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THE ROLE OF PATCH SIZE,
ISOLATION, AND FOREST
CONDITION ON PILEATED
WOODPECKER OCCUPANCY IN
SOUTHWESTERN OHIO

A thesis submitted in partial
fulfillment of the requirements for
the degree of Master of Science

By

ANNA LYNN KAMNYEV
B.S., Wright State University, 2010

2013
Wright State University

WRIGHT STATE UNIVERSITY
GRADUATE SCHOOL

AUGUST 19TH, 2013

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Anna Lynn Kamnyev ENTITLED The Role of Patch Size, Isolation, and Forest Condition on Pileated Woodpecker Occupancy in Southwestern Ohio BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science.

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ABSTRACT

Kamnyev, Anna Lynn. M.S. Department of Biological Sciences, Wright State University, 2013. The role of patch size, isolation, and forest condition in Pileated Woodpecker occupancy in southwestern Ohio.

No studies of Pileated Woodpeckers (*Dryocopus pileatus*) have been done in southwestern Ohio where agriculture is prevalent and forests are significantly fragmented. The objective of this study was to determine the forest fragment size, isolation, and structure preferred by *D. pileatus* for breeding habitat.

I sampled 37 forest fragments varying in size and isolation for *D. pileatus* cavities and forest characteristics and used LiDAR remote sensing data to analyze forest complexity. I hypothesized that *D. pileatus* relative abundance would increase with forest fragment size, density of dead trees, and forest vertical complexity but decrease with isolation.

The hypotheses that size and isolation of a forest fragment influence *D. pileatus* habitat choices were rejected. However, snag density, directly relating food and shelter requirements for *D. pileatus*, showed the predicted association with woodpecker activity as did forest height and forest complexity.

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Chapter 1: The effects of patch size, isolation, and forest condition on Pileated Woodpecker occupancy in southwest Ohio

Introduction

In southwestern Ohio, agriculture dominates the landscape leaving old growth forests as scarce entities, few and far between. Old growth forests are ecologically important for many woodland dwelling specialists such as the Wood Thrush (*Hylocichla mustelina*), the Ovenbird (*Seiurus aurocapilla*), or the Northern Parula (*Setophaga Americana*). Mature trees are tall and provide protection from adverse weather conditions and predators by averting terrestrial threats. Additionally, old growth forests provide old trees experiencing senescence, eventually leading to softer, penetrable wood, a valuable asset for woodpeckers. The softer wood that results from the decaying process of the dead tree allows for easier excavation and access by woodpeckers to their prey, small invertebrates.

As one of the largest Primary Cavity Excavators (PCE), the Pileated Woodpecker (*Dryocopus pileatus*) may serve as an ecosystem engineer and a keystone species, providing Secondary Cavity Users (SCU) (i.e. bats, birds, and insects) with a place for shelter for nesting, roosting, and breeding (Bonar, 2000; Adkins Geise and Cuthbert, 2003; Thomas et al., 1979). Although excavation sites made by the Pileated Woodpecker are important for smaller cavity using species, some cavities are large enough to

accommodate ducks, squirrels, and owls that cannot fit into cavities made by other PCE (Bonar, 2000). Research within the Foothills Model Forest of Alberta, Canada, found that of 878 visually inspected Pileated Woodpecker cavities, 67.2% showed signs of use by other species and that cavity use by SCU peaked in May, the primary month of reproduction for many species (Bonar, 2000), indicating that Pileated Woodpecker cavities are especially useful during the breeding season. In addition to the cavities *D. pileatus* provides to the SCU community, it also assists in the breakdown of decomposing trees, aiding in natural forest turnover.

Pileated Woodpeckers have been shown typically to prey upon carpenter ants, which colonize downed or standing dead wood (Bull, 1987; Sanders, 1970). Carpenter ants are commonly found in large old, dying, or dead trees that are greater than 30 cm diameter and in live trees that are greater than 20 cm in diameter (Sanders, 1970). Generally, ant abundance is directly related to tree size. A larger tree can potentially retain more water, eventually increasing the amount of deadwood, allowing for the accommodation of more woodborers (Bull, 1987, Raley and Aubry, 2006), therefore making snags a potential buffet hot spot. A study on the Olympic Peninsula of northwestern Washington revealed that most plots (0.4 ha) containing more than three snags revealed signs of foraging by *D. pileatus*, whereas plots containing less than three snags generally had no signs of foraging (Raley and Aubry, 2006). Aside from using these decaying structures for foraging, *D. pileatus* also heavily uses them for the excavation of roosting and nesting cavities (Bull et al., 2007; Raley and Aubry, 2006; Lemaitre and Villard, 2005; Renken and Wiggers, 1989).

