Characteristics of foraging sites and the use of structural elements by the pileated woodpecker (*Dryocopus pileatus*) on southeastern Vancouver Island, British Columbia, Canada

Carol L. Hartwig[1], Donald S. Eastman[2] & Alton S. Harestad[3]

[1] Ecodomain Consulting, 934 Khenipsen Road, Duncan, British Columbia, V9L 5L3, Canada (e-mail: clhartwig@shaw.ca)
[2] Department of Biology, University of Victoria, P.O. Box 1700, Victoria, British Columbia, V8W 2Y2, Canada (e-mail: deastman@uvic.ca)
[3] Department of Biological Sciences, Simon Fraser University, 8888 University Way, Burnaby, British Columbia, V5A 1S6, Canada (e-mail: harestad@sfu.ca)

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In four 1450-ha landscapes of differently aged coastal western hemlock (*Tsuga heterophylla*) forests on Vancouver Island (British Columbia, Canada), sites and elements used by pileated woodpeckers for foraging were examined. Snags and defective trees (decayed or damaged) used for foraging ($n = 94$) were larger, more decayed, and had less bark remaining than those not used; also, more were in the upper and main canopy strata ($n = 587$). Pileated woodpeckers foraged on sites ($n = 23$) where there was greater basal area of snags and defective trees, more coarse woody debris, and more western red cedar (*Thuja plicata*) than sites that were not used ($n = 36$). Logs used for foraging ($n = 27$) were larger, longer and less decayed than unused logs ($n = 360$). The reduction of remnants of old forests and their structures could have negative consequences for pileated woodpecker, particularly where heavy rainfall or deep snow limit prey availability. Foraging habitat must be provided in managed forests.

Introduction

Until recently, feeding habitat was not considered as important as nesting habitat for pileated woodpeckers because any standing or fallen dead wood > 18 cm in diameter was considered available for feeding year round (Bull & Meslow 1977). It has been suggested that the pileated woodpecker forages in all habitat types within the forests it occupies in the Olympic Moun- tains of Western Washington (Zarnowitz 1982). Mellen *et al*. (1992) questioned the role of the pileated woodpecker as an indicator species of old-growth forests, because it forages extensively in immature forests in western Oregon.

Nesting habitat consists of much larger, old trees which are presumed to be in more limited supply than structures used for foraging. Consequently, fewer data have been gathered on foraging sites and on structural elements used for

foraging by pileated woodpeckers than data on nesting sites and trees.

With increasing attention to foraging habitat, the size of structures needed for foraging has been re-evaluated. Bull (1987) found that in northeastern Oregon 82% of the log-foraging observations were from logs > 25 cm in diameter. Additional research points to selection for much larger trees and logs than previously thought to be important in northeastern Oregon, New Brunswick, Quebec, Alberta and Washington (Bull & Holthausen 1993, Flemming *et al.* 1999, Savignac *et al.* 2000, Bonar 2001, Raley & Aubrey 2006).

To access wood-boring prey, mainly carpenter ants (*Camponotus* spp.), pileated woodpeckers excavate large, rectangular cavities (Bull & Jackson 1995). These cavities are an important indicator of the types of structures used and preferred by pileated woodpecker because the greatest percentage of foraging observations have been of pileated woodpeckers excavating cavities and, because carpenter ants are their main food, particularly in winter when other foods may be unavailable (Bull & Jackson 1995).

The purpose of this paper is to compare plots (areas of about 0.4 ha) and elements (trees, snags and fallen logs) that have evidence of use by foraging pileated woodpeckers to plots and elements that showed no evidence of such use. Our hypotheses are: (1) densities of snags and defective trees are significantly greater in habitats used by pileated woodpeckers for foraging than in unused habitats; (2) amounts of coarse woody debris are significantly greater in foraging habitats than in unused habitats; and (3) large diameter snags, defective trees and logs are used for foraging significantly more than smaller diameter ones.

Materials and methods

Study area

We chose a study area on southeastern Vancouver Island between Victoria and Duncan, because it has a population of pileated woodpeckers as determined from pilot surveys and historical records (Campbell *et al.* 1990), and offered a range of stand conditions and age classes typically found in commercially harvested forests. The study area is located within the very dry maritime Coastal Western Hemlock biogeoclimatic subzone (CWHxm) (Ministry of Forests 1993). Forests in the CWHxm subzone are largely coniferous, dominated by Douglas fir (*Pseudotsuga menziesii*), western hemlock, and minor amounts of western red cedar, with some deciduous species such as red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*) (Green & Klinka 1994). The study area has warm, dry summers and moist, mild winters. Elevations range from 140–850 m.

