Habitat Preferences of Primary Cavity Excavators in Washington's East Cascades[1]

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Abstract

Primary cavity excavator (PCE) bird densities and habitat preferences in relation to forest management treatments and snag characteristics were investigated in grand fir forests of eastern Washington. PCE birds selected large diameter, broken top snags for feeding and nesting. They selected western larch and Douglas-fir for feeding excavations and ponderosa pine and Douglas-fir for nest cavity snags. Grand fir were also utilized as available on managed plots. Soft snags with advanced wood decay were particularly important for nest sites. Species composition of PCE birds varied significantly in different forest management treatments, with unique species groups associated with unmanaged and heavily managed sites. Total population densities of PCE birds were most closely associated with snag density, particularly large diameter snags (> 25 cm DBH).

Introduction

Dead wood, particularly standing dead trees (snags) or down logs, is important habitat for many species in forest ecosystems. Primary cavity excavator (PCE) birds, best represented by woodpeckers, use this dead wood extensively. These species excavate hollow cavities in tree stems, usually in dead and decayed wood, as a part of regular nesting and courtship behavior. These cavities are critical for life history needs of other species of birds and mammals, known as secondary cavity users. Thus, PCE birds can be considered "keystone species" in forest ecosystems, because many other species of forest wildlife are dependent on them for cavities (Wilson 1992).

Characterizing snags selected by PCE birds in any given forest type can provide important basic information for biologists and land managers. This information was unavailable for grand fir *(Abies grandis)* stands in Washington's East Cascades, a major vegetation type in this region, prior to the initiation of our project.

Previous research suggests that important attributes of snags selected by PCE birds in coniferous forests of the western United States include large diameters, advanced decay, and broken tops (Raphael and White 1984, Zarnowitz and Manuwal 1985). Snag abundance has been hypothesized as a limiting factor for PCE populations. A model for predicting "potential population" levels of cavity

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excavating birds based upon numbers of available snags and nesting territory sizes (Thomas and others 1979) has been used extensively as a forest management guideline in the Pacific Northwest. This model assumes a direct relationship between PCE bird and snag abundance. Our study examined the relationship between snags and PCE bird densities in grand fir forests.

Questions we sought to answer with our study included: 1) What are the characteristics of snags selected by PCE birds for feeding and nest cavity excavation? 2) How does PCE species composition and abundance differ among forest management treatments? 3) What habitat variables best predict the abundance of PCE birds across a series of forest management treatments?

Methods

The research was conducted 6 km south of Cle Elum, Washington, in and adjacent to the central portions of the Taneum Creek basin *(fig. 1).* Lands in the study area are owned and managed either by the USDA Forest Service or the Plum Creek Timber Company. Forest conditions in this basin range from recent clearcuts to late-seral mixed-conifer stands.

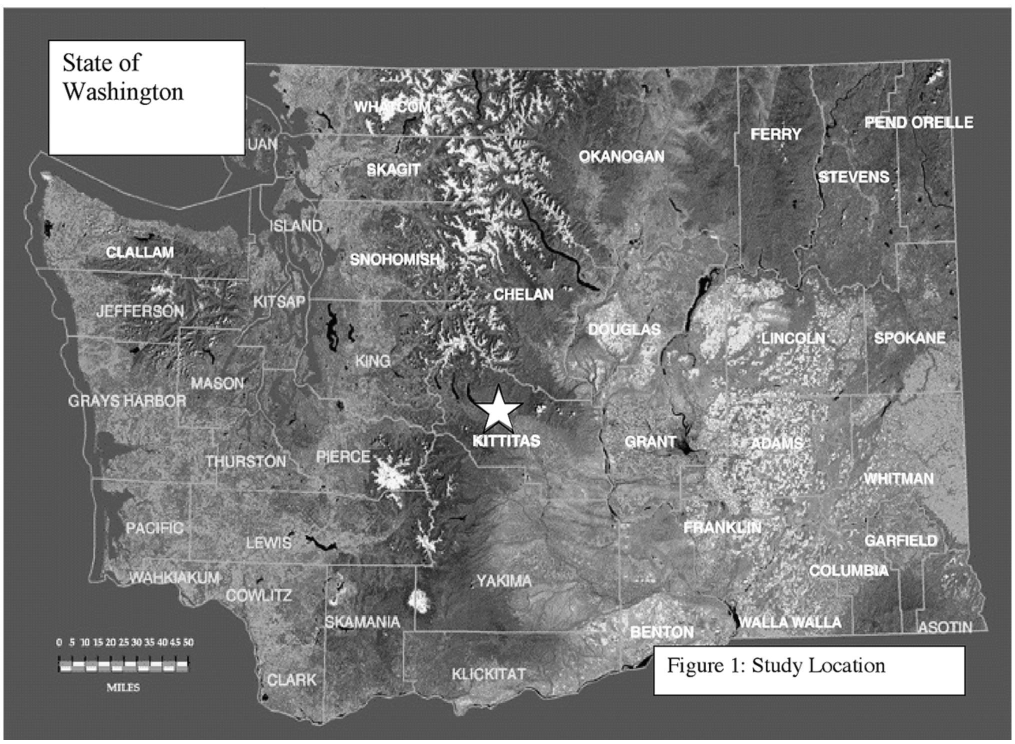

Figure 1—Study location.

