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INFLUENCE OF LANDSCAPE-SCALE FOREST STRUCTURE ON THE PRESENCE OF PILEATED WOODPECKERS (*Dryocopus pileatus*) IN CENTRAL ONTARIO FORESTS

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Abstract

Bush, P.G. 1999. Influence of landscape-scale forest structure on the presence of pileated woodpeckers (*Dryocopus pileatus)* in central Ontario forests. M.Sc. F. Thesis. Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, Ontario, Canada, 87 pp.

Key Words: *Dryocopus pileatus*, pileated woodpeckers, landscape analysis, landscape ecology, habitat, habitat supply model.

The goal of my research was to investigate the influence of landscape-scale forest structure on the presence of pileated woodpeckers (*Dryocopus pileatus*) in central Ontario forests. Study sites were located in Algonquin Provincial Park. The presence of pileated woodpeckers was recorded along 5 km transect lines. The area around each transect line was used for landscape analysis and represented 5 km^2. Landscape-scale structure analysis was conducted on the composition and configuration of pileated woodpecker habitat. The habitat was classified based on several methods and focused on the variations of the pileated woodpecker habitat supply model (PWPHSM) for central Ontario. To determine which of the classifications best predicted the presence of pileated woodpeckers, logistic regression was run on the variable "percent of land (%LAND)" for each classification. The landscape structure of the best classification was further examined to explain the presence of pileated woodpeckers by entering all landscape-level and class-level FRAGSTATS variables into a logistic regression procedure.

The relative densities of pileated woodpeckers in Algonquin Park averaged 0.27 breeding pairs per km^2 (SD = 0.146 SD, range = 0.2 to 0.8). The preferred habitat classification was the best predictor of the pileated woodpecker presence. Total, used, and feeding habitats were less able to predict the presence of pileated woodpeckers. CAD (core area density), NCA (number of core areas), and LPI (landscape patch index) predicted pileated woodpecker presence better than %LAND. The final logistic regression equation using the CAD variable was:

Probability (presence) = $1/(1 + e^{-(Y)})$ where $Y = -1.5204 + 1.1039*(CAD)$

The equation correctly classified 71.67% of the original data ($X^2 = 10.4493$ df = 1, p= 0.0012). The PWPHSM used to classify preferred nesting habitat was verified as an adequate tool for the management of pileated woodpeckers. The ability of the core area variable to predict pileated woodpecker presence supports consideration of the influence of edge effects on this species. Forest managers are also encouraged to continue to move toward spatial HSA in management planning.

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1.0 Introduction

Forest-management activities involve decisions that alter the landscape pattern of ecosystems (Turner, 1989). Ecosystems that provide the environmental conditions needed for a wildlife species are called habitats (Thomas, 1979). The landscape structure (pattern) of habitats can influence wildlife populations and distributions (McGarigal and Marks, 1994). Understanding the influence of the landscape structure of wildlife habitats is therefore an important part of the management of any wildlife species. With this understanding, forest managers can be informed how their alterations of the landscape structure can affect wildlife populations.

Wildlife-habitat studies have focused on three levels: the individual tree, the forest-stand and the landscape. Wildlife-habitat studies at the tree level focus on the species, age and physical condition of the trees that are used for habitat (e.g. nest trees). Forest-stand-level studies focus on the type of forest stands and characteristics of those stands (e.g. canopy closure or snag density). Landscape-scale structure studies focus on the composition and configuration of wildlife habitats across a broad area. Until recently, most studies on wildlife-habitat relationships were based on tree- and stand-level findings and principles (McGarigal and McComb, 1995).

Featured species are used in forest-management activities to help conserve habitat for a wildlife species of concern and for other species that have similar habitat requirements (Baker and Euler, 1989). In Ontario, the pileated woodpecker (*Dryocopus pileatus*) has been designed by the government as a featured species in management of the Great Lakes-

St. Lawrence forests of central Ontario (Naylor et al., 1996). The pileated woodpecker generally requires mature and old forest with cavity trees, snags and downed woody debris (Hoyt, 1957; Bull and Meslow, 1977; Renken and Wiggers, 1989; Millar, 1994; Bonar, 1995; Kirk and Naylor, 1996). The pileated woodpecker is also a concern for forest managers because abandoned pileated woodpecker nest cavities provide critical habitat for other wildlife species. Species that use pileated woodpecker nest cavities in central Ontario include: boreal owl (*Aegolius funereus*), screech owl (*Otus asio*), saw-whet owl (*Aegolius acadicus*), wood duck (*Aix sponsa*), common merganser (*Mergus merganser*), American kestral (*Faco sparverius*), common flicker (*Colaptes auratus*), northern flying squirrel (*Glaucomys sabrinus*) southern flying squirrel (*G. volans*) and American marten (*Martes americana*) (McClelland, 1979; Millar, 1994; Kirk and Naylor, 1996).

A number of studies (Bull and Meslow, 1977; Bull et al., 1992; Renken and Wiggers, 1993; D'Eon and Watt, 1994; Bonar, 1995) have examined and defined both preferred and used habitat for the pileated woodpecker. These studies have focused on the species' tree- and stand-level habitat requirements. The effect of the arrangement of these habitats on the presence of pileated woodpeckers is not known (Kirk and Naylor, 1996). It is hypothesized that in addition to tree- and stand-level requirements, landscape-scale structure also influences the presence of pileated woodpeckers in an area.

1.1 Study Objective

The goal of this research project was to determine how the landscape-scale structure of used and preferred habitats appeared to influence the presence of pileated woodpeckers in central Ontario forests. Used and preferred pileated woodpecker feeding and nesting habitat is defined by using the pileated woodpecker habitat supply model (PWPHSM) of Naylor et al. (1997).

2.0 Pileated Woodpecker Ecology

2.1 Introduction to the Pileated Woodpecker

The pileated woodpecker is the largest woodpecker in North America, averaging 42 cm in length (Kilham, 1983). This large red-crested woodpecker is mainly black and has black and white stripes on the face (Farrand, 1988). The species is widely distributed throughout forested regions in North America from Great Slave Lake to Texas and Florida (Dance, 1987). The pileated woodpecker is found in all Canadian provinces and territories, except Newfoundland and Prince Edward Island (Godfrey, 1986). In Ontario, the species favours forested areas south of the Hudson Bay Lowland (Kirk and Naylor, 1996). It is generally recognized that large tracts of mature forest are preferred (Bull, 1987; Dance, 1987; Renken and Wiggers, 1989; Bonar, 1995). As a resident species, the pileated woodpecker occupies a territory for successive years, actively defending the territory from the threat of intruders (Kilham, 1983; Bonar, 1995).

The pileated woodpecker has an important ecological role as a primary cavity excavator (Bonar, 1995). New nest cavities are excavated annually in large living or dead trees. Cavities have a dome-shaped entrance 10-12 cm in height and 7-10 cm in width. The excavated interior has a width of 18-25 cm and a depth of 60 cm (Bull et al., 1990). Abandoned nest cavities provide nesting and roosting sites for other cavity-using wildlife species (Bonar, 1995). Both the male and female participate in the excavation of the nest. The nest takes 3-6 weeks to complete and construction occurs between March and May (Bent, 1939; Kilham, 1983; Bull and Meslow, 1988; Bull et al., 1990; Bonar, 1994). Egg laying takes place from the end of April to late June and an average clutch consists of 2-4 eggs (Peck and James, 1983; Bull and Meslow, 1988; Bonar, 1994). The incubation period lasts approximately 18 days (Hoyt, 1957). Nestlings are able to fledge after 24-28 days (Bull and Meslow, 1988). Young pileated woodpeckers stay with the parents for several months while learning to feed. They leave the parents in the fall to look for their own territory and a mate for the coming spring (Bull and Jackson, 1995).

There are several natural predators of the pileated woodpecker. The northern goshawk (*Accipter gentilis*) is considered the species' primary threat (Bull et al., 1992; Bonar, 1995; Kirk and Naylor, 1996). Other avian predators include the Cooper's hawk (*Accipter cooperi*), great horned owl (*Bubo virginianus*), barred owl (*Strix varia*), and red-tailed hawk (*Buto jamaicensis*). Research in Oregon found that avian predators were responsible for all deaths of adult pileated woodpeckers (Bull et al., 1992). Other predators concentrate attacks on the eggs and nestlings, and include the raccoon (*Procyon lotor*), black bear (*Ursus americanus*), American marten, weasel (*Mustela spp.*), and black rat snakes (*Elaphe obsoleta*) (Millar, 1994; Bull and Jackson, 1995; Kirk and Naylor, 1996). With the exception of the black rat snake, all of these species are present in central Ontario.

Studies in North America have found breeding bird densities in the range of 0.2-4.0 pairs per km^2. Regional differences appear to exist between eastern and western North American findings (Kirk and Naylor, 1996). Findings from eastern North America field studies reported densities in the range of 1.25-4.0 pairs per km^2 (Graber et al., 1977; Welsh and Capen, 1992; Renken and Wiggers, 1993). However, the finding from northwestern United States were lower, 0.2 to 1.23 pairs per km^2 (Mannan, 1984; Bull, 1987; Bull and

Holthausen, 1993). In Ontario, Dance (1987) estimated densities to be lower than other eastern North American studies (0.2-1.0 pairs per km^2).

Estimates of pileated woodpecker home range size vary considerably. Differences in sampling technique and forest type account for some of this variability. Home ranges appear to be larger in the conifer-dominated forests of western North America (Mellen et al., 1992; Bull and Holthausen, 1993). In Oregon, Bull and Holthausen (1993) found the average home range to be 407 ha for mated pairs (range = 321-630 ha) and Mellen et al. (1992) found the average to be 478 ha (range = 267-1056 ha). Bonar (pers. comm. to Kirk and Naylor, 1996) reported home range sizes between 500 and 3500 ha in Alberta. Smaller home ranges are reported in eastern North American deciduous forests (Renken and Wiggers, 1989). In Missouri, Renken and Wiggers (1989) found home ranges averaging 87 ha (range = 53-160 ha). Although no radio-tracking of pileated woodpeckers has taken place in Ontario, the average range is estimated to be between 40 and 250 ha (James, 1984; Speirs, 1985; Kirk and Naylor, 1996).

2.2 Habitat Selection

The pileated woodpecker seeks habitat that will support feeding, roosting, and nesting activities. Habitat characteristics at the tree- and stand-level influence habitat selection to varying degrees. Although pileated woodpeckers will use immature forest habitat, it is generally accepted that mature, dense forest types are preferred (Hoyt, 1957; Bull and Meslow, 1977; Millar, 1994; Bonar, 1995; Kirk and Naylor, 1996).

The pileated woodpecker spends an enormous amount of time foraging for its primary food source, carpenter ants (*Camponotus spp.*) (Bonar, 1994). Colonies of these ants are often found in dead wood (snags or downed woody debris) or living trees with advanced heartwood decay (Kirk and Naylor, 1996). Although pileated woodpeckers do forage on a number of tree species, preference is shown for some tree species. In Oregon, Bull and Holthausen (1993) found that Douglas fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*) were preferred, while lodgepole pine (*Pinus contorta*) were avoided. The physical properties of the tree also influenced selection. Larger snags and logs were foraged more actively than smaller ones, suggesting that size and height of the snag influenced selection (Bull and Meslow, 1977; Brawn et al., 1982; Bull and Holthausen, 1993). Studies have also shown that snags and logs with a greater degree of decay are preferred (Kirk and Naylor, 1996).

Stand-level characteristics also affect foraging habitat selection. Bull and Meslow (1977) found that denser, mixed-species forest types were more heavily used, while the open ponderosa pine (*Pinus ponderosa*) forest type was foraged to a lesser extent. Although all

25 forest types in central Ontario showed evidence of foraging, the amount of activity was limited in several of these (Naylor et al., 1997). The amount of canopy closure exhibited by the forest type also influences the habitat selected for foraging. Although foraging can occur in open canopy areas including clearcuts (Bonar, 1994), denser canopies are preferred (Bull and Meslow, 1977). Naylor et al. (1997) found that 60% canopy closure supported the most active foraging.

The tree- and stand-level characteristics of nesting habitat are more restrictive than those required for foraging habitat (Kirk and Naylor, 1996). Pileated woodpeckers will nest in a number of tree species within their range (Kirk and Naylor, 1996), although preference is given to some species. Western larch and ponderosa pine appear to be preferred species in Oregon (Bull and Meslow, 1977; Bull, 1987). In Alberta (Bonar, 1994), Saskatchewan (Wedgewood, 1988), Manitoba (Millar, 1994) and Ontario (Peck and James, 1983), aspen (*Populus spp.*) is the preferred species. Both living and dead trees are selected for nests and some studies suggest that this choice is regionally based (Kirk and Naylor, 1996). The diameter of nesting trees is an important physical characteristic (Bull and Meslow, 1977). Trees need to be large enough for nest cavities (18-25 cm wide and 60 cm deep) (Millar, 1994). Some nest trees are as small as 26 cm diameter breast height (dbh), but most studies report an average greater than 40 cm dbh (Kirk and Naylor, 1996).

Stand-level characteristics (forest type and canopy closure) also affect nesting habitat selection. A number of forest types are used for nesting habitat, although certain forest-types are preferred at the regional level. Bull and Holthausen (1993) found that grand fir (*Abies grandis*) was the preferred forest type in northeastern Oregon. Millar (1994) found that deciduous forest types were the favoured nesting habitat in Manitoba. In central Ontario, Naylor et al. (1997) found the following forest types to be preferred: mixedwoods; red oak; intolerant hardwoods; white and red pine; and mixtures of intolerant and tolerant hardwoods. As with foraging habitat, canopy closure is also important for nesting habitat selection. Bull and Holthausen (1993) stated that greater than 60% canopy closure provided the most suitable coverage for nesting habitat.

Roost sites are additional cavities used by pileated woodpeckers within a pair's home range (Bull et al., 1992). They provide protection from poor weather and predation (Bull et al., 1992; Bonar, 1995; Kirk and Naylor, 1996). Bull et al. (1992) found that each bird used an average of 7 different roost sites in a 3-10 month period. These cavities occur in living or dead trees with a hollow internal chamber. The chambers are normally the result of decay and not excavation, although occasionally old nests are used for roosting (Bull et al., 1992; Bonar, 1994). Pileated woodpeckers have been known to excavate as many as 16 entrances to these hollow interiors (Bull et al., 1992). Often these entrances are within 0.5 m of each other (Bull et al., 1990). Multiple holes allow for easier escape from predators. The physical characteristics of the tree are important for selection, regardless of tree species (Bull et al., 1992). Stand-level characteristics are thought to be the same as those of nest habitat (Bull, 1987; Bonar, 1995).

2.3 Landscape-Scale Structure Analysis

Landscape-scale structure research has evolved from the field of landscape ecology. Landscape ecology looks at the spatial distribution of interacting ecosystems at broad scales (Turner, 1989). It focuses on the structure, function and change of landscapes comprised of these interacting ecosystems (Forman and Gordon, 1986). It is necessary to understand and quantify landscape structure before studying landscape function and change (McGarigal and Marks, 1994). Structure refers to the spatial relationships (composition and configuration) between ecosystems. Function refers to interactions between the spatial elements of the ecosystems. Change refers to changes to structure and function of the landscape over time (Turner, 1989). A landscape is defined as a heterogeneous land area composed of an interacting mosaic of patches relevant to the phenomenon under study (McGarigal and Marks, 1994). Patches are unique to the investigation, are dynamic, and can occur at multiple scales (McGarigal and Marks, 1994). For example, different forest types, soil types, or land uses could represent patches in a landscape. When analyzing landscape structure, one studies the composition and configuration of patches.

Composition measures the presence and amount of each patch type within the landscape (McGarigal and Marks, 1994). Composition does not consider the placement or location of the patches. The main quantitative measure of composition is proportion of the landscape in each patch type (McGarigal and Marks, 1994). Configuration measures the physical distribution or special characteristics of the patches in the landscape (McGarigal and Marks, 1994). The physical distribution looks at the placement of patch types relative to other patch types (e.g. patch isolation, nearest neighbour, and patch contagion).