Four 1450-ha study sites were selected to include a wide range of stand conditions commonly found in managed forests on Vancouver Island. Each study site encompassed an area that could be occupied by approximately two to three breeding pairs of pileated woodpeckers, based on home range size recorded by Mellen *et al.* (1992) in similar coastal forests of western Oregon. The Hillridge study site was a relatively homogeneous early seral forest, clear-cut logged mostly from 1947–1961. About 75% of the site's area was subsequently juvenile spaced (a silvicultural treatment to reduce the number of trees in young stands); there were no forest stands greater than 100 years old (Table 1). At the mid-seral Niagara study site, 40% of the area was clear-cut logged and 39% of the area was spaced. About 13% of the forest at Niagara was greater than 140 years old. At the mature forest Sooke study site, 20% of the area was clear-cut logged and 4% of the area was spaced; 51% of the forest was greater than 140 years old. At the mature/old growth Rithet study site, 20% of the area was clear-cut logged and 5% of the area was spaced. About 70% of the area's forest was greater than 140 years old. Thus these study sites varied widely in their age-class distributions and in their stand structure and composition. Hartwig *et al.* (2002) gives detailed information on characteristics of the study sites.

Data collection

During the summers of 1996 and 1997, 59 habitat plots (0.4-ha circular plots, 35.7-m radius,

systematically located to ensure a broad spatial distribution) were partitioned as follows: Niagara (19 plots), Sooke (20 plots), Hillridge (10 plots) and Rithet (10 plots). Thus the more homogenous Hillridge and Rithet study sites were sampled less intensively than the more heterogeneous Sooke and Niagara.

At each habitat plot the following data on trees were collected: diameter (cm) at breast height (i.e., 120 cm above the point of germination) measured with a diameter tape, height (m) measured with a clinometer, estimated percentage of bark remaining on trunk, species, decay class (four classes modified from Bartels *et al.* 1985), number of limbs ≥ 1 m in length, top condition (broken, dead and unbroken, live and unbroken, unknown), canopy position (above canopy, within upper canopy or below upper canopy), and lean (degrees measured with a clinometer). Information about each habitat plot was recorded using the Ecosystem Field Form and procedures of the B.C. Ministry of Forests and Ministry of Environment (Luttmerding *et al.* 1990, Ministry of Forests and Ministry of Environment 1996).

Variables used to describe the plot included basal area of snags and defective trees (m^2 ha^{-1}), mean dbh of snags or defective trees, tree stems density (stems per ha of live and dead trees), structural stage, successional stage, disturbance factor (none; fire, wind or edge; logging, thinning or spacing), and elevation (m). Basal area was calculated as = $0.0001963d^2$ (after Avery 1975), where *d* is the diameter (cm) at breast height of each snag or defective tree. Stem density was estimated for each plot by counting all stems ≥ 3 m tall within a 5.64-m radius circle in the centre of each plot, and then multiplying by 100. Structural stage categories were defined as follows: shrub; pole/sapling; young forest; mature forest; and old forest (Ministry of Forests and Ministry of Environment 1996). Five successional status classes were defined as follows: pioneer seral or young seral; mature or over-mature seral; young climatic climax; maturing climax or maturing; and climatic climax or disclimax (modified from Luttmerding *et al.* 1990). The percentage of the ground area covered by a vertical projection of the crown of all species of trees was estimated visually and also visually estimated for the total coverage of trees, shrubs, and herbs.

All snags (dead trees ≥ 1 m in height) and defective trees (those with broken tops, scars, decay or damage) ≥ 20-cm dbh and ≥ 1m in height within each plot were recorded.