Forest Management Treatments

Three plots—Gooseberry, North Fork, and South Fork—were characterized as unmanaged forest habitats. There was no evidence or record of historic logging activity on these sites. Unmanaged stands had heterogeneous overstories of large Douglas-fir and western larch, with understories of predominantly grand fir. Patches of even-aged co-dominant lodgepole pine and Douglas-fir also occurred. These areas were structurally heterogenous due to past fires and other natural disturbances.

Two plots, Taneum and Tillman, were characterized as dense shelterwood habitats where recent logging removed most of the dominant overstory trees and thinned the remaining co-dominant trees between 1983 and 1987. Canopy closure remained high. The residual stand consisted of predominantly Douglas-fir, in a moderately dense stand with high canopy closure. These stands were considerably denser than typical shelterwood treatments.

Two plots, Frosty and Currant, were characterized as seed tree habitats where only a few dispersed, large Douglas-fir or western larch trees were retained after harvest. At the time of this study, the planted understory trees (Douglas-fir and larch) were less than 1 m tall, and the shrub layer was poorly developed. Grazing by domestic sheep had minimized the shrub and herbaceous layers as well. These plots were also logged between 1983 and 1987.

Plot Description

Six 15 ha and one 12 ha rectangular plots were established and sampled for habitat characteristics and PCE birds in 1991 and 1992. The 12 ha plot (Tillman) was the best available replicate of the dense shelterwood treatment. Plots were located in interior portions of large, homogenous blocks of habitat, at least 50 m from substantially different adjacent habitats. A 50 x 50 m grid was established on each plot to facilitate bird and habitat measurements.

Plots were verified as occurring within *Abies grandis* vegetation associations by using the guide, *Forested Plant Associations for the Wenatchee National Forest* (Williams and Smith 1990). All plots had a predominantly north aspect and occupied mid- to upper slope positions. All plots possessed moderate slopes and were within 350 m elevation to each other. One habitat point was measured on each ha of each study plot. Nine habitat parameters were measured on each habitat point: slope, aspect, canopy closure, live tree basal area, live tree density, snag density, live tree and snag species composition, snags selected for feeding and/or nest cavity excavation, and down wood. Slope and aspect were measured with clinometer and compass, respectively. Canopy closure was taken with a spherical densiometer. Live tree basal area was measured with a relaskop or prism. Live tree density and species composition were taken using the point quarter method (Brewer and McCann 1982) at each habitat point. Down wood was tallied using a (Brown 1974) point intercept method to the estimate the approximate tons/acre of dead wood.

All snags were tallied on 20 x 200 m (1 acre) strips within the larger rectangular study plots, at a rate of 16 percent of the total plot area. These strips were systematically located along bird transect lines on the 50 m plot grid. A snag was defined as a standing dead tree with a minimum diameter breast height (DBH) of 10 cm and a minimum total height of 2 m. This definition was based on minimum nest tree diameters and heights for chickadees, the smallest excavator species group observed in the study area (Thomas and others 1979). Recorded for each snag were tree species, DBH, total height, decay class, presence of feeding excavations, presence of nest cavities, and presence of broken tops. Decay Class was recorded using a system developed by Cline and others (1977) using five stages, or Classes, of dead wood decay. Decay Class 5 was eliminated in 1992 surveys and subsequent analyses after 1991 data indicated that very few snags were described in this category. Heavily decayed (Class 5) snags were then described as Class 4. Diameter classes for snag densities were derived from minimum nest tree diameters required for three dominant PCE bird species occurring on this study area: mountain chickadee, hairy woodpecker, and pileated woodpecker (Thomas and others 1979).

Feeding excavations were considered present when the surface of the snag had obvious shallow holes chipped into it by woodpeckers (Mannan and others 1980, Swallow and others 1988). Nest and roost cavity excavations were identified by the presence of much larger circular or oval openings excavated by PCE birds (Horton and Mannan 1988, Mannan and others 1980). We increased the sample size for snags with visible nest cavities by measuring cavity excavated snags and active PCE nests from similar forest habitats within and adjacent to the study plots. No snag included in the data set was more than 150 m from a plot, or in a substantially different habitat from the nearby plot.