Some species of wildlife are adapting well to human development such as deforestation or forest fragmentation. Many species have been assigned a versatility score, which considers their preference for the number of plant communities and successional stages used for feeding and reproducing (Thomas et al., 1979). The Peregrine Falcon (*Falco peregrines*), Turkey Vulture (*Cathartes aura*), and American Robin (*Turdus migratorius*) are among many birds, mammals, and reptiles that have revealed a substantially high versatility rating (30-42), acclimatizing to industrialization. However, Pileated Woodpeckers exist on the lower end of the spectrum (10) (Thomas et al., 1979) requiring large forest fragments (>100 ha) (Morrison and Chapman, 2005; Thomas et al., 1979; Hoyt, 1957) that encompass large older or dead trees for foraging and excavating (Remm et al., 2006; Hartwig et al. 2004; Flemming et al., 1999; Bull, 1987). Large, older forests rarely accompany the agricultural and urban landscapes in southwestern Ohio, but Pileated Woodpeckers still maintain healthy populations and are a common suburban bird of Dayton raising the question, whether their habitat requirements in Ohio match the ones reported from western states.

Although conservation efforts are increasing as environmental awareness becomes more prominent, forest rescue attempts are still in their infancy, reviving former farmlands into successional forest stands or maintaining the old re-growth forest patches that conserve over half of Ohio's recorded birds (Means and Medley, 2010). In an attempt to maintain the forest aesthetically pleasing and prevent potential injuries from falling trees, forest managers may be under pressure to remove dead trees and snags. However, as seen above, many species rely on these structures for their home and their persistence, including *D. pileatus*.

Few studies of *D. pileatus* have been done in the eastern United States (Morrison and Chapman, 2005; Kilham, 1976; Conner et al., 1975; Renken and Wiggers, 1989) and none in Ohio, more specifically, southwestern Ohio where agriculture is prevalent and forests are significantly fragmented. The flight of *D. pileatus* is relatively slow and erratic and is, therefore, a critical factor in their habitat preference since they are more vulnerable to predation when outside the confines of a dense canopy (Raley and Aubry, 2006). As a sluggish flier, *D. pileatus* is able to use the forest canopy to its advantage when pursued by a predator such as a Cooper's Hawk (*Accipiter cooperii*), which is built for speed. Nevertheless, the species persists and is commonly seen in smaller woodlots and even residential neighborhoods containing highly developed areas with a low abundance of trees bringing up the question, whether habitat in southwestern Ohio differs from other areas.

Although *D. pileatus* was shown to have a low versatility rating in 1979 and is expected to require large forest fragments, only one study compared woodpeckers in managed urban areas to rural, less human impacted areas (Morrison and Chapman, 2005). After three decades of continuous human impact, further research quantifying Pileated Woodpecker cavities in a range of stand sizes and degrees of isolation is needed to determine this woodpecker's versatility. Therefore, the objective of this study was to determine the forest fragment size, isolation, and structure (specifically, snag density) preferred by Pileated Woodpeckers for breeding habitat in southwestern Ohio. I hypothesize that *D. pileatus* relative abundance increases with forest fragment size and density of large old, moribund, or dead trees, but decreases with isolation. The focus of the study is on these three factors. In addition, basal area and the percent of open water

within and surrounding the site will be included as potential exploratory covariates for *D. pileatus* relative abundance.

Methods

Data collection and preparation

Determining *D. pileatus* occurrence

This study used a non-traditional route for determining avian relative abundance. As one of the largest PCE, the Pileated Woodpecker's past or current presence is easily recognizable by its large foraging, roosting, and nesting cavities. Therefore, the relative abundance of *D. pileatus* was determined by counting excavated cavities. Excavated cavities provide an opportunity to collect much more data than direct counts.

Additionally, cavities are less vulnerable to annual variability, which may often affect the interpretation of direct counts. To avoid confusion with cavities made by Hairy Woodpeckers (*Picoides villosus*) and Red-bellied Woodpeckers (*Melanerpes carolinus*), only excavations at least 5cm wide x 5cm long x 5cm deep (Lemaitre and Andre, 2005) were recorded. Cavity counts were collected within 25 x 50 m plots and averaged within 37 forest fragments ("sites") (**Appendix A**) varying in size (1.10 - 856.63 ha) and isolation (Figure 1.1). All sites consisted mainly of deciduous hardwoods including but not limited to Maples (*Acer* spp.), Oaks (*Quercus* spp.), Ashes (*Fraxinus* spp.), Hickories (*Carya* spp.), Elms (*Ulmus* spp.), American Beeches (*Fagus grandifolia*), Black Walnuts (*Juglans nigra*), and Black Cherries (*Prunus serotina*).