Data for each log ≥ 20 cm in diameter were collected along two perpendicular transects along the length of the radius of the plot (35.7 m) at a random aspect through the centre of each plot. Logs were defined as fallen dead trees or pieces of coarse woody debris that were not self-supporting (fallen or suspended). Information collected about each log included species, decay class (modified from Sollins 1982, Bartels *et al.* 1985), diameter at centre point where the transect crossed (cm), length (m), presence of foraging sign, and the number of foraging cavities ≥ 4 cm in length. In addition, the 0.4-ha plot was searched for other logs with foraging sign. These logs were used to gather data about foraging elements and cavities, but were not included in the coarse woody debris calculations.

If pileated woodpecker cavities were present on the snags, defective trees or logs, the following information was collected: the type of

Table 1. Percentage of forest stand age classes in four pileated woodpecker study sites on southeastern Vancouver Island.

Study site	Seral stage (age class in years)				
	Early seral ≤ 60	Mid-seral 61–100	Mature 101–140	Mature/old > 140	Non-forest
Hillridge	73	27	0	0	0
Niagara	47	22	14	13	5
Sooke	26	9	0	51	13
Rithet	22	5	3	70	1

cavity (forage cavity or non-foraging cavities (nest, roost, or nest start), the number of cavities ≥ 4 cm in length, cavity entrance, and age (recent or old). Recently excavated foraging cavities were defined as those with a fresh appearance to the wood or evidence of fresh chips below the hole on the ground without litter on them.

Volume of coarse woody debris (m³ h⁻¹) was calculated using: CWD = $\pi^2 \Sigma d^2 8 L^{-1}$ (Harmon *et al.* 1986), where *d* (cm) is the diameter of the pieces where they intersect the transect, and *L* (m) is the length of the transect.

Data and statistical analysis

Characteristics of foraging plots (one that contained one or more elements with evidence of a pileated woodpecker foraging excavation) were compared with those of plots that had no evidence of foraging. We examined the variation among foraging plots by means of principal components analysis (Norušis 1990), following the approach used for data reduction, and ordination of habitat relationships for birds by Conner and Adkisson (1977) and Lundquist (1988). We interpreted

the principal components that had a minimum eigenvalue of one. Values between –0.3 and 0.3 for correlations of original variables were considered low and not meaningful. Comparisons of the frequency of used snags, defective trees and logs were made among the four study sites. An index of use was calculated by dividing the number of used snags and defective trees or logs by the number of plots surveyed in each area.

Because all habitat data were not normally distributed, we used the non-parametric Kruskal-Wallis test to examine differences in the dispersion of ratio habitat data from groups of more than two samples (Zar 1996, Norušis 1998). The Mann-Whitney *U*-test was used for ratio data to determine the differences between the dispersion of two groups (Sokal and Rohlf 1981, Zar 1996). For nominal habitat data, the χ^2-test was used to test for the hypothesis of independence of the rows and columns of a contingency table (Siegel and Castellan 1988, Zar 1996, Norušis 1998). For a variable of particular interest (e.g., diameter at breast height or species of snags) with significant results, the χ^2-test was used to test for significance within classes of the variable by comparing the values for an individual class with

Table 2. Characteristics of habitat plots used for foraging by pileated woodpecker and unused plots in four study sites on southeastern Vancouver Island, 1996–1997. Significant *P*'s are set in boldface.

Habitat characteristic	Mean ± SE or percentage		
	Used (23)	Not used (36)	*P*
Snag or defective tree basal area (m² ha⁻¹)	7.5 ± 1.1	3.5 ± 1.3	**< 0.01**[a]
CWD (m³ ha⁻¹)	192 ± 26	112 ± 23	**0.01**[a]
Stems (ha⁻¹)	867 ± 254	622 ± 116	0.93[a]
Structural stage (%)			**< 0.01**[b]
Shrub	0	22	
Pole/sapling	14	26	
Young forest	42	13	
Mature forest	28	30	
Old forest	17	9	
Successional stage (%)			0.43[b]
Pioneer or young seral	25	43	
Mature or overmature seral	17	13	
Young climatic climax	19	9	
Maturing climax, maturing climatic climax, and disclimax	39	35	
Disturbance (%)			0.12[b]
None	25	4	
Fire, wind, or edge	22	30	
Logging, thinning, or spacing	53	65	

[a] Mann-Whitney *U*-test, [b] χ^2-test.

the respective values for all other classes (Zar 1996). The level of significance used for table-wide comparisons was $\alpha = 0.05$. A Bonferroni correction was used for multiple comparison tests (Zar 1996).