Data on PCE bird abundance and species composition was collected on 100 m wide fixed-width transects (Manuwal and Carey 1991) by the first author and a field assistant working alone on each survey. Surveys began before 7 a.m. and were completed by 9 a.m. Time spent on each survey was standardized. Bird censuses occurred in June-July 1991 and May-July 1992. Results were pooled from both years for analyses.

Data were analyzed with Statistical Analysis System (SAS) software. DBH and height of snags with and without excavations were compared using T-tests. Decay class, species, and broken top selection were investigated using X^2 and Kolmogorov-Smirnof tests. Selection for individual categories was examined with two category X^2 tests with Yate's correction (Sokal and Rolf 1969). Species composition of PCE birds was examined using Duncan’s multiple range test, which identifies significant groupings among categorical data. Multiple regression analyses were used to determine which habitat variables were the strongest predictors of bird densities.

Results

PCE Bird Species Observed and Plot Characteristics

Ten species of PCE birds were observed on the study plots *(table 1).* Red-breasted nuthatch, chestnut-backed chickadee, mountain chickadee, and northern flicker were the most abundant species observed. Three-toed woodpeckers were detected only in unmanaged stands.

Basal area and canopy closure varied by treatment, with some significant variation (ANOVA results p=.05) within treatments. Live tree densities varied between treatments, with highest densities on the unmanaged plots. Dense shelterwoods had larger trees removed by logging, but maintained high densities of smaller trees and seed tree plots had few live trees *(table 2).* Six plots had Douglas-fir as the dominant live tree species. On the unmanaged Gooseberry plot, grand fir was the dominant species. Snag density varied across the plots, with the highest densities occurring on two unmanaged plots. The dense shelterwoods and one unmanaged plot had intermediate snag densities. The seed tree plots had the lowest snag densities *(table 3).*

Snag Habitat Selection by PCE birds

Snag selection by PCE birds for feeding and cavity excavation was investigated by analyzing the total sample of 1,638 snags and appropriate subsets. Five snag attributes were analyzed: DBH, height, Decay Class, snag species, and presence or absence of a broken top. Additionally, 40 snags containing active PCE nests were measured and compared with selection characteristics of snags with cavity excavations but without known active nests.

Table 1—*Primary cavity excavator bird species observed on study plots.*

Common name	Abbreviation	Scientific name
Red breasted nuthatch	RBNU	*Sitta canadensis*
Chestnut-backed chickadee	CHCH	*Poecita rufescens*
Mountain chickadee	MOCH	*Poecita gambeli*
Pileated woodpecker	PIWO	*Dryocopus pileatus*
Hairy woodpecker	HAWO	*Picoides villosus*
Black-backed woodpecker	BLWO	*Picoides arcticus*
Three-toed woodpecker	TTWO	*Picoides tridactylus*
Red-naped sapsucker	RNSA	*Syphrapicus nuchalis*
Williamson's sapsucker	WISA	*Syphrapicus thyroideus*
Northern flicker	NOFL	*Colaptes auratus*

Table 2—*Live tree plot characteristics.*

Treatment and plot[1]	Mean Pct canopy	Live tree Basal area M^2/ha	Live tree density > 25 cm DBH/ ha
Unmg			
Goo	89.3	17.6	179.9
SFk	77.6	12.9	175.3
NFk	86.2	18.3	277.8
Dshr			
Tan	64.6	9.9	119.1
Til	75.0	14.6	214.4
Seed			
Fro	8.0	.9	6.7
Cur	2.2	.3	4.9

[1] Treatment: Unmg = Unmanaged, Dshr = Dense Shelterwood, Seed = Seed Tree
Plot names: Goo = Gooseberry, SFk = South Fork, NFk = North Fork, Tan = Taneum, Til = Tillman, Fro = Frosty, Cur = Currant

Table 3—*Snag density/ha by diameter class.*

Treatment and plot[1]	Density/ha by diameter classes (cm DBH)				
	10-25	25-50	>50+	>25	total >10
Unmg					
Goo	88.5	48.5	20.6	69.1	157.6
SFk	113.9	42.4	9.5	51.8	165.8
NFk	78.2	19.7	2.0	21.8	100.0
Dshr					
Tan	58.0	20.2	.8	20.6	77.7
Til	67.9	15.4	1.0	16.5	84.4
Seed					
Fro	14.4	2.9	3.7	6.6	21.0
Cur	5.8	3.3	3.7	7.0	12.7

[1] Treatment: Unmg = Unmanaged, Dshr = Dense Shelterwood, Seed = Seed Tree; see *table 2* for plots.

