unit

Stand and tree structure differed among treatment types at the Hungry Bob research area (Table 2.18). Many variables measured (diameter, height, furrow depth, # of Douglas-fir) were similar between 'control' and 'thin', and 'burn' and 'thin and burn'. 'Thin and burn' was similar to 'control' only in the # of ponderosa pine within the treatment units.

2.4.4. Foraging Behavior Differences between Treatments

The proportion of time that birds were observed in behaviors other than foraging for food was not significantly different among treatments for Pygmy Nuthatches (Kruskal-Wallis, N=26, $H=1.29$, $p=0.731$), White-breasted Nuthatches (Kruskal-Wallis, N=50, $H=2.41$, $p=0.476$), or Red-breasted Nuthatches (Kruskal-Wallis, N=101, $H=1.59$, $p=0.662$). The proportion of foraging time that zones of the tree were used did not differ along a horizontal axis (bole, proximal branches, or distal branches) or along a vertical axis (top, middle, or bottom) among treatments for any species of nuthatch (Table 2.19 and 2.20). For Pygmy Nuthatches, there were too few observations in both 'thin' and 'burn' treatments to

Table 2.16. Information criteria of candidate models used to predict the structural characteristics of trees foraged upon by White-breasted Nuthatches.

Model	Parameters Included	*p*-value	AICc	Δ AICc	Akaike Weight
13	tree size + canopy connections + crown ratio	<0.001	511.285	0.000	0.411
10	height/diameter + canopy connections + crown ratio	<0.001	512.203	0.918	0.260
12	tree size + canopy connections + crown ratio + tree species	<0.001	513.114	1.829	0.165
11	height/diameter + canopy connections + crown ratio + tree species	<0.001	513.189	1.904	0.159
9	height + crown ratio + canopy connections	<0.001	520.721	9.436	0.004
8	height + crown ratio + canopy connections + tree species	<0.001	521.912	10.627	0.002
6	diameter + crown ratio	<0.001	558.014	46.729	0.000
7	diameter + crown ratio + tree species	<0.001	559.447	48.162	0.000
5	diameter/furrow depth + crown ratio + tree species	<0.001	572.108	60.823	0.000
4	diameter/furrow depth + crown ratio	<0.001	572.425	61.140	0.000
2	tree size	<0.001	582.381	71.096	0.000
3	tree size + tree species	<0.001	584.403	73.118	0.000
1	intercept	1.000	611.979	100.694	0.000

Table 2.17. Parameter estimates (PE), unconditional standard error (USE), and confidence intervals (CI) of each variable, derived by model averaging, using the structural characteristics of trees to predict foraging use of trees by White-breasted Nuthatches.

Variable	PE	USE	Lower 95% CI	Upper 95% CI
Crown Ratio	-0.019	0.007	-0.005	-0.033
Diameter/Height	0.731	0.127	0.979	0.482
Canopy Connections	0.065	0.097	0.255	-0.124
Tree Species	0.262	0.363	0.975	-0.450
Tree Size	0.736	0.127	0.985	0.487

Table 2.18. Differences in vegetation structure among treatment types. Values sharing letters are not statistically different at an alpha level <0.05. *represents the average # of ponderosa pine and Douglas-fir within 400^2 meters centered on each grid marker.

Variable	Control	Thin	Burn	Thin and Burn	χ^2	N	*p*-value
Diameter (cm)	17.8^{a}	17.2^{a}	24.8^{b}	25.0^{b}	292.52	3921	<0.001
Height (m)	12.0^{a}	11.4^{a}	14.9^{b}	15.2^{b}	183.40	3921	<0.001
Crown Ratio (%)	50.5^{a}	43.6^{b}	$43.5^{b,c}$	39.8^{c}	131.05	3908	<0.001
Canopy Connections (%)	21.4^{a}	$10.6^{b,c}$	10.8^{b}	7.5^{c}	78.28	1212	<0.001
Furrow Depth (mm)	11.6^{a}	11.5^{a}	13.0^{b}	13.5^{b}	37.54	1212	<0.001
*Ponderosa Pine (#)	11.2^{a}	9.6^{a}	9.6^{a}	6.8^{a}	3.51	297	0.319
*Douglas-fir (#)	8.4^{a}	6.3^{a}	1.4^{b}	1.0^{b}	68.88	297	<0.001

Table 2.19. Results of Mann-Whitney *U*-tests used to compare the amount of time that Pygmy Nuthatches spent foraging within different zones among treatments.

Zone	N	*U* value	*p*-value
Top	49	242.500	0.786
Middle		250.000	0.914
Bottom		186.500	0.137
Bole		225.000	0.515
Proximal		251.500	0.939
Distal		183.000	0.118

Table 2.20. Results of Kruskal-Wallis H-tests used to compare the amount of time that Red-breasted and White-breasted Nuthatches spent foraging within different zones among treatments. RBNU=Red-breasted Nuthatch and WBNU=White-breasted Nuthatch.

Bird Species	Zone	N	*H* value	*p*-value
RBNU	top	213	0.335	0.953
	middle		7.356	0.061
	bottom		6.918	0.075
	bole		3.396	0.335
	proximal		0.434	0.933
	distal		5.855	0.119
WBNU	top	83	7.718	0.052
	middle		8.376	0.039
	bottom		8.928	0.030
	bole		4.773	0.189
	proximal		6.574	0.087
	distal		3.300	0.348

allow comparison, so a Mann-Whitney *U* test was used to compare 'control' and 'thin/burn' units.

2.5. Discussion

The density of individuals in an area has been linked to fecundity and food availability and thus to habitat quality for avifauna (Enoksson and Nilsson 1983, Sergio and Newton 2003). Pygmy Nuthatches were observed less frequently in 'thin' units and 'burn' units, than in 'thin and burn' treatment units (Fig. 2.2). 'Thin and burn' treatment units had trees with fewer canopy connections than trees in any other treatment (Fig. 2.18). Pygmy Nuthatches may prefer forests with less than 70% canopy closure (Balda et al. 1983, Csuti et al. 1997, Kingery and Ghalambor 2001). Fewer White-breasted Nuthatches were observed in the 'control' units than in 'thin and burn' treatment units. The abundance of Red-breasted Nuthatches was not different between treatment types at the Hungry Bob research area. However, abundance differences were found after forest thinning and burning in other areas (Adams and Morrison 1993, Hagar et al. 1996, Artman 2002, Siegel and DeSante 2003). The selection criteria of habitat may vary by spatial scale for foraging birds. Red-breasted Nuthatches were more common on a landscape scale than the other two species of nuthatch studied at Hungry Bob. Territory boundaries may therefore confine nuthatches to a particular area (Hutto 1985, Allen et al. 1987). Perhaps competition for territories prevented Red-breasted Nuthatches from immigrating to other areas in response to treatment type, so instead, they altered their foraging behavior. This hypothesis could be tested by following a population of banded birds in order to determine: dominance hierarchy of neighbors, settling date of territories, and territory size (Enoksson and Nilsson 1983, Nilsson 1987). Taking these steps could eliminate one other possibility, that the increased foraging rate of Red-breasted Nuthatches in 'thin' units influenced the encounter rate between the nuthatches and field observers, masking a difference in the abundance of the birds.