Measurements of the special characteristics of patches include patch shape, mean patch size, and core areas. Patch shape is quantified based on the comparison of perimeter-area relationship of the patch to a standard shape (a square in the raster version). A core area is defined as area within a patch beyond a specified distance from the patch perimeter (McGarigal and Marks, 1994). The specified distance is referred to as the edge-width distance.

The software program called FRAGSTATS (McGarigal and Marks, 1994) measures the landscape structure by calculating values for variables that measure the composition and configuration of the landscape (Appendix I). The information is then organized at three levels: patch, class, and landscape. Patch-level analysis provides information for each individual patch. Class-level analysis quantifies the composition and configuration of each patch type. Landscape-level analysis quantifies the composition and configuration of all patches (regardless of class type) (McGarigal and Marks, 1994).

2.4 Landscape-Scale Structure of Pileated Woodpecker Habitat

The amount (composition) and physical distribution (configuration) of habitat (foraging, roosting, and nesting) may be important factors influencing the abundance of pileated woodpeckers across a landscape (Kirk and Naylor, 1996). Availability of water and wetland habitat in a landscape might also contribute to the landscape structure requirements.

Bull and Holthausen (1993) and Millar (1994) made suggestions on landscape composition requirements of pileated woodpecker habitat. Bull and Holthausen (1993) recommended that 25% (91 ha) of the home range size of 364 ha should be suitable nesting habitat. Millar (1994) recommended that in Manitoba, the minimum habitat area should be 250 ha and should include 40% (100 ha) of suitable nesting habitat. Robbins et al. (1989) found that the size of forest area significantly influences the abundance of pileated woodpeckers. They found that pileated woodpecker would most likely be found in continuous forest areas greater than 3000 ha, while the smallest forested area used was 42.2 ha.

The configuration could be important if pileated woodpeckers are an interior species or area-sensitive species (Kirk and Naylor, 1996). "The degree to which they are truly 'area sensitive' is debatable, given that they will nest in highly fragmented landscapes" (Kirk and Naylor, 1996, p. 18). Pileated woodpeckers have been found to nest in highly fragmented forest in Alberta (Bonar pers. comm. to Kirk and Naylor, 1996) and in fragmented agricultural landscapes in southern Ontario (Dance, 1987). McGarigal and McComb (1995) found that the pileated woodpeckers occupied landscapes that were more fragmented than landscapes that were not occupied. Kirk and Naylor (1996) conjectured that patch size would not 'strongly influence' habitat use by pileated woodpeckers in a relatively continuous forest. Similarly, Millar (1994) suggested that the interspersion of cover types would not affect the presence of pileated woodpecker in the contiguous forest of Manitoba.

McGarigal and McComb (1995) studied the relationship between landscape structure and abundance of a variety of breeding-bird species including the pileated woodpecker. They classified the landscape into two broad classes: conifer-large sawtimber (old growth) and early-seral (young growth). The conifer-large sawtimber forest was considered suitable nesting habitat for the pileated woodpecker while early-seral was considered unsuitable. They found the abundance of pileated woodpeckers to be moderately affected (0.011-p-0.092) with increased suitable habitat area (percentage of land). They also found that edge density of late-seral forest (conifer-large sawtimber) helped explain abundance of the pileated woodpeckers (McGarigal and McComb, 1995).

Some initial work on the influence of landscape-scale structure was done by Naylor et al. (1997). In addition to the PWPHSM (nonspatial model), Naylor et al. (1997) developed a spatial model. The spatial model was based on field data collected during road surveys for red-shouldered hawks (*Buto lineatus*). Volunteer observers also recorded any woodpeckers that responded to the red-shouldered hawk calls. Pileated woodpeckers responded at 35 stations. These 35 stations and 35 randomly selected unused stations were used for development of the spatial model. The area around the stations had the nonspatial PWPHSM applied to the forest polygons. Habitat within concentric circles of 500 m, 750, m and 1000 m in radius was used in the spatial analysis. The landscape variables analyzed were mostly composition (area of habitat, length of roads, and patch size) variables with one configuration (mean distance between patches) variable (Appendix II).

The results of Naylor et al.'s (1997) spatial habitat analysis suggested that the percentages of nesting-preferred and nesting used habitat are the key landscape-scale influences. Only the nesting habitat within the 500 m radius (80 ha) influenced detection of pileated woodpeckers. The influence of the percentage of nesting habitat decreased with larger

(750 m and 1000 m radius) habitat analysis. However, at the larger habitat analysis level the mean distance between patches did show a difference between used and unused sites. The mean patch size variables did not appear to influence where the pileated woodpeckers were detected at any of the habitat analysis levels.

The effect of wetlands in the landscape on the presence of pileated woodpeckers is unclear (Hoyt, 1957; Kilham, 1959; Millar, 1994; Kirk and Naylor, 1996). In Missouri, Renken and Wiggers (1989) found a positive relationship between woodpecker abundance and amount of bottomland forest. However, there was no determination whether the use was because of the close spatial association of water. Selection of wetland environments may be coincidental as these areas produce large trees suitable for nesting (Hoyt, 1957; Conner et al., 1975). The nest trees within wetland areas might be preferable because of increased rot due to occasion flooding.

2.5 Wildlife Habitat Models

A wildlife habitat model (WHM) can be defined as a mechanism for synthesizing information about a species and its habitat requirements (Thomas, 1982). This definition leaves room for interpretation. Examining the three key words is useful in clarifying the definition. Wildlife refers to "all land vertebrate animals" (Thomas, 1979). Habitat can be defined as "the sum total of environmental conditions of a specific place occupied by a wildlife species or a population of such species" (Thomas, 1979). A model can be defined as any representation or abstraction of a system or process (Walters, 1986).

To further complicate one's understanding of WHMs, many researchers have used a variety of terms to infer WHM. In some cases the terms can be interchangeable. However, it is necessary to examine each of these terms to find a consistent operational definition.

The following terms fit Thomas's (1982) definition of a WHM. A habitat supply model (HSM) is defined as a dynamic simulation of habitat values for a wildlife species (Greig et al., 1991). This type of WHM is dynamic in nature, allowing it to predict future supply of wildlife habitat. In the context of forest management, the term habitat supply analysis (HSA) is the process of using an HSM to predict the impacts of management activities on the supply of wildlife habitats through time (Naylor et al., 1994a). The two terms HSM and HSA have been used primarily in Canadian modelling. Another common term is Habitat Suitability Index (HSI) model. This type of model rates the value of habitat for wildlife with a unitless index between 0 and 1. An HSI is considered a static model because it only considers the value of the habitat at one point in time (Greig et al., 1991). All of these terms are considered different types of WHMs.

Some terms used do not fit Thomas's (1982) definition. The terms "wildlife models" and "wildlife modelling" have a much broader connotation. These terms usually refer to population, predator-prey, life-cycle, or food-chain models (Starfield and Bleloch, 1991). These models concentrate on natural histories of the species rather than habitat use.

The origins of WHMs can be found in early American wildlife management strategies. Leopold (1933) was first to suggest that wildlife populations could be managed through their habitat. Wildlife management focused on simple habitat surveys that measured only a few habitat components and were usually restricted to game species (Cooperrider et al., 1986). The WHMs that arose from these surveys were primarily simple verbal models that provided a better understanding of the relationship between wildlife and habitat. An example of an early WHM would be "the Nashville Warbler is common in open second-growth deciduous woods and spruce bogs" (Robbins et al., 1966). Although descriptive, these qualitative models were limited.

Thomas's (1979) work is considered by many researchers to be a "landmark work aimed at incorporating both broad and specific wildlife-habitat considerations into forest-landscape planning" (Greig et al., 1991, p.5). Thomas developed a qualitative WHM to help managers in forest land-use planning. The model looked at how "all terrestrial vertebrates relate to wildlife habitats that are described by plant communities and their successional stage or condition" (Thomas, 1979, p.21). Thomas suggested that "each species is adapted to a particular habitat and the welfare of each species can be predicted by the quantity and quality of available habitat" (Thomas, 1979, p.21).

The use of WHMs increased dramatically in the early 1980's with the development of HSI models (Bonar and Beck, 1994). HSI models were simple equations of a number of selected habitat variables that could be used in predicting the suitability of habitat for a wildlife species. "The model synthesizes the habitat use information into a framework appropriate for field application and is scaled to produce an index valued between 0.0 (unsuitable habitat) and 1.0 (optimum habitat)" (Allen, 1983, p. iii). For example, the HSI model equation for the fisher (*Martes pennanti*) is: $HSI = (V_1 \times V_2 \times V_3)^{1/3} \times V_4$, where V_1

is percent tree canopy, V_2 is average dbh of overstory trees, V_3 is tree canopy diversity, and V_4 is percent of overstory canopy comprised of deciduous species (Allen, 1983).

HSI models have also been used to represent carrying capacity, where the index of 1 represents the maximum carrying capacity for that species (Cooperrider et al., 1986). HSI equations have most often been applied to individual forest stands but at times have been applied to multiple forest stands. The US Fish and Wildlife Service produced over 150 HSI models (Bonar and Beck, 1994). Among these were single-species models, for example pileated woodpecker (Schroeder, 1983) and fisher (Allen, 1983). Some HSIs were developed for single species for a small specific geographic area, including: black bear in the Upper Great Lakes Region (Roger and Allen, 1987), and moose (*Alces alces*) in the Lake Superior Region (Allen et al., 1987). There have also been some multiple species models, including an HSI Model on Wildlife Species Richness in Shelterbelts (Schroeder, 1986). Other agencies, including universities, have also generated a number of HSI models, pushing the total number of HSI models developed in the US to over 300 by the mid-1980's (Cooperrider et al., 1986).

Development and use of WHMs in Canada for the research and management of various species has occurred in a number of provinces. British Columbia (Eng and McKay, 1990; Eng and Janz, 1990), Alberta (Kansas and Raine, 1990; Beck and Beck, 1995; Duinker, 1995), Manitoba (Millar, 1994), New Brunswick (Sullivan, 1995), and Newfoundland (Knox, 1995) have been active in the development and use of WHMs. Ontario has also been active the development and use of wildlife-habitat-relationship type models (D'Eon and Watt, 1994; Davis, 1996; Bellhouse and Naylor, 1997), and HSI models (Naylor et al., 1992; Duinker et al., 1993, Naylor et al., 1994b; Duinker et al., 1996; Naylor et al. 1997).

2.6 Pileated Woodpecker Habitat Supply Model for Central Ontario

Extensive fieldwork in central Ontario led to the development of the Pileated Woodpecker Habitat Supply Model (PWPHSM). The PWPHSM was designed for use with the current Ontario forest inventory information and projection tools to conduct analyses of habitat supply for pileated woodpeckers (Naylor et al., 1997). Fieldwork leading to the model's development involved collection of data from 466 vegetation sample plots. These plots were established during the development of the Central Ontario Forest Ecosystem Classification (COFEC). The system classifies the forest into 25 forest ecosites (Chambers et al., 1997). Evidence of pileated woodpecker activity (foraging, nesting, or roosting) was recorded for each site. The evidence of activity was then used along with information on ecosite type, stand age, and canopy closure to develop the PWPHSM.

The PWPHSM includes two major components. First, the model calculates an HSI score for the forest stand. Next, the forest stand is classified into one of three categories (unsuitable, used and preferred) for both feeding and nesting habitat based on the HSI score and the development stage the forest stand.

The model calculates the HSI score using a group of equations. A unique equation for each forest ecosite-type predicts the probability of pileated woodpecker use based on stand age and canopy closure (Naylor et al., 1997). The 25 equations were developed using logistic regression and have similar slopes but different intercepts (e.g. Figure 2.1).

The equation form is represented by $P(Y) = e^{Y} / 1+e^{Y}$ where $P(Y)$= probability of plot being used and $Y = \text{intercept} + 3.9691 * \text{age} - 1.9764 * \text{age}^2 + 4.1486 * \text{cc} - 3.2455 * \text{cc}^2$ (Naylor et al., 1997). The intercept in the model is ecosite-specific and represents the relative suitability of ecosites (Appendix III).

The PWPHSM uses the HSI score (P) of greater than 0.4013 as a cut-off for preferred habitat. The value of 0.4013 was used because 187 of the 466 plots (40.13%) had some evidence of activity. An HSI score of less than 0.4013 is considered to be used habitat but not preferred. PWPHSM than reclassifies the forest stands based on the HSI score and the development stage. The development stages, for which the age limits are unique for each forest ecosite-type, include presapling, sapling, immature, mature, and old (Appendix IV) (Naylor et al., 1997).

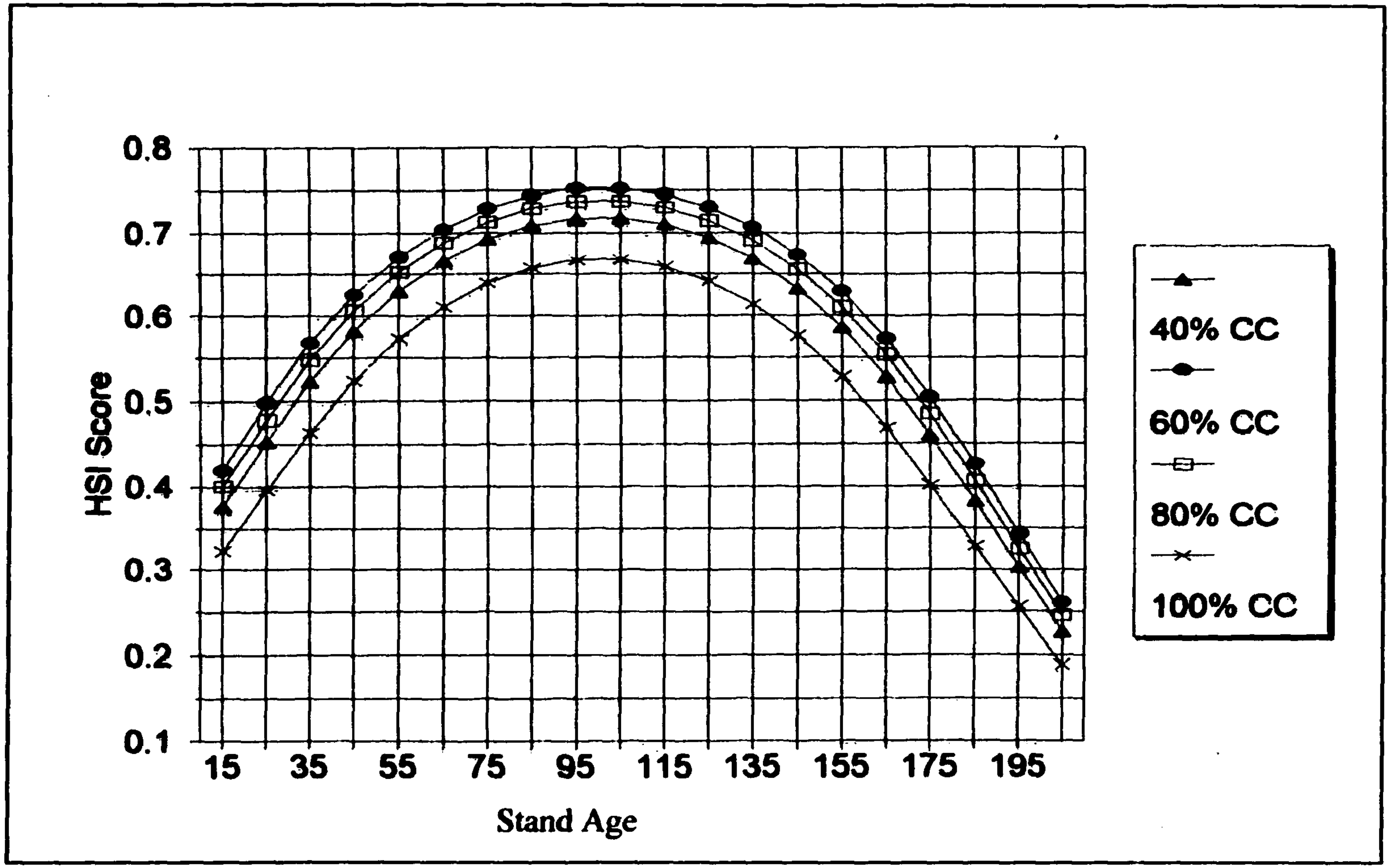

Figure 2.1 HSI Scores for the PwPr Ecosite. (CC stands for canopy closure)

For feeding habitat, presapling development stage is considered unsuitable for feeding habitat, regardless of the HSI score. All stands in the sapling development stage (quadratic mean dbh 2.0 - 9.5 cm) are considered used for feeding, even if the HSI is greater than 0.4013. Stands in the mature development stage are considered to be used or preferred feeding habitat depending on their HSI score (Naylor et al., 1997).