Characteristics of Feeding Snags

The mean DBH for 677 feeding snags (ave. = 29.3 cm, $p < .0001$) was significantly larger than mean DBH of snags without feeding excavations (n = 775, ave. = 16.7 cm; T-test, $p < .0001$). Feeding snags were also significantly taller (ave. = 14.3 m) than non-excavated snags (ave. = 11.7 m; T-test, $p < .0001$).

Selection of tree species used for feeding snags was found when utilized snags were compared to the total snag sample. Grand fir (X^2, $p = .05$) and lodgepole pine (X^2, $p < .005$) were selected against, while selection for Western larch (X^2, $p < .005$) was found. Douglas-fir and ponderosa pine were neutral for feeding selection. Broken top snags were significantly selected for feeding (X^2, $p < .005$). Preferred characteristics of feeding snags therefore were: large DBH (>25 cm), tall (> 10 m) western larch snag, , with a broken top.

Characteristics of Cavity Snags

It was not known what PCE bird species were responsible for excavating the observed cavities. Mean diameters of cavity and non-cavity snags were compared. Mean diameters of cavity snags (n = 239, ave. = 47.9 cm) were significantly larger than that of non-selected snags (n = 1,399, ave. = 21.9 cm; T-test, $p < .001$) *(table 4).* Heights of cavity snags (ave. = 9.8 m) were significantly shorter than height of snags without cavities (ave. = 13.0 m; T-test, $p < .0001$).

Cline (1977) used a 5 class system to describe relative decay state: Class 1—a recently dead, hard snag with fine needles and branches remaining; Class 2—a hard snag with most of the bark remaining and fine branches gone; Class 3—early decay phase soft snag, with wood difficult to break by hand and bark sloughing; Class 4—advanced decay with bark blocky and wood easily hand broken; and Class 5—advanced decay with wood extremely soft and nearly humus.

Snags in Decay Class 1 were significantly selected against for cavity excavation in all forest management treatments ($p < .005$) and when compared to all snags ($p < .005$). Decay Class 2 was selected against when compared with total snags ($p < .05$). Snags in Decay Class 3 were significantly selected for cavity snags well above their availability on all treatments and when compared with total snags ($p < .005$). Class 4 snags were neutral in selection for total snags, but indicated selection on the dense shelterwood treatment *(table 5).*

Broken top snags were significantly selected as cavity snags on unmanaged plots and within the total snag population. On all managed plots, however, selection of broken top snags was not significant, likely because of the large proportion of snags existing on managed plots that were broken mid-stem.

Different tree species produce snags with different characteristics, affecting use for cavity excavation by PCE birds. Douglas-fir was the most consistently selected species of cavity snag; selection for this species was significant in the unmanaged treatment plots ($p < .005$) and for all available snags ($p < .005$). Ponderosa pine was selected for cavity excavation on the unmanaged plots (the only treatment where this species occurred) and for total snags. Western larch and lodgepole pine were selected against for cavity snags. Grand fir was neutral in selection when compared with total snag frequency. This suggests that grand fir is not preferred when other species are available, but is utilized when more preferred species are not present. Species selection for cavity snags was neutral in dense shelterwood and seed tree treatments *(table 6)*.

Table 4—*DBH of cavity and non-cavity snags with T-test results.*

Treatment and plot[1]	Cavity		Cavity	Non-cavity Mean	
	n	n	DBH (cm)	DBH	P>[T]
Unmg					
Goo	56	354	53.3	24.9	.0001
SFk	53	388	51.9	21.7	.0001
NFk	45	235	40.0	19.3	.0001
Dshr					
Tan	19	188	33.1	19.6	.0015
Til	13	159	32.8	20.3	.0144
Seed					
Fro	29	49	57.4	24.3	.0000
Cur	24	26	50.2	31.8	.0011
Total snags	239	1,399	47.9	21.9	.0001

[1] Treatment: Unmg = Unmanaged, Dshr = Dense Shelterwood, Seed = Seed Tree
Plot names: Goo = Gooseberry, SFk = South Fork, NFk = North Fork, Tan = Taneum, Til = Tillman, Fro = Frosty, Cur = Currant

Table 5—*Decay class of cavity and non-cavity snags.*[1]

Treatment	Decay 1	Decay 2	Decay 3	Decay 4
Unmn[2]	x*	x	+*	0
DShltr	x*	0	+*	+
Seed	x*	0	+*	0
Total snags	x*	x*	+*	0

[1]Results from 2 category X^2 tests; @ p=.05, + = Selected for,
x = Selected against, 0 = no selection;
* = significant at <.005
[2] Unmn = Unmanaged, Dshltr = Dense Shelterwood

Table 6—*Tree species selection for cavity snags.*[1]

Treatment	ABGR[2]	LAOC	PICO	PIPO	PSME
Unmn[3]	x	x*	x*	+*	+*
DShltr	0	0	.	.	0
Seed	0	0	.	.	0
Total snags	0	x*	x*	+*	+*