Results

Characteristics of used and unused plots

Data from plots with recent and old foraging signs were pooled because they did not vary significantly. Although used and unused plots had similar tree stem densities, foraging plots had significantly greater basal areas of snags and defective trees and significantly greater amounts of coarse woody debris (Table 2). The mean percentage cover of three canopy strata was compared for three species of trees between used and unused plots. The mean canopy-cover percentage for western red cedar was significantly greater in the tallest tree stratum (4% ± 2%) and the main tree canopy stratum (11% ± 3%) for plots used for foraging than in those not used (0%); $P =$

0.03 and (2% ± 1%), $P = 0.02$, respectively.

The principal component analysis of the foraging plots identified six principal components with eigenvalue greater than 1.0. These cumulatively accounted for 74.3% of the total variance among foraging plots (Table 3). The first principal component (19.0% of total variance) was most highly positively correlated with successional stage, structural stage, cedar canopy cover, and basal area of snags and defective trees. The first component was most highly negatively correlated with number of stems and elevation. Thus, high values for this component represented forage plots with more advanced successional and structural stages, high canopy cover of cedar and high basal area of snags and defective trees.

The second principal component accounted for 13.9% of total variance. It was most highly positively correlated with total tree canopy cover, stems per ha, Douglas-fir canopy cover, and cedar canopy cover. It was negatively correlated with shrub cover, volume of coarse woody debris, and red alder canopy cover. High values on the second component correspond to a habi-

Table 3. Summary of principal component analysis of characteristics of pileated woodpecker foraging plots on southeastern Vancouver Island, 1996–1997.

	Principal components					
	1	2	3	4	5	6
Percent of total variance explained	19.0	13.9	13.1	10.2	9.3	8.7
Cumulative total variance	19.0	33.0	46.1	56.3	65.6	74.3
Eigenvalues	2.86	2.09	1.97	1.53	1.40	1.31
	Correlations of original variables with principal components					
Successional stage	0.84	0.02	–0.25	–0.08	0.11	0.09
Structural stage	0.81	0.18	–0.30	0.00	0.02	–0.22
Cedar canopy cover	0.65	0.35	0.54	–0.03	–0.08	–0.11
Basal area snags, defective trees	0.61	–0.21	–0.37	–0.14	0.08	0.04
Total tree canopy cover	0.15	0.75	0.38	0.15	0.28	0.14
Shrub cover	–0.10	–0.72	0.10	0.28	–0.21	–0.16
Stems per ha	–0.45	0.61	0.00	0.26	–0.10	–0.09
Herb cover	–0.07	–0.20	0.67	0.06	0.28	0.12
Coarse woody debris	0.24	–0.34	0.49	0.34	0.44	0.30
Grand fir canopy cover	0.16	–0.33	–0.25	0.76	0.08	0.10
Douglas fir canopy cover	–0.08	0.41	–0.34	0.75	–0.13	–0.04
Alder canopy cover	0.36	0.00	0.21	0.09	–0.78	0.13
Slope	0.12	0.10	–0.40	0.05	0.42	0.29
Hemlock canopy cover	0.22	0.03	0.14	0.03	–0.42	0.76
Elevation	–0.42	0.08	–0.38	–0.24	0.02	0.62

tat with high canopy cover, high frequencies of Douglas fir and cedar in the canopy cover and a high density of stems.

The third component (13.1% of total variance) was most highly positively correlated with herb cover, cedar canopy cover, volume of coarse woody debris, and total tree canopy cover. It was negatively correlated with slope, elevation, basal area of snags and defective trees, and Douglas-fir canopy cover. Thus high values for the third component correspond to areas of high herb cover and high volume of coarse woody debris, high cedar canopy cover and high total tree canopy cover. The three remaining components, although significant, accounted for less variation.

Where basal area of snags and defective trees is high and of more advanced successional and structural stages as in component 1, the volume of coarse woody debris is not considered meaningful. Where the basal area of snags and defective trees is low, the volume of coarse woody debris ranges from being negatively correlated (component 2) to being positively correlated (components 3, 4, 5, 6). In components 2, 3, 4, and 6, total tree canopy cover or various other tree species canopy cover or herb cover are more highly correlated than volume of coarse woody debris. Only in component 5 is volume of coarse woody debris the most highly correlated variable.