Red-breasted Nuthatches spent more time foraging on each tree in 'thin and burn' units than in 'thin' or 'control' treatment units (Fig. 2.3, Fig. 2.4). They also spent more time on trees in 'burn' treatments than 'thin' treatments. The other two species of nuthatch were not different in the amount of time they spent on each tree among treatments. According to the marginal value theorem, birds should leave trees sooner in areas where food resources are rich (Charnov 1976). In contrast, the rate of travel for foraging birds has been shown to be inversely proportional to resource abundance, including food and cover (Morrison et al. 1989, Olsson et al. 2001). The difference may be that the marginal value theorem fails to take into account: increased predation risk of traveling between trees (Post and Götmark 2006), interspecific competition for food (Stallcup 1968), and assumes that resources are equal on all trees.

Arthropod populations were not adversely affected by prescribed fire in oak (*Quercus*)-savannah habitats (Siemann et al. 1997) or longleaf pine (*Pinus palustris*) habitats (Taylor 2003). More bark-surface arthropods, and more arthropod species, were found in areas that had been disturbed by fire than areas that had not (Volker 1991). Many arthropods found on the bark of trees actually migrate there from the leaf litter layer (Apigian et al. 2006). The community structure of arthropods in the leaf litter layer was more affected by fire than thinning in the Sierra Nevada, but the effects on arthropod density were taxa-specific and moderate (Apigian et al. 2006).

Longer durations of time spent foraging upon each tree may indicate a greater abundance of food on that substrate (Morrison et al. 1989). The models that performed best for predicting the amount of time that nuthatches would stay upon trees while foraging did not include any structural variables for either Red-breasted or White-breasted Nuthatches. Adams and Morrison (1993) also failed to find a correlation between structural attributes of foraged trees and time spent on the trees foraging.

All species of nuthatch exhibited preference between structural characteristics of trees that were used for foraging, and trees that were not used. Comparison of the models used to predict use of trees for foraging by nuthatches revealed differences in model performance among nuthatch species. Because of the nature of regression analyses, the regression models found a significant difference between trees used for foraging and those not used only when the preferred structure was not the average condition in the stand (Dodge et al. 1990). Therefore, these results should be interpreted not as absolute models of tree structure preferences of nuthatches, but as an identification of preferences that were outside of the average condition found on each treatment unit. From model selection alone, it would seem that trees deviated from the desired condition in the fewest structural attributes for Pygmy Nuthatches. Pygmy Nuthatches were also nearly restricted to 'control' and 'thin and burn' areas, indicating that they are more selective in the habitat they occupy than the other two species. Differences in the structural characteristics of trees among treatment types (Fig. 2.18) do not entirely dictate the abundance of each nuthatch species in each treatment unit. For example, Red-breasted Nuthatches selected Douglas-fir more frequently for foraging than it was randomly available at Hungry Bob. 'Burn' and 'thin and burn' units had less Douglas-fir than 'control' or 'thin' units, however, there was no difference in the number of encounters of Red-breasted Nuthatches among units.

Variables measuring tree size were always significant predictors of foraging use by nuthatches. Bark furrow depth has been positively linked to the abundance and size of bark-surface arthropods (Volker 1989, Adams and Morrison 1993). A preference by bark-foraging birds for larger trees has been found in most studies where it has been tested, perhaps simply due to increased surface area for foraging (Morrison et al 1987, Weikel and Hayes 1999).

Trees with less live crown covering the bole were more likely to be foraged on by Red-breasted Nuthatches and White-breasted Nuthatches. Birds may prefer to forage upon sections of the bole that are not covered by foliage in these treatments. The percent of the crown free from contact with the rest of the canopy was not significant in logistic regression models to predict which trees nuthatches would use for foraging. Trees with a greater proportion of connections to the canopy were used more in mixed-coniferous forests of Oregon (Weikel and Hayes 1999), presumably because birds could use crown connections to travel between trees while foraging in the canopy. However, adjacent trees may not fulfill the strong structural preferences demonstrated by nuthatches, negating the use of canopy connections to travel between foraging substrates.

If food were more limiting in one treatment than another, one would expect that nuthatches would have to spend more time foraging in the treatment where food was more limiting — especially since foraging effort has been linked to predation risk in Eurasian Blackbirds (*Turdus merula*; Post and Götmark 2006). Non-foraging behaviors were not observed more or less frequently in any treatment for any species. Research on foraging dynamics and population density has indicated that food is not limiting for birds in ponderosa pine (Brawn 1987, Brawn et al. 1987, Brawn and Balda 1988a). Nuthatches habitually cache food items in bark crevices of trees (Heinrich et al. 1997), confounding the interpretation of the amount of time spent foraging as an indication of food availability.

Red-breasted Nuthatches selected only the heaviest seeds at feeders (Heinrich et al. 1997), demonstrating that these birds are selective in the food resources they choose, even when in general those resources are abundant. An alteration in the use of foraging zones depending on treatment type might indicate a disparity in prey abundance in different areas of the trees, and an adaptation by nuthatches to this variation in food resources (Block 1990, Sallabanks 1993). Nuthatches did not alter their use of vertical or horizontal axes among treatments. In a study of geographic variation in foraging behavior, nuthatches were less plastic in their foraging behavior than most species, with Pygmy and White-breasted Nuthatches scoring lower than Red-breasted Nuthatches (Petit et al. 1990). However, White-breasted Nuthatches showed the greatest diversity of prey selection in pine forests of Oregon, when compared to either Pygmy or Red-breasted Nuthatches (Anderson 1976). As generalist and opportunistic insectivores, Red-breasted Nuthatches are found in a much wider range of habitats than either Pygmy or White-breasted Nuthatches (Ghalambor and Martin 1999). Pygmy Nuthatches may be the most highly specialized of the foragers in this study, and therefore, the most sensitive to changes in vegetation structure caused by restorative treatments. This is illustrated by the paucity of individuals detected in any unit where 'thin' or 'burn' were applied.

In general, the results of this research indicate that thinning combined with burning increases use of the area by White-breasted and Pygmy Nuthatches. Burning or thinning alone appeared to alter foraging habitat little for Red-breasted and White-breasted Nuthatches; however, Pygmy Nuthatches seem to disappear in habitats where thinning or burning alone are applied. In ponderosa pine forests of Arizona, no population change was reported for Pygmy or White-breasted Nuthatches after prescribed fire was applied to the area (Horton and Mannan 1988, Machmer 2002). The failure of the analyses reported here, to find an increase in detection rate between 'control' and 'burn' treatments, indicates that the combination of thinning and burning impacts habitat quality differently than thinning or burning alone.

There is a variation in foraging behavior by birds that occurs: between years in ponderosa pine ecosystems (Szaro et al. 1990); between months for other bark-gleaning birds (Hejl and Verner 1990); between stages of the breeding cycle (Sakai and Noon 1990) and; between sexes (Grubb and Woodrey 1990, Hanowski and Niemi 1990), ages, or dominance status of the birds (Grubb and Woodrey 1990). The research reported in this thesis was not designed to take into account these variations. Models with greater complexity than those presented here may capture more of the error inherent in each model. For example, density estimates alone without a measure of individual reproductive success or survivorship, fail to differentiate high-quality territories from ecological sinks that are attractive to low-quality or first-year breeding pairs (Smallwood 2001). An analysis of nesting abundance and success is necessary to determine whether the frequency of encounters of foraging individuals was due to foraging habitat alone, or nesting habitat differences between treatments.