[1] p=.05, + = Selected for, x = Selected against, 0 = no selection;
* = significant at <.005
[2] ABGR = Grand fir, LAOC = W. larch, PICO = lodgepole pine, PIPO = ponderos pine, PSME = Douglas-fir
[3] Unmn =Unmanaged , DShltr = Dense Shelterwood

Active PCE Nests

Active nest trees were significantly larger in diameter (n = 40, ave. = 56.9 cm) than cavity snags (n = 239, ave. = 47.9 cm; T-test, p < .001). Active nest trees were also significantly taller than cavity snags (active nest trees ave. = 13.8 m, cavity snags ave. = 9.8 m; T-test, p < .05). Nest trees used by Williamson's sapsuckers had the largest diameter (n = 4, ave. = 92.1 cm). Nest trees used by the two species with the largest number of observed nests, northern flicker and red-breasted nuthatch, had similar diameters at 53.4 (n = 14) and 56.8 cm (n = 13), respectively. Northern flickers used the shortest nest snags; they consistently were found nesting in broken off, well-rotted snags in the managed forest treatments. Broken tops were found on 73 percent of active nests and 83 percent of cavity snags.

Fifteen percent of active nests were in either live trees or Decay Class 1 snags. Twenty percent of active nests were in Decay Class 2, and no nests were found in Decay Class 4. Sixty-five percent of active nests were in Decay Class 3 snags, a category previously shown as selected for excavation.

Fifty percent of active nests were in Douglas-fir, a species also found to be significantly selected for cavity excavation. Thirty-five percent of active nests were in grand fir, a species not significantly selected in cavity snags. The active nests in grand fir were mostly northern flicker nests on the seed tree plots, where large diameter, broken-topped, Decay Class 3, grand fir snags were available and well used by flickers. Western larch nest sites were primarily those of Williamson's sapsuckers, in live trees. No nests were found in lodgepole pine, a species also not selected as cavity snags. Three nests were found in ponderosa pine, in areas with low abundance of this snag species. The hypothesis that ponderosa pine is a preferred cavity species is also supported by the significant selection for ponderosa pine for cavity snags Preferred characteristics of nest snags identified in this study were: large diameter (>50 cm), medium height (> 9 m), Decay Class 3, Douglas-fir, or ponderosa pine with a broken top.

Relative frequencies of tree species selected for cavity excavation were similar for those for known nest sites. Grand fir, Western larch, ponderosa pine and Douglas-fir comprised all observed nests, and similarly comprised all cavity snags. A slightly higher percent of observed nests were in Grand fir (32 percent) than for cavity snags (28 percent), and a slightly higher percent of cavity snags (57 percent) were in Douglas fir than for known nests (50 percent). Western larch had exactly the same percent of observed nests as cavity snags (10 percent).

PCE Densities and Species Composition

The highest PCE species transect counts during this study were, in descending order: red-breasted nuthatch, mountain and chestnut-backed chickadee, hairy woodpecker and northern flicker *(table 7).* Total PCE plot densities decreased from highest levels in unmanaged stands, to intermediate levels in dense shelterwoods, to lowest levels on seed tree plots. Species composition was also significantly different among management treatments *(table 8).* The species group identified for unmanaged plots, was dominated by small excavators: red-breasted nuthatch, mountain chickadee and chestnut-backed chickadee. Highest red-breasted nuthatch counts were found on the Gooseberry and South Fork plots, which were unmanaged stands with large trees and high snag densities. The species group found on unmanaged plots also included three-toed and black-backed woodpeckers, species known to be associated with fires, high snag densities, and recently killed trees (Bock 1974, Herr 1992).

The species compositions of birds found on unmanaged and seed tree plots were distinctive, while the species composition of birds on the dense shelterwood plots were an intermediate mix between the other two treatment types (Duncan's Multiple Range Test, *table 8).* Hairy woodpeckers were counted most often on a dense shelterwood plot (Taneum), but occurred in all treatment types. Other species found on dense shelterwood plots included those found on unmanaged forest plots (red-breasted nuthatch, chickadees, pileated and hairy woodpeckers), and a small number of birds also found on the seed tree plots (red-naped and Williamson's sapsucker, and northern flicker). The PCE group found on seed tree plots included the largest proportion of a single species on any treatment, northern flicker. Red-naped and Williamson's sapsuckers were observed most often on seed tree plots, but were still uncommon.

