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# FORAGING ECOLOGY OF PILEATED WOODPECKERS IN DUKES EXPERIMENTAL FOREST IN THE UPPER PENINSULA OF MICHIGAN

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EXPERIMENTAL FOREST IN THE UPPER PENINSULA OF MICHIGAN


By


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ABSTRACT

FORAGING ECOLOGY OF PILEATED WOODPECKERS IN DUKES
EXPERIMENTAL FOREST IN THE UPPER PENINSULA OF MICHIGAN

By

Michael Ray Wierda


Pileated woodpecker selection of foraged trees was studied using a multiple

spatial scale study in coniferous and deciduous forests in the Upper Penninsula of

Michigan.  Most previous works on pileated woodpecker foraging have been conducted

in large homogeneous, contiguous tracts of forests of a single assemblage type.  These

studies found foraging preferences for stand type, tree type, and tree species; specifically,

conifers in the western range, and deciduous trees in the eastern range.  However, it was

unclear if this selection resulted from availability because studied areas were dominated

by preferred tree types and species or habitat data was not reported.  The availability of

suitable coniferous and deciduous assemblages in Dukes Experimental Forest in northern

Michigan provided an opportunity to examine foraged tree selection with both habitat

types present.  Foraged trees were associated with a suite of characteristics: they were

declining to moderately decayed (d.f. = 4, $\chi^2$ = 10.29 and 297.38, respectively, $P \leq 0.05$),

injured, and more had conks than expected (d.f. = 4, $\chi^2$ = 360.05 and 644.08, respectively,

$P \leq 0.05$).  Coarse examination of the data suggested that deciduous trees in general and

aspens and yellow birch in particular were preferred.  Further examination suggested that

these trees were selected by pileated woodpeckers based on their characteristics alone,

which are similar to characteristics of trees inhabited by carpenter ants, the primary prey

of pileated woodpeckers.

DEDICATION

This thesis is dedicated to my parents Ron and Sue Wierda who always knew I had it in me.

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**INTRODUCTION**

Pileated woodpeckers (*Dryocopus pileatus*) are an important habitat modifying species in late successional forest communities.  These birds create large cavities in trees that provide feeding, roosting and nesting sites for many organisms and accelerate nutrient cycling and decomposition (Aubry & Raley, 2000; Aubry & Raley, 2002a; Aubry & Raley, 2002b; Bonar, 2000; Jackson & Jackson, 2004).  Avian species using pileated woodpecker cavities for nests and roosts include the common merganser (*Mergus merganser*), American kestrel (*Falco sparverius*) and the hairy woodpecker (*Picoides villosus*; Aubry & Raley, 2002b).  In addition, barred owls (*Strix varia*) nest almost exclusively in abandoned pileated woodpecker nests (Harestad & Keisker, 1989).  Mammalian species also use pileated woodpecker cavities.  Fishers (*Martes pennati*) use old nests for natal dens (Aubrey & Raley, 2002a), eastern gray squirrels (*Sciurus carolinensis*) and raccoons (*Procyon lotor*) used red-cockaded woodpecker (*Picoides borealis*) nests after pileated woodpeckers had increased the cavity size and entrance hole (Aubry & Raley, 2002b).  Opportunistic foraging by hairy woodpeckers in relation to pileated woodpeckers has been observed (Maxson & Maxson, 1981).  In that study at least three hairy woodpeckers foraged on a dead red oak (*Quercus rubra*) following the removal of bark by pileated woodpeckers, and one male hairy woodpecker and a pileated woodpecker foraged simultaneously.

Through foraging, nest construction, nest starts (i.e., nest cavities that were not completed) and roost construction, pileated woodpeckers accelerate decomposition and nutrient cycling of snags (standing dead trees), live trees and decadent trees.  These processes are accelerated directly by the breaking apart of sound and decomposed wood

and indirectly by exposing interior wood of trees and snags to insects and fungal infection (Aubry & Raley, 2002b; Jackson & Jackson, 2004).

The current distribution of pileated woodpeckers covers the majority of the eastern third of the United States (U.S.), southern Canada, and portions of the Rocky and Cascade Mountains (Bohlen, 1989; Bull & Jackson, 1995; Peterjohn, 1989). Availability of suitable habitat is apparently a limiting factor for most populations of pileated woodpeckers (Bull & Jackson, 1995). The primary component defining suitable pileated woodpecker habitat is the presence of late successional forests, typically with trees ≥ 50 cm in diameter at breast height (dbh) and high densities of snags (Bull, 1987; McClelland & McClelland, 1999; Mellen, Meslow, & Mannan, 1992).

The pileated woodpecker's diet consists mainly of insects (primarily carpenter ants, *Camponotus* spp.), wild fruits and nuts. Excavating deep into the tree, scaling bark off the surface and surface pecking are three foraging behaviors used by pileated woodpeckers (Bull, 1987; Bull & Holthausen, 1993; Conner, 1981). Excavation foraging into the interior of trees is the pileated woodpecker's primary means of obtaining food (Bull, 1987; Bull & Holthausen, 1993; Flemming, Holloway, Watts, & Lawrance, 1999). Pileated woodpeckers remove large slivers of wood to gain access to carpenter ant galleries, creating highly visible rectangular cavities. A long extensible tongue with barbs and sticky saliva is then used to extract ants from tunnels within the wood (Bull & Jackson, 1995). Foraging often occurs in stands ≥ 40 years old with trees and snags ≥ 50 cm dbh and on down trees, and stumps of similar size (Bull, 1987; Conner, Hooper, Crawford, & Mosby, 1975; Mellen et al., 1992).

Studies of pileated woodpecker ecology in its western range in Oregon and western Montana, have documented a strong preference for nearly exclusive usage of coniferous species (Bull, 1987; Bull & Holthausen, 1993; McClelland & McClelland, 1999). Studies in the eastern range in southern Québec and Virginia showed preferences for deciduous species and shade tolerant hardwood assemblages (Conner, 1981; Savignac, Desrochers, & Huot, 1994). However, whether this indicates a foraging preference is unclear because western study areas and eastern study areas were dominated by coniferous and deciduous species, respectively (Bull, 1987; Conner et al., 1975).

Intra-community preferences for tree characteristics in coniferous forests and deciduous forests (e.g., dbh, tree species, stand composition, height, and level of decay) have been demonstrated (Bull, 1987; Flemming et al., 1999; Savignac et al., 2000). In coniferous forests of the north western U.S., foraged tree dbhs were on average ≥ 30 cm (Bull, 1987; Bull & Holthausen, 1993; Bull & Meslow, 1977). In New Brunswick, Canada, the median dbh of foraged trees was 27 cm (Flemming et al., 1999). Bonar (1999) suggested that clusters of more than 8 snags ≥ 16 cm dbh per ha. resulted in optimal conditions for pileated woodpecker foraging. Flemming et al. (1999) demonstrated that red spruce (*Picea rubens*) was used more frequently in contiguous coniferous dominated forests while deciduous species were used more frequently in fragmented mixed forests. Flemming et al. (1999) suggested that preference for deciduous trees in the fragmented forest may have simply been a preference for larger trees, because, in the fragmented forests larger coniferous trees had been removed. Flemming et al. (1999) found that the intensity of foraging on dead and declining balsam firs (*Abies balsamea*) was negatively correlated with availability. Lack of suitably sized

trees of this preferred species was thought to have forced pileated woodpeckers to use greater portions of the available balsam firs (Flemming et al., 1999). Flemming et al. (1999) argued that pileated woodpeckers preferred red spruce and balsam fir because the bark loosened relatively rapidly once dead and because the wood was softer than shade tolerant hardwood species. However, Savignac et al. (2000) reported that highly decomposed large firs in similar low densities were not preferred over large shade tolerant hardwood snags. In eastern Canada, pileated woodpeckers preferred large yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), and balsam firs in mature shade tolerant hardwood stands, but firs were more frequently used than hardwoods in immature mixed shade-intolerant stands (Savignac et al., 2000). Flemming et al. (1999) reported a significant difference in heights between foraged trees and available trees. Foraged trees were generally shorter than available trees, typically due to a heightened state of decay. Foraged trees were characterized as dead with a broken top, while the average available tree was characterized as live.

Previous studies of foraging site selection by pileated woodpeckers were done in landscapes with relatively large, homogeneous, contiguous tracts of one habitat type. In predominantly coniferous habitats (west coast studies) and in predominately deciduous habitats (mid-west and east coast studies), fundamentally different foraged tree selection occurred (Bull, Holthausen, & Henjum, 1992; Conner & Crawford, 1974; Mannan, 1984; McClelland & McClelland, 1999). These differences were correlated to the predominant assemblages in the study areas.

The availability of suitable coniferous and deciduous assemblages in the upper peninsula of Michigan and the mosaic arrangement of these assemblages provided an

opportunity to examine pileated woodpecker foraging when both suitable deciduous and coniferous habitats were available. The forests of the upper peninsula Michigan are transitional zones between northern deciduous and northern coniferous forests with mature (60-70 years old) and climax ($\geq$ 100 year) patches of deciduous and coniferous assemblages (Wolford, 2002). Sugar maple and eastern hemlock (*Tsuga canadensis*) were the most common tree species in the mature to climax forests of the upper peninsula of Michigan (Wolford, 2002). Pileated woodpecker foraging signs have been noted on both of these species (personal observation) and foraging on sugar maples has been documented (Flemming et al., 1999).

This study was designed to examine pileated woodpeckers' foraging site selection 1) at the stand level (i.e., are deciduous or mixed assemblages preferred), 2) at the tree type level (i.e., are deciduous or coniferous trees preferred), 3) at the tree species level (i.e., are any tree species preferred), and 4) at the tree characteristic level (i.e., are any tree characteristics correlated with foraging). This study is representative of pileated woodpecker fall and winter foraging preferences. Pileated woodpeckers typically forage on the ground during the summer because carpenter ants have moved out of trees and into tunnels under leaf litter. Carpenter ants move back into trees for the fall and winter (unpublished data per comm. Savignac, 2005).