For nesting habitat, stands in the presapling, sapling, and immature development stages are considered to be unsuitable for nesting regardless of HSI. Plots in the mature or old development stages are considered used or preferred for nesting depending on their HSI score. Only these development stages were considered used or preferred for nesting because stands in these classes would likely contain trees large enough for the excavation of nesting cavities (quadratic mean dbh at least 25 cm) (Naylor et al., 1997).

2.7 Other Ontario Pileated Woodpecker Habitat Models

D'Eon and Watt (1994) developed a qualitative WHM entitled "A Forest Habitat Suitability Matrix for Northeastern Ontario". The work was a preliminary attempt to identify relationships between forest-dependent wildlife species and a Forest Ecosystem Classification (FEC) for Northeastern Ontario. A matrix was developed based on 16 FEC site types and five development stages of those site types. Habitat suitability for each wildlife species in the region is rated as either "used" habitat or "preferred" habitat. This suitability matrix is qualitative in nature, based on expert opinion and literature (D'Eon and Watt, 1994).

D'Eon and Watt (1994) suggested that pileated woodpeckers in northeastern Ontario preferred the following forest types, all in their old-growth development stage: hardwood, hardwood/moist soil, tolerant hardwoods/mixedwood, and sugar maple/yellow birch. Used forest types in either the mature or old-growth development stages included mixedwood/ aspen mix, hardwood, conifer/moist soil, and hardwoods/moist soil. D'Eon and Watt (1994) suggested that no forests in their initiation, regeneration, or young development stages were used by pileated woodpeckers. The following forest types were unsuitable at any development stage: black spruce, jack pine, and jack pine/black spruce.

Other matrices similar to D'Eon and Watt (1994) have been developed in central and northwestern Ontario for use in the provincial Strategic Forest Management Model (Naylor pers. comm.). The central Ontario matrix (Bellhouse and Naylor, 1997) uses the PWPHSM (Naylor et al., 1997) to rank forest ecosite-types. The Ontario Ministry of Natural Resources has also developed a software program called Ontario Wildlife Habitat Models (OWHAM) which includes the PWPHSM as well as other wildlife habitat models for moose, red-shouldered hawks, and marten.

Hounsell (1989) also developed a qualitative WHM for Ontario Hydro that looked at the relationships between forest birds and their habitats. Hounsell (1989) suggested that pileated woodpeckers in southern Ontario preferred habitat of the following forest types in their mature and old-growth development stages: upland hardwoods; lowland hardwoods; hemlock; pine; cedar-larch; upland mixed; and lowland mixed.

3.0 Methods

3.1 Study Sites

Study sites were located in Algonquin Provincial Park (Figure 3.1) which is found within the Great Lakes-St. Lawrence forest of central Ontario (Rowe, 1972). The presence of pileated woodpeckers was recorded along 5 km transect lines. Sixty transect lines were surveyed for pileated woodpeckers. The area around each transect line was used for landscape analysis and represented 5 km^2 (1 km width by 5 km length).

3.2 Site Selection

A total of 320 forest resource inventory (FRI) map sheets (each 25 km^2) represent the area of Algonquin Park. For selection purposes, only map sheets with 80% of their area inside the park were used. Next, the maps were grouped into the two broad forest landscapes: mixedwood and tolerant hardwood. Trembling aspen (*Populus tremuloides*), white pine (*Pinus strobus*), red pine (*P. resinosa*), and white birch (*Betula papyrifera*) are dominant in mixedwood forest landscapes. The tolerant hardwood forest landscapes are dominated by sugar maple (*Acer saccharum*), yellow birch (*Betula allegheniensis*) and hemlock (*Tsuga canadensis*) (Chambers et al., 1997). Subsequently, the PWPHSM was applied to the FRI database for all map sheets. The model classified all forest stands with respect to pileated woodpecker habitat supply according to the PWPHSM.

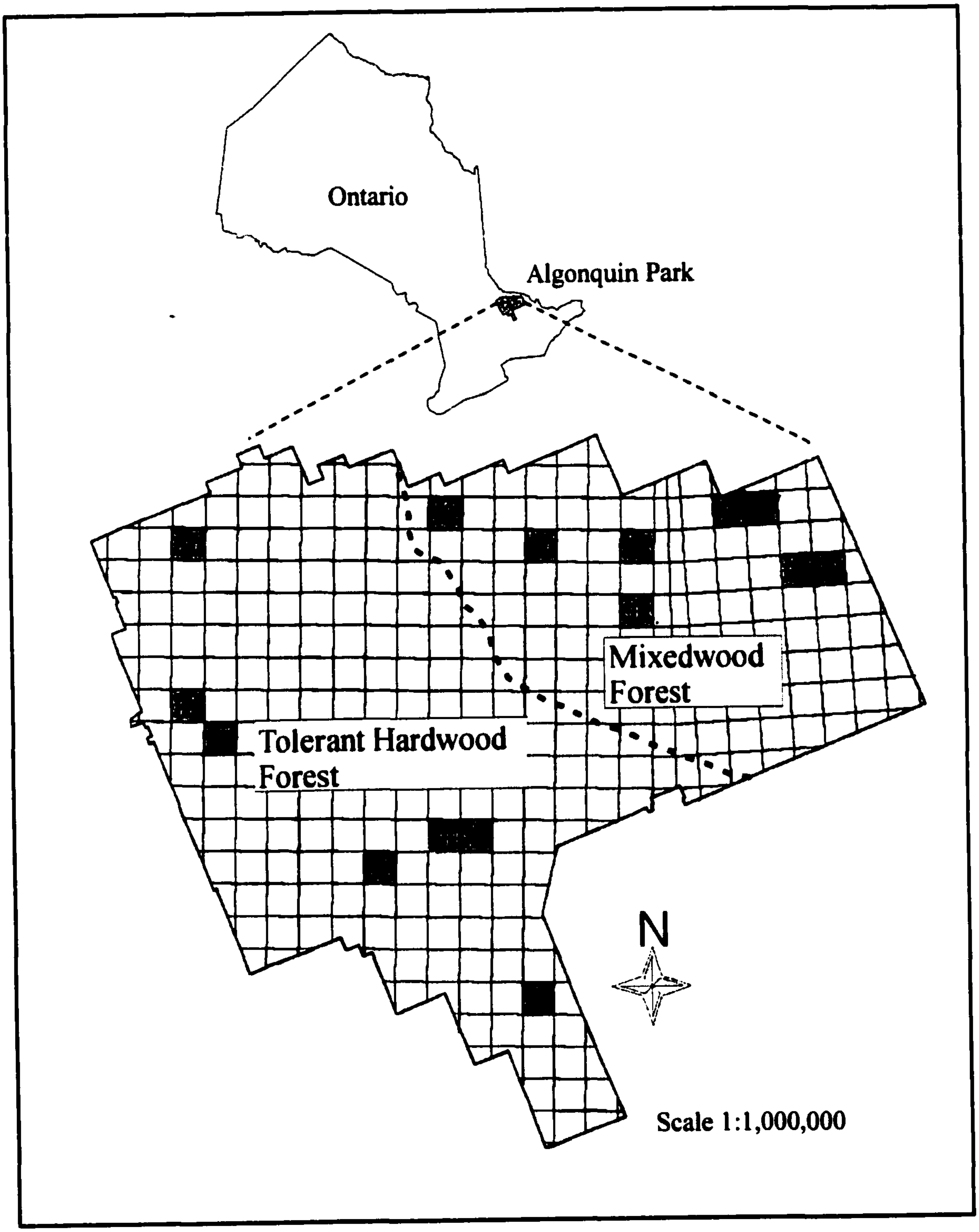

Figure 3.1 Map sheets selected in Algonquin Park.

The total (used + preferred) nesting habitat values produced by the PWPHSM were the selection criteria. Map sheets with total nesting habitat between 50% and 85% were grouped before random selection. Total nesting habitat was grouped for selection in an attempt to isolate the effect of spatial pattern while attempting to control for total amount of habitat. Random selection was done on the map sheet numbers using a random numbers table. Fifteen map sheets were selected. Each map sheet was then divided into five study-sites 1000 m by 5000 m (Figure 3.2). The orientation of the study-sites was either north-south or east-west and was chosen on the basis of avoidance of the transect lines crossing large bodies of water.

3.3 Pileated Woodpecker Presence/Absence Monitoring Procedures

To determine the presence of pileated woodpecker, field data were collected following the procedures of Bull et al. (1990). The monitoring procedure involved walking line transects 5000 m in length in the middle of the study sites. While walking along transect lines, I stopped every 400 m and listened and looked for pileated woodpeckers. Distance was determined using a hip chain (Fieldranger 6500) and direction using a compass. If a bird was not observed after 30 seconds, I would broadcast pileated woodpecker vocalizations from a tape recorder at 30-second intervals for a total of 6 minutes. A portable cassette player (Panasonic RQ-SW5) and 20-watt amplified speakers (Sony) were used to broadcast

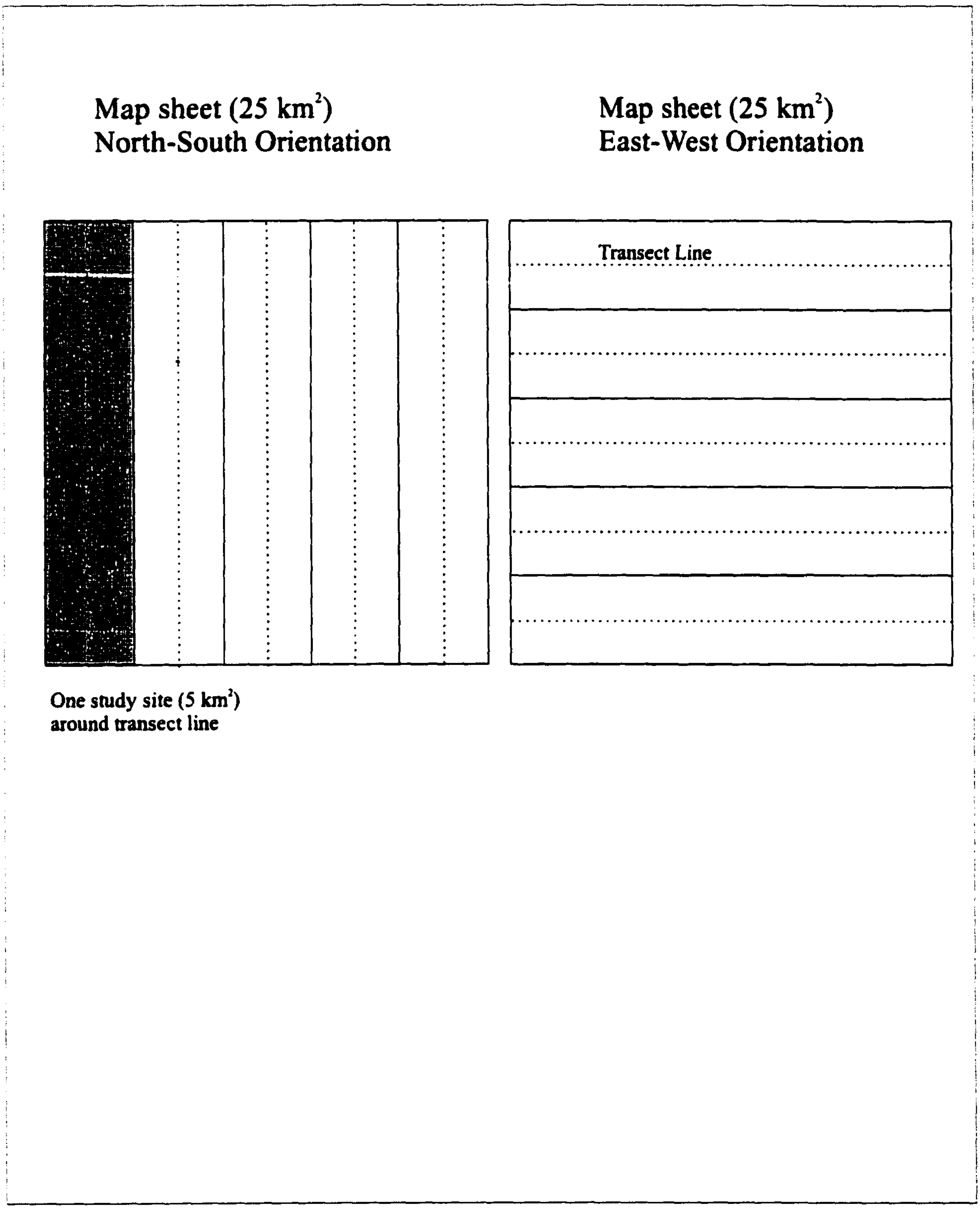

Figure 3.2 Map sheets and study sites.

vocalizations. Bull et al. (1990) report that territorial calls can be heard from 400 m to 800 m away. The next broadcast stop was skipped if there was a previous positive response. Double counts of birds were avoided by: skipping a stop after a positive response; marking of location and direction on a map; and personal judgment. The line transects were surveyed between April 29 and July 10, 1997. Transects were not surveyed on days of steady rain or days with an average wind velocity of greater than 20 km/hr. One map sheet (up to 5 transects) was surveyed from the tolerant hardwood forest and then one map sheet from the mixedwood forest. Each transect was walked only once. Sixty transect lines in total were surveyed. There were 30 lines from the mixedwood forest (east side of park) and 30 from the tolerant hardwood forest (west side of park).

When possible, a survey of pileated woodpecker foraging, roosting, or nesting activity was conducted at a broadcast stop. A search for evidence of activity was conducted within an 11 metre radius (0.04 ha) around the broadcast stop. Foraging by pileated woodpeckers was distinguished from other species by noting holes that were at least 5 cm in depth and/or 5 cm in length (Bull et al., 1990). The frequency of the holes was also considered. The parameter for frequency was somewhat subjective, but the following guidelines were used as a reference. Low frequency was assigned to trees with up to three small holes (5 cm long) or one large hole (> 15 cm long). Medium frequency was assigned when there were up to ten small holes or a few large holes. High frequency required four or more large holes on a tree (Naylor et al., 1997). This activity information was given a weight index value to emphasize higher frequency foraging as well as nests and roosts sites (Table 3.1).

Table 3.1 Pileated woodpecker activity weighted index.

Activity	Weight Index
Foraging Low	1
Foraging Medium	2
Foraging High	3
Nest tree	3
Roost tree	3

The difference in weight index of pileated woodpecker activity was analyzed between presence and absence transects.

The project only analyzed the presence or absence of pileated woodpeckers based on response to the vocalizations in study sites. There were insufficient sites with multiple responses for the project to compare between lower and higher density sites. The fitness of the individuals that responded to the broadcast vocalizations was also not analyzed.