The fifth component accounts for the contribution of foraging sites in areas with high volume of coarse woody debris and steep slope with low canopy cover of alder. The sixth component accounts for the contribution of foraging sites in areas of high hemlock and alder canopy cover and high elevation.

Comparisons among study sites

Among the study sites, used and unused plots differed in basal area of snags and defective trees (data not presented). The basal area of dead and defective trees was larger in the used plots than in the unused plots at Sooke ($P < 0.01$) and at Niagara ($P = 0.01$). At all four study sites, none of the other physical and forest variables differed significantly between used and unused plots.

Foraging elements: snags and defective trees

Data from snags and defective trees from all four study sites were pooled and comparisons were made between those used and not used. There were a number of significant differences for dbh, species, decay class, amount of bark remaining, number of limbs, top condition, canopy position, and conk height (Table 4). Snags and defective trees used for foraging were larger and more decayed and had significantly less bark and fewer limbs than those unused. In addition, used snags and trees had more live and unbroken tops than unused snags and trees that had more dead and unbroken tops. There were also more used snags and defective trees below the upper canopy than there were ones unused. Conks were present in only 4% of the samples ($n = 33$). There was no significant difference in height, or lean. The sample size of recently used snags, trees or logs was small ($n = 10$) and thus not useful for comparisons other than identifying recently used plots.

Used snags and defective trees were significantly larger in mean dbh than were unused ones ($P < 0.01$). The numbers of snags used in the two largest dbh classes were significantly greater than those in all other classes of snags and defective trees that were used. The smallest class was utilized significantly less than other classes combined.

Pileated woodpeckers utilized tree species differentially as foraging elements. Douglas fir, western hemlock, and western red cedar were the species of particular interest and their sample sizes were large enough to allow some comparisons. Due to small sample sizes, bigleaf maple and red alder were pooled as deciduous. The numbers of used and unused of each of these species (and the deciduous class) were compared with the numbers of the other species classes. The most abundant species, Douglas fir, did not differ significantly ($P > 0.05$) from the other pooled species in frequency between used and unused snags and defective trees.

The numbers of western red cedar and deciduous trees exhibiting signs of use were significantly greater than the number of used elements from other pooled species. The use of western

hemlock was significantly less than the use of other pooled species that were used. Shore pine (*Pinus contorta*) was not used for foraging. Some species of trees were removed from the data set because their sample sizes were too small to draw conclusions: arbutus (*Arbutus menziesii*) ($n = 1$), western white pine (*Pinus monticola*) ($n = 2$), and grand fir (*Abies grandis*) ($n = 2$). None of these species had signs of use by pileated woodpecker, although grand fir is utilized in Oregon (Bull & Holthausen 1993).

There was a significant difference in decay class between the used snags and defective trees and those not used ($P < 0.01$). The two least decayed classes had significantly less use than other classes combined ($P < 0.05$) and the most decayed class had significantly more use than

other classes combined ($P < 0.05$). The proportion of extensively decayed snags and defective trees used by pileated woodpeckers was significantly different than that not used ($P = 0.05$). Some caution must be exercised with conclusions about the degree of decay, however, because most of our observations of foraging substrates were not of recent foraging.

Foraging elements: logs

Logs used for foraging differed from unused logs in size and decay class, but not species (Table 5). Used logs had a mean diameter of 43 cm and a mean length of 9.5 m; both were significantly larger than unused logs. Logs in the most

Table 4. Characteristics of snags and defective trees, used and unused, for foraging by pileated woodpecker in four study sites on southeastern Vancouver Island, 1996–1997. Significant *P*'s are set in boldface.