3. The effects of restorative treatments in ponderosa pine on nesting ecology of Red-breasted (*Sitta canadensis*) and Pygmy (*Sitta pygmaea*) Nuthatches

3.1. Abstract

*Fire exclusion, logging, and other management practices have changed the composition and structure of historic ponderosa pine (*Pinus ponderosa*) ecosystems. As a result, ponderosa pine habitats are now more susceptible to stand-replacing fire. Mechanical thinning and prescribed burning have both reduced the risk of crowning fire when applied to forests; however, their effects on avian nesting ecology are poorly understood. Three restorative treatments ('thin', 'burn', and 'thin and burn') and 'control' were applied to ponderosa pine forests within northeastern Oregon. The effects of these restorative treatments upon the daily nest survival, nest density, and nest structural characteristics of Red-breasted (*Sitta canadensis*) and Pygmy (*S. pygmaea*) Nuthatches were determined by finding and monitoring nests and comparing differences among treatments and controls. The success of Red-breasted Nuthatch nests was not significantly different among treatment types. Models of nest survival containing diameter of the nest tree, nest height, and canopy cover performed poorly. Models of daily nest survival that included structural characteristics of nest trees of Pygmy Nuthatches did not perform better than a constant estimate of daily nest survival. There were fewer nests of Red-breasted Nuthatches within 'thin and burn' treatment units than were expected. Red-breasted Nuthatches nested within snags that had less canopy cover and more snags within an 11.3 m radius. Pygmy Nuthatches nested within snags with a larger diameter than that most commonly available. Further research on nesting behavior that incorporates provisioning rates, fecundity, or settling date of territories may improve our understanding of the effects of restorative treatments on the nesting ecology of nuthatches.*

3.2. Introduction

Fire suppression initiatives within North America, combined with logging, grazing, and other forest management practices, have contributed to the loss of ecosystems with historic fire-regimes that were high-frequency and low-severity, such as ponderosa pine ecosystems (Allen et al. 2002; Brown et al. 2004). Increased fire-return intervals within these western forests have created forests that are more dense and uniform in their stem dispersion (Mast et al. 1999), and have fewer large old trees and more small young trees (Swetnam 1990, Mast et al. 1999). These changes in forest composition and structure have shifted the fire regime from frequent understory fires to infrequent, crowning wildfires to which ponderosa pine forests and their associated organisms are not adapted (Agee 1996). Mechanical thinning and prescribed burning have both been responsible for decreasing fire intensity when they are applied to ponderosa pine forests (Pearson et al. 1972, Pollet and Omi 2002). Restoration methods will vary according to the extent of deviation from reference (historic) conditions, and other factors such as economic interests and climate change (Moore et al. 1999).

The effects of various restorative treatments within ponderosa pine on biological aspects of ecosystem function, such as avian nesting dynamics, are poorly understood. Maintaining a population of primary cavity-nesting birds ensures the creation of suitable nesting and roosting habitat for a number of cavity-dwelling bird and mammal species (Bate et al. 1999, Aitken et al. 2002). Each excavating species tends to create cavities with different qualities (depth, entrance width, volume, height on bole, distance to edge habitat edge, decay type and extent, etc). Therefore, the diversity of cavity-excavators can influence the diversity of secondary-cavity-nesters in an ecosystem (Brawn and Balda 1988a). Three species of cavity-excavator present within the Blue Mountains of Oregon are nuthatches: White-breasted (*S. carolinensis*), Red-breasted, and Pygmy. Few studies have documented the effects of restorative treatments on the nest-site selection and nest density of nuthatches. The objectives of this research are to 1) compare the density of nuthatch nests among control and restorative treatments, 2) model daily nest survival among restorative treatments and control units for Red-breasted Nuthatches, and 3) report on the nest-site structural characteristics of nest trees used by Pygmy and Red-breasted Nuthatches within ponderosa pine forests of northeastern Oregon.

3.3. Methodology

3.3.1. Study Site

The Hungry Bob study site was located in the Blue Mountains of northeastern Oregon, within the Wallowa-Whitman National Forest (45° 37' N, 117° 15' W). Please see section 1.4. for a detailed description of the Hungry Bob site.

3.3.2. Treatments and Study Units

Four treatments were included in the study design (prescribed burning only -'burn', mechanical thinning only -'thin', mechanical thinning followed by prescribed burning -'thin and burn', and no treatment - 'control'). Four replicates of each treatment were created, totaling 16 experimental units. For more details about the placement of treatments, please see section 1.4.

3.3.3. Nest-site Preferences

Twelve experimental study units were randomly selected in which to search for Pygmy and Red-breasted Nuthatch nests during 2003 and an additional 3 in 2004. Research was conducted during the breeding season of nuthatches at the latitude of the study sites, which was typically from the beginning of May through the end of July. Field research began by the 21st of April and ended when all known nests had fledged or failed.

All snags within each unit were searched for cavities. Upon discovery of a cavity, the snag was monitored for at least 30 minutes at least once per week for the first month of the breeding season. Also, research units were walked systematically twice per week for 2-3 hours at a time. If a bird exhibiting nesting behavior (i.e., holding food in its bill, collecting lichen or twigs, dumping shavings from its bill) was observed, it was followed back to its nest (Martin and Geupel 1993). Also, excavation noises and territorial songs were followed within areas where nests had not been discovered.

Nest monitoring methods were based on techniques standardized by the Breeding Bird Field Protocol (BBIRD) established in 1997 by the Institute of Bird Populations observed (Martin et al. 1997), and modified according to Dudley and Saab (2003). Nests were watched once every 3 days for 45 minutes, or until nest activity was confirmed. Behavioral cues that were used to confirm nest activity included an adult bird bringing food to the nest and leaving without it, or hearing begging of nestlings within the nest cavity. If no activity was seen at a nest, it was visited an additional 3 times before nest fate (fledge or failure) was declared. Nest fating decisions were made according to standards set forth by Martin et al. (1997). In example, if the nest was estimated to be within 2 days of fledging between the last two visits to the nest, and the nest was empty on the last nest check, the nest was assumed to have fledged young.

To minimize the risk of observer-induced depredation of nests, some precautions were taken according to the advice of Martin and Geupel (1993). The observers immediately moved away from the nest if met with agitation from the parent birds during nest-checks. Flagging marking the nest-check location was then placed more distantly to prevent the same stress during subsequent nest checks. See Figure 3.1 as an example of a nest-observation location. The observer moved away from the nest upon sight of a nest predator. A quick check for nest predators was conducted before attempting to approach or check a nest. A comment was written whenever an observer saw a nest predator within the same tree as a nest. Observers never left a dead-end trail to any nest, or even a nest observation site. A different route away from the nest was used on each visit whenever possible.

Once the fate of each nest was established (i.e., fledge or failure), an 11.3 m radius (0.04 ha) was surveyed around the nest to determine microhabitat characteristics. Vegetation data were gathered based on methods used by James and Shugart (1970) and Noon (1981), and revised according to Anderson and Crompton (2002). Species, height category, and diameter category of all trees greater than 1.3 m in height were recorded. The density of canopy cover was estimated using an ocular tube. At all nest sites, measurements of canopy cover were taken along two transects, one running east from the nest tree and one running north from the nest tree (these compass points were selected randomly at the start of the season). One measurement was taken with the ocular tube every 2nd m along each transect, which yielded 6 measurements. Height, diameter at breast height (dbh), and decay class (Bull et al. 1997) of all snags within the survey area (including the nest tree) were quantified.

Figure 3.1: Example of a typical nest observation site on the Hungry Bob research units. The nest is indicated by a white arrow. The picture was taken with a 35mm lens from the nest observation location.