3.4 Landscape-Scale Structure Analysis

Landscape structure analysis was conducted on the 5 km^2 study sites that surrounded the transect lines. When analyzing landscape structure, it is important to have a sound basis for the classification of patches (McGarigal and Marks, 1994). The basis for classification in this study was pileated woodpecker habitat supply. Digital FRI maps provided the base polygon information and structure. The FRI maps used had been derived from air-photo interpretation at the scale of 1:10000 (photos taken in 1979 and 1984). Although there are some pitfalls in using FRI maps for landscape analysis (Doyon et al., 1997), these maps provided adequate information on stand age, cover and composition for determining pileated woodpecker habitat supply. The FRI maps were assumed to be correct, although no information on the accuracy of the FRI database was available. The FRI database for Algonquin Park is in constant updating procedure (Peter VanderKraan, Algonquin Forestry Authority, pers. comm. 1998). The long-term cutting or logging history of study sites was not available for this project and was therefore not considered in the analysis. Patches of forest were classified into pileated woodpecker supply based solely on the FRI database information.

There are several ways to classify the landscape for pileated woodpecker supply, and a number of different pileated woodpecker habitat supply models exist (e.g. Schroeder, 1983; D'Eon and Watt, 1994; Millar, 1994; Bonar, 1995; Naylor et al., 1997). The habitat supply chosen was based on the central Ontario model (PWPHSM) by Naylor et al. (1997). D'Eon and Watt (1994) model was modified and then used as an alternative to test against the PWPHSM. Both of these models are presently used in Ontario forest management planning and use FRI information to predict pileated woodpecker habitat supply for forest stands.

The habitat supply was classified based on the selected models using several means: PWPHSM Feeding; PWPHSM Nesting1; PWPHSM Nesting2 with a higher HSI cutoff; PWPHSM Nesting3 with a lower HSI cutoff; PWPHSM Nesting4 with water removed from the landscape; and the D'Eon and Watt Modified nesting model (Figure 3.3).

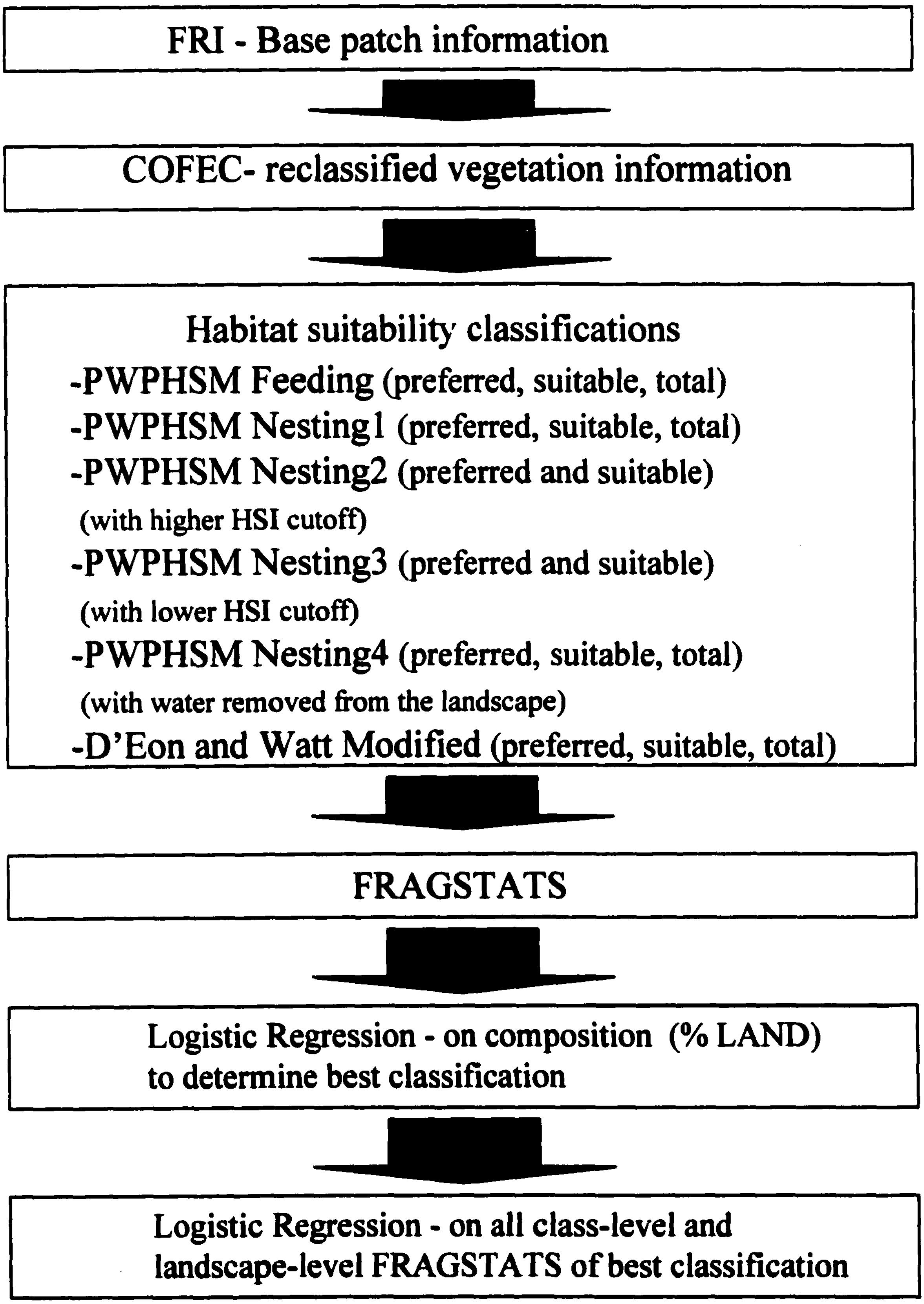

Figure 3.3 Landscape-scale structure analysis.

PWPHSM Nesting2 and PWPHSM Nesting3 classifications were developed to test the sensitivity of the base PWPHSM Nesting1 by adjusting the HSI cutoff value between used and preferred nesting. A higher HSI cutoff of 0.5 was used in PWPHSM Nesting2 and resulted in less preferred habitat. A lower HSI cutoff of 0.3 was used in PWPHSM Nesting3 and resulted in more preferred habitat. Removing open water from the landscape resulted in the PWPHSM Nesting4 classification. This classification changed only the unsuitable class from the base PWPHSM Nesting1. However, the overall area for each study site was then reduced, therefore changing the percentage of the landscape each class represented. An alternative nesting-habitat supply model was used to compare with the PWPHSM. This model was based on the D'Eon and Watt (1994) suitability matrix for the pileated woodpecker in northeastern Ontario. The D'Eon and Watt (1994) suitability matrix is more restrictive than the PWPHSM. The matrix lists fewer forest-ecosite types as used or preferred for the pileated woodpecker. The D'Eon and Watt Modified Nesting model was developed by re-coding the PWPHSM to classify the following ecosite types as unsuitable (0): ES13, ES 15, ES 16, ES 30, ES 31, ES 32. There were no modifications made based on the development stage.

A program was developed in ARC/INFO Geographic Information System to run the six different classifications on all 60 study sites. First, the program reclassified digital FRI forest polygon information (species composition, age, and height, stocking) into COFEC ecosite types and seral development stages. Then, the program reclassified each polygon into one of three habitat classes: unsuitable, used, or preferred. The program FRAGSTATS (McGarigal and Marks, 1994) was then run on all reclassified landscapes to quantify the landscape structure. FRAGSTATS produces a number of landscape structure variables for both composition and configuration (Appendix I). Study sites were prepared for FRAGSTATS by converting the vector files to raster files with 10 m grid cells. A 100 m edge-width distance was initially used. This distance was used in previous landscape structure studies (Temple, 1986; McGarigal and McComb, 1995). After one classification was chosen, alternative edge-width distances of 50 m and 200 m were tested. The study site boundary was considered a patch edge for the purpose of calculating patch size, shape and other metrics, even though most boundary patches would, in reality, continue beyond the study site boundary (McGarigal and McComb, 1995).

To determine which of the six classifications best predicted the presence of pileated woodpeckers, logistic regression was run on the percent of land (%LAND) for used, preferred and total (used + preferred) habitat of each classification. The presence/absence of pileated woodpeckers is the dependent variable and is recorded as either one or zero. The %LAND (independent variable) is calculated at the class level by FRAGSTATS and represents the main quantitative measure of composition of habitat in each of the study sites. Logistic regression can be used to estimate directly the probability of an event occurring (SPSS Inc., 1994). Logistic regression performs better than multiple regression and discriminant analysis when the dependent variable can only have two values - an event occurring, or not occurring (SPSS Inc., 1994). Logistic regression has been used in wildlife habitat modelling with species absence/presence data by a number of researchers (e.g. Brennan et al., 1986; Smith and Connors, 1986; Pereira and Itami, 1991; Naylor et al., 1997). The regression equation for a single independent variable is:

$$\text{Prob (event)} = \frac{1}{1 + e^{-(B_0 + B_1 X)}}$$

where B_0 and B_1 are coefficients estimated from the data, X is the independent variable, and e is the base of the natural logarithm (approximately 2.718) (SPSS Inc., 1994). Independent variables can be evaluated on their ability to predict the dependent variable by examining the log-likelihood ratio and its significance. The best classification was determined based on the highest log-likelihood ratio (lowest significance value).

The landscape structure of the best classification was further examined to explain the presence of pileated woodpeckers (Figure 3.3). All landscape-level and class-level FRAGSTATS variables were entered into forward step-wise logistic regression procedure (using the log likelihood method) with the F-to-enter and F-to-remove initially set at 0.10 (SPSS Inc., 1994). Additional logistic regression was done on the data separated by broad forest type. A final logistic regression model is presented as a landscape-scale habitat model based on the analysis and biological importance of the variable.

4.0 Results

4.1 Pileated Woodpecker Presence/Absence Monitoring

A total of 38 separate responses by pileated woodpeckers were recorded during the field survey from April 29 to July 11, 1997 (Appendix V). The 38 responses occurred on 28 of the 60 surveyed transect lines. The majority of lines (n=21) had one response, while five lines had two responses, one line had three responses, and one line had four responses. The majority of pileated woodpeckers that responded were single birds (34), although a few pairs (4) did respond together. All the respondents flew close by and were either: silent (n=5, 13%); called (n=22, 58%); drummed (n=6; 16%); or called and drummed (n=5, 13%).

The minimum densities estimates of pileated woodpeckers in Algonquin Park can be calculated to be from 0.2 to 0.8 breeding pairs per km^2, assuming that all single bird responses where part of a breeding pair. The average density was calculated to be 0.271 (± 0.146 SD) (breeding pairs per km^2. These reported densities should not be viewed as absolute densities but rather as relative estimates because bird territories did not fit entirely within the study sites (Renken and Wiggers, 1993). The densities reported are also relative because of the selection criteria used to select the map sheets. Although densities were calculated on the smaller study areas, the map sheet selection could have affected the densities reported. Map sheets were selected with total nesting habitat making up 50% to 85% of the total area. This study could have missed some higher densities on map sheets with greater than 85% total nesting habitat. Lower densities could possibly exist on map sheet with total nesting habitat lower than 50%.

Activity information was collected at 322 plots on 22 transect lines with pileated woodpeckers present and 19 where they where absent (Appendix VI). Transect lines with pileated woodpeckers present had significantly higher index of activity (T test, p=.000278). The mean activity index per plot on the used transect lines was 1.2, while the average activity index per plot on the unused transect lines was 0.34.

The mixedwood forest had significant more study sites with pileated woodpeckers presence ($X^2 = 4.286$, $p = 0.038$) than tolerant hardwood forest (Table 4.1).

Table 4.1 Pileated woodpecker responses by broad forest-type.

	Tolerant Hardwood Forest	Mixedwood Forest	Total
Present	10	18	28
Absent	20	12	32
Total	30	30	60

4.2 Landscape-Scale Structure Analysis

The areas around transect lines were used for landscape structure analysis. Landscape analysis attempts to predict or explain the presence/absence as determined by the field survey. First, the variables, "%LAND" of used, preferred and total habitat for each classification were entered as explanatory variables of pileated woodpecker presence into logistic regression (Table 4.2).

Table 4.2. Results of logistic regression of different classifications (%LAND) in predicting the presence of pileated woodpeckers.

Classification	Likelihood-ratio	Significance	Relationship
PWPHSM Nesting4 preferred	6.7303	0.0095	+
PWPHSM Nesting1 preferred	6.0279	0.0141	+
D'Eon and Watt Nesting preferred	5.8344	0.0157	+
PWPHSM Feeding preferred	5.2959	0.0218	+
PWPHSM Feeding used	5.1065	0.0238	-
D'Eon and Watt Nesting used	4.9392	0.0268	-
PWPHSM Nesting1 used	4.839	0.0278	-
PWPHSM Nesting3 preferred	4.8061	0.0284	+
PWPHSM Nesting4 used	4.712	0.03	-
PWPHSM Nesting2 preferred	3.6487	0.0561	+
PWPHSM Nesting3 used	2.9668	0.085	-
PWPHSM Nesting2 used	2.8564	0.091	-
D'Eon and Watt Nesting total	0.423	0.5154	+
PWPHSM Nesting4 total	0.25	0.6171	+
PWPHSM Nesting1 total	0.2404	0.6239	+
PWPHSM Feeding total	0.0007	0.9796	+
Initial Log-Likelihood	82.9108		

The PWPHSM Nesting4 was the best predictor of the pileated woodpecker presence. The PWPHSM Nesting4 was only different from PWPHSM Nesting1 because the water was removed and therefore changed the percentage of land. PWPHSM Nesting1 was the second best predictor of pileated woodpecker presence. The alternative model (D'Eon and Watt Nesting) also performed well in predicting pileated woodpecker presence. The preferred PWPHSM Feeding habitat was the next best classification. All of the classifications' preferred habitats were highly significant (< 0.05) with the exception of PWPHSM Nesting2 (0.0561), which reduced preferred habitat because of the increased

HSI cutoff. All of the classifications' total habitats (used + preferred) were poor predictors of pileated woodpecker presence. All of the classifications' used habitats had a negative relationship and were significant. Total PWPHSM Feeding habitat was the poorest predictor of pileated woodpecker presence. The %LAND of PWPHSM Nesting4 ranged from 0 to 93.52% for the 60 sites (Appendix VII). The mean %LAND for sites with pileated woodpeckers present was 49.54% and the mean for sites without pileated woodpeckers was 28.75%.

Having determined that PWPHSM4 Nesting was the best classification, all FRAGSTATS variables (from the class and landscape levels) from this classification were then entered as explanatory variables of pileated woodpecker presence into forward stepwise logistic regression. The forward stepwise logistic regression produced only one variable (CAD) with the initial F-to-enter and F-to-remove values. Increasing the F-to-enter and F-to-remove were increased to a conservative 0.5, but the model still failed to improve (i.e. no additional variables were added). The FRAGSTATS variables were therefore examined as single independent variables before they entered the forward stepwise logistic regression. Correlation with %LAND was also performed on all class-level variables.

A number of FRAGSTATS variables were significant in predicting the presence of pileated woodpeckers (Table 4.3). CAD (core area density) was the most significant variable.

Table 4.3 Significant class-level variables (FRAGSTATS) in predicting the presence of pileated woodpeckers.

Variable	Log-Likelihood Ratio	Significance	Correlation with %LAND
CAD	9.8738	0.0017	0.7755
NCA	6.0279	0.0022	0.7787
LPI	5.8344	0.0053	0.9089
%LAND	6.7303	0.0095	1.0000
CA	6.0383	0.014	0.9945
TCAI	5.1501	0.0232	0.9375
C%LAND	4.9144	0.0266	0.9507
TCA	4.4486	0.0349	0.9487
ED	4.2258	0.0398	0.7298

Initial Log-Likelihood 82.9108

CAD, NCA (number of core areas), and LPI (landscape patch index) predicted pileated woodpecker presence better than %LAND. CA (class area), LPI, TCA (total core area), C%LAND (core area % of landscape) were all highly correlated with %LAND (0.9089-0.9945). NCA, CAD, and ED were moderately correlated with %LAND (0.7298-0.7787). All of other class-level variables were not significant ($p > 0.05$) in predicting pileated woodpecker presence(Appendix VII). There were no FRAGSTATS variables at the landscape-level that were significant in predicting presence (Appendix IX). The most meaningful landscape-level variables were PR (patch richness) ($p= 0.1391$), PRD (patch richness density) ($p= 0.1468$) and PD (patch density) ($p= 0.2427$).