Table 7—*Average density/15 ha by bird species by treatment.*[1]

Treatment	RBNU	TCH[2]	PIWO	HAWO	TTWO	BLWO	RNSA	WISA	NOFL	Total
Unmg[3]	9.87	6.00	.20	.94	.21	.43	0	0	.16	17.84
DShr	4.50	3.54	.20	1.10	0	.06	.06	.14	.34	9.97
Seed	.04	.30	0	.69	0	.08	.11	.50	4.04	5.77

[1] See *table 1* for bird species abbreviations.
[2] TCH= Total chickadees, mountain and chestnut-backed combined.
[3] Unmg = Unmanaged, DShr = Dense Shelterwood

Table 8—*Bird species composition shift summarized by treatment.*[1]

		Treatment	
PCE species	Unmanaged	Shelterwood	Seed tree
RBNU[2]	X	X	
TCH	X	X	*
PIWO	X	X	
HAWO	X	X	X
TTWO	X		
BLWO	X	*	*
RNSA	*	*	
WISA	*	X	
NOFL			X

[1] X = major component; * = minor component
[2] See *table 1* for bird species abbreviations.

PCE Bird Densities and Habitat Variables

Relationships of PCE bird densities by species with habitat variables were investigated using stepwise multiple regression analyses. A close correlation was found showing density of red-breasted nuthatches best predicted by snag densities in the 25-50 cm diameter class (R^2 = .94). Total chickadee densities were also best predicted by snag densities in the same diameter class (R^2 = .83). In both cases, greater densities of these small PCE birds were found in habitats with greater densities of snags. No habitat variables significantly predicted densities of hairy woodpeckers. Similarly, no significant relationships were distinguished for densities of pileated woodpecker, three-toed woodpecker, black-backed woodpecker or red-naped sapsucker, likely due to small sample sizes for these birds. Williamson's sapsucker and northern flicker densities varied significantly and inversely with canopy closure in regression analyses (R^2 = .96, and R^2 = .91, respectively). Total PCE bird abundance was best predicted by snag density >25 cm DBH (R^2 = .93).

Discussion

Snag Selection

Observed feeding snags, cavity snags and observed nests shared many characteristics. All were larger diameter and in advanced decay states, often with broken tops. Larger diameter snags may be needed to meet the thermal and mechanical needs dictated by the size of the PCE birds (Thomas and others 1979). Most excavated cavities and nests occurred in broken off snags, likely due to the increased opportunity for introduction of various stem rots, thus facilitating excavation. Many excavated cavities were observed within a few meters of the break off point on the tree stem. Because of the variability introduced by these broken tops, height is a poor measure of suitability of snags for PCE birds, other than to help determine acceptable minimums and target heights for snag viability in management. These results strongly suggest that larger snags may be critical to PCE birds.

Decay Class indicated time since death of the tree and affected characteristics important to PCE birds. Snags in Decay Class 1 were recently dead and probably had not been dead long enough to develop substantial insect populations or accumulated evidence of PCE feeding. Class 2 snags probably had active insect populations available for PCE birds. By the time a snag reached Class 3, enough time had elapsed for such activity and evidence to accumulate; hence, significant selection for this Decay Class was found. Snags in Class 4 were very decayed, often with large areas of missing bark, with evidence of PCE bird use obscured by the effects of decay. Decay class 3 snags showed the highest abundance of feeding evidence, but this was probably the result of accumulation over time, and does not demonstrate an immediate feeding preference for decay class. Because of the cumulative nature of feeding evidence on snags, analysis of feeding selection in decay class was inconclusive.

Snags in Decay Class 3 were significantly selected for cavity excavation on all plots, treatments, and for total snags. In addition, 65 percent of observed active nests were in Decay Class 3 snags. Snags in earlier Decay Classes were likely not softened enough by decay to facilitate excavation. Some excavation occurred in Class 2 snags (20 percent of nests), usually in portions of the stem with decay.

As expected, similar tree species were selected for cavity snags and observed nests, with Douglas-fir and ponderosa pine preferred. Western larch was selected for feeding snags but not for cavity snags. This may have been due to the smaller average diameter for most western larch present on the study sites, which may have been insufficient for cavity excavation. Lodgepole pine was not selected for any excavations, and this is consistent with the literature, implying that this species, may not be a good choice for retention if PCE birds are an objective. Grand fir was neutral for feeding selection, but was sometimes used for cavities. Grand fir wood appears to decay more quickly than other species, perhaps supplying a less durable substrate for nest cavities. Our data, however, suggest considerable PCE bird use of grand fir on the east side of the Cascades. The role of grand fir as a component of PCE habitat needs further investigation.

We found that snags are used by PCE birds for feeding in earlier decay states than those snags chosen for nesting. Habitat needs of PCE birds, therefore, encompass snags in all stages of decay. Additionally, because decay progresses through time, live and declining trees must be maintained after timber harvests as replacement snags. Results from this study support the work of many others in identifying snags in more advanced decay classes as particularly valuable habitat elements for PCE birds (Conner and others 1976, Madsen 1985, Raphael and White 1984). The need for snags with advanced decay means that snag management is a long-term endeavor, requiring protection of existing snags and an adequate supply of all diameter "legacy" snag recruits to be maintained over time.