To make a comparison between the snags that were chosen for nesting and the snags available within each treatment unit, a survey of snags was conducted. All snags located within each treatment unit within decay classes two and three and over 11 cm in diameter were surveyed in the same manner as nest trees. Trees within these structural parameters were the most likely to be used as nest-sites by nuthatches (Ghalambor and Martin 1999). This method allowed comparisons of available snags among treatment units (Martin and Li 1992, Sherry and Holmes 1992), which aided in connecting nest usage to specific structural characteristics on the nest-tree and microhabitat scale (Martin 1988, Knopf et al. 1990, Ralph et al. 1993).

3.3.4. Analysis

Daily nest survival rates of Red-breasted Nuthatch nests were calculated using logistic exposure models (Shaffer 2004). All continuous variables that were hypothesized to influence the nest success of cavity-nesting birds (treatment, dbh of the nest tree, nest height, and average canopy cover within 6 m of the nest tree) were modeled separately because of sample size limitations. Daily survival estimates were linked to covariate measures using a logit link, which is most appropriate for binomial distributions such as nest survival (Rotella et al. 2004). Akaike's Information Criterion adapted for small sample sizes (AICc) was used in order to select the best-fitting of the candidate models (Hurvich and Tsai 1989, Burnham and Anderson 2002, Table 3.1). Unlike the Mayfield method (Johnson 1979), logistic exposure analysis allows each nest to have unique covariate values and permits variability in daily nest survival.

Chi-square goodness-of-fit tests were used to compare the total number of nests of Red-breasted Nuthatches among treatments and then to compare the number of potential

Table 3.1. Candidate models to predict the structural characteristics of snags that nuthatches nested within.

Model Number	Factors Included
1	(global) height + canopy cover + diameter + decay class + # of snags
2	height + canopy cover + diameter
3	diameter + decay class
4	# of snags + diameter
5	intercept

nesting snags among treatments (Siegel and Castellan 1988). Nonparametric tests were used because these count data were not normally distributed.

Nest-site structural characteristics and microhabitat measurements of nest-trees and non-nest-trees were compared using logistic regressions in order to determine which variables were important in separating nest snags from non-nest snags (Agresti 1990, Trexler and Travis 1993, Steeger and Hitchcock 1998). Candidate models were developed based on what the literature has shown affects cavity-nesting birds' choice of nest site (Table 3.1). Cavity nests placed higher with little canopy cover around them are depredated less often (Rendell and Robertson 1989, Pingjun and Martin 1991). Nests in a more advanced state of decay and with a larger diameter are easier to excavate (Swallow et al. 1986). Cavity-nests placed within trees surrounded by other snags provide a choice of nesting locations within a single territory. Diameter is nearly always an important factor in nest-location for cavity-nesting birds, so it is included within all models (Harestad and Keisker 1989, Dobkin et al. 1995). Candidate models were compared using Akaike's Information Criterion corrected for small sample sizes (AICc, Hurvich and Tsai 1989, Burnham and Anderson 2002). Predictive ability of models were assessed using reciever operating characteristic (ROC) scores (Zweig and Campbell 1993). Models with ROC scores exceeding 0.70 were considered useful models (Swets 1988, Manel et al. 2001).

Analyses were run using SPSS (Version 14, 2005), MINITAB (Version 14, 2003), and SAS (Version 9.1.3, 2003). Post-hoc multiple comparisons for Kruskal-Wallis tests were done using methods described in Siegel and Castellan (1988). The alpha level for each test was set at 0.05. Cases with standardized residuals >2.58 or <-2.58 and Cook's distance of < 1 were eliminated as outliers within analyses.

3.4. Results

A total of 67 Red-breasted Nuthatch and 13 Pygmy Nuthatch nests were found in the 2 breeding seasons of the study. Rigorous definitions for nest fating decreased the samples used in modeling daily nest success to 15 Red-breasted Nuthatch nests and 11 Pygmy Nuthatch nests. Of the nests used in the analysis, 5 Red-breasted and 3 Pygmy Nuthatch nests failed during the course of nest monitoring. The constant daily nest survival rate of Red-breasted Nuthatches and Pygmy Nuthatches at the Hungry Bob research units was 0.993. Models with single continuous variables performed as well as the constant estimate of daily nest survival of Red-breasted Nuthatches (Delta AICc < 2, Burnham and Anderson 2000; Table 3.2). Snags with a greater dbh, greater canopy cover, and higher nests tended to have higher daily nest survival (Table 3.3, Figures 3.2-3.4). Small sample sizes prohibited the analysis of treatment type in modeling daily nest survival for Pygmy Nuthatches. The model containing canopy cover performed as well as the constant daily survival estimate for Pygmy Nuthatches in the Hungry Bob research area (Logistic exposure, N=358, AICc=80.073, Table 3.4). Daily survival of Pygmy Nuthatch nests tended to decrease with increased canopy cover (Table 3.5, Figure 3.5).

There was a difference in the number of Red-breasted Nuthatch nests found in each treatment (chi-square goodness-of-fit test, df=3, $\chi^2 = 8.353$, $p<0.05$; Figure 3.6). Post-hoc comparisons of the chi-square values indicated that fewer nests were found within ‘thin and burn’ treatment units than were expected (Sokal and Rohlf 1994). Sample sizes were insufficient to compare the number of nests of Pygmy Nuthatches among treatment types (Fig. 3.7). The number of snags available and superficially appropriate for excavation by

Table 3.2. Information criteria of candidate models used to model daily nest survival of Red-breasted Nuthatches within Hungry Bob.

Model Number	Parameters Included	AICc	Δ AICc	Akaike Weight
1	intercept	26.948	0.000	0.333
3	diameter of nest tree	27.580	0.633	0.243
2	nest height	28.216	1.269	0.177
4	canopy cover around nest tree	28.905	1.958	0.125
5	treatment	28.949	2.002	0.122

Table 3.3. Parameter estimate (PE), standard error (SE), and 95% confidence intervals (CI) of nest-tree structural variables in predicting nest success for Red-breasted Nuthatches.

Variable	PE	SE	Lower 95% CI	Upper 95% CI
Intercept	5.021	0.449	4.142	5.901
Diameter	0.105	0.067	-0.026	0.236
Canopy Cover	0.010	0.026	-0.042	0.062
Height	0.153	0.137	-0.116	0.422
Treatment	-0.236	0.916	-2.031	1.559

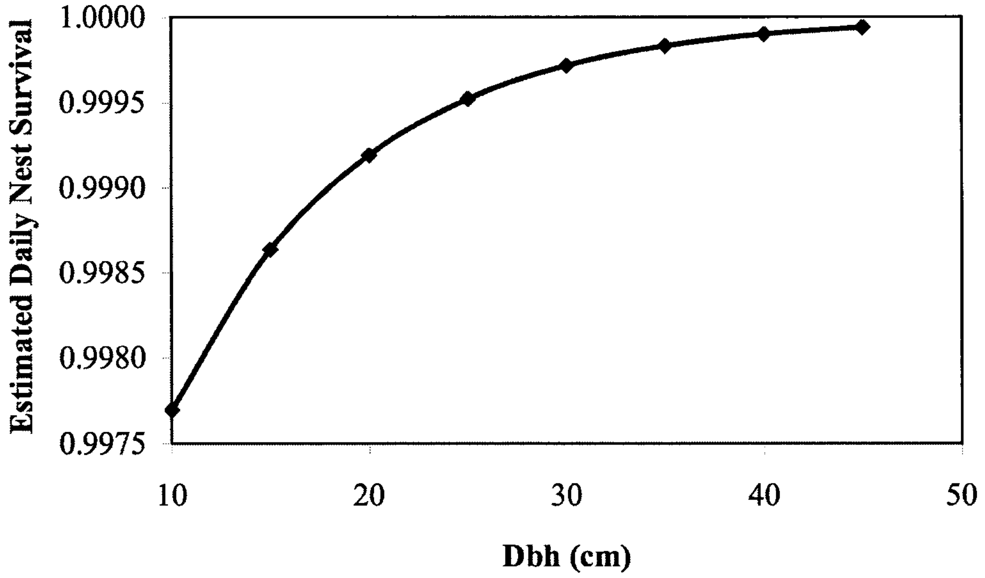

Figure 3.2: Daily nest survival of Red-breasted Nuthatches increased as diameter increased.