Characteristic	Mean ± SE or percentage		*P*
	Used (*n* = 94)	Not used (*n* = 587)	
Height (m)	9.5 ± 0.9	10.5 ± 0.3	0.18[a]
Bark remaining (%)	49 ± 4	72 ± 1	**< 0.01**[a]
Minimum height of conk (m)	2.7 ± 0.6	1.6 ± 0.4	**0.02**[a]
Diameter at breast height (cm)	56 ± 3	40 ± 1	**< 0.01**[a]
Diameter intervals (%)			**< 0.01**[b]
20–32.49 cm	18	48	**< 0.01**[c]
32.50–44.99 cm	20	28	0.19[c]
45–57.49 cm	27	9	**< 0.01**[c]
> 57.49 cm	35	15	**< 0.01**[c]
Decay class (%)			**< 0.01**[b]
Live healthy/unhealthy	8	16	
Dead with twigs	10	25	
Dead branches gone	23	26	
Dead, extensive decay	57	34	
Lean	2 ± 1	3 ± 1	**0.72**[a]
Number of limbs > 1 m long (%)			**0.01**[b]
None	72	56	
1–10	9	18	
11–20	4	9	
> 20	14	16	
Top condition (%)			**< 0.01**[b]
Broken	90	86	
Dead and unbroken	0	11	
Live and unbroken	10	3	
Canopy position (%)			**0.02**
Above canopy	5	3	
Within upper canopy	12	24	
Below upper canopy	83	73	

[a] Mann-Whitney *U*-test, [b] χ^2-test, [c] χ^2-test and Cramer's V comparison between particular class and all other classes.

decayed class were not used by pileated woodpecker. Though not statistically significant (P = 0.08), woodpeckers seemed to prefer western hemlock, western red cedar and bigleaf maple as foraging logs.

Discussion

We accepted all three hypotheses for pileated woodpeckers' selection of foraging habitat at the site and element levels. Habitats used for foraging had higher densities of snags and defective trees and higher volumes of coarse woody debris. Snags, defective trees and logs used by pileated woodpecker for foraging were of larger mean diameter (and longer) than those not used for foraging. Our findings are consistent with the results of other studies of foraging by pileated woodpeckers.

Foraging plots

The suitability of sites for foraging depends on a variety of factors, including the presence of

attributes selected by insect prey, particularly carpenter ants. Although we did not examine prey habitat requirements in this paper, the principal components analysis suggested that they were associated with advanced successional and structural stages and the basal area of snags and defective trees. Another important factor was tree canopy cover, our results support those of Raley and Aubrey (2006) who found that all of their pileated woodpecker foraging cavity-tree plots were in closed-canopy stands (typically ≥ 70% canopy cover) and that pileated woodpecker rarely foraged in open conditions, probably due to inadequate escape cover. These relations may explain the significance of tree canopy cover in our results.

Coarse woody debris seems more important where older trees and snags are less abundant, with the exception of forests with sufficient canopy cover of cedar and Douglas fir (as in principal component 2). Areas of dense forest, high herb cover, high grand fir canopy cover, steep slopes and high elevation make contributions to foraging habitat, but these areas appear to also have high densities of coarse woody debris, and in the case of high elevations, high

Table 5. Characteristics of logs used and unused for foraging by pileated woodpecker and of unused logs in four study sites on southeastern Vancouver Island, 1996–1997. Significant P's are set in boldface.

Characteristic	Mean ± SE or percentage frequency		
	Used (n = 27)	Not used (n = 360)	P
Diameter (cm)	43 ± 4	34 ± 1	**0.02**[a]
Length (m)	9.5 ± 1.3	7.3 ± 0.3	**0.03**[a]
Species (%)		(first 4 species)	0.08[b]
Douglas fir (n = 109)	30	28	
Western hemlock (n = 49)	22	12	
Western red cedar (n = 36)	15	9	
Unidentified (n = 155)	19	42	
Red alder (n = 21)	4	6	
Western white pine (n = 2)	4	0	
Shore pine (n = 8)	0	2	
Bigleaf maple (n = 7)	7	1	
Decay class (%)			**< 0.01**[b]
Elevated on support points	15	5	
Elevated but sagging lightly	22	12	
Sagging near ground or broken	56	33	
All of log on ground, sinking	7	23	
All of log on ground, partly sunken	0	28	

[a] Mann-Whitney U-test, [b] χ^2-test.

canopy cover of western hemlock. The number of principal components that contribute to pileated woodpecker foraging habitat indicates that the species can use a variety of habitats although with specific requirements, particularly for structural elements.