**MATERIALS AND METHODS**

*Study Area*

The research was conducted in Dukes Experimental Forest (2201 ha) in the upper peninsula of Michigan. Dukes Experimental Forest is located in the Hiawatha National

Forest in Marquette County Transects 46 and 45 N. Range 23 W.  Dukes Experimental

Forest contains mature deciduous assemblages and mature mixed assemblages.  Mixed

assemblages were composed of a 1:1 ratio of deciduous and coniferous trees.  In the

mixed assemblages, sugar maples and eastern hemlocks co-dominated.  In the mature

deciduous assemblages, sugar maples dominated the available trees.

*Sampling Methods*

Mature/climax mixed and deciduous assemblages were selected from a National

Forest Service stand survey map.  Selected assemblages were at least 40 m x 500 m.

Within each assemblage, one to four "ribbon plots" were established.  Ribbon plots were

30 m wide, 400 m long and spaced a minimum of 30 m apart (Figure 1a, b).  Ten mixed

and 12 deciduous ribbon plots were established.  Systematic searches of ribbon plots

were conducted from May to September 2004.  Starting at a corner and walking the plot

boundary, trees inside the ribbon plot were scanned for subcambial excavation foraging

sites (SEFS).  At 25 m intervals, a full 360° was scanned for SEFS (Figure 1b, c).  Data

were collected on all current and recent SEFS.  Current and recent foraging was indicated

by the presence of woodchips on top of the leaf litter from the previous fall.  When the

line of vision was obscured (generally in dense hemlock stands), a third pass was made

up the middle of the ribbon plot.  The same scanning technique was used.  If SEFS were

spotted outside of the plot during ribbon plot searches, the same data were collected.

The location of each SEFS was recorded with a global positioning system, and its

characteristics were recorded.  Subcambial excavation foraging site characteristics

included: location, plot type, tree species, dbh, tree/snag height, foraging location

(maximum height), decay class, presence or absence of injury (e.g., fire, lightning, frost

crack, forked top, broken top), presence or absence of conk, canopy height, and canopy cover. Mutually exclusive decay classes were defined:

- Decomposed snags$_{(DC)}$: No branches, stem very punky or rotten, bark mostly gone.

- Loose Bark snags$_{(DC)}$: few or no branches, stem mostly intact but may be starting to soften, bark loose and easily removed.

- Recently dead trees$_{(DC)}$: fine branches gone, major branches still present, stem mostly sound.

- Declining trees$_{(DC)}$: fine branches still present, major branches mostly present, often one or more major branches had brown or no needles or leaves.

- Live trees$_{(DC)}$: all remaining standing trees that do not fit the above categories.

Characteristics of trees available for foraging were estimated by subsampling ribbon plots. Each ribbon plot was divided into sixteen equal blocks and three blocks were selected using a random number generator (Microsoft Excel®). Within each selected block, a 15 m radius habitat plot was centered. For all snags and trees with a dbh $\geq 6.36$ cm, plot type, tree species, dbh, decay class, presence or absence of injury, and conk were recorded. Red and sugar maple (*Acer rubrum* and *A. saccharum*, respectively), black and white spruce (*Picea mariana* and *P. glauca*, respectively) and quaking and big tooth aspen (*Populus tremuloides* and *P. grandidentata*, respectively) trees were grouped into maples, spruces, and aspens because some individual trees could not be identified to the species level.

*Statistical Methods*

The proportion of trees foraged inside the plots and the proportion of trees foraged outside the plots were compared for deciduous plots and mixed plots combined to determine if data sets (i.e., trees foraged inside ribbon plots and trees foraged outside ribbon plots) could be pooled. The numbers of available trees were estimated based on the number of habitat trees and the differences in search areas. Because the proportion of trees foraged inside ribbon plots was different from the proportion of trees foraged outside ribbon plots; stand type, tree type, and tree species proportion analyses used only inside ribbons plot data. Proportions were compared using a normal approximation of a continuity-corrected chi-square ($\chi_c^2$) test (Zar, 1999).

Tree characteristic analyses used all applicable foraged trees (n ≤ 120) and all applicable habitat trees (i.e., non foraged trees ≥ 6.36 cm dbh, n ≤ 3155). Tree characteristics were selected from past pileated woodpecker foraging, nesting, and roosting literature. Because these characteristics previously had been correlated with pileated woodpecker habitat possible colinearity between variables was investigated.

To investigate how much variables interacted, five variables previously correlated with foraged trees were considered post-hoc. They were: presence of injury (injury), presence of fungal infection (conk), decay class of the tree (decay), dbh, and tree species (spp). These variables were chosen because of previously published correlations with pileated woodpecker foraged tree selection (Bull et al., 1992; Conner & Crawford, 1974; Flemming et al., 1999; Mannan, 1984; McClelland & McClelland, 1999; Savignac et al., 2000). Injury and conk were analyzed as 0-1 variables indicating absence (0) or presence (1) of the characteristic. Decay was analyzed in a collapsed form based on the results of

preliminary analysis. Because dead and loose bark decay classes did not demonstrated statistically significant differences in the preliminary analysis, they were collapsed into a single category, resulting in four values for the decay variable: (0) live, (1) declining, (2) dead/loose bark, and (3) decomposed. Three tree species (Aspen, Yellow Birch, and Eastern Hemlock) were included in this investigation based on results of preliminary analysis. An indicator variable was created for each species (indicating absence (0) or presence (1)).

Tests of colinearity were conducted between all combinations of individual tree characteristic variables and categorical variables for tree species to determine if any variables were too closely related to be meaningfully combined as interaction variables. Ordinal variable pairs with Kendall's tau-b correlations of greater than 0.80 (i.e., > 64% of variance shared) were considered too closely related to be meaningfully combined for further analysis regarding variable interaction (Table 1). To further test whether tree characteristics or tree species were driving foraging selection, a logistic regression model was constructed with interaction variables (Table 2, Hosmer, 1989). The null hypothesis was that coefficients for tree characteristic interaction variables were as likely to be zero as coefficients including species indicator variables.

In general, contingency table analyses were used to determine if the frequency of one variable was independent of the frequency of a second variable. Because average expected count was always > 6, contingency tables were analyzed with the chi-square statistic (Zar, 1999). If variables were not independent, post-hoc chi-square tests were conducted to determine which observed counts deviated significantly from expected counts. Bonferroni's corrections were used to avoid alpha inflation in the post-hoc chi-

square tests.  Student's t-test was used to compare averages where applicable.  Pair-wise comparisons between proportions of foraged tree species were made for each individual tree species using the Dunnett test statistic (Zar, 1999).  For a summation of all statistical tests conducted see appendix A.  An alpha of 0.05 was used as the criterion for rejection of null hypothesis.

## RESULTS

Total areas surveyed for foraged trees inside (n = 40) and outside (n = 25) of 12 deciduous plots were 144,000 $m^2$ and 274,802 $m^2$, respectively.  Total areas surveyed for foraged trees inside (n = 28) and outside (n = 27) of 10 mixed plots were 120,000 $m^2$ and 316,726 $m^2$, respectively.  One-hundred deciduous and 20 coniferous foraged trees were characterized in total.  Two thousand and twenty non-foraged deciduous trees and 935 non-foraged coniferous trees were characterized during habitat surveys.  The total area of habitat surveyed in deciduous plots and in mixed plots were 25,446.96 $m^2$ and 16,964.64 $m^2$, respectively.

Tests for colinearity between ordinal variables did not result in the exclusion of any variable combinations.  Although significant correlations existed between all combinations (P < 0.05), none of the variables attained the rejection level of 64% shared variance (Kendall's tau-b = 0.80).  Maximum shared variance was 27% (Kendall's tau-b = 0.52) between conk and decay (Table 1).

In the final regression model, five interaction variables met the criteria for model retention.  They were DBH by Decay, DBH by Injury, Injury by Decay, Injury by Conk, and Conk by Decay, listed here in increasing order of significance for the score statistic.

The full model explained approximately 57.3% of the variance as approximated by Negelkerke's R Square. This model included all but one of the variables from the individual tree characteristic subset. No species indicator variables met the criteria for inclusion in the model. These results suggest that the null hypothesis should be rejected.

Mean dbh of foraged trees (45.16 cm, n = 100) was greater than the mean dbh of non-foraged trees (20.80 cm, n = 2220, P < 0.001). Foraging was not independent of decay class (d.f. = 4, $\chi^2$ = 670.99, P < 0.001; Table 3). Foraged trees had fewer live trees$_{(DC)}$ and more declining trees$_{(DC)}$, dead trees$_{(DC)}$ and loose bark snags$_{(DC)}$ than expected (d.f. = 1, $\chi^2$ = 81.20, 10.29, 297.38 and 256.87, respectively, P ≤ 0.05). Non-foraged trees had fewer dead trees$_{(DC)}$ and loose bark snags$_{(DC)}$ than expected (d.f. = 1, $\chi^2$ = 11.28 and 9.63, respectively, P ≤ 0.05).

Foraging was not independent of injuries and conks (d.f. = 1, $\chi^2$ = 457.50 and 702.78 respectively, P < 0.001; Tables 4 and 5, respectively). Foraged trees had fewer trees without injuries and conks and more trees with injuries and conks than expected (d.f. = 1, $\chi^2$ = 81.66, 38.03, 360.05 and 644.08, respectively, P < 0.05). Non-foraged trees had fewer trees with injuries and conks than expected (d.f. = 1, $\chi^2$ = 13.96 and 22.96 respectively, P < 0.05).

Proportionately more trees were foraged inside plots (68/19,706.90) than were foraged outside plots (52/44,055.80; $Z_C$ = 6.01, P < 0.001). Thus, only inside plots data were used for stand type, tree type, and tree species proportion analyses.

The proportion of trees foraged in deciduous plots (40/12,562.6) was equal to the proportion of trees foraged in mixed plots (28/6,613.76; $Z_C$ = 1.03, 0.20 < P < 0.50; Table 6). Mean dbh of trees in deciduous plots (21.65 cm, n = 1810) was equal to the

mean dbh of trees in mixed plots (20.79 cm, n = 1465, $0.05 < P < 0.10$). Plot type was not independent of decay class (d.f. = 4, $\chi^2 = 15.26$, $0.001 < P < 0.005$; Table 7). Deciduous plots had fewer live trees$_{DC}$ than expected (d.f. =1, $\chi^2 = 4.22$, $P \leq 0.05$). However, frequency of trees with injury and conk was independent of plot type (d.f. = 1, and 1, $\chi^2 = 1.97$ and 0.75, $0.10 < P < 0.25$ and $0.25 < P < 0.50$, respectively; Table 8 and 9).