The significant selection by PCE birds for broken tops may be explained by a preference for snags with more decay, and perhaps increased insect activity. Broken top snags probably collect precipitation moisture directly into their stems, thus improving fungal growth conditions and allowing the broader introduction of wood-softening fungi.

Active nests were found in significantly larger stems than cavity snags, lending support to the conclusion that PCE birds prefer large snags for nest cavity sites. Known nest snags were also found to be significantly taller than cavity snags in this study. The minimum height of an observed nest tree in this study was 2.1 m, which is similar to the minimum height of snags (2 m) recommended by Thomas and others (1979). This minimum, however, constitutes a poor management guideline. The influence of decay, rather than height, is likely the most important factor regarding cavity site location by PCE birds. Height is only relevant as a management (i.e., safety) factor.

The active nest sample effectively acted as a control group to compare with measured cavity snags, adding considerable meaning to the data set. The most numerous observed nests were those of red-breasted nuthatches and northern flickers. Nuthatch nests were found predominantly in large diameter, highly rotted stems in unmanaged stands with high densities of large trees and snags. Flicker nests were located exclusively in seed tree areas, where large DBH, short stubs (residuals from the mature, pre-logged stand) were likely retained because they posed no safety hazard to logging operations. Northern flicker nests were found mostly in large-diameter, broken-top, well-decayed grand fir snags. These two species were the most different in habitats used in this study, yet their nest snag characteristics were very similar. This suggests that the characteristics of snags preferred by PCE birds are consistent across habitat types.

PCE Bird Density and Abundance

Red-breasted nuthatch densities were most closely predicted in the regression analyses by density of snags between 25 and 50 cm DBH (R^2 = .94). Habitat with high densities of snags of this diameter category was most prevalent in unmanaged forest. Basal area was the second predictor for red-breasted nuthatch density in our study, suggesting a preference for denser forests. These plots also had the highest abundance of large diameter trees. Other researchers have found that red-breasted Nuthatches prefer older forest stands with larger stems and high structural diversity (Adams and Morrison 1993, Mannan and Meslow 1984). Timber harvest, which simplifies stand structure, opens the canopy, and removes large stems and dead wood, undoubtedly reduces habitat quality for red-breasted nuthatches.

Chickadees nest and feed in dead, rotting wood, and utilize thick forest and brushy areas in northwestern coniferous forests (Thomas and others 1979). Our study reinforced this finding, as we documented decreased abundance of chickadees in dense shelterwood plots, compared to unmanaged forest, and lowest abundance in seed tree plots. Chickadees are also likely to be negatively impacted by timber harvest in the central Cascades, which reduces forest complexity and snag density.

Black-backed and three-toed woodpeckers were observed in highest densities on the North Fork and South Fork plots, areas with high densities of relatively small snags *(tables 3, 8)*. The literature also reports that these woodpeckers nest in smaller snags than many other PCE birds (McClelland and others 1979, Thomas and others 1979). The four nests occupied by these species in this study were in smaller snags (diameter range 26.7 to 34.4 cm dbh, n = 4), suggesting that these two species may be able to utilize younger stands.

Pileated woodpeckers were counted on all unmanaged plots and on both shelterwood plots, but in low densities *(table 8)*. These birds are known to have large territories, estimated between 200 and 689 ha (494 to 1,650 acres) for similar habitat types in the Blue Mountains of Oregon (Bull and Holthausen 1993). These woodpeckers were not tallied on the seed tree plots where canopy closure, tree density, and snag density were all relatively low. Heavy timber harvest probably negatively effects this species, but their presence on the dense shelterwood plots in our study suggests that active forest management that retains adequate dead wood for feeding, nesting, and roosting needs, may result in habitat that remains suitable for pileated woodpeckers.

Williamson's and red-naped sapsuckers were found more frequently on the more open plots in our study, perhaps as a reflection of increased visibility, rather than higher densities. Previous work (Madsen 1985, Raphael and White 1984) found Williamson's sapsucker nest sites to occur largely in areas of dense snags and high basal area. Our result may suggest that sapsucker breeding territories are determined by the presence of adequate suitable structures, such as large diameter western larch, rather than forest density.

Northern flickers prefer habitats where open ground for feeding and snags for nest sites occur together (Ehrlich and others 1988). Flicker densities were most closely predicted by canopy closure in this study (R^2= .82), showing a distinct preference for open, meadow-edge habitat types, represented in this study by seed tree plots. Their breeding presence, however, is probably limited by the availability of suitable snags. Seed tree plots with snags present may represent nearly optimal habitat for breeding northern flickers, based upon their density as the third highest for any species by treatment in this study *(table 7)*. Western bluebirds and Kestrels commonly utilized old cavities, most likely excavated by flickers, on the seed tree plots.