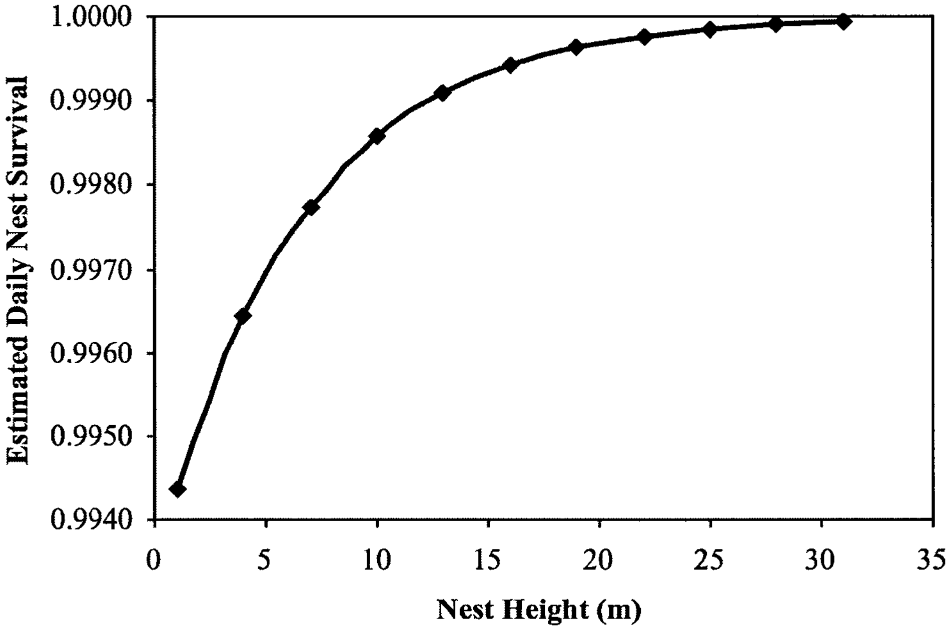

Figure 3.3: Daily nest survival of Red-breasted Nuthatches increased as nest height increased.

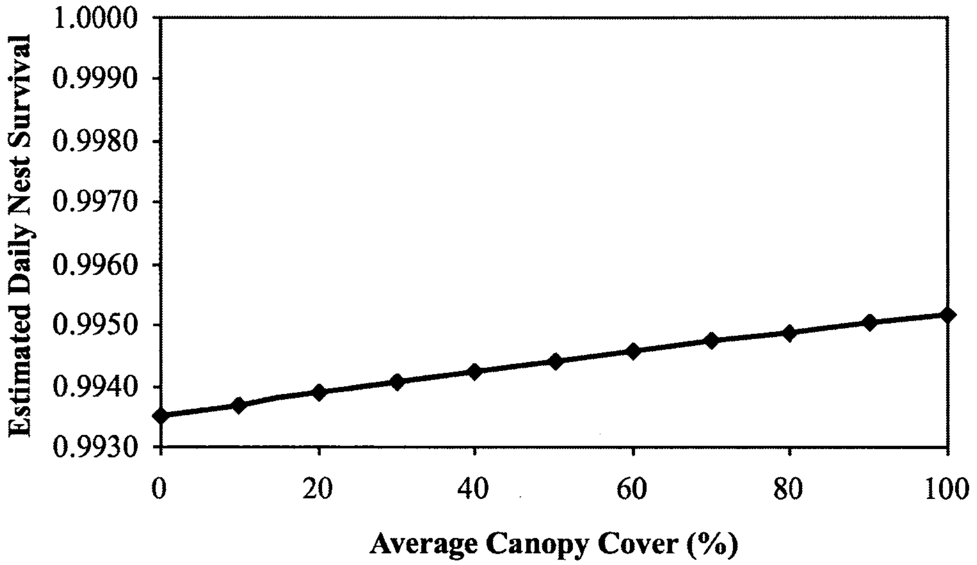

Figure 3.4: Daily nest survival of Red-breasted Nuthatches increased as canopy cover increased.

Table 3.4. Information criteria of candidate models used to model daily nest survival of Pygmy Nuthatches within Hungry Bob.

Model Number	Parameters Included	AICc	Δ AICc	Akaike Weight
1	(null) intercept	16.102	0.000	0.433
4	canopy cover around nest tree	17.186	1.084	0.252
3	diameter of nest tree	18.103	2.001	0.159
2	nest height	18.139	2.037	0.156

Table 3.5. Parameter estimate (PE), standard error (SE), and 95% confidence intervals (CI) of nest-tree structural variables in predicting nest success for Pygmy Nuthatches.

Variable	PE	SE	Lower 95% CI	Upper 95% CI
Intercept	4.879	0.580	3.683	5.955
Canopy Cover	-0.058	0.043	-0.142	0.026
Diameter	-0.016	0.043	-0.101	0.069
Height	-0.027	0.104	-0.231	0.177

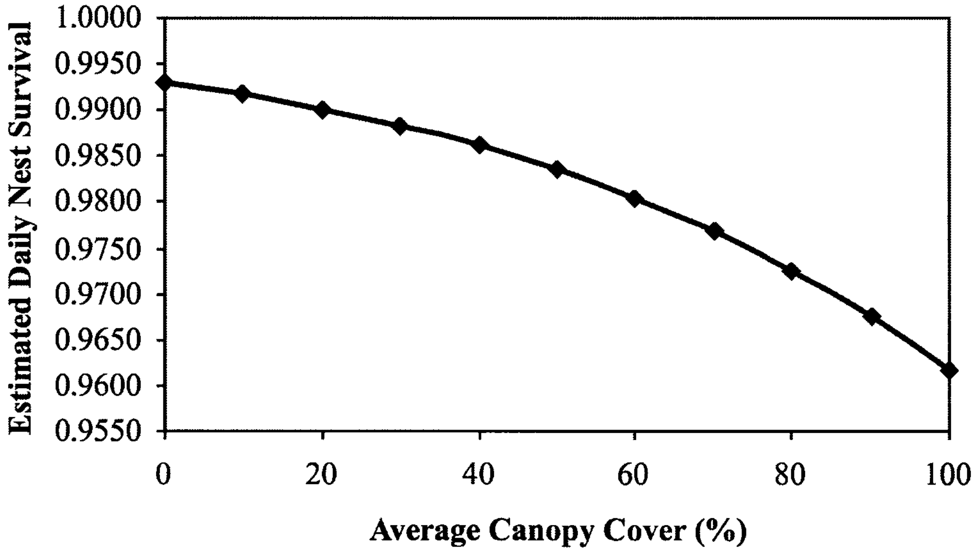

Figure 3.5: Daily nest survival of Pygmy Nuthatches tended to decrease as canopy cover increased.