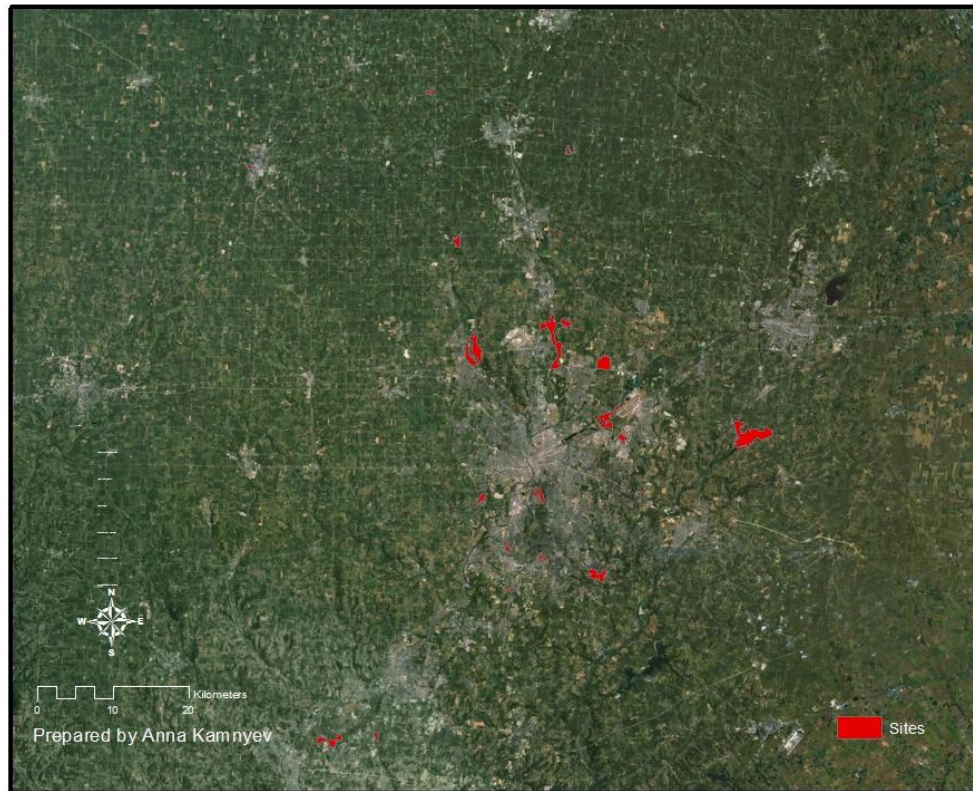


Figure 1.1 Site locations for *D. pileatus* cavity density data collection. Some sites are not visible due to their small size.

The locations of the plots within the site were established on Google Earth using a stratified random approach. Stratification was along forest types within a site determined by degree of canopy homogeneity in aerial images as proxy for site age, composition, and condition. The stratified-randomly chosen coordinate pair served initially as the southwest corner of a plot which was rotated according to a bearing established by randomly selecting a number between 0 and 360 (Figure 1.2b).