Several factors that affect snag density include disturbance, initial stand conditions, falling rates, and tree mortality (Raphael & Morrison 1987). The importance of these factors varied across our study sites. At Rithet, the falling rate or disturbance were probably critical factors because wind or wildfires may have removed some older structures that were not removed at Sooke or Niagara. Fire was a factor for both Hillridge and Rithet, and both had significantly less coarse woody debris. Rithet had many snags that were not as intensively used for foraging as those in Niagara and Sooke. Unburned plots of Douglas fir in northern California tended to have snags that were larger in diameter, less decayed, and with intact tops as compared with snags in burned plots (Raphael & Morrison 1987). When these factors are added to diameter, decay stages can be predicted over time (Raphael & Morrison 1987): predictions such as this one may be useful in projecting the future supply of woodpecker habitat.

Foraging elements: snags and defective trees

Trees used by pileated woodpeckers for foraging were characterized by being the most decayed larger diameter snags and defective trees (mean 56 cm), with no limbs, broken tops and less than half the bark remaining. This is consistent with the findings of other foraging studies. Decaying wood is an important structural element for foraging because it is a suitable substrate for wood-boring and channelizing invertebrates (Renken & Wiggers 1989). In northeastern Oregon pileated woodpeckers preferred snags and logs ≥ 38 cm diameter (Bull & Holthausen 1993). In northwestern Washington, plots with recent foraging activity by pileated woodpeckers had high densities of large snags > 51 cm dbh (Raley & Aubrey 2006).

Foraging elements: logs

Pileated woodpeckers foraged on large logs with a mean diameter of 43 cm and a mean length of 9.5 m. The relative use of western hemlock was significantly greater than the use of Douglas fir, western red cedar, and red alder. The relative use of logs of the three least decayed classes was significantly greater than the most decayed class of logs.

Use of foraging structures

Pileated woodpeckers use a variety of habitat structures for foraging including dead trees, live trees, logs, and stumps. The frequency of each type of structure used varied between geographical and ecological areas (Table 6). These differences probably correspond to a number of ecological and behavioural factors including the prey's preference for habitat, prey availability due to seasonal factors (e.g., snow covering logs), and seasonal foraging strategies (e.g., more excavating in winter).

Pileated woodpeckers rarely forage on fallen

Table 6. Distribution of excavation foraging activity (percentage of total) by pileated woodpecker by substrate in North American studies.

Location	Snags (%)	Live trees (%)	Logs (%)	Reference
Virginia	58	36	–	Conner 1981
N.E. Oregon	38 (6 on stumps)	18	38	Bull & Holthausen 1993
W. Oregon	44	–	36	Mannan 1984
W. Washington	95 standing structures + 3 on stumps	–	2	Raley & Aubrey 2006
Vancouver Island	72	8	22	This paper

logs in the closed-canopy forests of western Washington, concentrating instead on standing decaying wood (95% snags) (Raley & Aubrey 2006). A similar, although not as pronounced, tendency occurred in our study (72% snags). At all study sites, the percentage of plots with evidence of foraging on logs was smaller than the number of plots with sign of foraging on snags.

Comparison of study sites

Indices of foraging sign on snags were positively correlated with the relative abundance data of pileated woodpeckers (Hartwig *et al.* 2002). Areas with the highest pileated woodpecker abundance had higher foraging indices (Niagara and Sooke), and also the highest volumes of coarse woody debris. Just as the relative abundance data in that study demonstrated that pileated woodpeckers have some flexibility in age and quality of forest, the foraging evidence in this study reveals some flexibility.

Another indication of flexibility relates to other types of behaviour. For example, in northeastern Oregon during the breeding and post-breeding periods, behaviours like gleaning, pecking or scaling may increase (Bull & Holthausen 1993). Therefore although use of Rithet for excavating may be limited during heavy winter snowfalls, pileated woodpecker may use different prey (e.g., beetle larvae, flies, vegetable food) than carpenter ants during the summer.

Conclusions

Landscape level

On southeastern Vancouver Island, uniform stands of intensively managed forests < 80 years old were little used by pileated woodpeckers for foraging because structures suitable for their prey were not abundant. This low abundance probably resulted from the previous forest practices, such as harvesting advanced successional and structural stages of forest, removal of snags and coarse woody debris and intense slash (logging debris) fires. Consequently, these forests had relatively few pileated woodpeckers (Hartwig

et al. 2002). Previous studies found that pileated woodpeckers preferred forests > 40 years old for foraging (Mellen *et al.* 1992) but on southeastern Vancouver Island, pileated woodpeckers preferred forests > 80 years old (Hartwig *et al.* 2002).