CAD ranged from 0 to 2.84 per 100 ha for the 60 sites (Appendix X). The mean CAD of sites where pileated woodpeckers were present was 1.58 per 100 ha while the mean for sites without pileated woodpeckers was 0.91 per 100 ha (Table 4.4)

Table 4.4 Class-level variable (FRAGSTATS) means for present and absent sites.

Variable	Present	Absent	Total
CAD (#/100 ha)	1.58	0.91	1.22
NCA (#)	7.36	4.25	5.70
LPI (%)	29.63	14.82	21.73
%LAND (%)	49.54	28.75	38.45
CA (ha)	230.09	136.89	180.38
TCAI	29.26	18.16	23.34
C%LAND (%)	19.21	10.31	14.47
TCA (ha)	89.05	49.21	67.80
ED (m/ha)	39.82	28.32	33.69
TE (m)	18581.07	13490.94	15866.33
TA (ha)	427.32	397.07	411.19
NP (#)	7.07	5.84	6.42
PD (#/100 ha)	1.53	1.23	1.37
MPS (ha)	32.17	20.62	26.01
LSI	4.09	3.29	3.66
MSI	1.83	1.59	1.70
AWMSI	2.46	1.95	2.19
DLFD	1.11	0.97	1.03
MPFD	1.03	0.93	0.98
AWMPFD	1.05	0.95	1.00
MCA1 (ha)	12.52	7.69	9.94
MCA2 (ha)	13.21	7.50	10.17
MCAI (%)	10.10	7.60	8.76
MNN (m)	85.76	151.22	12.67
IJI (%)	30.63	47.67	39.72

Because the core-area variables showed to be significant, the sensitivity of the edge-width used in FRAGSTATS to calculate core was tested using alternative distances of 50 m and 200 m. When the edge-width distance was increased to 200 m, the CAD was still significant (p= 0.0554), but to a lesser degree. When the edge-width distance was decreased to 50 m, the CAD was no longer significant (p=0.4794). Based on this analysis, the edge-width distance of 100 m was retained.

Separate logistic regression on only the tolerant-hardwood forest study sites showed similar results to the overall data. NCA and CAD were the two best predictors of presence of the PWPHSM Nesting4 preferred classification. TE, CA and LPI were also important variables in predicting presence (Table 4.5).

Table 4.5 Significant class-level variables (FRAGSTATS) in predicting the presence of pileated woodpeckers in the tolerant hardwood study sites.

Variable	Log-Likelihood Ratio	Significance
NCA	6.3463	0.0118
CAD	5.5470	0.0185
TE	4.3575	0.0368
ED	4.1894	0.0407
CA	3.9792	0.0461
LPI	3.3539	0.0670

Initial Log-Likelihood 38.19085

The study sites that represent the mixedwood forest type, by contrast, did not show results similar to the overall data. Total area (TA) was the only significant variable (Log-likelihood Ratio = 4.1058, p = 0.04107, starting LLR = 34.943). CAD (p = 0.3204) and NCA (0.5091) were not significant in predicting presence.

Logistic regression was also performed on the PWPHSM Nesting4 total habitat separately for mixedwood forest and tolerant hardwood sites. For the mixedwood forest sites CAD (Log-Likelihood Ratio = 3.0809, p = 0.0792, starting LLR = 40.3807) and NCA (Log-

Likelihood Ratio = 3.0881, p = 0.0789) showed to be the most important variables in predicting presence. For the tolerant hardwood sites (total habitat) no variables were important (i.e. $p < 0.2$).

The final logistic regression equation using the CAD variable was:

Probability (presence) = $1/(1 + e^{-(Y)})$ where $Y = -1.5204 + 1.1039 * (CAD)$.

The equation correctly classified 71.67 % of the original data ($X^2 = 10.4493$ df = 1, p= 0.0012). A Hosmer-Lemeshow test was also performed to assess the fit of the model (Table 4.6). It tests how the model performs by dividing the data into deciles and calculating a chi-squared statistic on the expected and observed values in the deciles (Hosmer and Lemeshow, 1989).

Table 4.6 Results of applying the Hosmer-Lemeshow test: observed and expected frequencies by decile.

Decile	Obs. Yes	Exp. Yes	Obs. No	Exp. No	Total N
2	3	2.15	9	9.85	12
3	1	1.52	5	4.48	6
4	1	2.26	5	3.74	6
5	2	2.34	3	2.66	5
6	3	3.70	4	3.30	7
7	4	3.52	2	2.48	6
8	5	3.79	1	2.21	6
9	5	4.06	1	1.94	6
10	4	4.66	2	1.34	6

$X^2 = 4.45$, df=7, Significance = 0.7269

The Hosmer-Lemeshow test confirms that the model fits the data (p= 0.73) through all the deciles in concordance with the expected values. The p-value of 0.73 is greater than 0.05

and therefore indicates that there is insufficient evidence for the model not fitting the data adequately. A pseudo R^2 was calculated to be $R^2 = 0.4012$ (Nagelkerke, 1991).

5.0 Discussion

5.1 Pileated Woodpecker Presence/Absence Monitoring

The monitoring procedures were conducted later in the season than recommended by Bull et al. (1990) and Bonar (pers. comm. 1996). However, I feel the responses obtained were normal and reliable. Responses to the broadcast vocalizations occurred throughout the field survey from the end of April to the beginning of July (Appendix V). Although broadcasting vocalizations during the breeding season was recommended, responses were obtained after the breeding season because the pileated woodpecker actively defends its territory throughout the year (Kilham, 1983). One consequence of broadcasting later in the season was the high number of single bird responses. The majority of monitoring took place during a pairs' nest construction, egg laying, and incubation periods. During these periods only one of the pair (usually the male) responded to defend the pair's territory. Later during the field survey (end of June and beginning of July) after the young had fledged, some pairs responded together.

The monitoring procedures used to determine pileated woodpecker presence/absence obtained responses on 28 of the 60 transect lines. The project assumes that there is a correlation between the number of responses in the area and population density. The correlation between the activity information and the presence/absent data supports this assumption. Transect lines where pileated woodpeckers were present showed significantly more activity than the transect lines where they were absent. There was less activity on transect lines where no pileated woodpecker responded, although there was still some evidence. One explanation for why the birds were not present to respond may be because these areas are on the perimeter of a pair's home range and not defended at this time of year (Mellen et al., 1992). Another explanation may be that the observed activity is the result of a recently deceased pileated woodpecker. A majority of the sites with high activity (22 of the 26) were found on transects with pileated woodpeckers present.

The minimum relative density estimates of pileated woodpeckers calculated in this study are similar to Dance's (1987) estimates from 0.2 to 1.0 pairs per km^2. Dance's (1987) estimates were based on volunteer field-observers in northern and southern Ontario. The relative densities reported in both of these studies are lower than other studies in eastern North American forests of 1.0 to 4.0 pairs per km^2 (Kirk and Naylor, 1996). These lower density estimates may be a safer, more conservative guideline for wildlife managers to use in Ontario.

5.2 Landscape-Scale Structure Analysis

The PWPHSM Nesting4 preferred habitat best predicted the presence of pileated woodpeckers. The comparison of classifications was based on the %LAND variable for each habitat type. The PWPHSM Nesting4 classification was similar to the PWPHSM Nesting1 with the exception that open water was removed. Open-water habitat (i.e. lakes) is thought to be unusable habitat for the pileated woodpecker because it provides no nesting trees or food reservoirs.

The PWPHSM Nesting1 preferred was the second best predictor of pileated woodpecker presence. The ability of the PWPHSM Nesting1 to be a significant predictor of presence helps to verify that the model (unchanged) can distinguish important habitat for the pileated woodpecker. The actual number or sizes of preferred habitat polygons did not change between PWPHSM Nesting4 and Nesting1. As a result, the landscape variables that were not calculated as a percentage of the total area did not change. Landscape analysis results of these variables (e.g. NP, NCA, TE, MPS, and CA) are therefore the same for PWPHSM Nesting1.

The D'Eon and Watt Modified Nesting preferred habitat also proved to be an adequate predictor of pileated woodpecker presence. The D'Eon and Watt Modified classification differed from the PWPHSM Nesting1 and PWPHSM Nesting4 in that some of the used or preferred ecosite types were reclassified as unsuitable. Even though some of the ecosites types were reclassified from preferred to unsuitable, the D'Eon and Watt Modified Nesting preferred habitat was only slightly less significant in predicting presence. This suggests that most of the reclassified ecosite-types (ES13 Jack Pine-White Pine-Red Pine, ES 15 Jack Pine, ES 16 Black Spruce-Pine, ES 30 Hemlock-Yellow Birch, ES 31 Black Spruce-Tamarack, ES 32 White Cedar-Black Spruce Tamarack) from the PWPHSM Nesting1 may not be important in determining presence. Although the D'Eon and Watt Modified classification was developed for northeastern Ontario, a number of the forest ecosite-types are similar to the central Ontario, particularly in the mixedwood forest. The ability of D'Eon and Watt Modified Nesting preferred to be a significant predictor of presence helps to verify that this model can also distinguish important habitat for the pileated woodpecker.

PWPHSM Feeding preferred habitat was also a good predictor of pileated woodpecker presence. The PWPHSM classified feeding habitat differently from nesting habitat based on the development stages of the forest stand. Feeding preferred habitat includes immature, mature and old development stages, while nesting preferred habitat can only include mature and old development stages. The nesting preferred habitat ability to predict presence only slightly increased in significance (0.0218 to 0.0095) by excluding the immature forest.

Adjusting the HSI cutoff value did not improve the base PWPHSM Nesting1 classification. Lowering the HSI cutoff value (PWPHSM Nesting3) performed better than increasing the HSI (PWPHSM Nesting2). The higher HSI cutoff value lowered the amount of preferred habitat by forcing some forest stands to be excluded. This means that a number of the forest stands that had an HSI value between 0.413 and 0.5 are still important habitat in predicting presence. The higher HSI cutoff value affected the ecosite types with the lower-value intercepts of the logistic equation model (Appendix I).

Used habitat in all of the classifications had a negative relationship with presence of pileated woodpeckers. As a study site's percentage of preferred habitat increased, the percentage of used habitat correspondingly decreased. Therefore because of the strong positive relationship of presence with preferred habitat, a negative relationship was noted with presence and used habitat. These results suggest that used habitat, as a percentage of the landscape, is not a good predictor of presence.

For all of the classifications, total (used + preferred) habitat was a poor predictor of pileated woodpecker presence. The poor ability of total habitat to predict pileated woodpecker presence may mean that either the model was weak in identifying total habitat or total habitat is not important in determining the presence of pileated woodpeckers. I feel that the latter statement is true because of the trend of all classifications' preferred habitats to be a better predictor of presence than used or total habitats. Total feeding habitat classification had the poorest ability to predict pileated woodpecker presence. This finding supports the findings of other researchers (Bull and Meslow, 1977, Millar 1994, Bonar, 1995) that foraging habitat is not as critical as nesting habitat. The PWPHSM Nesting1 total habitat was initially used in the selection criteria of larger (25 km^2) map sheets. The larger map sheets selected had total habitat between 50% and 85%. The study sites (5 km^2 located within the 25 km^2 map sheets) had a range of total habitat between 24% and 92%. Only four of the sixty study sites dropped below the initial selection criterion of 50%. There was a woodpecker pair present on two of those low-percentage study sites. The assumption that each study site had enough total habitat to support one pair was still maintained. However, these results showed that sufficient total habitat is not good in determining pileated woodpecker presence.

The inability of total habitat classifications to predict pileated woodpecker presence is an important finding for the management of pileated woodpeckers. Managers in the Great Lakes-St. Lawrence Forest Region use the PWPHSM to perform habitat supply analysis (Naylor et al., 1996). Findings from this project support the Strategic Forest Management Model (Davis, 1996) that sets management objectives to look at preferred habitat rather than total habitat. Managing for preferred nesting habitat would better conserve critical forest habitat for the pileated woodpecker.

Additional FRAGSTATS variables were examined to determine if they were better than %LAND in predicting pileated woodpecker presence. CAD (core area density), NCA (number of core areas), and LPI (largest patch index) variables were better than %LAND at predicting presence. CAD and NCA are essentially the same variable with CAD simply being the NCA per 100 ha. CAD is a better variable for comparing landscapes and for model development because it normalizes the value for a given area (McGarigal and Marks, 1994). NCA is only valuable when one is dealing with landscapes of the same size. CAD became a slightly better predictor when open water was removed because this led to differences in the sizes of study sites.

Core areas are important for forest-interior species. These species are sensitive to forest-edge effects of predation, competition, and brood parasitism (McGarigal and Marks, 1994). Temple (1986) suggested that core area can be a better predictor of habitat quality than patch area. The pileated woodpecker has not been clearly identified is an interior species in the literature and the debate continues (Kirk and Naylor, 1996). The importance of CAD and NCA in my results may suggest that the pileated woodpecker is sensitive to some edge effects. The type or degree of the edge effect is difficult to determine from this study but does warrant further research.

The edge-width of 100 m was better at maintaining CAD significance than 50 m and 200 m edge-widths. The 200 m edge-width produced a CAD that was still moderately significant (p = 0.0554) and indicates that the edge effects might extend further than 100 m. A circular forest polygon with a 100 m edge-width needs to be at least 3.14 ha to maintain any core area. Circular forest polygons with edge-widths of 50 m and 200 m would need to at least 0.785 ha and 12.56 ha in size respectively. Adjusting edge-width affects the number of core areas by removing polygons smaller than these minimum required areas. The number of small core areas (less than 12.56 ha) that were removed by increasing the edge-width to 200 appear to be important. This finding suggests that even smaller core areas of preferred habitat are important in the landscape configuration.

In this study there was no distinction between types of edges. The edge effects may be different between preferred and used, preferred and unsuitable, and preferred and water habitats. Because the pileated woodpecker has been viewed as an interior species, studies have not examined whether they respond to different edge types.

The LPI variable measures the largest patch as a percentage of the total landscape area. Because the LPI values are highly correlated with the %LAND values, it is difficult to determine the effect on patch size of habitat selection. The LPI was higher for sites where pileated woodpeckers were present (mean = 29.63%) than for sites where there was no response (mean = 14.82). If the %LAND were the same for all sites, then we could say that based on the higher LPI, sites with pileated woodpecker presence were less fragmented. However, with the high degree of correlation between the two variables, this statement can not be made.

The %LAND variable, which was used to determine which classification best predicted presence, was the fourth most significant variable. The mean %LAND of sites where pileated woodpeckers were present was 49.5%, while the mean for sites without pileated woodpeckers was 28.75%. The mean %LAND values of sites with pileated woodpeckers present is consistent with Millar's (1994) recommended 40% of a habitat area to be nesting habitat. Naylor et al. (1997) found that sites with pileated woodpeckers present had a mean of 37% preferred habitat.

The variable CA (class area) reports the total area of preferred habitat in hectares. The variable is highly correlated with %LAND and mostly redundant because it reports the actual area as compared to the percentage of area. However, the variable does provide a look at the real area values that are influencing the presence of pileated woodpeckers. The mean CA for sites with birds present was 230 ha as compared to the mean of 137 ha for the sites without birds. The sites without birds had enough preferred nesting habitat when compared with Bull and Holthausen (1993) and Millar (1994) minimum nesting habitat requirement areas of 91 ha and 100 ha respectively. Based on these findings, the pileated woodpecker might have a higher minimum nesting habitat requirement in central Ontario than in Oregon and Manitoba.