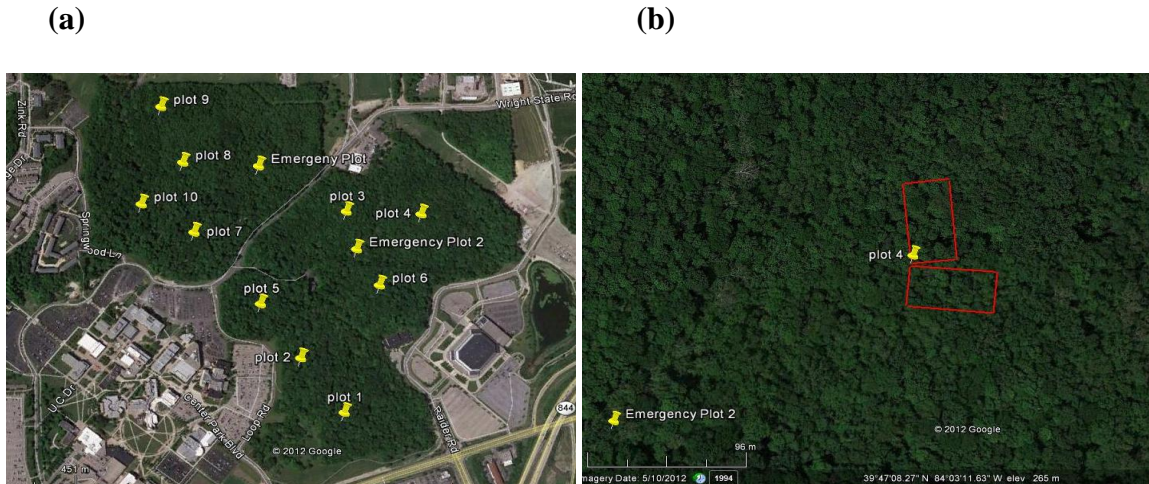


Figure 1.2 (a) Plot corners chosen in a stratified random fashion at the Wright State University site. (b) WSU plot 4 is rotated according to a bearing containing a random number selected from 0 to 36

Forest Composition

Forest structure was collected at 18 sites and assessed based on the basal area and tree density at each site of trees greater than 20 cm DBH, both of which were determined using the Point-Centered Quarter Method (PCQM) (Mitchell, 2007) within each rectangular plot at 25 meter intervals, along a 50 meter transect (i.e. sampling 3 times per plot – beginning, middle, and end).

To evaluate if snag density related to Pileated Woodpecker occurrence, I quantified the number of snags greater than 20 cm DBH and greater than 1 m tall (Raley and Aubry, 2006). Snag and cavity densities per ha were averaged from cavity counts taken at plot locations throughout each study site, divided by 1250 (area of each plot in m²) and multiplied by 10,000 m² to obtain hectare densities.

Site Size, Isolation, and Matrix

I processed stand size, isolation and matrix using ArcGIS10. Stand size was determined by creating a polygon shapefile containing all sites, each of which was traced around the perimeter to calculate the area within (hectares). Stand isolation and matrix were evaluated based on the percent of forested landuse within a 1 km buffer surrounding the boundaries of each site. I obtained the landuse raster file from the National Land Cover Database (NLCD) products that are offered by the U.S. Geological Survey and created under a cooperative project conducted by the Multi-Resolution Land Characteristics Consortium (Fry et al., 2011). The NLCD raster file was projected under North American Datum 1983 UTM Zone 17N. Areas for landuse classes consisting of forested regions (**Appendix B**) were combined into the explanatory variable Percent Forested and divided by the total area of each buffered site for percentages. Further, the distance from the stand to the closest forested region greater than 45 ha (slightly below the lower end of the suggested territory range of *D. pileatus*; Renken and Wiggers, 1989) was determined as a covariate for stand isolation using the Nearest Neighbor within the Spatial Statistics extension in ArcGIS10. The percent of open water was also determined at each stand containing the buffer using the NLCD raster file. The explanatory variables for this study were listed under four categories: Resource Availability, Forest Composition, Matrix Evaluation, and the Degree of Fragmentation/Isolation (Table 1.1).

Table 1.1 Description of the explanatory variables.

Variable Name	Category	Description
Density of Snags	Resource Availability	Density of resources available to <i>D. pileatus</i> extrapolated from snag counts taken from sample plot locations (1250 square meters), divided by 1250 throughout each study site and multiplied by 10,000 square meters to obtain hectare densities.
Site Size	Resource Availability	The size of each site in hectares.
Basal Area	Forest Structure	The basal area of trees greater than 20 cm DBH at each site from PCQM. It has been previously shown that trees of this size are necessary for foraging and also since Pileated Woodpeckers have been shown to forage near their roosting and nesting cavities (Hartwig et al., 2004).
Tree Density	Forest Structure	The tree density at each site per ha.
Percent Open Water	Matrix Evaluation	All areas of open water with < %25 cover of vegetation or soil.
Percent Forested	Degree of Fragmentation/Isolation	Percentage of the landscape including areas dominated by deciduous and evergreen trees that are generally greater than 5 meters tall and greater than 20 % of total vegetation cover. Also includes the areas dominated by woody wetlands where forest or shrubland vegetation accounts for greater than 20% vegetative cover.
Distance to Forested Region Greater than 45 ha	Degree of Fragmentation/Isolation	Distance in the landscape from the stand edge to the nearest forested region large enough to potentially encompass a breeding pair measured in meters.