The proportion of deciduous trees foraged (57/11,306.73) was approximately 4.2 times greater than the proportion of coniferous trees foraged (11/9,147.20; $Z_C = 4.62$, $P < 0.001$; Table 10). The mean dbh of deciduous trees (21.85 cm, n = 2320) was larger than the mean dbh of coniferous trees (19.85 cm, n = 955; $P < 0.001$). Tree type was not independent of decay class (d.f. = 4, $\chi^2 = 58.79$, $P < 0.001$; Table 11). Deciduous trees had more declining trees$_{DC}$, and loose bark snags$_{DC}$, (d.f. = 1, $\chi^2 = 6.28$ and 6.52, respectively, $P \leq 0.05$). Coniferous trees had fewer declining trees$_{DC}$, and loose bark snags$_{DC}$ (d.f. = 1, $\chi^2 = 15.28$ and 15.83, respectively, $P \leq 0.05$). Frequencies of injured trees differed with tree type (d.f. = 1, $\chi^2 = 37.25$, $P < 0.001$; Table 12). Deciduous trees had more trees with injuries than expected (d.f. = 1, $\chi^2 = 8.84$, $P \leq 0.05$). Coniferous trees had fewer trees with injuries than expected (d.f. = 1, $\chi^2 = 21.49$, $P \leq 0.05$). Frequencies of trees with conks differed with tree type (d.f. = 1, $\chi^2 = 43.45$, $P < 0.001$; Table 13). Deciduous trees had more trees with conks than expected (d.f. = 1, $\chi^2 = 11.98$, $P \leq 0.05$). Conifers had fewer trees with conks than expected (d.f. = 1, $\chi^2 = 29.07$, $P \leq 0.05$).

Foraging was not independent of tree species (d.f. = 15, $\chi^2 = 180.70$, $P < 0.001$; Table 14). Aspens, yellow birch, white cedar, and white pine had significantly more

foraged trees than expected (d.f. = 1, $\chi^2$ = 73.50, 59.82, 11.22, and 6.4, respectively, $P \leq 0.05$). Eastern hemlock had significantly fewer foraged trees than expected (d.f. = 1, $\chi^2$ = 10.41, $P \leq 0.05$).

Aspens were foraged in significantly greater proportions than all other tree species ($P \leq 0.05$). Yellow birch was foraged in significantly greater proportion than eastern hemlock, balsam fir and maples ($P \leq 0.05$). Maples and spruces were foraged in significantly greater proportions than eastern hemlock ($P \leq 0.05$). Aspens mean dbh (32.89 cm, n = 42) compared to all other species (21.11 cm, n = 3233) was significantly larger ($P < 0.001$). Yellow birch (29.77 cm, n = 292) mean dbh compared to eastern hemlock, balsam fir and maples (20.32 cm, n = 2569) was significantly larger ($P < 0.001$). Maple (20.98 cm, n = 1761) and spruce (18.83 cm, n = 67) mean dbhs were significantly smaller than eastern hemlock (21.55 cm, n = 605; $0.20 < P < 0.50$ and $0.02 < P < 0.05$, respectively).

Tree species was not independent of decay class (d.f. = 60, $\chi^2$ = 338.47, $P < 0.001$; Table 15). Aspens had fewer live trees$_{DC}$ and more loose bark snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 9.56 and 72.90, respectively, $P \leq 0.05$). Yellow birch had fewer live trees$_{DC}$, more dead trees$_{DC}$, more loose bark snags$_{DC}$, and more decomposed snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 11.50, 22.67, 11.53, and 44.00, respectively, $P \leq 0.05$). Maples had fewer decomposed snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ =9.12, $P \leq 0.05$). Eastern hemlock had more live trees$_{DC}$, fewer declining trees$_{DC}$, fewer dead trees$_{DC}$, and more loose bark snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 8.91, 13.05, 10.53, and 26.01, respectively, $P \leq 0.05$). Spruces had more decomposed snags$_{DC}$ than expected (d.f. = 1,

$\chi^2 = 10.68$, $P \leq 0.05$), and black locust had more declining trees$_{DC}$ than expected (d.f. = 1,
$\chi^2 = 31.34$, $P \leq 0.01$).

Frequency of injured trees differed among tree species (d.f. = 15, $\chi^2 = 291.44$, $P < 0.001$; Table 16). Aspens and yellow birch both had fewer trees without injuries and more trees with injuries than expected (d.f = 1, $\chi^2 = 15.73$, 22.34 and 69.05, 98.23, respectively, $P \leq 0.05$). Eastern hemlock had more trees without injuries and fewer trees with injuries than expected (d.f. = 1, $\chi^2 = 6.14$ and 27.01, $P \leq 0.05$). Balsam fir had fewer trees with injuries than expected (d.f. = 1, $\chi^2 = 11.29$, $P \leq 0.05$). Black walnut had fewer trees with injuries than expected (d.f. = 1, $\chi^2 = 6.40$, $P \leq 0.05$).

Frequency of trees with conks differed among tree species (d.f = 15, $\chi^2 = 364.07$, $P < 0.001$; Table 17). Aspens and yellow birch had fewer trees without conks (d.f. = 1, $\chi^2 = 5.58$ and 12.20, respectively, $P \leq 0.05$) and more trees with conks than expected (d.f. = 1, $\chi^2 = 93.95$ and 206.22, respectively, $P \leq 0.05$). Maples and eastern hemlock had fewer trees with conks than expected (d.f. = 1, $\chi^2 = 5.14$ and 19.78, respectively, $P \leq 0.05$).

*Mixed plots*

Mixed plots consisted of 49.9% deciduous species and 50.1% coniferous species. Thirty-eight foraged deciduous and 17 foraged coniferous trees were characterized in total. Six hundred ninety-three non-foraged deciduous trees and 717 non-foraged coniferous trees were characterized during habitat surveys. The proportion of deciduous trees foraged (38/4,939.96) was approximately 2.3 times greater than the proportion of coniferous trees foraged (17/5,088.73; $P = 0.14$; Table 18). In contrast to that of all plots (pooled mixed and deciduous plots), mean dbh of deciduous trees (20.88 cm, n = 731)

was not significantly different from the mean dbh of coniferous trees (20.69 cm, n = 734; P = 0.79).

The same pattern emerged in mixed plots as was reported in all plots. Foraging was not independent of decay class (d.f = 4, $\chi^2$ = 299.04, P < 0.001; Table 19). Non-foraged trees had fewer loose bark trees$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 6.64, P $\le$ 0.05), and foraged trees had fewer live trees$_{DC}$, more dead trees$_{DC}$ and loose bark snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 32.87, 79.75 and 176.04, respectively, P $\le$ 0.05).

Foraging was not independent of injuries and conks (d.f. = 1, $\chi^2$ = 175.08 and 335.66, respectively, P < 0.001; Tables 20 and 21). Foraged trees had fewer trees without injuries and conks and more trees with injuries and conks than expected (d.f. = 1, $\chi^2$ = 33.01, 19.53, 135.11 and 308.00, respectively, P < 0.001), and non-foraged trees had fewer trees with injuries and conks than expected (d.f. = 1, $\chi^2$ = 5.28 and 11.24, respectively, P $\le$ 0.05).

Tree type was not independent of decay class, injury or conk (d.f., 4, 1, and 1, $\chi^2$ = 33.66, 31.60 and 43.79, respectively, P < 0.001; Tables 22, 23, and 24). Deciduous trees had more declining trees$_{DC}$, more loose bark snags$_{DC}$, more trees with injuries, and more trees with conks (d.f. = 1, $\chi^2$ = 6.26, 6.34, 12.72 and 20.63, respectively, P $\le$ 0.05) and coniferous trees had fewer declining trees$_{DC}$, fewer loose bark trees$_{DC}$, fewer trees with injuries and fewer trees with conks than expected ( d.f. = 1, $\chi^2$ = 6.26, 6.31, 12.69 and 20.54, respectively, P $\le$ 0.05). In contrast to deciduous trees in all plots, deciduous trees had fewer live trees$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 17.25, P $\le$ 0.05).

Foraging was not independent of tree species (d.f. = 8, $\chi^2$ = 93.82, P < 0.001; Table 25). As reported for all plots above: aspens, yellow birch and white pine had

significantly more foraged trees than expected (d.f. = 1, $\chi^2$ = 18.68, 46.61, and 6.40, respectively, $P \leq 0.05$), and eastern hemlocks had significantly fewer foraged trees than expected (d.f. = 1, $\chi^2$ = 8.98, $P \leq 0.05$).

Contingency table analyses showed that the tree species was not independent of decay class (d.f. =32, $\chi^2$ = 258.12, $P < 0.001$; Table 26). Aspens had more loose bark snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 105.30, $P \leq 0.05$), yellow birch had fewer live trees$_{DC}$, more dead trees$_{DC}$ and more decomposed snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 6.08, 12.89 and 17.38, respectively, $P \leq 0.05$), eastern hemlock had more live trees$_{DC}$, fewer declining trees$_{DC}$, fewer dead trees$_{DC}$ and fewer loose bark snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 6.00, 6.25, 8.50 and 19.40, respectively, $P \leq 0.05$), maples had fewer decomposed snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 6.00, $P \leq 0.05$), and spruces had significantly more decomposed snags$_{DC}$ than expected (d.f. = 1, $\chi^2$ = 7.65, $P \leq 0.05$). In contrast to these tree species in all plots, yellow birch had more declining trees$_{DC}$, than expected (d.f. = 1, $\chi^2$ = 5.63, $P \leq 0.05$), and balsam fir had more loose bark snags$_{DC}$ and decayed snags$_{DC}$ (d.f. = 1, $\chi^2$ = 5.98 and 10.88, respectively, $P \leq 0.5$).

Tree species was not independent of injury (d.f. = 8, $\chi^2$ = 168.05, $P < 0.001$; Table 27). Aspens and yellow birch had fewer trees without injuries (d.f. = 1, $\chi^2$ = 9.89 and 13.00, respectively, $P \leq 0.05$) and more trees with injuries than expected (d.f. = 1, $\chi^2$ = 40.57 and 53.33, respectively, $P \leq 0.05$), eastern hemlock had more trees without injuries and fewer with injuries than expected (d.f. = 1, $\chi^2$ = 7.07 and 295.35, respectively, $P \leq 0.05$).