Methods

The bird count method utilized in this study may have resulted in undercounts of birds in the unmanaged and dense shelterwood habitats due to the quiet nature of woodpeckers during the latter portion of the breeding season when many of our transects were measured. In addition, observer bias in distance estimation can be a significant problem that affects results in bird surveys that we employed. In future PCE studies or monitoring, we recommend using simple transect or point counts, thus minimizing distance estimates. We also recommend use of as few highly trained observers as possible conducting all surveys, to eliminate intra-observer bias. Two different field assistants in 2 years complicated results on this study, particularly in reference to chickadee identification. PCE bird monitoring and research should include red-breasted nuthatches. We observed these birds excavating cavities in soft wood, and their calls are quite distinctive. If possible, surveys should occur earlier in the breeding season, beginning in April and ending in early June. This would more closely coincide with territorial displays. Nest searches should occur in June and early July, when young are readying to fledge, and nests are easiest to find.

Treatment Effects

Treatments were not always uniform, and therefore effects were not entirely clearly evident. Approximately the same PCE bird species composition was found in the dense shelterwood plots as the unmanaged plots, but PCE birds were less abundant in the dense shelterwoods *(table 7).* While the life requirements of the PCE species were apparently met in the shelterwoods, some habitat limitation resulted in lower population density. It is possible that these shelterwoods are population sinks. It is noteworthy that the North Fork plot, although characterized as unmanaged forest, had snag densities more similar to the dense shelterwoods than the other unmanaged plots *(table 3).* PCE species composition and abundance measured on the North Fork plot were also more similar to those recorded on the dense shelterwood plots. These data support the hypothesis that snag abundance is likely a key habitat component supporting PCE density. Hairy woodpecker occurrence in all treatment types supports their description by several authors as habitat generalists (Mannan and Meslow 1984, Thomas and others 1979). The seed tree treatments held low numbers of all PCE bird species, except for northern flickers, suggesting that these highly managed areas were currently unsuitable habitat for most forest PCE species.

PCE Populations and Habitat

A strong relationship found in the regression analysis was between total birds and snag density > 25 cm (R^2 = .94). Therefore, density of large snags may be the most important habitat component affecting PCE bird abundance in grand fir forests in eastern Washington. Our study supports conclusions of similar research (Raphael and White 1984, Zarnowitz and Manuwal 1985). The maintenance of adequate densities of larger snags, with a continuum of decay conditions present at all times, is undoubtedly a significant factor in sustaining populations of PCE birds.

Preferred Snag Characteristics and Management Recommendations

Preferred species for PCE feeding snags are western larch and Douglas-fir and preferred species for cavity snags are Douglas-fir and ponderosa pine. Grand fir is also utilized, but may not be a preferred species. Snags should be maintained in all Decay Classes, particularly in Classes 2 and 3. Snags and green recruitment trees should be retained in the larger diameter classes (minimum of >35 cm (14 in) DBH) to provide a continuous supply of snags over time. This DBH is based upon the minimum nest snag utilized by hairy woodpeckers and northern flickers on this study. Minimum snag height should be 5 m (15 ft), based upon the observed minimum height of snag used by hairy woodpeckers. This is recommended as a management guideline rather than the minimum diameters and heights (25 cm and 2 m) determined by chickadees and used by many land management agencies. We maintain that snags should be managed for larger diameters and heights than currently practiced to provide the best chance of population viability for the host of cavity dependent species. Large diameter western larch should be retained in forest management because of the importance of these trees for Williamson’s sapsuckers.

Maintaining high snag densities alone will not provide quality habitat for PCE birds. Snags with specific characteristics (Decay Class, broken tops, and species) must also be maintained. The importance of decay trajectories to habitat use by PCE species remains a rich area for future research. In addition, target bird species compositions and territory sizes should be considered in PCE management.

Despite the well-documented fact that snags are important components of forest ecosystems, they are often removed from forest stands during timber harvest, forest management activities, and for fuel wood. Cutting of the largest snags (especially Douglas-fir and Western larch) for firewood is a common practice throughout the Northwest, but contributes to habitat degradation for all cavity species. Snags are also cut for hazard reduction at parks and public facilities. Quality wildlife trees are often removed during logging that could have been maintained through planning and forethought. Protection of existing high quality snags and maintenance of adequate recruitment trees must become more widely recognized as key tools for forest biodiversity preservation, and elevated to common practice. This would promote healthy populations of cavity nesting birds and associated species across the forested landscape over time.

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