TCAI (total core area index), which quantifies the amount of core area as a percent of the total preferred area, and C%LAND (core area % of landscape) were other significant core area variables. The mean C%LAND for sites with pileated woodpeckers present was reduced from the %LAND (49.5%) to only 19.2%. TCA (total core area) is another significant core area variable that is mostly redundant with C%LAND. The variable does provide a look at the real area values for core area. The mean TCA for sites with pileated woodpeckers present was 89 ha while the mean for sites without pileated woodpeckers was 49. By using the 100 m edge-width, the preferred habitat in core area is significantly reduced from the total preferred habitat (CA).

The ED (edge distance) was another significant landscape configuration variable. As the percentage of preferred habitat increased, so did the ED. The ED can be an indication of a more fragmented landscape with more-complex patch shapes. The difference in ED between sites where birds were present and sites with no response suggests that pileated woodpeckers preferred a more fragmented landscape with more complex patches. However, this statement is difficult to confirm due to differences in %LAND. If the %LAND for all study sites were similar, then a statement of preference for fragmented forest could be made. McGarigal and McComb (1995) also found that ED was a significant landscape variable for the pileated woodpecker and had a similar limitation in that there were large differences in %LAND.

A number of other variables, even though they were not significant in predicting presence of pileated woodpeckers, still contribute to understanding the role of landscape-scale forest structure for this species. Total area (TA) for most of the study sites was similar (range = 299.7-499.91 ha). All study sites started out as 500 km^2 and then with the PWPHSM Nesting4 had the open water removed. The TA was a poor predictor of pileated woodpecker presence. This result supports the statement that pileated woodpeckers are selective in terms of habitat and also shows that composition and configuration of the forest are more important than total area of the forest.

The number of patches (NP) and patch density (PD) of preferred habitat were poor predictors of pileated woodpecker presence. At the landscape level, NP and PD were also poor predictors of presence. The fact that NP and PD were not significant and CAD and NCA were further suggests that pileated woodpeckers are influenced by edge effects and not just the number of patches of preferred habitat in a landscape.

The mean patch size (MPS) was only marginally significant ($p = 0.079$) in predicting pileated woodpecker presence. The influence of MPS in this study is difficult to interpret due to its relatively high correlation (0.808) with %LAND. This supports Kirk and Naylor's (1996) suggestion "that patch size does not strongly influence habitat use in a continuous forest". Naylor et al. (1997) also found that MPS of preferred habitat was not significant in determining pileated woodpecker presence.

The landscape shape index (LSI) shows that the shape of the patches of preferred habitat is moderately more complex for sites with pileated woodpeckers. The LSI compares the perimeter/area ratio to a standard shape (square for raster data). Although this variable is moderately significant ($p = 0.069$), it is not meaningful because the borders of the study sites were not true ecological edges (McGarigal and Marks, 1994). If the boundaries of the study sites would had followed the forest stand boundaries, then the results for LPI would possibly have been meaningful.

No landscape-level FRAGSTATS variables were significant in predicting PWP presence. This finding suggests that the landscape patterns of patches (not considering the patch types, unsuitable, used or preferred) are similar between used and unused sites. If there were significant landscape level variables, it would have been more difficult to determine the influence of the class-level variables. The patch richness (PR) was the most important landscape-level variable (LLR = 2.1875, sig. = 0.1391). PR measures how many types of patches (unsuitable, used, or preferred) are in each landscape. The mean PR measured higher for sites without pileated woodpeckers (2.69) than for sites with pileated woodpeckers (2.50).

Broad forest types appeared to influence the presence of pileated woodpeckers. The number of sites with birds present was greater in mixedwood forests than in the tolerant hardwood forests. The two highest relative densities (ER3-0.8 pairs per km^2 and DV2-0.6 pairs per km^2) were found in the mixedwood forest. When the study areas were examined separately for landscape-scale structure influence, some differences from the overall findings were noted. CAD, NCA, ED, and LPI were still important in the tolerant hardwood forest. However, in the mixedwood forest these variables of preferred habitat were no longer significant. TA of preferred habitat was the only significant variable in the mixedwood forest. CAD was an important variable in the mixed forest sites when total nesting habitat was examined.

The difference in the influence of landscape structure between the two broad forest types can partly be explained by the difference in the amount of preferred nesting habitat. The mixedwood forest sites had significantly more preferred habitat (mean = 64%, SD = 18.8%) than tolerant hardwood forest sites (mean = 12%, SD = 13.5%). The configuration variables (CAD, NCA, ED, and LPI) seemed to be more important when there were smaller amounts of preferred habitat. In the mixedwood forest only the total area of land (unsuitable, used, and preferred) influenced pileated woodpecker presence. There appears to be a threshold after which the influence of the configuration of preferred habitat decreases. Andren (1994) suggested that total area of suitable habitat is of greater importance than spatial arrangements for landscape with greater than 30 % suitable habitat, thus supporting the theory of a threshold.

The final logistic equation used to predict presence – Probability (presence) = $1/(1 + e^{-(Y)})$ where $Y = -1.5204 + 1.1039 * (CAD)$ – performed well across all study sites. Therefore, the logistic regression equation provides a good spatial habitat model that incorporates the important landscape-scale configuration requirements. Although there is some difference in the landscape-scale influence between the two broad forest types, I did not feel it was warranted to create two separate spatial models. For both landscapes, core areas and preferred habitat had some importance. Also, forest and wildlife management at the landscape-scale in Ontario generally occurs across both broad forest types.

Forest managers can use the spatial model in two different methods to predict the probability of pileated woodpecker presence. One method is to apply the spatial model to individual areas to assess a probability of pileated woodpecker presence. These individual areas should be restricted to areas approximately 5 km^2. A second method is to apply the spatial model to larger landscapes by analyzing individual habitat assessment units of 5 km^2. First, the PWPHSM would be run on the forest landscape, assigning the habitat supply classes to forest polygons. The next step would involve a movable habitat assessment unit or window across the landscape (Duinker, 1986). This technique would involve overlaying a, say, 5 km^2 window (2240 m X 2240 m) on the map of habitat supply classes created by using the PWPHSM. All of the preferred habitat would then be selected. The logistic regression equation (spatial model) would be applied to the preferred habitat in the 5 km^2 window. If the probability were greater than or equal to 0.5, then all the forest stands would be flagged to retain the original habitat supply category (unsuitable, used, or preferred). If the habitat window has a probability less than 0.5, then all stands will not be flagged for conversion to the unsuitable category. There could be a 50 % overlap of these windows in both X and Y directions. The flagged stands would retain that notation if a second overlay has a probability less than 0.5. Forest stands not flagged would be assigned an unsuitable classification. The habitat window would move across the entire landscape until all areas have been analyzed.

The spatial model allows the important landscape-scale influences to be incorporated into the analysis of supply of pileated woodpecker habitat. Forest managers in central Ontario can assess how possible forest management strategies could affect pileated woodpecker habitat using the results of application of the model. In addition to the tree- and stand-level management strategies outlined by Naylor et al. (1996), this landscape-scale management is important for the conservation of pileated woodpecker habitat.

The scope of this research project was restricted in several ways. First, the study looked at the landscape-scale forest structure for sites of 5 km^2. There might be important landscape-scale forest structure considerations at smaller and larger scales. Secondly, the study relied on the base FRI map information. The accuracy of the FRI information used in Algonquin

Park has not been documented. Some errors in stand boundaries, stand age, and tree species may be present on the FRI maps. The FRI information was used because it is the same information used by forest managers across central Ontario and it is practical and affordable for this type of landscape-scale habitat work. Finally, the study assessed only the influence of landscape-scale structure on the presence of pileated woodpeckers and not influence of landscape-scale structure on the density of pileated woodpecker or fitness of those individuals: The study did not have enough sites with higher densities to statistically compare with the lower density sites. These limitations should be considered when interpreting the results of this study.

6.0 Conclusions

This study demonstrated that landscape-scale forest structure has an important influence on the presence of pileated woodpecker. Preferred nesting habitat was clearly identified as the best habitat for predicting the presence. The composition (%LAND) and configuration (CAD) of the preferred habitat were the most important landscape-scale structure measures of the habitat. The PWPHSM used to classify preferred nesting habitat was verified as a good tool for the management of pileated woodpecker habitat. The PWPHSM can be improved for landscape analysis when comparing percentage of habitat available between areas by removing the open water from the landscape.

Total, used, and feeding habitats were less able to predict the presence of pileated woodpeckers. This is an important consideration for management of this species in Great Lakes-St. Lawrence forests of central Ontario. The study demonstrates that although these sites are utilized, they are unreliable in predicting pileated woodpecker presence.

Edge effects appear to have a greater influence on pileated woodpecker presence than previous research has suggested (Millar, 1994; Kirk and Naylor, 1996). The ability of the core area variables to predict pileated woodpecker presence supports consideration of the influence of such effects. Based on sensitivity analysis of the edge-width, the edge effects are on the order of 100 m. Although this study was unable to identify the type and magnitude of the edge effects, they do merit further investigation.

The difference in the influence of landscape structure between the two forest-types suggests that the landscape configuration is more important with low percentages of preferred nesting habitat. Further research could focus on better defining the threshold where landscape configuration becomes more important. Forest managers could then pay close attention to landscape configuration when managing landscapes with lower percentages of preferred habitat.

6.1 Recommendations

The PWPHSM should continue to be used by forest managers in central Ontario. When landscape analysis is comparing percentage of habitat available, it is recommended that water be removed from the landscape. Forest managers are also encouraged to continue to move toward spatial HSA in management planning. It is also recommended that HSA for pileated woodpecker is applied to preferred nesting habitat rather than on used or total nesting habitat.

In Ontario, detailed information on the home ranges of pileated woodpeckers is needed for management of this species to be effective. Extensive radio-tracking surveys (e.g. Bull and Holthausen, 1993) need to be conducted to determine home range sizes and patterns. Landscape-scale analysis of habitat within the home range areas could help further explain the importance of landscape-scale forest structure.

Population monitoring of pileated woodpecker populations is also recommended in central Ontario. A monitoring program of populations of this species could use field methods similar to this study. Monitoring across central Ontario would be best undertaken by broadcasting vocalizations from a vehicle using secondary and tertiary roads. Broadcast stops every 400 m (as used in this survey) would be recommended. The population monitoring could be conducted beyond the breeding season into July. Information on pileated woodpecker locations and populations collected during a red-shoulder hawk survey (Naylor et al., 1997) or the Breeding Bird Surveys can provide good supplementary data. Separate pileated woodpecker surveys are recommended to build a larger, more-detailed data set.

At both the tree- and stand-levels, there is a good understanding of foraging and nesting requirements of the pileated woodpecker. However, there is a need for more research on roosting characteristics at tree- and stand-levels. The landscape-level relationship between roosting and nesting habitats also needs to be examined.

The effects of selection and shelterwood harvesting on pileated woodpecker are not fully known. Both of these silviculture techniques are practiced in Algonquin Park. Selection harvesting is thought to have less of an effect (Wedeles and Van Damme, 1995; Kirk and Naylor, 1996). However, there is no understanding how these silviculture systems may influence pileated woodpecker populations at the landscape level.

This research project demonstrates that landscape-scale forest structure can be important for the conservation of pileated woodpecker habitat. The methods used in this landscape-scale analysis can be applied to other birds or mammals where the influences of landscape-scale forest structure could be important. Thomas (1986) stated: "Models are merely the means to an end. They are not the end in and of themselves." We must view this pileated woodpecker spatial model as a tool to help assist in making better decisions for the conservation of this species. This study serves as preliminary understanding of the influence of landscape-scale forest structure on the pileated woodpecker and as a guide to future landscape-scale analysis.

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8.0 Appendices

Appendix I: Landscape structure variables calculated by FRAGSTATS.

Scale	Acronym	Metric (units)
Area metrics		
Class	CA	Class area (ha)
Class	%LAND	Percent of landscape (%)
Class/landscape	TA	Total landscape area (ha)
Class/landscape	LPI	Largest patch index (%)
Patch density, patch size and variability metrics		
Class/landscape	NP	Number of patches (#)
Class/landscape	PD	Patch density (#/100 ha)
Class/landscape	MPS	Mean patch size (ha)
Class/landscape	PSSD	Patch size standard deviation (ha)
Class/landscape	PSCV	Patch size coefficient of variation (%)
Edge metrics		
Class/landscape	TE	Total edge (m)
Class/landscape	ED	Edge density (m/ha)
Class/landscape	CWED	Contrast-weighted edge density (m/ha)
Class/landscape	TECI	Total edge contrast index (%)
Class/landscape	MECI	Mean edge contrast index (%)
Class/landscape	AWMECI	Area-weighted mean edge contrast index (%)
Shape metrics		
Class/landscape	LSI	Landscape shape index
Class/landscape	MSI	Mean shape index
Class/landscape	AWMSI	Area-weighted mean shape index
Class/landscape	DLFD	Double log fractal dimension
Class/landscape	MPFD	Mean patch fractal dimension
Class/landscape	AWMPFD	Area-weighted mean patch fractal dimension

Appendix I: Landscape structure variables calculated by FRAGSTATS (Continued).

Scale	Acronym	Metric (units)
Core area metrics		
Class	C%LAND	Core area percent of landscape (%)
Class/landscape	TCA	Total core area (ha)
Class/landscape	NCA	Number of cores areas (#)
Class/landscape	CAD	Core area density (#/100 ha)
Class/landscape	MCA1	Mean core are per patch (ha)
Class/landscape	MCA2	Mean area per disjunct core (ha)
Class/landscape	TCAI	Total core area index (%)
Class/landscape	MCAI	Mean core area index (%)
Nearest-neighbor metrics		
Class/landscape	MNN	Mean nearest-neighbor distance (m)
Class/landscape	MPI	Mean proximity index
Diversity metrics		
Landscape	SHDI	Shannon's diversity index
Landscape	SIDI	Simpson's diversity index
Landscape	MSIDI	Modified Simpson's diversity index
Landscape	PR	Patch richness (#)
Landscape	PRD	Patch richness density (#/100 ha)
Landscape	RPR	Relative patch richness (%)
Landscape	SHEI	Shannon's evenness index
Landscape	SIEI	Simpson's evenness index
Landscape	MSIEI	Modified Simpson's evenness index
Contagion and interspersion metrics		
Class/landscape	IJI	Interspersion and juxtaposition index (%)
Landscape	CONTAG	Contagion index (%)

McGarigal and Marks (1994)

Appendix II: Variables used by Naylor et al. (1997) in spatial analysis of pileated woodpecker habitat.

Variables
Area of preferred nesting habitat (ha)
Area of all nesting habitat (ha)
Area of preferred feeding habitat (ha)
Area of all feeding habitat (ha)
Nesting units (sum of HSI score for nesting multiplied by the area of the polygon)
Feeding units (sum of HSI score for feeding multiplied by the area of the polygon)
Area of forest (ha)
Area of open water (ha)
Area of wetlands (ha)
Area of barren rock (ha)
Area of gravel pits (ha)
Area of agricultural land (ha)
Length of paved, all weather-roads (m)
Length of seasonal roads (m)
Length of rivers and streams (m)
Mean size of patches of preferred nesting habitat
Mean size of patches of nesting habitat
Mean size of preferred feeding habitat
Mean size of feeding habitat
Mean distance between patches of preferred nesting habitat
Mean distance between patches of nesting habitat
Mean distance between patches of preferred feeding habitat
Mean distance between patches of feeding habitat

Appendix III: Ecosite-specific intercepts for the PWPHSM model.