Tree species was not independent of conk (d.f. = 8, $\chi^2$ = 194.59, $P < 0.001$; Table 28). Aspens had more trees with conks than expected (d.f. = 1, $\chi^2$ = 60.17, $P \leq 0.05$),

yellow birch had fewer trees without conks and more trees with conks than expected (d.f. = 1, $\chi^2$ = 6.22 and 96.53, respectively, $P \leq 0.05$), and eastern hemlock had fewer trees with conks than expected (d.f. = 1, $\chi^2$ = 16.79, $P \leq 0.05$).

Tree species were not foraged equally. Aspens and yellow birch were foraged in significantly greater proportions than eastern hemlock, maples, spruces and balsam fir ($P \leq 0.05$). White cedar was foraged in significantly greater proportions than eastern hemlock and maples ($P \leq 0.05$). Aspen and yellow birch mean dbh (27.95 cm, n = 178) were significantly larger than eastern hemlock, maples, spruces, and balsam fir (19.22 cm, n = 1184, $P < 0.001$). White cedar mean dbh (28.22 cm, n = 68) was significantly larger than eastern hemlock and maples (19.81 cm, n = 1037; $P < 0.001$).


**DISCUSSION**

In Dukes Experimental Forest pileated woodpeckers appeared to select for foraged trees based on tree type (deciduous trees), tree species (aspens and yellow birch) and tree characteristics (decay class, injury and conk). However, these selections were associated with a suite of tree characteristics. In general, foraged trees/snags were declining to moderately decayed, injured and had conks. Proportionately more deciduous trees, which were foraged more than coniferous trees, followed this general trend as did the highly foraged aspens and yellow birch.

Savignac et al. (2000) reported in southern Quebec that pileated woodpeckers avoided coniferous stands and preferred "mature mixed shade-tolerant hardwood stands" for foraging. Pileated woodpeckers in Dukes Experimental Forest used mixed stands and deciduous stands equally. Savignac et al. (2000) suggested that the negative relationship

between foraging and coniferous stands was possibly due to the lack of high quality trees for foraging (e.g., large yellow birch, sugar maple and balsam fir). Sugar maple and yellow birch were the highly foraged species in the mature and over mature shade-tolerant hardwood stands in southern Quebec, while balsam fir was the highly foraged species in the immature mixed shade-intolerant stands. The coniferous stands in their study were actually coniferous plantations that were < 30 years old. The next closest stand age in the study was 10 – 50 year old stands (Savignac et al., 2000). Thus, it is possible that coniferous stands were avoided because of their characteristics (i.e., they were younger than other stands in the study) and potential habitat for pileated woodpecker's food sources (i.e., carpenter ants and bugs in dead and down wood), may have been removed for ease of planting and future harvesting. The findings in Dukes Experimental Forest support the hypothesis of selection based on characteristics. Unfortunately, characteristic profiles for individual stand types were not reported by Savignac et al. (2000).

Flemming et al. (1999) reported that deciduous trees were foraged more than coniferous trees (33.6% vs. 12.9%, respectively) in the fragmented forests of New Brunswick, Canada. They also reported that deciduous trees in the fragmented forests were more decayed and injured more often than the conifers. Pileated woodpeckers in Dukes Experimental Forest foraged similarly. Selection of deciduous trees in Dukes Experimental Forest was associated with three tree characteristics: declining to moderately decayed and trees with injuries, and conks. This suggests that deciduous trees were selected according to state of decay and presence of injury. Bunnel, Houde, Johnston & Wind (2002) reported that coniferous trees in the Pacific Northwest were

avoided until they reached a suitable decay class (recently dead), and with further decay their attractiveness as foraging sites increased.

Bull & Meslow (1977) reported that Douglas fir and larch were selected for while ponderosa pine was selected against.  Bull (1987) reported preferences for ponderosa pine, Douglas fir and western larch.  These studies were conducted in two sites in the Blue Mountains in north east Oregon.  The selection against ponderosa pine in 1977 and then selection for in 1987 suggests that selection is not based on species.  Ponderosa pines in 1977 may not have reached suitable levels of decay for carpenter ants to be present, and thus were not foraged by pileated woodpeckers.  While pileated woodpecker foraging was distributed in Dukes Experimental Forest in a way that could suggest selection and avoidance according to tree species, selection of forage trees and avoidance of non-forage trees correlate well with tree characteristics.  Trees with injuries, fungal growth, and signs of more advanced decay (i.e., aspen and yellow birch) were foraged more than expected while trees without injuries, fungal growth, and signs of slight decay (i.e., eastern hemlock) were foraged less than expected.  Thus, these species followed the characteristic trends of foraged and non-foraged trees.

Five species of trees were foraged significantly more than other species.  For two of these species, aspens and yellow birch (which were foraged more than expected and more than most other species), it was the characteristics of the more foraged species which influenced selection (Figures 3 and 4).  Maples, spruces and white cedar were foraged according to availability and were foraged significantly more than eastern hemlock only.  Eastern hemlock was the only species of tree in the study foraged significantly less than expected (Figure 5).  Thus, aspens and yellow birch are the best

representatives of foraged trees, and eastern hemlock is the best representative of non-foraged tree species in Dukes Experimental Forest.

Bull (1987) reported that live trees were foraged almost as often as dead trees. However, the majority of the foraging activity on live trees was scaling, not subcambial excavation foraging. In the Dukes Experimental Forest study, subcambial excavation foraging cavities were used to identify pileated woodpecker foraging activity and actual foraging activities were not observed. Therefore, the importance of live trees may have been underestimated. Bull (1987) reported that pileated woodpeckers foraged on larger recently dead trees (within 5 years). Bull & Holthausen (1993) reported that snags $\geq 38$ cm dbh were preferred. In Dukes Experimental Forest, foraged trees (median = 43.6 cm, range = 7.95 cm to 85.31 cm) were larger than non-foraged trees (median = 16.23 cm, range = 2.23 cm to 91.35 cm). However, dbh data was not separated into size classes for the Dukes Experimental Forest study, and thus a preference for a specific size is not reported. Savignac et al. (2000) reported a positive association between pileated woodpecker foraging and density of small ($\leq 30$ cm) snags and large ($\geq 31$ cm) snags, and a negative association for small live trees ($\leq 30$ cm). This suggests that while tree size is associated with foraged trees, the physical state of the tree (i.e., decay class) is more important. Bunnell et al. (2002) reported that decay state may reflect the likelihood of hosting carpenter ants, and size of tree may not influence feeding preference.

Large trees are older, and thus have more potential for injury simply due to exposure. Injuries make trees more likely to have fungal heart rot via exposure of the sap wood, and carpenter ants are more likely to have colonies in trees with heart rot (Farris,

Martin & Zack, 2004; Jackson & Jackson, 2004; McClelland & McClelland, 1999; Sanders, 1964).

Carpenter ants create tunnels in decomposed cores of trees which start at the bole and typically extend up the tree, sometimes invading sound wood (Conners et al., 1975; Sanders, 1964). Sanders (1964) reported that the majority of carpenter ant galleries were correlated with slight fungal decay rather than extensive fungal decay. Foraged trees in Dukes Experimental Forest were declining to moderately decayed.

Fungal infection of trees improves habitat for pileated woodpeckers directly and indirectly. Directly it results in the softening of heartwood and loosening of bark thus making excavation foraging easier. Indirectly it creates highly suitable habitat for carpenter ants (Sanders, 1964). In this study, the presence of conks was used as the indicator of fungal infection. Thus, the presence of heart-rot fungus was probably underestimated. Jackson & Jackson (2004) reported that heart-rot fungi may grow unnoticed in a tree for several years before conks appear on the surface.

Injuries exposing the interior of the tree to the environment increase the likelihood of heart rot (Bull et al., 1992). Farris et al. (2004) reported that wood-inhabiting fungi were isolated from woodpecker bills at greater frequencies than expected at random. Thus, pileated woodpeckers may also promote fungal invasion of sapwood by physically creating injuries that expose the interior of the tree and by acting as vectors for wood decomposing fungal spores, yeast cells, or hyphae (Farris et al., 2004).

## CONCLUSIONS

This study has potentially underestimated three things: first, the importance of live trees as food sources, second, the importance of decomposed trees as food sources, and third the occurrence of fungal infection in foraged trees.

In Dukes Experimental Forest, a suite of characteristics were associated with pileated woodpecker foraged trees. Coarser examination of the data suggested that deciduous trees and two species in particular (aspens and yellow birch) were being selected. However, this analysis suggested trees were selected due to their characteristics.

Interactions between characteristics such as size, exposure of heartwood (i.e., injury), and extent of fungal infection demonstrated the strongest associations to foraged trees and have a strong ecological bases. Tree size is likely indirectly correlated through carpenter ant and heart-rot fungus ecology. The two levels of decay most strongly associated with foraged trees (declining and dead) showed high injury and conk rates. Rates for conks were higher in foraged trees also, and even so, probably underestimated the presence of fungal infection. Because 1) carpenter ants make up the majority of the pileated woodpeckers diet, 2) trees with fungal infections are highly suitable habitats for carpenter ants, and 3) trees need to reach a suitable level of decay to be attractive as pileated woodpecker foraging sites, decay class is an important characteristic related to foraged tree selection. The selection of foraged trees is probably also directly related to the extent of fungal infection. Because injuries expose the interior of the tree to the environment increasing the likelihood of heart rot and pileated woodpeckers promote fungal infection of trees by creating injuries and acting as vectors for wood decomposing

fungal spores, injury is an important characteristic in foraged tree selection.  Thus, fungal infection seems to be the ultimate basis for pileated woodpecker foraged tree selection.  While decay class is an important characteristic related to foraged tree selection, it is unrealistic to separate it from the occurrences of injuries or conks because all three are intimately related.  This suggests that new criteria are needed for categorizing trees according to physical state.  A measure of the presence and extent of fungal infection is possibly the most direct way to establish if a tree will become a future foraging site for pileated woodpeckers.