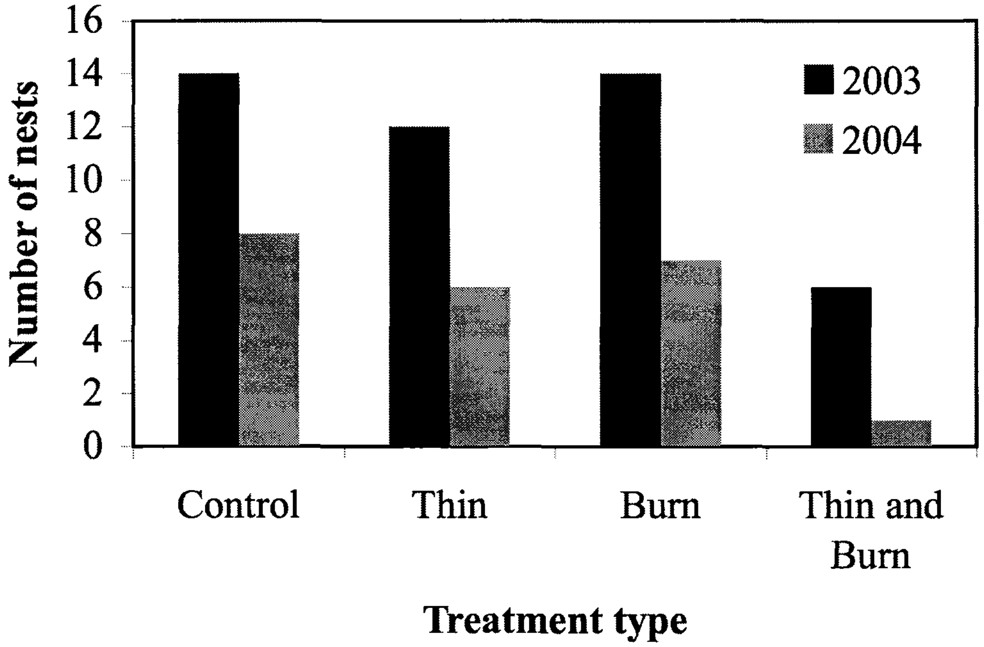

Figure 3.6: The number of nests of Red-breasted Nuthatch found within each treatment type and each year.

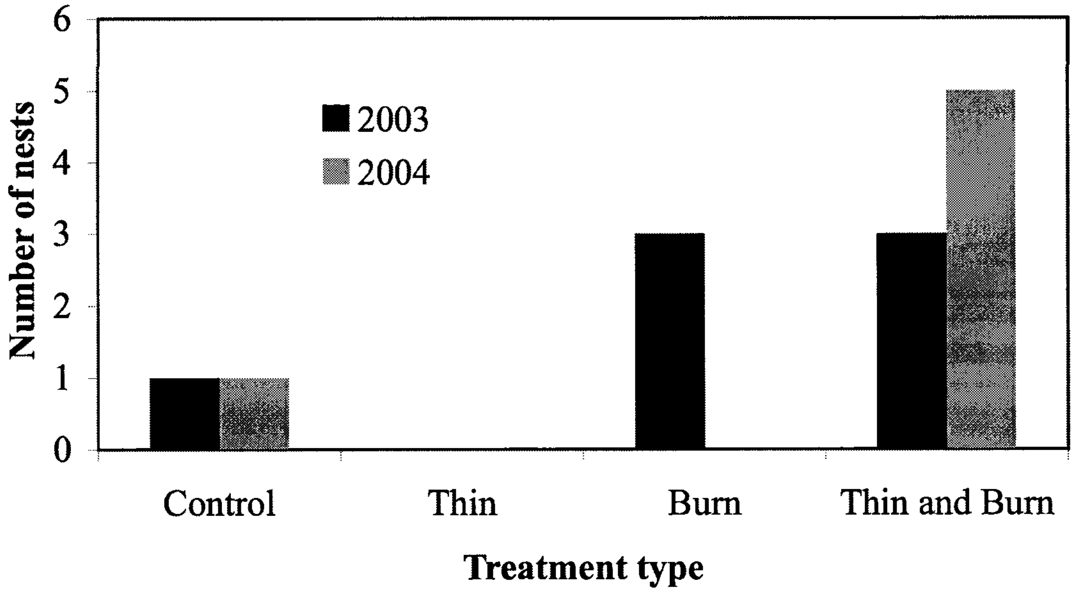

Figure 3.7: The number of Pygmy Nuthatch nests found within each treatment type and each year.

nuthatches was different among treatment types (chi-square goodness-of-fit test, df=3, χ^2 = 13.559, $p<0.05$; Table 3.6); fewer snags were found within ‘thin and burn’ units, and more snags were found within ‘burn’ treatments, than expected.

Logistic regression models were able to use structural variables and microhabitat characteristics to predict which trees would be used for nesting by Red-breasted Nuthatches (Logistic regression, N=144, χ^2 = 127.682, $p<0.001$; Table 3.7). The model had acceptable predictive accuracy (ROC = 0.762). Snags with nests of Red-breasted Nuthatches had less canopy cover and more snags within 11.3 m than snags without nests (Table 3.8). No other variables were significant within the model. Logistic regression models were able to use structural variables and microhabitat characteristics to predict which trees would be used for nesting by Pygmy Nuthatches as well (ROC model 4 = 0.812, ROC model 2 = 0.867; Table 3.9 and 3.10; Figure 3.8).

3.5. Discussion

The number of nests of Red-breasted Nuthatches differed among treatments (Fig. 3.6). This does not agree with research in prescribed burns in southeastern Arizona, where the nest-density of Red-breasted Nuthatches did not differ between treated areas and controls (Horton and Mannan 1988). There were about half as many snags with characteristics most likely to provide suitable nesting habitat (decay classes 2-4 and >11 cm dbh) in ‘thin and burn’ treatment units than in any other treatment or control (Table 3.6). Competition for nest sites might be more significant for cavity nesters than selection between possible nest-sites when the resource is limiting (Martin et al. 2004).

Table 3.6. The number of snags within decay classes 2, 3 or 4 and over 11 cm in diameter within each treatment type.

	Control	Thin	Burn	Thin and Burn
# of Snags	40	37	48	18

Table 3.7. Information criteria of candidate models to predict the structural characteristics of snags that Red-breasted Nuthatches nested within.

Model	Parameters Included	*p*-value	AICc	Δ AICc	Akaike Weight
1	(global) height + canopy cover + diameter + decay class + # of snags	<0.001	140.295	0.000	0.999
3	diameter + decay class	0.047	153.941	13.646	0.001
2	height + canopy cover + diameter	0.042	157.488	17.193	0.000
4	# of snags + diameter	0.091	158.776	18.481	0.000
5	(null) intercept		159.436	19.141	0.000

Table 3.8. Parameter estimate (PE), standard error (SE), and *p*-value of nest-tree structural variables in predicting which snags were used for nesting by Red-breasted Nuthatches.

Variable	PE	SE	Wald	*p*-value
Canopy Cover	-0.053	0.016	11.140	0.001
# Snags	0.183	0.054	11.715	0.001
Decay Class			6.742	0.081
Decay Class 1	1.275	1.229	1.077	0.299
Decay Class 2	2.179	1.124	3.756	0.053
Decay Class 3	1.041	1.073	0.941	0.332
Height	0.040	0.047	0.722	0.396
Diameter	0.009	0.022	0.171	0.679

Table 3.9. Information criteria of candidate models to predict the structural characteristics of snags that Pygmy Nuthatches nested within.