Ecosite type	Intercept
ES11 (White Pine-Red Pine)	-2.1955
ES12 (Red Pine)	-3.3000
ES13 (Jack Pine-White Pine-Red Pine)	-3.3000
ES14 (White Pine-Largetooth Aspen-Red Oak)	-2.2764
ES15 (Jack Pine)	-4.1233
ES16 (Black Spruce-Pine)	-3.3000
ES17 (Polar-White Birch)	-2.7594
ES18 (Poplar-White Birch-White Spruce-Balsam Fir)	-3.3000
ES19 (Poplar-Jack Pine-White Spruce-Black Spruce)	-2.4746
ES20 (White Pine-Red Pine-White Spruce-White Birch-Trembling Aspen)	-3.3000
ES21 (White cedar-White Pine-White Birch-White Spruce)	-3.3000
ES22 (White Cedar-Other Conifer)	-3.3000
ES23 (Red oak-Hardwood)	-3.3000
ES24 (Sugar Maple-Red Oak-Basswood)	-3.6465
ES25 (Sugar Maple-Beech-Red Oak)	-3.9308
ES26 (Sugar Maple-Basswood)	-3.8963
ES27 (Sugar Maple-White Birch-Poplar-White Pine)	-3.3000
ES28 (Sugar Maple-Hemlock-Yellow Birch)	-3.7098
ES29 (Sugar Maple-Yellow Birch)	-4.2640
ES30 (Hemlock-Yellow Birch)	-3.8965
ES31 (Black Spruce-Tamarack)	-4.5929
ES32 (White Cedar-Black Spruce-Tamarack)	-3.6842
ES33 (White Cedar-Other Conifer)	-3.3000
ES34 (White Cedar-Lowland Hardwoods)	-3.3000
ES35 (Lowland Hardwoods)	-3.7342

Naylor et al. (1997)

Appendix IV: Development stages for COFEC ecosite type.

Ecosite type	Presapling	Sapling	Immature	Mature and Old
ES11	0-14	15-24	25-64	65+
ES12	0-9	10-24	25-59	60+
ES13	0-14	15-29	30-69	70+
ES14	0-14	15-24	25-59	60+
ES15	0-9	10-24	25-89	90+
ES16	0-19	20-39	40-89	90+
ES17	0-14	15-34	35-69	70+
ES18	0-14	15-29	30-64	65+
ES19	0-9	10-24	25-64	65+
ES20	0-19	20-29	30-59	60+
ES21	0-19	20-34	35-69	70+
ES22	0-14	15-29	30-84	85+
ES23	0-14	15-24	25-54	55+
ES24	0-19	20-34	35-69	70+
ES25	0-14	15-29	30-59	60+
ES26	0-19	20-34	35-64	65+
ES27	0-14	15-29	30-64	65+
ES28	0-19	20-34	35-69	70+
ES29	0-19	20-34	35-69	70+
ES30	0-19	20-34	35-69	70+
ES31	0-24	25-59	60+	
ES32	0-24	25-49	50-119	120+
ES33	0-14	15-29	30-84	85+
ES34	0-14	15-29	30-64	65+

Naylor et al. (1997)

Appendix V: Pileated woodpecker response locations

Transect	Map sheet and number		Date	Forest-type of transect	UTM of Broadcast stop	Stand #	Working Group
NM1	NM	17 7000 50500	29-Apr	Tolerant hardwoods	17 701950 5050950	1705	Mh
EO4	EO	17 7100 50950	07-May	Mixedwoods	17 714500 5099800	3496	Po
EO2	EO	17 7100 50950	09-May	Mixedwoods	17 711480 5099810	1279	Po
EO5	EO	17 7100 50950	13-May	Mixedwoods	17 714480 5096820	4164	Po
EO3	EO	17 7100 50950	08-May	Mixedwoods	17 712700 5098953	3083	Po
ER3	ER	17 7250 50950	14-May	Mixedwoods	17 725985 5097500	5974	B
ER3	ER	17 7250 50950	14-May	Mixedwoods	17 726970 5097540	Wetland	
ER3	ER	17 7250 50950	14-May	Mixedwoods	17 727450 5097500	7580	Po
ER3	ER	17 7250 50950	14-May	Mixedwoods	17 728000 5097500	8074	Pj
ER2	ER	17 7250 50950	14-May	Mixedwoods	17 726640 5096400	6765	Po
ER1	ER	17 7250 50950	20-May	Mixedwoods	17 726600 5095450	6555	Po
ER4	ER	17 7250 50950	26-May	Mixedwoods	17 728840 5098420	8784	Or
KE1	KE	17 6600 50650	27-May	Tolerant hardwoods	17 662860 5065380	3256	Mh
KE1	KE	17 6600 50650	27-May	Tolerant hardwoods	17 660270 5065530	355	Mh
NL1	NL	17 6950 50500	04-Jun	Tolerant hardwoods	17 695550 5053640	5536	Mh
NL2	NL	17 6950 50500	04-Jun	Tolerant hardwoods	17 696650 5050950	6811	Mh
ED3	ED	17 6550 50950	06-Jun	Tolerant hardwoods	17 658960 5097600	8774	By
DW1	DW	18 2800 51000	10-Jun	Mixedwoods	18 282660 5100520	2507	Pw
DW2	DW	18 2800 51000	10-Jun	Mixedwoods	18 281960 5101450	1912	Pw
DW3	DW	18 2800 51000	09-Jun	Mixedwoods	18 283250 5102400	3223	Pw
DW4	DW	18 2800 51000	11-Jun	Mixedwoods	18 284430 5103350	4641	Or
DL1	DL	17 6950 51000	12-Jun	Tolerant hardwoods	17 695500 5103090	5331	Mh

Appendix V: Pileated woodpecker response locations (Continued).

Transect	Map sheet and number	Date	Forest-type of transect	UTM of Broadcast stop	Stand #	Working Group
DL3	DL 17 6950 51000	30-Jun	Tolerant hardwoods	17 697530 5101400	7613	Pw
DL3	DL 17 6950 51000	30-Jun	Tolerant hardwoods	17 697500 5102700	7425	B
FX1	FX 18 2850 50900	17-Jun	Mixedwoods	18 285520 5094120	5443	Po
FX3	FX 18 2850 50900	17-Jun	Mixedwoods	18 287240 5094860	Wetland	
DV1	DV 18 2750 51000	19-Jun	Mixedwoods	18 277040 5101504	7111	Pw
DV1	DV 18 2750 51000	19-Jun	Mixedwoods	18 276100 5101500	Wetland	
DV1	DV 18 2750 51000	19-Jun	Mixedwoods	18 279048 5101502	9313	Pw
DV4	DV 18 2750 51000	19-Jun	Mixedwoods	18 278460 5103220	8532	Pw
DV4	DV 18 2750 51000	19-Jun	Mixedwoods	18 279460 5103130	8532	Pw
SO4	SO 17 7100 50250	27-Jun	Tolerant hardwoods	17 710700 5028580	882	Po
SO4	SO 17 7100 50250	26-Jun	Tolerant hardwoods	17 711950 5028600	1985	Mh
SO3	SO 17 7100 50250	25-Jun	Tolerant hardwoods	17 713200 5027300	3275	Bw
GR3	GR 17 7250 50850	01-Jul	Mixedwoods	17 727500 5085820	7555	Po
GR3	GR 17 7250 50850	01-Jul	Mixedwoods	17 727500 5087100	7570	Po
FY3	FY 18 2900 50900	07-Jul	Mixedwoods	18 292480 5093950	2444	Pw
OJ1	OJ 17 6850 50450	11-Jul	Tolerant hardwoods	17 685680 5046635	5668	Mh

(Collected in Algonquin Provincial Park, Ontario by Peter Bush and Andrew Rees, April 29-July 11, 1997)

Appendix VI: Activity information collected on surveyed transects lines.

Transect	PWP 0/1	# of Pairs	# of Plots	Activity	Weighted Index	Index per Plot
dl1	1	1	4	1 high, 1 low	4	1.000
dl2	0	0	8	3 low	3	0.375
dl3	1	2	10	1 medium 1 low	3	0.300
dl4	0	0	12	1 high, 1 Medium, 3 low	8	0.667
dw3	1	1	7	3 medium	6	0.857
dw4	1	1	11	1 high, 4 low	7	0.636
dw5	0	0	11	1 high, 3 medium, 1 low	10	0.909
eo1	0	0	6	1 medium, 2 low	3	0.500
eo2	1	1	6	1 medium	2	0.333
eo3	1	1	4	1 nest	3	0.750
eo4	1	1	3	1 nest, 1 medium, 5 low	10	3.333
eo5	1	1	7	3 medium, 3 low	9	1.286
er1	1	1	8	1 high, 4 medium, 2 low	13	1.625
er2	1	1	4	1 low	1	0.250
er3	1	4	8	4 high, 4 medium, 5 low	25	3.125
er4	1	1	9	nest, 1 high, 3 medium	12	1.333
er5	0	0	8	1 high, 1 medium, 4 low	9	1.125
fx1	1	1	8	1 medium, 1 low	3	0.375
fx2	0	0	6	1 low	1	0.167
fx4	0	0	9		0	0.000
fy1	0	0	9	I high, 1 low	4	0.444
fy2	0	0	11	1 medium	2	0.182
fy3	1	1	9	1 roost, 1 high, 1 medium, 1 low	9	1.000
fy4	0	0	9		0	0.000
gr3	1	2	10	2 medium, 7 low	9	0.900
gr4	0	0	8	2 medium	4	0.500
jd1	0	0	6		0	0.000
jd2	0	0	7	1 medium	2	0.286
ke1	1	2	8	1 roost, 2 low	5	0.625
ke2	0	0	9	2 low	2	0.222
ke3	0	0	5		0	0.000
ke4	0	0	4	1 low	1	0.250
nl1	1	1	10	1 high, 1 low	4	0.400
nl2	1	1	7	nest, 1high, 3 medium, 2 low	14	2.000
nl5	0	0	11	1 medium, 3 low	5	0.455
nm1	1	1	6	1 high, 4 medium, 4 low	15	2.500
oj1	1	1	9	1 high, 4 medium	11	1.222
oj2	0	0	11	1 low	1	0.091
so3	1	1	6	1 medium, 2 low	4	0.667
so4	1	2	10	1 nest, 1 roost, 2 high, 3 medium	18	1.800
so5	0	0	8	1 medium, 1 low	3	0.375

Appendix VII: Each classification's habitat composition (%LAND) for all 60 study sites.

Transect	PWP	PWPHSM			D'Eon and Watt Modified		
	0/1	Nesting1			Nesting		
		Used	Preferred	Total	Used	Preferred	Total
dl1	1	21.50	54.62	76.12	54.62	20.47	75.09
dl2	0	37.37	22.12	59.49	13.55	36.92	50.47
dl3	1	28.26	41.23	69.49	37.99	28.26	66.25
dl4	0	18.29	39.43	57.72	39.43	18.29	57.72
dv1	1	40.03	0.00	40.03	0.00	40.03	40.03
dv2	0	52.69	0.00	52.69	0.00	52.69	52.69
dv3	0	70.97	0.00	70.97	0.00	70.97	70.97
dv4	1	83.38	0.00	83.38	0.00	83.38	83.38
dw1	1	66.86	0.00	66.86	0.00	66.86	66.86
dw2	1	78.77	0.00	78.77	0.00	78.77	78.77
dw3	1	79.13	0.00	79.13	0.00	79.13	79.13
dw4	1	87.74	2.09	89.83	2.09	87.74	89.83
dw5	0	74.21	12.31	86.52	12.31	74.21	86.52
ed1	0	0.00	29.21	29.21	27.61	0.00	27.61
ed2	0	0.00	54.78	54.78	45.91	0.00	45.91
ed3	1	0.31	67.10	67.41	50.22	0.31	50.53
ed4	0	0.72	87.43	88.15	84.39	0.00	84.39
ed5	0	1.02	35.46	36.48	26.80	0.00	26.80
eo1	0	30.09	0.00	30.09	0.00	30.09	30.09
eo2	1	23.98	0.05	24.03	0.05	23.98	24.03
eo3	1	34.49	0.71	35.20	0.71	34.39	35.10
eo4	1	47.26	0.00	47.26	0.00	39.77	39.77
eo5	1	53.54	0.00	53.54	0.00	50.12	50.12
er1	1	53.49	0.00	53.49	0.00	53.49	53.49
er2	1	52.46	0.00	52.46	0.00	52.46	52.46
er3	1	56.03	0.00	56.03	0.00	51.56	51.56
er4	1	73.52	2.41	75.93	2.41	73.45	75.86
er5	0	74.85	1.23	76.08	1.23	74.85	76.08
fx1	1	70.75	0.00	70.75	0.00	63.22	63.22
fx2	0	79.35	0.00	79.35	0.00	74.76	74.76
fx3	1	54.04	0.56	54.60	0.56	54.04	54.60
fx4	0	41.69	3.49	45.18	3.49	41.69	45.18
fx5	0	42.02	0.10	42.12	0.10	42.02	42.12
fy1	0	44.89	4.62	49.51	4.62	44.89	49.51
fy2	0	71.19	0.00	71.19	0.00	70.51	70.51
fy3	1	75.13	0.00	75.13	0.00	74.19	74.19
fy4	0	65.78	1.29	67.07	1.29	65.78	67.07
gr3	1	90.46	1.78	92.24	1.78	90.46	92.24
gr4	0	71.73	1.29	73.02	1.29	69.25	70.54
jd1	0	2.63	71.17	73.80	68.91	2.63	71.54
jd2	0	5.86	65.34	71.20	61.37	5.86	67.23

Appendix VII: Each classification's habitat composition (%LAND) for all
60 study sites (Continued).

Transect	PWP	PWPHSM			D'Eon and Watt Modified		
	0/1	Nesting1			Nesting		
		Used	Preferred	Total	Used	Preferred	Total
ke1	1	0.00	74.83	74.83	69.49	0.00	69.49
ke2	0	0.94	71.25	72.19	67.92	0.00	67.92
ke3	0	0.00	55.27	55.27	48.63	0.00	48.63
ke4	0	0.00	51.22	51.22	50.88	0.00	50.88
nl1	1	27.48	43.85	71.33	43.85	27.48	71.33
nl2	1	14.22	54.03	68.25	50.66	14.22	64.88
nl3	0	0.00	67.43	67.43	57.69	0.00	57.69
nl4	0	21.60	35.74	57.34	32.40	21.60	54.00
nl5	0	16.61	39.46	56.07	36.40	16.61	53.01
nm1	1	16.84	13.23	30.07	13.23	16.84	30.07
nm2	0	20.95	25.83	46.78	25.83	20.95	46.78
nm3	0	11.05	46.08	57.13	44.37	10.24	54.61
nm4	0	0.49	73.55	74.04	68.59	0.49	69.08
nm5	0	6.53	73.85	80.38	63.74	6.53	70.27
oj1	1	0.00	74.47	74.47	63.10	0.00	63.10
oj2	0	3.26	81.46	84.72	76.47	3.26	79.73
so3	1	26.84	39.08	65.92	37.81	26.84	64.65
so4	1	31.40	35.18	66.58	30.46	31.40	61.86
so5	0	9.33	56.90	66.23	50.85	9.33	60.18

Appendix VII: Each classification's habitat composition (%LAND) for all 60 study sites (Continued).