Future research on pileated woodpecker foraging ecology would be wise to focus on carpenter ant ecology.  Because carpenter ants make up the majority of the pileated woodpecker's diet, it stands to reason that selection criteria of carpenter ants for nest trees should be similar to selection criteria of pileated woodpeckers for foraged trees.  Because it is unlikely that pileated woodpeckers locate carpenter ants immediately upon invasion, it follows that foraged trees would be slightly larger, more decomposed, and have higher occurrences of injuries and conks than those selected for invasion by carpenter ants.

In relation to the foraging ecology of pileated woodpeckers further work on tree characteristics is needed.  While understanding the preferences of pileated woodpeckers for foraged trees is important in the management of pileated woodpeckers, this researcher would suggest that any future work should concentrate on the characteristics of the trees.  Tree species, tree type and stand type should not be ignored but to look at preferences without looking at tree characteristics is to miss the forest among the trees.

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Appendix A

SUMMARY OF STATISTICAL ANALYSES

Kendall's tau-b & Logistic regression

Ordinal variable pairs with Kendall's tau-b correlations of greater than 0.8 (>64%
of variance shared) were considered too closely related to be meaningfully combined for
further analysis regarding variable interaction. That is, these variables were considered
indistinguishable for the purposes of this analysis. Variables sharing less than 64% of
variance were used to create interaction variables and entered into a logistic regression
using the forward stepwise selection procedure.

Variables were combined by multiplying the values in order to create a new
variable for each combination. For example, interaction variable values for DBH by
Decay (IVDBHxDecay) were calculated by multiplying the DBH (cm) of each tree by its
value for the Decay (0-3) variable. This was done for the following 18 variable
combinations:

Using SPSS, the forward stepwise selection procedure was used to build the
regression model. The Likelihood-Ratio Test was used as the criterion for determining
variables to be removed. Conservative significance levels were used to reduce the
influence of the large sample size ($3300 > n > 2800$ for all analyses). Entry and removal
probabilities for each step of the stepwise procedure were set at 0.01 and 0.05,
respectively (Hosmer 1989). It was hypothesized that individual tree characteristics

would be the primary influence on foraging site selection. The null hypothesis was that coefficients for tree characteristic interaction variables were as likely to be zero as coefficients including species indicator variables. If the subgroup of six individual tree characteristic interaction variables entered the model first, and no further variables from the species indicator subset satisfied the criteria for inclusion in the model, the null hypothesis would be rejected.

Foraged trees vs. Non-foraged trees:

Contingency table analyses were used to determine whether the frequency of foraging was independent of frequency of decay class, of injury, and of conk. Student's t-test was used to compare average dbh of foraged to non-foraged trees.

Mixed plots vs. Deciduous plots:

The $\chi_c^2$ goodness-of-fit test was used to compare proportion of trees foraged in mixed plots to proportion of trees foraged in deciduous plots. Student's t-test was used to compare average dbh of foraged trees in mixed plots to that in deciduous plots. Contingency table analyses were used to determine whether frequency of stand type was independent of frequency of decay class, of injury, and of conk.

Coniferous trees vs. Deciduous trees:

The $\chi_c^2$ goodness-of-fit test was used to compare the proportion of foraged coniferous trees to the proportion of foraged deciduous trees. Student's t-test was used to compare dbhs of coniferous and deciduous trees. Student's t-test was also used to compare canopy height and canopy cover at foraged coniferous and deciduous trees and tree/snag height of foraged coniferous and deciduous trees. Contingency table analyses

were used to determine whether frequency of tree type was independent of frequency of decay class, of injury, and of conk.

## Tree species vs. Tree species:

Contingency table analysis was used to determine if frequency of foraging was independent of frequency of tree species. Pair-wise comparisons between proportions of foraged tree species were made for each individual tree species using the Dunnett test statistic (i.e., the species being compared to all others was treated as the control, Zar 1999). Mean dbhs of significantly different groups (i.e., tree species that were significantly different according to the Dunnett test statistic) were compared with student's t-test. Contingency table analyses were used to determine whether the frequency of tree species was independent of the frequency of decay class, of injury, and of conk.

### *Mixed plots:*

In mixed plots, deciduous and coniferous species were analyzed for foraging selection under conditions of their equal availability.

## Foraged trees vs. Non-foraged trees:

Contingency table analyses were used to determine whether frequency of foraging was independent of frequency of decay class, of injury, and of conk.

## Coniferous trees vs. Deciduous trees:

Proportions of foraged deciduous and foraged coniferous trees were compared using $\chi_c^2$ goodness-of-fit test. Student's t-test was used to compare mean dbhs of deciduous and coniferous trees. Contingency table analyses were used to determine

whether frequency of tree type was independent of frequency of decay class, of injury, and of conk.

<div align="center">Tree species vs. Tree species:</div>

A contingency table analysis was used to determine if frequency of foraging was independent of frequency of tree species. Pair-wise comparisons between proportions of foraged tree species were made for each individual tree species using the Dunnett test statistic (i.e., the species being compared to all others was treated as the control, Zar 1999). Mean dbhs of significantly different groups were compared with student's t-test. Contingency table analyses were used to determine whether frequency of tree species was independent of frequency of decay class, of injury, and of conk.

APPENDIX B:

TABLES AND FIGURES CITED IN TEXT.

Table 1. Kendall's tau-b values and % variance shared for interaction variable combinations of tree characteristic variables and of species by tree characteristic variables.

| Variable Pair | Kendall's tau-b | % shared variance |
|---|---|---|
| Conk * Decay | 0.523 | 27.04 |
| Injury * Decay | 0.500 | 25.00 |
| Injury * Conk | 0.421 | 17.72 |
| Yellow Birch * Conk | 0.270 | 7.30 |
| Yellow Birch * Injury | 0.201 | 4.04 |
| Aspen * Conk | 0.176 | 3.10 |
| Aspen * Injury | 0.162 | 2.62 |
| Yellow Birch * Decay | 0.158 | 2.50 |
| Eastern Hemlock * Decay | -0.141 | 1.99 |
| Aspen * Decay | 0.135 | 1.82 |
| Eastern Hemlock * Injury | -0.111 | 1.23 |
| Eastern Hemlock * Conk | -0.089 | 0.79 |

Table 2: Interaction variable combinations for individual tree characteristic (ITC) variables and interaction variable combinations for species by characteristic (S-by-C) for aspens, Yellow Birch, and Eastern Hemlock used in logistic regression model.

| ITC | S-by-C |
|---|---|
| Conk by Decay | Aspen by Conk |
| Injury by Decay | Aspen by Decay |
| DBH by Decay | Aspen by DBH |
| Injury by Conk | Aspen by Injury |
| Injury by DBH | Yellow Birch by Conk |
| Conk by DBH | Yellow Birch by Decay |
| | Yellow Birch by DBH |
| | Yellow Birch by Injury |
| | Eastern Hemlock by Conk |
| | Eastern Hemlock by Decay |
| | Eastern Hemlock by DBH |
| | Eastern Hemlock by Injury |

Table 3. Frequency of foraging among trees in 5 decay classes (see text for definition of decay classes). Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Foraging | | Decay class | | | | |
|---|---|---|---|---|---|---|
| | | Live | Declining | Dead | Loose Bark | Decomposed |
| **Absent** | Observed | 2747 | 124 | 100 **11.28** | 142 **9.63** | 41 |
| | Expected | 2656.8 | 131 | 139.7 | 184.1 | 42.4 |
| **Present** | Observed | 10 **81.20** | 12 **10.29** | 45 **297.4** | 49 **256.87** | 3 |
| | Expected | 100.2 | 4.9 | 5.3 | 6.9 | 1.6 |

d.f. = 4, chi-square = 671.94, P < 0.001

Table 4. Frequency of foraging in injured and uninjured
trees. Bold underlined numbers represent statistically
significant post-hoc chi-square test results.

| Foraging | | Injury | | | |
| | | Absent | | Present | |
| --- | --- | --- | --- | --- | --- |
| Absent | Observed | 2659 | | 495 | **13.56** |
| | Expected | 2570 | | 584 | |
| Present | Observed | 8 | **81.66** | 111 | **360.1** |
| | Expected | 97 | | 22 | |
| d.f. = 1, chi-square = 457.50, P < 0.001 | | | | | |

Table 5. Frequency of foraging in trees with conks and
without conks. Bold underlined numbers represent
statistically significant post-hoc chi-square test results.

| Foraging | | Conk | | | |
| | | Absent | | Present | |
| --- | --- | --- | --- | --- | --- |
| Absent | Observed | 3041 | | 113 | **22.96** |
| | Expected | 2977.3 | | 177 | |
| Present | Observed | 43 | **38.03** | 70 | **644.1** |
| | Expected | 106.7 | | 6.3 | |
| d.f. = 1, chi-square = 702.78, P < 0.001 | | | | | |

Table 6:  Number of foraged and available trees in 12
deciduous and 10 mixed plots.

| Plot type | Foraged | Available | Proportion Foraged |
|-----------|---------|-----------|--------------------|
| Deciduous | 40 | 12,602.60 | 0.00320 |
| Coniferous | 28 | 6,641.76 | 0.00420 |
| Zc = 1.03 | | | |

Table 7. Frequency of trees in deciduous plots and mixed plot in 5 decay classes. Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Plot type | | | Decay class | | | | |
|---|---|---|---|---|---|---|---|
| | | Live | | Declining | Dead | Loose Bark | Decomposed |
| **Deciduous** | observed | 1515 | **<u>4.22</u>** | 90 | 75 | 114 | 16 |
| | expected | 1524.6 | | 72.5 | 80.2 | 105.6 | 24.3 |
| **Mixed** | observed | 1242 | | 46 | 70 | 77 | 28 |
| | expected | 1232.4 | | 60.8 | 64.8 | 85.4 | 19.7 |

d.f. = 4, chi-square = 15.26, 0.001 < P < 0.005

Table 8: Frequency of trees in deciduous and mixed plots with and without injuries.

| Plot type | | **Injury** | |
| | | **Absent** | **Present** |
|---|---|---|---|
| **Deciduous** | observed | 1490 | 319 |
| | expected | 1474.5 | 334.5 |
| **Mixed** | observed | 1177 | 286 |
| | expected | 1192.5 | 270.5 |
| d.f. = 1, chi-square = 1.97, 0.10 < P < 0.25 | | | |