Not all mature forests or mixed forests with abundant older forest will have the same foraging use by pileated woodpeckers because greater foraging use occurred in this study on larger structural elements. The greater basal area of decayed wood and greater coarse woody debris per ha of used plots are probably related to the greater chance of encountering abundant food sources. Dense numbers of snags and logs of larger diameters are likely to have more nesting sites for carpenter ants (Sanders 1970). These two factors are interrelated and there is a number of additional characteristics, which influence their suitability such as successional and structural stages, tree species, decay characteristics, canopy cover, and elevation. Most of the structural elements that were present were legacies from original old forests or the result of disease and decay processes in second-growth stands.

Recruitment of legacies of older forests

Snag densities in Douglas-fir forests decrease over time in both managed and unmanaged stands in western Oregon (Cline *et al.* 1980). Tree mortality of shade-tolerant species such as western hemlock, true firs, and western red cedar increased in old-growth forests but since these were also susceptible to uprooting, they therefore did not necessarily increase snag production (Cline *et al.* 1980). Thus snag production probably requires extensive areas of land rather than smaller areas of dense snags because many snags are lost over time. Forest management systems that increase rotation times in certain small areas or create riparian reserves connected to small patches of older forest may not be large enough to produce the legacies of older forest equal to legacies found in a site like Niagara or Sooke simply because they are not as extensive as these legacies remaining from earlier times.

Stumps, logs and keystone species

In managed forests of southcentral Scandinavia, Rolstad *et al.* (1998) found that black wood-peckers (*Dryocopus martius*) forage on stumps. These authors suggested that stumps in second-growth forests are a substitute for snags and logs as feeding substrate for pileated woodpeckers in old-growth forests. However, the two species probably face different ecological conditions, particularly because past forest management practices in British Columbia often have not retained stumps, high cut stumps, or stubs. Their suggestion likely underestimates the problems faced by pileated woodpeckers living in short-rotation plantations with periodic thinning, clear-cutting and slash-burning, and natural events such as fires and blow-down. As well, stubs, as structural elements of habitat, have constraints because they are shorter lived than snags and, in areas of high rainfall (or snowfall) experience similar constraints to those of logs. Logs offer fewer foraging opportunities in areas of high rainfall because logs are likely too cool and wet to support abundant populations of carpenter ants (Raley & Aubrey 2006).

Recent work by Rolstad and Rolstad (2000) demonstrates that snow depths can limit black woodpecker populations in managed forests of southcentral Norway where stumps and logs are covered by snow, and standing dead and dying trees are salvage-logged. Their study confirms the hypothesis that inaccessibility to winter food restricts some woodpecker ranges in snow-rich managed forests and may be the reason for black woodpecker population declines in northern areas (Mikusiński 1995, 1997). In addition, smaller, although numerous, ant colonies and beetle larvae concentrations in smaller stumps, logs and snags, while seemingly sufficient in southern climates, may impose energetic constraints in snow-rich areas (Mikusiński 1995). Home range size increased four to five-fold as the feeding habitat declined in the study sites of southcentral Norway (Rolstad & Rolstad 2000). These same energetic constraints are likely a factor for pile-ated woodpeckers in managed forests.

Predation rate is another factor for pileated woodpeckers because they seem to avoid open areas with inadequate escape cover (Raley & Aubrey 2006). In managed Scandinavian forests, where increased arboreal feeding on bark beetles in response to reduced food availability closer to the ground makes the black woodpecker more vulnerable to goshawk (*Accipiter gentilis*) preda-tion (Rolstad & Rolstad 2000). This interaction between forest structure, prey availability and predation likely occurs in managed forests of British Columbia.

Perhaps the reduction and elimination of remnants of old forests could have negative consequences for pileated woodpeckers, particu-larly where heavy rainfall or deep snow limits prey availability. The loss of larger structures for carpenter ants and other prey could reduce prey concentrations for pileated woodpeckers. Less concentrated prey could result in larger ter-ritories and increased energy demands. Coupled with increased predation, these factors could lead to reduced numbers of pileated woodpeckers. These interactions could also negatively affect species that depend on pileated woodpeckers to excavate cavities, i.e., secondary cavity-users. Future studies should investigate prey avail-ability and concentration, home range size, and predation rates in landscapes with different types of forest management to further elucidate these types of interactions and consequences.

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