Transect	PWP 0/1	PWPHSM Nesting2 Used	Preferred	Total	PWPHSM Nesting3 Used	Preferred	Total
dl1	1	51.05	27.88	78.93	76.88	2.05	78.93
dl2	0	13.53	45.95	59.48	38.14	21.34	59.48
dl3	1	37.99	31.51	69.50	53.74	15.75	69.49
dl4	0	39.43	18.29	57.72	51.83	5.88	57.71
dv1	1	0.00	40.03	40.03	25.41	14.61	40.02
dv2	0	0.00	52.69	52.69	32.13	20.55	52.68
dv3	0	0.00	70.97	70.97	35.44	35.53	70.97
dv4	1	0.00	83.38	83.38	16.20	67.18	83.38
dw1	1	0.00	66.86	66.86	2.97	63.89	66.86
dw2	1	0.00	78.77	78.77	37.04	41.73	78.77
dw3	1	0.00	79.13	79.13	31.22	47.91	79.13
dw4	1	2.09	87.74	89.83	10.38	79.44	89.82
dw5	0	12.31	74.21	86.52	37.57	48.94	86.51
ed1	0	28.57	0.64	29.21	29.21	0.00	29.21
ed2	0	47.05	7.73	54.78	54.78	0.00	54.78
ed3	1	60.38	7.03	67.41	67.41	0.00	67.41
ed4	0	60.36	27.79	88.15	88.15	0.00	88.15
ed5	0	29.14	7.35	36.49	36.49	0.00	36.49
eo1	0	0.00	30.09	30.09	12.08	18.01	30.09
eo2	1	0.00	24.03	24.03	15.15	8.87	24.02
eo3	1	0.00	35.20	35.20	9.54	25.66	35.20
eo4	1	0.00	47.26	47.26	21.90	25.37	47.27
eo5	1	0.00	53.54	53.54	25.45	28.09	53.54
er1	1	0.00	53.49	53.49	28.60	24.88	53.48
er2	1	0.00	52.46	52.46	33.63	18.84	52.47
er3	1	0.00	56.03	56.03	28.67	27.36	56.03
er4	1	2.41	73.52	75.93	28.08	47.84	75.92
er5	0	1.23	74.85	76.08	23.93	52.14	76.07
fx1	1	0.00	70.75	70.75	25.88	44.87	70.75
fx2	0	0.00	79.35	79.35	41.58	37.77	79.35
fx3	1	0.56	54.04	54.60	16.17	38.43	54.60
fx4	0	3.49	41.69	45.18	16.05	29.12	45.17
fx5	0	0.00	42.12	42.12	18.27	23.85	42.12
fy1	0	0.00	49.51	49.51	25.35	24.15	49.50
fy2	0	0.00	71.19	71.19	22.24	48.95	71.19
fy3	1	0.00	75.13	75.13	28.32	46.81	75.13
fy4	0	0.00	67.07	67.07	27.31	39.76	67.07
gr3	1	0.00	92.24	92.24	40.72	51.51	92.23
gr4	0	0.00	73.02	73.02	33.08	39.93	73.01
jd1	0	66.55	7.25	73.80	73.80	0.00	73.80
jd2	0	59.41	11.79	71.20	71.20	0.00	71.20

Appendix VII: Each classification's habitat composition (%LAND) for all 60 study sites (Continued).

Transect	PWP	PWPHSM			PWPHSM		
	0/1	Nesting2			Nesting3		
		Used	Preferred	Total	Used	Preferred	Total
ke1	1	69.91	4.99	74.90	74.83	0.00	74.83
ke2	0	71.25	0.94	72.19	71.25	0.94	72.19
ke3	0	50.61	4.80	55.41	55.27	0.00	55.27
ke4	0	50.89	0.35	51.24	51.22	0.00	51.22
nl1	1	40.10	31.23	71.33	71.12	0.21	71.33
nl2	1	44.46	23.79	68.25	68.25	0.00	68.25
nl3	0	48.03	19.40	67.43	67.43	0.00	67.43
nl4	0	15.57	41.77	57.34	50.70	6.64	57.34
nl5	0	12.89	43.18	56.07	42.72	13.35	56.07
nm1	1	12.49	17.58	30.07	23.95	6.12	30.07
nm2	0	23.05	23.73	46.78	39.96	6.82	46.78
nm3	0	30.36	26.77	57.13	50.71	6.42	57.13
nm4	0	35.02	51.26	86.28	86.27	0.01	86.28
nm5	0	43.88	36.50	80.38	79.38	1.00	80.38
oj1	1	72.61	1.86	74.47	74.47	0.00	74.47
oj2	0	75.16	9.57	84.73	84.72	0.00	84.72
so3	1	20.90	45.01	65.91	53.07	12.85	65.92
so4	1	24.32	42.26	66.58	58.82	7.76	66.58
so5	0	25.34	40.89	66.23	66.15	0.07	66.22

Appendix VII: Each classification's habitat composition (%LAND) for all 60 study sites (Continued).

Transect	PWP 0/1	PWPHSM Nesting4 Used	Preferred	Total	PWPHSM Feeding Used	Preferred	Total
dl1	1	61.10	24.05	85.15	54.62	24.31	78.93
dl2	0	30.40	51.35	81.75	22.12	41.76	63.88
dl3	1	47.10	32.28	79.38	41.23	37.01	78.24
dl4	0	40.70	18.88	59.58	46.62	38.18	84.80
dv1	1	0.00	40.54	40.54	31.00	44.07	75.07
dv2	0	0.00	53.76	53.76	10.43	54.41	64.84
dv3	0	0.00	71.36	71.36	1.96	71.65	73.61
dv4	1	0.00	93.52	93.52	0.00	83.38	83.38
dw1	1	0.00	67.67	67.67	13.03	71.89	84.92
dw2	1	0.00	81.62	81.62	1.45	84.48	85.93
dw3	1	0.00	88.61	88.61	0.00	83.02	83.02
dw4	1	2.16	90.66	92.82	2.09	87.74	89.83
dw5	0	12.99	78.33	91.32	12.31	74.21	86.52
ed1	0	41.27	0.00	41.27	29.49	0.00	29.49
ed2	0	91.38	0.00	91.38	54.78	0.00	54.78
ed3	1	90.74	0.42	91.16	67.10	0.31	67.41
ed4	0	92.27	0.76	93.03	89.21	2.61	91.82
ed5	0	48.99	1.41	50.40	35.96	17.87	53.83
eo1	0	0.00	30.54	30.54	1.65	30.09	31.74
eo2	1	0.05	27.02	27.07	0.44	23.98	24.42
eo3	1	0.74	35.91	36.65	0.71	34.49	35.20
eo4	1	0.00	49.46	49.46	0.00	47.26	47.26
eo5	1	0.00	55.72	55.72	1.46	53.54	55.00
er1	1	0.00	70.68	70.68	13.13	54.76	67.89
er2	1	0.00	62.72	62.72	9.47	55.36	64.83
er3	1	0.00	66.17	66.17	13.64	56.03	69.67
er4	1	2.60	79.49	82.09	15.59	73.52	89.11
er5	0	1.30	79.16	80.46	18.05	75.38	93.43
fx1	1	0.00	72.80	72.80	0.00	75.95	75.95
fx2	0	0.00	80.21	80.21	0.00	79.79	79.79
fx3	1	0.59	56.75	57.34	2.09	56.12	58.21
fx4	0	3.50	41.90	45.40	6.89	54.06	60.95
fx5	0	0.10	42.89	42.99	9.73	44.48	54.21
fy1	0	4.86	47.22	52.08	9.26	47.53	56.79
fy2	0	0.00	71.65	71.65	3.10	73.60	76.70
fy3	1	0.00	75.77	75.77	0.00	75.13	75.13
fy4	0	1.41	71.76	73.17	3.85	65.78	69.63
gr3	1	1.81	91.95	93.76	2.74	92.26	95.00
gr4	0	1.31	72.77	74.08	7.95	73.77	81.72
jd1	0	71.98	2.66	74.64	71.69	8.94	80.63
jd2	0	65.81	5.91	71.72	71.15	5.86	77.01

Appendix VII: Each classification's habitat composition (%LAND) for all 60 study sites (Continued).

Transect	PWP	PWPHSM			PWPHSM		
	0/1	Nesting4			Feeding		
		Used	Preferred	Total	Used	Preferred	Total
ke1	1	82.65	0.00	82.65	74.96	0.00	74.96
ke2	0	71.55	0.94	72.49	75.77	1.99	77.76
ke3	0	56.86	0.00	56.86	65.20	8.30	73.50
ke4	0	66.95	0.00	66.95	54.98	9.13	64.11
nl1	1	48.99	30.70	79.69	46.99	27.48	74.47
nl2	1	63.96	16.84	80.80	56.06	18.72	74.78
nl3	0	80.40	0.00	80.40	68.73	8.03	76.76
nl4	0	37.00	22.36	59.36	43.41	37.23	80.64
nl5	0	42.31	17.81	60.12	49.90	32.42	82.32
nm1	1	13.69	17.42	31.11	13.23	68.33	81.56
nm2	0	27.27	22.11	49.38	25.98	51.84	77.82
nm3	0	52.57	12.61	65.18	48.72	34.59	83.31
nm4	0	80.80	0.54	81.34	73.55	12.73	86.28
nm5	0	75.39	6.67	82.06	74.16	13.78	87.94
oj1	1	85.41	0.00	85.41	74.47	0.93	75.40
oj2	0	87.19	3.49	90.68	81.46	3.26	84.72
so3	1	39.43	27.07	66.50	41.34	40.72	82.06
so4	1	35.85	31.99	67.84	40.95	43.35	84.30
so5	0	66.73	10.94	77.67	67.23	10.35	77.58

Appendix VIII: Class-level variables (FRAGSTATS) in predicting the presence of pileated woodpeckers.

Variable	Log Likelihood-ratio	Significance	Correlation with with %LAND
CAD	9.8738	0.0017	0.7755
NCA	9.3964	0.0022	0.7787
LPI	7.7820	0.0053	0.9089
%LAND	6.7303	0.0095	1.0000
CA	6.0383	0.0140	0.9945
TCAI	5.1501	0.0232	0.9375
C%LAND	4.9144	0.0266	0.9507
TCA	4.4486	0.0349	0.9487
ED	4.2258	0.0398	0.7298
AWMSI	3.8057	0.0511	0.5075
TE	3.5288	0.0603	0.7171
LSI	3.3037	0.0691	0.7187
MPS	3.0845	0.0790	0.8077
IJI	2.6538	0.1033	0.4217
MCA1	2.0035	0.1569	0.7894
MNN	1.8798	0.1704	0.2424
MSI	1.7458	0.1864	0.4526
MCA2	1.7347	0.1878	0.6119
PD	1.5855	0.2080	0.5594
MCAI	1.5275	0.2165	0.8298
AWMPFD	1.2778	0.2583	0.4562
NP	1.2030	0.2727	0.5522
DLFD	1.1404	0.2856	0.4920
MPFD	1.1173	0.2905	0.4459
TA	0.5825	0.4453	0.4695

Appendix IX: Landscape-level variables (FRAGSTATS) in predicting the presence of pileated woodpeckers.

Variable	Log-Likelihood-ratio	Significance
PR	2.1875	0.1391
PRD	2.1048	0.1468
PD	1.3649	0.2427
NP	0.9759	0.3232
MSI	0.9365	0.3332
LPI	0.8715	0.3505
SHDI	0.862	0.3532
SIDI	0.7167	0.3972
IJI	0.706	0.4008
MSIDI	0.506	0.4769
MPFD	0.4997	0.4796
DFLD	0.4807	0.4881
ED	0.3707	0.5426
TE	0.363	0.5468
TCA	0.283	0.5948
TCAI	0.2053	0.6504
MPS	0.1711	0.6791
MCA2	0.1465	0.7019
MCAI	0.1288	0.7197
LSI	0.1275	0.721
SIEI	0.0882	0.7665
AWMSI	0.057	0.8112
MCA1	0.015	0.9025
TA	0.0121	0.9126
MNN	0.0097	0.9216
CONTAG	0.0089	0.9247
MSIEI	0.0006	0.981
NCA	0.0004	0.9831
AWMPFD	0	0.9952
CAD	0	0.9983
SHEI	0	0.9987

Appendix X: Selected class-level FRAGSTATS for 60 study sites.

Transcect	PWP	CA	TA	%LAND	LPI	NP	ED	C%LAND	TCA	NCA	CAD
dv4	1	417	446	94	49	11	39	38	168	11	2.5
gr3	1	452	492	92	59	7	34	50	245	9	1.8
dw4	1	439	484	91	86	6	36	50	243	9	1.9
dw3	1	396	447	89	43	10	33	37	166	9	2.0
dw2	1	394	483	82	62	4	52	30	147	11	2.3
fx2	0	397	495	80	28	6	55	38	188	6	1.2
er4	1	368	462	79	73	5	25	49	229	2	0.4
er5	0	374	473	79	42	5	32	44	208	4	0.9
dw5	0	371	474	78	41	3	45	37	176	7	1.5
fy3	1	376	496	76	35	8	61	31	155	11	2.2
fx1	1	354	486	73	37	11	67	23	113	13	2.7
gr4	0	359	493	73	45	9	61	27	134	13	2.6
fy4	0	329	458	72	30	11	58	26	119	13	2.8
fy2	0	356	497	72	36	13	68	26	129	8	1.6
dv3	0	355	497	71	58	9	60	33	164	7	1.4
er1	1	267	378	71	47	8	35	37	140	7	1.9
dw1	1	334	494	68	33	7	52	27	134	10	2.0
er3	1	280	423	66	45	11	49	30	125	8	1.9
er2	1	262	418	63	28	7	45	23	98	8	1.9
fx3	1	273	486	56	25	14	65	16	79	10	2.1
eo5	1	268	480	56	26	7	50	22	105	9	1.9
dv2	0	263	490	54	36	18	73	16	80	7	1.4
dl2	0	187	364	51	30	4	40	20	73	8	2.2
eo4	1	236	478	49	22	8	42	19	91	8	1.7
fy1	0	224	475	47	11	18	61	11	50	9	1.9
fx5	0	210	490	43	18	12	43	14	67	7	1.4
fx4	0	208	497	42	20	10	42	13	67	9	1.8
dv1	1	200	494	41	11	12	63	9	45	9	1.8
eo3	1	172	480	36	20	11	40	11	55	5	1.0
dl3	1	141	438	32	32	4	33	9	38	7	1.6
so4	1	157	491	32	17	9	42	9	43	7	1.4
nl1	1	137	448	31	21	5	61	3	13	7	1.6
eo1	0	150	493	31	13	7	25	10	49	5	1.0
so3	1	134	496	27	10	6	42	4	20	7	1.4
eo2	1	120	444	27	18	7	41	4	18	5	1.1
dl1	1	108	447	24	12	4	37	3	16	7	1.6
nl4	0	108	483	22	9	6	31	6	27	5	1.0
nm2	0	105	474	22	5	10	53	0	2	7	1.5
dl4	0	91	484	19	18	3	22	5	23	3	0.6
nl5	0	83	466	18	11	5	31	2	10	4	0.9
nm1	1	84	483	17	8	10	37	0	2	10	2.1

Appendix X: Selected class-level FRAGSTATS for 60 study sites (Continued).

Transect	PWP	CA	TA	%LAND	LPI	NP	ED	C%LAND	TCA	NCA	CAD
nl2	1	71	422	17	10	5	32	2	7	7	1.7
nm3	0	55	438	13	4	8	27	0	1	5	1.1
so5	0	47	426	11	3	8	18	1	3	3	0.7
nm5	0	33	490	7	3	5	12	1	3	2	0.4
jd2	0	29	496	6	3	4	19	0	1	1	0.2
oj2	0	16	467	3	3	4	10	0	0	2	0.4
jd1	0	13	494	3	2	3	9	0	0	0	0.0
ed5	0	5	362	1	1	1	3	0	0	1	0.3
ke2	0	5	500	1	1	1	4	0	0	0	0.0
ed4	0	4	474	1	1	1	1	0	0	0	0.0
nm4	0	2	455	1	1	3	2	0	0	0	0.0
ed3	1	2	370	0	0	1	1	0	0	0	0.0
ed1	0	0	354	0	0	0	0	0	0	0	0.0
ed2	0	0	300	0	0	0	0	0	0	0	0.0
ke1	1	0	455	0	0	0	0	0	0	0	0.0
ke3	0	0	489	0	0	0	0	0	0	0	0.0
ke4	0	0	384	0	0	0	0	0	0	0	0.0
nl3	0	0	419	0	0	0	0	0	0	0	0.0
oj1	1	0	436	0	0	0	0	0	0	0	0.0

Note: Sorted on %LAND