Table 9: Frequency of trees in deciduous and mixed plots with and without conks.

| Plot type | | **Conk** | |
| | | **Absent** | **Present** |
|---|---|---|---|
| **Deciduous** | observed | 1711 | 95 |
| | expected | 1705.4 | 100.6 |
| **Mixed** | observed | 1373 | 87 |
| | expected | 1378.6 | 81.4 |
| d.f. = 1, chi-square = 0.75 0.25 < P < 0.50 | | | |

Table 10: Number of foraged and available deciduous and coniferous trees in 12 deciduous and 10 mixed plots.

| Tree type | Foraged | Available | Proportion Foraged |
|-----------|---------|-----------|--------------------|
| Deciduous | 57 | 11,306.73 | 0.00504 |
| Coniferous | 11 | 9,147.20 | 0.00120 |
| Zc = 4.62 | | | |

Table 11. Frequency of deciduous and coniferous trees in 5 decay classes. Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Tree Type | | Live | Declining | Decay class Dead | Loose Bark | Decomposed |
|---|---|---|---|---|---|---|
| **Deciduous** | Observed | 1890 | 121 | 116 | 165 | 27 |
| | Expected | 1953.4 | 96.4 | 102.7 | 135.3 | 31.2 |
| **Coniferous** | Observed | 867 | 15 | 29 | 26 | 17 |
| | Expected | 803.6 | 39.6 | 42.3 | 55.7 | 12.8 |
| | | | **6.28** | | **6.52** | |
| | | | **15.28** | | **15.83** | |

d.f. = 4, chi-square = 58.79, P < 0.001

Table 12.  Frequency of deciduous and coniferous trees with and without injuries.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

|  |  | Injury | |  |
| --- | --- | --- | --- | --- |
| **Tree Type** |  | **Absent** | **Present** |  |
| **Deciduous** | Observed | 1828 | 491 | **8.84** |
|  | Expected | 1889.6 | 429.4 |  |
| **Coniferous** | Observed | 839 | 115 | **21.49** |
|  | Expected | 777.4 | 176.6 |  |
| d.f. = 1, chi-square = 37.25 P < 0.001 | | | | |

Table 13.  Frequency of deciduous and coniferous trees with and without conks.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

|  |  | Conk | |  |
| --- | --- | --- | --- | --- |
| **Tree Type** |  | **Absent** | **Present** |  |
| **Deciduous** | Observed | 2145 | 169 | **11.98** |
|  | Expected | 2184.4 | 129.6 |  |
| **Coniferous** | Observed | 939 | 14 | **29.07** |
|  | Expected | 899.6 | 53.4 |  |
| d.f. = 1, chi-square = 43.45, P < 0.001 | | | | |

Table 14. Frequency of foraging among 5 species of trees. Bold underlined numbers represent statistically significant post-hoc chi-square test results. Only the data for species in which post-hoc chi-square tests showed significant differences are reported.

| Foraging | | Aspen | Eastern Hemlock | Species White Cedar | White Pine | Yellow Birch |
|---|---|---|---|---|---|---|
| **Absent** | Observed | 30 | 598 | 62 | 8 | 256 |
| | Expected | 40.5 | 582.8 | 67.4 | 9.6 | 281.3 |
| **Present** | Observed | 12  **73.50** | 7  **10.41** | 8  **11.22** | 2  **6.4** | 36  **59.82** |
| | Expected | 1.5 | 22.2 | 2.6 | 0.4 | 10.7 |

d.f. = 15, chi-square = 180.70, P < 0.001

Table 15. Frequency of 7 tree species in 5 decay classes. Bold underlined numbers represent statistically significant post-hoc chi-square test results. Only the data for species in which post-hoc chi-square tests showed significant differences are reported.

| Species | | Live | Declining | Dead | Loose Bark | Decomposed |
|---|---|---|---|---|---|---|
| | | | | | **Decay Class** | |
| **Aspens** | Observed | 17 | 4 | 5 | 16 | 0 |
| | | **9.56** | | | **72.90** | |
| | Expected | 35.4 | 1.7 | 1.9 | 2.5 | 0.6 |
| **Black Locust** | Observed | 27 | 9 | 2 | 0 | 0 |
| | | | **31.34** | | | |
| | Expected | 34.5 | 1.7 | 1.8 | 0.5 | 0.1 |
| **Eastern Hemlock** | Observed | 577 | 7 | 10 | 6 | 6 |
| | | **8.91** | **13.05** | **10.53** | **26.01** | |
| | Expected | 509.6 | 25.1 | 26.8 | 5 | 8.1 |
| **Maples** | Observed | 1488 | 81 | 75 | 0 | 9 |
| | | | | | | **9.12** |
| | Expected | 1483.4 | 73.2 | 78 | 0.9 | 23.7 |
| **Spruces** | Observed | 50 | 1 | 6 | 3 | 4 |
| | | | | | | **10.68** |
| | Expected | 55.6 | 2.7 | 2.9 | 4.1 | 0.9 |
| **White Pine** | Observed | 7 | 0 | 0 | 31 | 1 |
| | | | | | | **8.10** |
| | Expected | 8.4 | 0.4 | 0.4 | 17 | 0.1 |
| **Yellow Birch** | Observed | 192 | 21 | 30 | 31 | 17 |
| | | **11.50** | | **22.67** | **11.53** | **44.00** |
| | Expected | 245.1 | 12.2 | 12.9 | 17 | 3.9 |

d.f. = 60, chi-square = 338.47, P < 0.001

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Table 16. Frequency of 5 tree species with and without injuries.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.  Only the data for species in which post-hoc chi-square tests showed significant differences are reported.

| Species | | Injury | | | |
|---|---|---|---|---|---|
| | | Absent | | Present | |
| Aspens | Observed | 24 | **15.73** | 17 | **69.05** |
| | Expected | 38.7 | | 2.3 | |
| Black Walnut | Observed | 2 | | 0 | **6.40** |
| | Expected | 1.9 | - | 0.1 | |
| Balsam Fir | Observed | 199 | | 4 | **11.29** |
| | Expected | 191.6 | - | 11.4 | |
| Eastern Hemlock | Observed | 597 | **6.14** | 8 | **27.01** |
| | Expected | 571.1 | | 33.9 | |
| Yellow Birch | Observed | 216 | **22.34** | 74 | **98.23** |
| | Expected | 273.8 | | 16.2 | |
| d.f. = 15, chi-square = 291.44, P < 0.001 | | | | | |

Table 17. Frequency of 4 tree species with and without conks. Bold underlined numbers represent statistically significant post-hoc chi-square test results.  Only the data for species in which post-hoc chi-square tests showed significant differences are reported.

| Species | | Conk | | | |
|---|---|---|---|---|---|
| | | Absent | | Present | |
| Aspens | Observed | 11 | **5.58** | 31 | **93.95** |
| | Expected | 34.2 | | 7.8 | |
| Eastern Hemlock | Observed | 548 | | 57 | **19.78** |
| | Expected | 493 | - | 112 | |
| Maples | Observed | 1453 | | 307 | **5.14** |
| | Expected | 1434.1 | - | 326 | |
| Yellow Birch | Observed | 165 | **12.20** | 127 | **206.22** |
| | Expected | 237.9 | | 54.1 | |
| d.f. = 15, chi-square = 364.07, P < 0.001 | | | | | |

Table 18.  Number of foraged and available deciduous and coniferous trees in mixed plots.

| | Foraged | Available | Proportion Foraged |
|---|---|---|---|
| **Deciduous** | 38 | 4,939.96 | 0.00769 |
| **Coniferous** | 17 | 5,088.73 | 0.00334 |
| **Zc = 4.62** | | | |

Table 19. Frequency of foraging among trees in mixed plots in 5 decay classes. Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Foraging | | Live | Declining | Decay class Dead | Loose Bark | Decomposed |
|---|---|---|---|---|---|---|
| **Absent** | Observed | 1235 | 43 | 53 | 52 | 26 |
| | Expected | 1196.2 | 44.3 | 67.4 | 74.2 | 27 |
| **Present** | Observed | 7 | 3 | 17 | 25 | 2 |
| | Expected | 45.8 | 1.7 | 2.6 | 2.8 | 1 |
| | | **<u>32.87</u>** | | **<u>79.75</u>** | **<u>6.64</u>** | |
| | | | | | **<u>176.04</u>** | |

d.f. = 4, chi-square = 299.04, P < 0.001

Table 20. Frequency of foraging among trees in mixed plots with and without injuries.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Foraging | | Injury | | | |
| --- | --- | --- | --- | --- | --- |
| | | **Absent** | | **Present** | |
| **Absent** | Observed | 1171 | | 238 | **5.28** |
| | Expected | 1132.8 | | 276 | |
| **Present** | Observed | 6 | **33.01** | 49 | **135.11** |
| | Expected | 44.2 | | 10.8 | |
| d.f. = 1, chi-square = 175.08, P < 0.001 | | | | | |

Table 21. Frequency of foraging among trees in mixed plots with and without conks.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Foraging | | Conk | | | |
| --- | --- | --- | --- | --- | --- |
| | | **Absent** | | **Present** | |
| **Absent** | Observed | 1355 | | 54 | **11.24** |
| | Expected | 1324.1 | | 84.9 | |
| **Present** | Observed | 18 | **19.53** | 34 | **308** |
| | Expected | 48.9 | | 3.1 | |
| d.f. = 1, chi-square = 335.66, P < 0.001 | | | | | |

Table 22. Frequency of deciduous and coniferous trees in mixed plots in 5 decay classes.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Tree Type | | Live | Declining | Dead | Loose Bark | Decomposed |
|---|---|---|---|---|---|---|
| | | | | **Decay class** | | |
| **Deciduous** | Observed | 587 | 63 | 43 | 54 | 11 |
| | Expected | 619.7 **17.25** | 23 **6.26** | 34.9 | 38.4 **6.34** | 14 |
| **Coniferous** | Observed | 655 | 11 | 27 | 23 | 17 |
| | Expected | 622.3 | 23 **6.26** | 35.1 | 38 **6.31** | 14 |

d.f. = 4, chi-square = 33.66, P < 0.001

Table 23. Frequency of deciduous and coniferous trees in mixed plots with and without injuries.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Tree Type | | Injury | | |
| --- | --- | --- | --- | --- |
| | | Absent | Present | |
| Deciduous | Observed | 545 | 186 | **12.72** |
| | Expected | 587.7 | 143.3 | |
| Coniferous | Observed | 632 | 101 | **12.69** |
| | Expected | 589.3 | 143.7 | |
| d.f. = 1, chi-square = 31.60, P < 0.001 | | | | |