Model	Parameters included	*p*-value	AICc	Δ AICc	Akaike Weight
4	# of snags + diameter	0.018	35.521	0.000	0.624
2	height + canopy cover + diameter	0.031	37.470	1.949	0.236
5	(null) intercept		38.659	3.138	0.130
1	(global) height + canopy cover + diameter + # snags	0.061	43.696	8.174	0.010

Table 3.10. Parameter estimate (PE), standard error (SE), and confidence interval (CI) of nest-tree structural variables in predicting which snags were used for nesting by Pygmy Nuthatches. * Indicates a variable that appeared within more than one model, so all information has been derived from model averaging.

Variable	PE	SE	Lower 95% CI	Upper 95% CI
*Diameter	0.065	0.033	0.130	0.001
Canopy Cover	0.007	0.038	0.081	-0.067
Height	0.071	0.081	0.230	-0.088
# Snags	0.066	0.144	0.348	-0.216

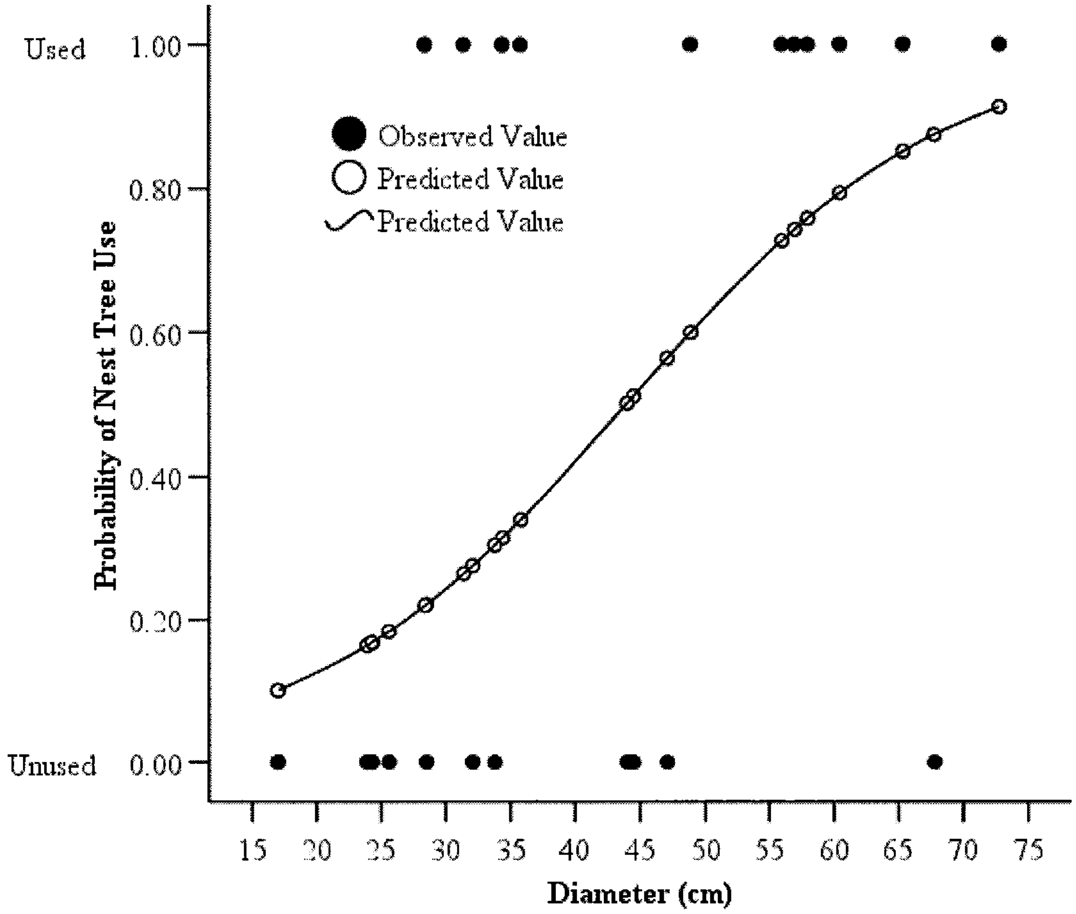

Figure 3.8: The probability of a snag being used for nesting by Pygmy Nuthatches increased as the diameter (cm) of the snag increased. The y-axis represents both the observed value of nest use and the value predicted by the logistic regression model.

Though not statistically significant, no nests of Pygmy Nuthatches were found in 'thin' treatment units (Fig. 3.7). Thinning has decreased numbers of Pygmy Nuthatches in other areas as well (Hejl 1994). Pygmy Nuthatches are more restricted in their habitat requirements than Red-breasted Nuthatches, yet they occupy more diverse nest-sites (McEllin 1979, Brawn 1987, Wisdom et al. 2000). Pygmy Nuthatches were often able to excavate the bark layer of ponderosa pine and nest between the loose bark and the bole of the tree within the Hungry Bob research units. They were also found within natural cavities, while Red-breasted Nuthatches occupied only excavated cavities at Hungry Bob.

Density estimates alone without a measure of individual reproductive success or survivorship fails to differentiate high-quality territories from ecological sinks that are attractive to low-quality or first-year breeding pairs (Smallwood 2001). There was no difference in daily nest survival of Red-breasted Nuthatches in different treatment types (Table 3.2). Similarly, nest success was not influenced by thinning in mixed conifer stands in the Sierra Nevada (Siegel and DeSante 2003) or pine stands in Arkansas (Barber et al. 2001).

Daily survival of nests of Red-breasted Nuthatches tended to increase as diameter of the tree (Fig. 3.2) and height of the nest (Fig. 3.3) increased. Other studies have documented higher success with these characteristics as well (Pingjun and Martin 1991, Christman and Dhondt 1997, Spiering and Knight 2005). Daily nest survival tended to increase with increased average canopy cover around the nest-site for Red-breasted Nuthatches (Fig. 3.4). This association has been seen for open-cup nesters, however, cavity-nesting species generally rely on vigilance to prevent nest failure due to depredation and so usually prefer less cover around the nest-site (Martin and Roper 1988, Nilsson 1984, Finch 1989, Li and

Martin 1991). Daily survival of Pygmy Nuthatch nests showed the opposite trend with respect to canopy cover, as their success tended to decrease with increased canopy cover (Fig. 3.5). Pygmy Nuthatches are sensitive to stand-level canopy cover, exclusively inhabiting stands with less than 70% canopy cover on average within some areas (Balda et al. 1983, Csuti et al. 1997, Kingery and Ghalambor 2001). Associations between habitat and nest-site structure and daily nest survival were weak within Hungry Bob, however, and all 95% confidence intervals of parameter estimates included zero. Martin (1998) found that birds were selective in nest placement, and nests within areas with habitat structures that were most often used by the birds were more successful than nests placed in other areas.