Table 24. Frequency of deciduous and coniferous trees in mixed plots with and without conks.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.

| Tree Type | | Conk | | |
| --- | --- | --- | --- | --- |
| | | Absent | Present | |
| Deciduous | Observed | 655 | 74 | **20.63** |
| | Expected | 685.1 | 43.9 | |
| Coniferous | Observed | 718 | 14 | **20.54** |
| | Expected | 687.9 | 44.1 | |
| d.f. = 1, chi-square = 43.79, P < 0.001 | | | | |

Table 25. Frequency of foraging among 5 species of trees in mixed plots. Bold underlined numbers represent statistically significant post-hoc chi-square test results. Only data for species in which post-hoc chi-square tests showed significant differences are reported.

| Foraging | | Aspen | Eastern Hemlock | Species White Cedar | White Pine | Yellow Birch |
|---|---|---|---|---|---|---|
| **Absent** | Observed | 20 | 503 | 62 | 8 | 131 |
| | Expected | 24.1 | 489.9 | 67.4 | 9.6 | 147.3 |
| **Present** | Observed | 5 **18.68** | 6 **8.98** | 8 **11.22** | 2 **6.4** | 22 **46.61** |
| | Expected | 0.9 | 19.1 | 2.6 | 0.4 | 5.7 |

d.f. = 8, chi-square = 93.82, P < 0.001

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Table 26. Frequency of 6 tree species in mixed plots among 5 decay classes. Bold underlined numbers represent statistically significant post-hoc chi-square test results. Only data for species in which post-hoc chi-square tests showed significant differences are shown.

| Species | | Decay Class | | | | |
|---|---|---|---|---|---|---|
| | | **Live** | **Declining** | **Dead** | **Loose Bark** | **Decomposed** |
| **Aspens** | Observed | 12 | 0 | 0 | 13 | 0 |
| | Expected | 21.2 | 0.8 | 0.8 | 1.3 | 0.5 |
| | Significant | | | | **105.3** | |
| **Balsam Fir** | Observed | 63 | 3 | 7 | 10 | 6 |
| | Expected | 75.6 | 2.8 | 4.3 | 4.7 | 1.7 |
| | Significant | | | | **5.98** | **10.88** |
| **Eastern Hemlock** | Observed | 483 | 6 | 10 | 4 | 6 |
| | Expected | 432.1 | 16.6 | 24.4 | 26.8 | 9.7 |
| | Significant | **6** | **6.25** | **8.5** | **19.4** | |
| **Maples** | Observed | 450 | 24 | 26 | 27 | 1 |
| | Expected | 448.2 | 16.6 | 25.3 | 27.8 | 10.1 |
| | Significant | | | | | **8.2** |
| **Spruces** | Observed | 42 | 1 | 6 | 4 | 4 |
| | Expected | 48.4 | 1.8 | 2.7 | 3 | 1.1 |
| | Significant | | | | | **7.65** |
| **Yellow Birch** | Observed | 101 | 10 | 17 | 14 | 10 |
| | Expected | 129 | 4.8 | 7.3 | 8 | 2.9 |
| | Significant | **6.08** | **5.63** | **12.89** | | **17.38** |

d.f. = 32, chi-square = 258.12, $P < 0.001$

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Table 27. Frequency of 3 tree species in mixed plots with and without injuries.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.  Only data for species in which post-hoc chi-square tests showed significant differences are shown.

| Species | | Injury | | | |
|---|---|---|---|---|---|
| | | Absent | | Present | |
| Aspens | Observed | 6 | **9.89** | 19 | **40.57** |
| | Expected | 20.1 | | 4.9 | |
| Eastern Hemlock | Observed | 463 | **7.07** | 46 | **295.35** |
| | Expected | 409.2 | | 99.8 | |
| Yellow Birch | Observed | 83 | **13** | 70 | **53.33** |
| | Expected | 123 | | 30 | |
| d.f. = 8, chi-square = 168.05, P < 0.001 | | | | | |

Table 28. Frequency of 3 tree species in mixed plots with and without conk.  Bold underlined numbers represent statistically significant post-hoc chi-square test results.  Only data for species in which post-hoc chi-square tests showed significant differences are shown.

| Species | | Conk | | | |
|---|---|---|---|---|---|
| | | Absent | | Present | |
| Aspens | Observed | 14 | - | 11 | **60.17** |
| | Expected | 23.5 | | 1.5 | |
| Eastern Hemlock | Observed | 501 | - | 8 | **16.79** |
| | Expected | 478.3 | | 30.7 | |
| Yellow Birch | Observed | 113 | **6.22** | 39 | **96.53** |
| | Expected | 142.8 | | 9.2 | |
| d.f. = 8, chi-square = 194.59, P < 0.001 | | | | | |
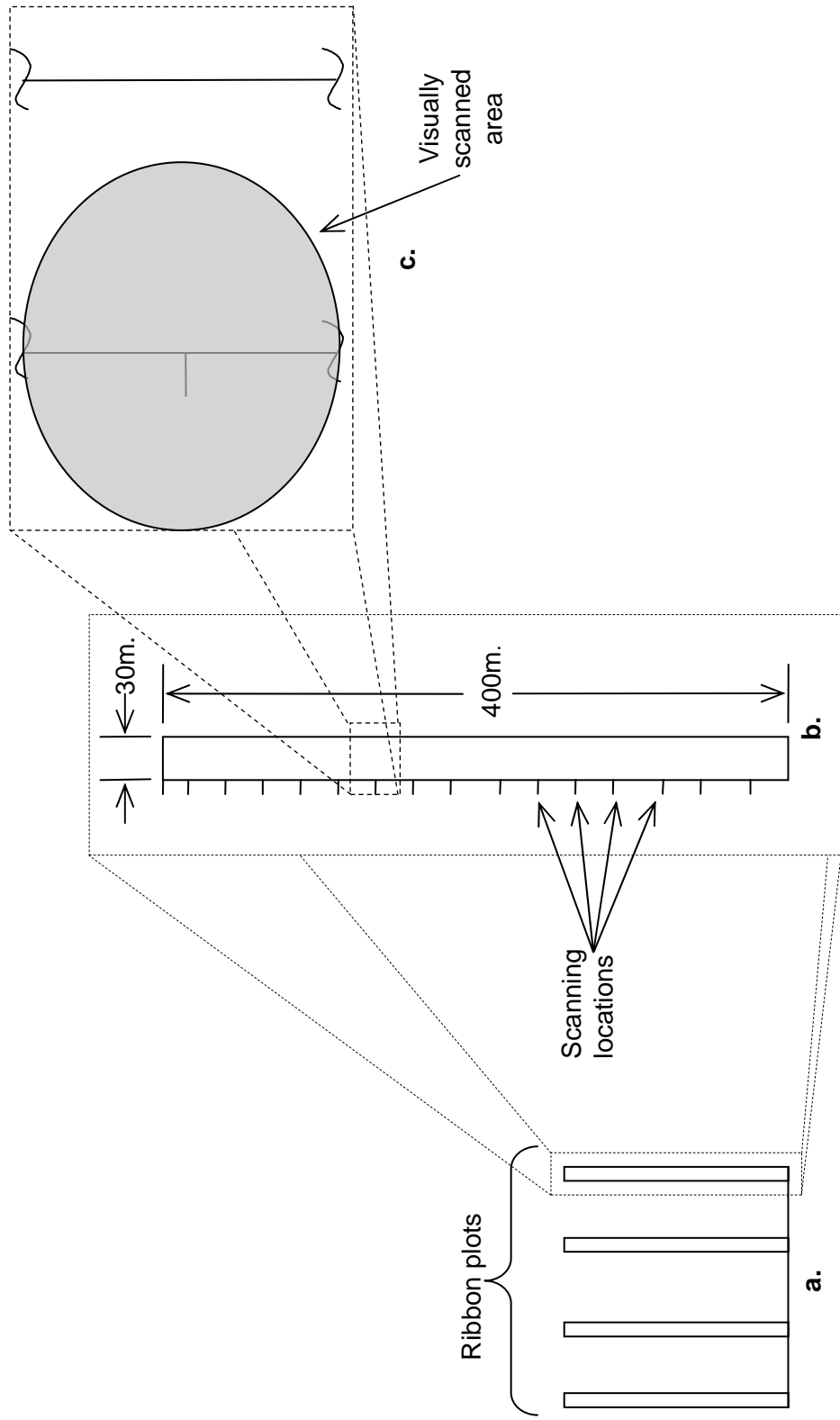
Figure 1: Diagram of **a.** ribbon plot distribution design, **b.** individual ribbon plot, demonstrating location of 25m interval scanning locations and **c.** individual scanning location, approximating area covered in 360° arc scan.

Figure 2: Percents of decay classes for non-foraged and foraged trees in Dukes Experimental Forest.
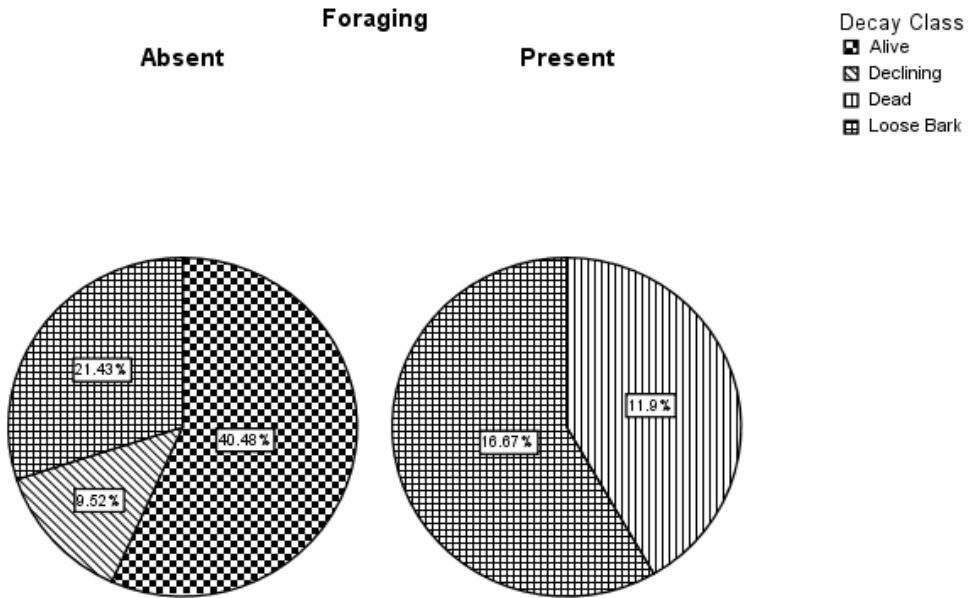
Figure 3: Percents of decay classes for non-foraged and foraged aspen trees in Dukes Experimental Forest.
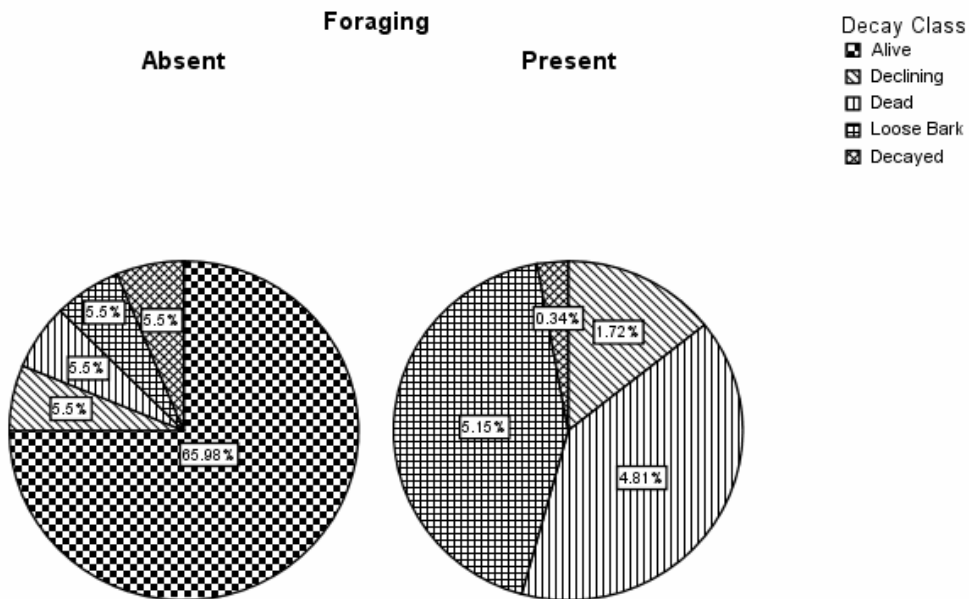


Figure 4: Percents of decay classes for non-foraged and foraged yellow birch trees in Dukes Experimental Forest.
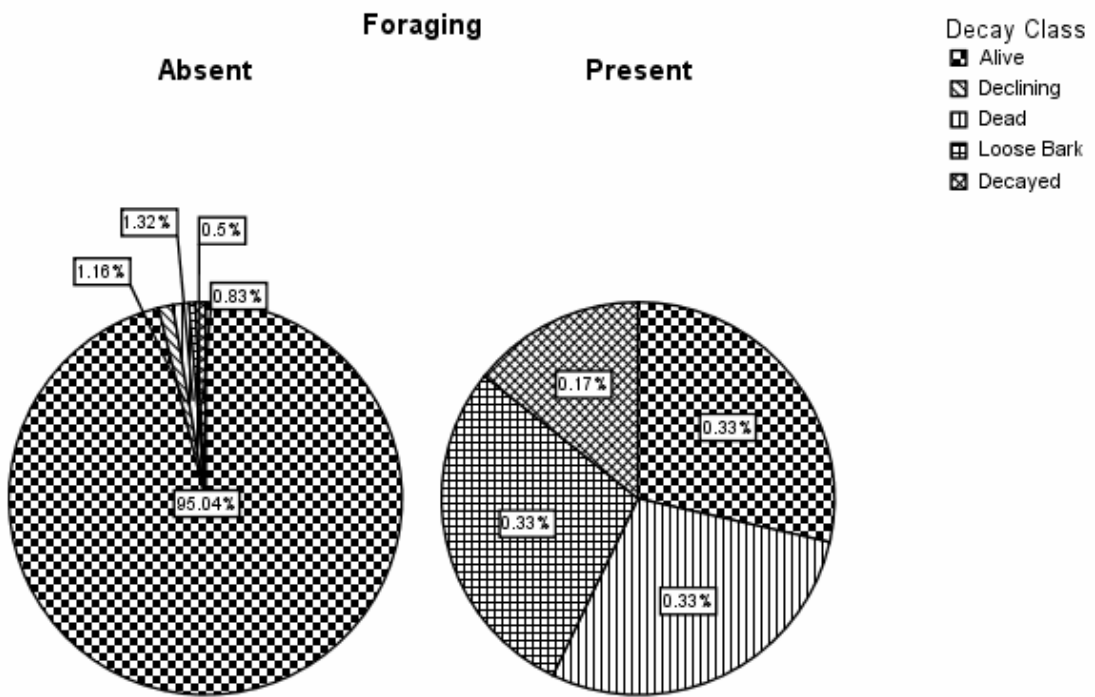
Figure 5: Percents of decay classes for non-foraged and foraged eastern hemlock trees in Dukes Experimental Forest.
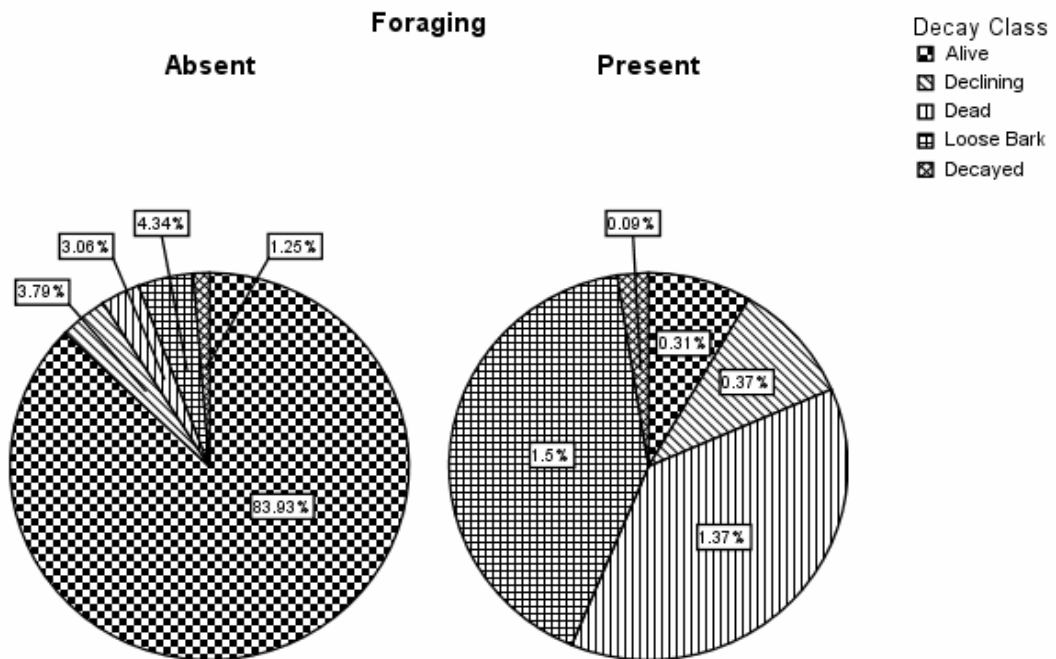
APPENDIX C


SAMPLE FORAGING DATA SHEET


**FORAGING TREE RECORD**

**Plot** _____

**Tree #** _____

**Date** _____

**UTM** _____          _____

**Species** _____

**DBH** _____

**Tree/snag height** @_____m._____°

**Max foraging height** @_____m._____°

**Decay class:--**Live—Declining—Dead—Loose Bark—No Bark—Decomposed

**Injury** (fire, lightning, frost crack, forked top, broken top) **present-----absent**

**Conk---**present----absent

**Canopy height** @_____m._____°

**Canopy cover:** (count of ¼ squares not filled with canopy)

          **N_____, E_____, S_____, W_____          AVERAGE_____**

**Foraging age** _____

APPENDIX D:

SAMPLE HABITAT DATA SHEET

HABITAT PLOT RECORD

Plot _____

Block # _____

UTM  _____                _____

Canopy Height   C____:____   N____:____   E____:____   S____:____   W____:____

Canopy Cover   C_____   N_____   E_____   S_____   W_____

|    | TREE # | SPECIES | DBH | HEIGHT<br>Dist : Deg | DECAY | INJURY | CONK |
|----|--------|---------|-----|-----------|-------|--------|------|
| 1  |        |         |     | :         |       |        |      |
| 2  |        |         |     | :         |       |        |      |
| 3  |        |         |     | :         |       |        |      |
| 4  |        |         |     | :         |       |        |      |
| 5  |        |         |     | :         |       |        |      |
| 6  |        |         |     | :         |       |        |      |
| 7  |        |         |     | :         |       |        |      |
| 8  |        |         |     | :         |       |        |      |
| 9  |        |         |     | :         |       |        |      |
| 10 |        |         |     | :         |       |        |      |
| 11 |        |         |     | :         |       |        |      |
| 12 |        |         |     | :         |       |        |      |
| 13 |        |         |     | :         |       |        |      |
| 14 |        |         |     | :         |       |        |      |
| 15 |        |         |     | :         |       |        |      |
| 16 |        |         |     | :         |       |        |      |
| 17 |        |         |     | :         |       |        |      |
| 18 |        |         |     | :         |       |        |      |
| 19 |        |         |     | :         |       |        |      |
| 20 |        |         |     | :         |       |        |      |
| 21 |        |         |     | :         |       |        |      |
| 22 |        |         |     | :         |       |        |      |