Microhabitat often differs between nest trees and non-nest trees of cavity-nesting species (Li and Martin 1991, Lundquist and Mariani 1991, Adkins-Giese and Cuthbert 2003). Snags were more likely to be used as nest-sites by Red-breasted Nuthatches as cavity-cover decreased (Table 3.8). Although dense vegetation is important in avoiding nest predation for cup nesters, cavity nesters rely more on nest defense than on nest concealment (Martin 1992). Failed nests tended to have more canopy cover (Li and Martin 1991). Therefore, cavity nesters may prefer nest sites that are more open and less concealed by vegetation (Belles-Isles and Picman 1986, Finch 1989, Li and Martin 1991, Lawler 1999). Cavity-nesters often choose nest-sites among clusters of snags rather than snags surrounded by live trees (Swallow et al. 1986, Lundquist and Mariani 1991, Martin 1998). The association between the number of snags around potential nest trees and nest placement was significant at Hungry Bob for Red-breasted Nuthatches as well (Table 3.8). Trees with larger diameters were more likely to be used as nest-sites by Pygmy Nuthatches (Fig. 3.8). Preference by cavity-nesting birds for large diameter snags has been extensively documented, and has been proposed to be due to a greater proportion of sapwood which is softer for excavation as well as increased wall thickness which makes predator entry more difficult (Bull et al. 1997).

There was no difference in daily nest survival or nest density to support the hypothesis that habitat quality differed for Red-breasted Nuthatches between restorative treatment units and control units. However, 'thin and burn' units had the least amount of snags (Table 3.6). Density of Red-breasted Nuthatch nests has been correlated with snag density in other studies (Swallow et al. 1986, Steeger and Hitchcock 1998). There may have been a preference for 'thin and burn' treatments that was masked by limited nest-sites. Comparison of fecundity of nuthatch nests among treatment types may have shown differences in habitat quality that were more subtle than binary measures of nest success.

Pygmy Nuthatches are excellent indicators of ecosystem health within ponderosa pine owing to their preference for mature, heterogeneous, and open stands (Diem and Zeveloff 1980, Szaro and Balda 1982). The Pygmy Nuthatch is classified as a sensitive species within the Blue Mountains of Oregon and is listed on conservation watch lists in Colorado, Montana, and Wyoming because of habitat loss (Webb 1985, Clark et al. 1989, Luce et al. 1997, US Fish and Wildlife Service 2002, Idaho Bureau of Land Management 2003). As a result, Wisdom et al. (2000) recommended restoration within ponderosa pine habitats after a thorough analysis of the effects of treatments upon Pygmy Nuthatches. Habitat quality for Pygmy Nuthatches may be increased by a combination of restorative thinning and burning within ponderosa pine ecosystems. Thinning alone may be detrimental to the species. Pygmy Nuthatches were less common within Hungry Bob than Red-breasted Nuthatches. For this reason, a larger study area or more years of research are needed in order to compare daily nest survival among treatment types. This could reveal the reasons behind decreased nesting density within the ‘thin’ treatment units.

4. General Discussion

4.1. The Effects of Restorative Treatments within Ponderosa Pine on Nuthatches

Pygmy Nuthatches (*Sitta pygmaea*) appear on state conservation watch lists across the western United States (Webb 1985, Clark et al. 1989, Luce et al. 1997, US Fish and Wildlife Service 2002, Idaho Bureau of Land Management 2003). Silvicultural and burning treatments that restore ponderosa pine (*Pinus ponderosa*) as the dominant tree species need to be evaluated as part of a conservation effort for Pygmy Nuthatches as well as other birds closely associated with ponderosa pine habitats, such as the White-headed Woodpecker (*Picoides albolarvatus*; Wisdom et al. 2000). Pygmy Nuthatches and White-breasted Nuthatches (*S. carolinensis*) were encountered least frequently in 'thin' units and 'control' units, respectively. Sample size of nests for both species of nuthatch were too small to determine statistically whether nest density followed the same pattern. Pygmy Nuthatches, however, had no nests in 'thin' units. The preference of Pygmy Nuthatches for open stands (Balda et al. 1983, Csuti et al. 1997, Kingery and Ghalambor 2001) cannot explain their absence in 'thin' units. Both 'control' and 'burn' areas had a similar or greater amount of canopy closure (Table 2.18). A strong preference for large diameter trees was exhibited by Pygmy Nuthatches by both their foraging and nesting behavior (Figs 2.5 and 3.8). The largest trees were found in 'burn' and 'thin and burn' treatment units (Fig. 2.18).

The encounter rate and nest density of Red-breasted Nuthatches (*S. canadensis*) was consistent among treatments. There were fewer snags within 'thin and burn' units. Most cavity-nesting bird densities are positively correlated with the number of snags within an area, especially when snags are limiting (Hejl et al. 1995, Beese and Bryant 1999, Chambers et al. 1999, and Machmer 2002). Nest-sites may be limiting within this area of the Blue

Mountains (Rothenbach and Opio 2005), so the reduced snag numbers within the 'thin and burn' explains the reduced Red-breasted Nuthatch nest density. Red-breasted Nuthatches spent significantly more time on each tree in 'thin and burn' units than any other unit, indicating that food may be more abundant or desirable within stands treated with thinning and burning (Morrison et al. 1989).

None of the species spent a different proportion of their time actively foraging between treatments. This result is hard to interpret because nuthatches are known to cache their food, and cache far more than they eat in one day (Grubb and Waite 1987). Food might not have been limiting within this system, as has been shown for other ponderosa pine forests (Brawn et al. 1987). If this is the case, nuthatches may allocate a consistent proportion of their time in foraging, and cache any extra food that is captured during the day.

Pygmy Nuthatches serve as excellent indicators of ecosystem health within ponderosa pine owing to their near exclusive residence within mature, heterogeneous, and open stands (Diem and Zeveloff 1980, Szaro and Balda 1982). Thinning and burning, when applied together, seem to increase habitat quality for nuthatches. Burning and thinning, when applied separately, seem to alter habitat little for White-breasted and Red-breasted Nuthatches, and may decrease habitat quality for Pygmy Nuthatches. In light of the results of this research, restorative treatments that use a combination of thinning and burning may be beneficial to Pygmy and White-breasted Nuthatches.

4.2. Future Research

The behaviors of foraging birds vary across time within ponderosa pine ecosystems (Hejl and Verner 1990, Szaro et al. 1990), among stages of the nesting cycle (Sakai and Noon 1990), and even among birds within differing social structures and dominance hierarchies (Grubb and Woodrey 1990, Hanowski and Niemi 1990). The research reported in this thesis was not designed to take into account these variations. Models with greater complexity than those presented here may capture more of the error inherent in the assumptions of each model taken separately. For example, density estimates alone without a measure of individual reproductive success or survivorship fails to differentiate high quality territories from ecological sinks that are attractive to low-quality or first-year breeding pairs (Smallwood 2001).

There were many facets undertaken at the beginning of this research that could have added to the interpretation of the results, but were not pursued further because of financial and time constraints. For example, the analysis of nest density could have been augmented by an analysis of territory size. Nest density can be a comparative measure of territory size, so long as birds are located consistently across the landscape (Krebs 1971). This was not the case with Pygmy and White-breasted Nuthatches. A direct measurement of territory size can be an excellent indication of habitat quality, especially when combined with foraging analyses (Brooker and Rowley 1995). This would have to be accomplished with a longer term study so that a population of birds could be banded during the winter months. Mist-netting using call-playback methods had a very low rate of success during the breeding season. Also, fecundity measurements could have added the ability to differentiate between source and sink areas in Hungry Bob (Brawn and Robinson 1996). A peeper camera was purchased in order to compare fecundity between treatments, but it was unsuccessful, so other methods would have to be used to obtain those data in future studies.

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