Statistical Methods

Confirmatory Research

Three explanatory variables, snag density, site size, and site isolation, were checked against the dependent variable Pileated Woodpecker cavity densities, to evaluate the

original hypothesis. Collinearity was tested and present between the Degree of Fragmentation/Isolation variables (Table 1.1) and therefore only the distance to the nearest forested region greater than 45 ha was used as an explanatory variable for isolation. Inspections of residuals in a regular regression showed a non-random pattern, indicating a violation of this model, therefore rejecting its use in these analyses. Since my experimental units (plots) were within sites, Generalized Linear Mixed Models (GLMM) with a Poisson link and with site as a random factor were implemented to avoid pseudo replication. Statistics were calculated using the statistical programming environment, R and the lme4 library for the computation of mixed models (R Core Team, 2012). Statistical tests were deemed significant for $p < 0.05$.

Exploratory Research

Collinearity was tested and present between basal area and tree density. Therefore, correlation tests and mixed models were executed only for log-transformed basal areas to observe any potential correlations between this aspect of forest composition and *D. pileatus* cavity occurrence.

Provided that water could increase decomposition rates and provide softer wood, correlation tests and linear models were first executed to observe any potential relationships between the percent of open water and snag density at each site.

Additionally, GLMMs including the percent of open water and snag density against Pileated Woodpecker cavity density with site as a random effect were also implemented to avoid pseudo replication.

Results

Confirmatory Research

Snag density was the only explanatory variable that significantly ($P = 2.00 \text{ E}^{-16}$) correlated *D. pileatus* cavity density (Table 1.2) within a GLMM having a Poisson link and including site as a random effect. A caterpillar plot (Figure 1.3), which represents the 95% confidence interval for the coefficient for each of the sites, confirms the appropriateness of including site as a random effect in a GLMM by showing that over half of the sites do not overlap zero.

Table 1.2 Generalized Linear Mixed Model fit by the Laplace approximation for explanatory variables snag density, site size, and site isolation on *D. pileatus* cavity density.

	Estimate	Std. Error	Z value	P-value
Snag Density	0.0175	0.00107	16.463	2.00E-16**
Site Size	-0.000927	0.000591	-0.326	0.744
Site Isolation	-0.0000156	0.000011	-1.41	0.158

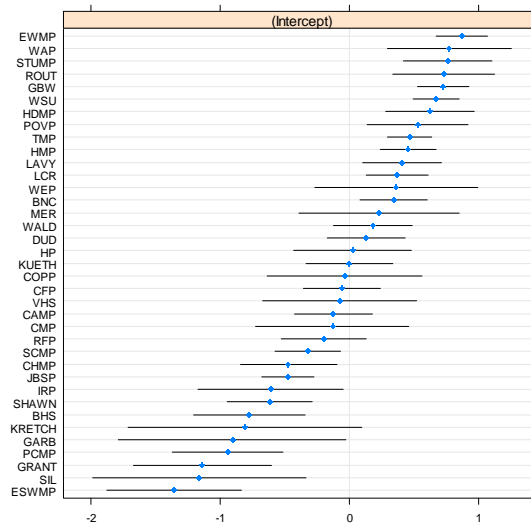


Figure 1.3 Caterpillar plot showing coefficient estimates for individual research sites and 95% confidence intervals from a General Mixed Model on Pileated Woodpecker cavity density.

Exploratory Research

Basal area was not significantly correlated with Pileated Woodpecker cavity density

(Table 1.3).

Table 1.3 Pearson's product moment correlation results between Basal Area and Pileated Woodpecker Cavity Density.

	t-value	df	correlation coefficient	P-value
Basal Area	-0.0887	145	-0.00736	0.9295

Similarly, a GLMM including snag density and site as a random affect revealed only snag density to significantly ($P = 2.00 \text{ E } -16$) affect *D. pileatus* cavity density while basal area was not (Table 1.4).

Table 1.4 Generalized Linear Mixed Model fit by the Laplace approximation for explanatory variables snag density and basal area on *D. pileatus* cavity density

	Estimate	Std. Error	Z value	P-value
Snag Density	0.0197	0.0013	15.218	2.00E-16**
Basal Area	-0.0323	0.07	-0.461	0.645

In contrast, snag density was shown to significantly correlate ($P = 0.0046$) with the percent of open water at each site (Table 1.5).

Table 1.5 Pearson's product moment correlation results between snag density and the percent of open water at each site.

	t-value	df	correlation coefficient	P-value
Percent of Open Water	2.858	255	0.176	0.0046*

However, when included in a GLMM and combined with snag density and site as a random effect, the percent of open water did not significantly affect the density of *D. pileatus* cavities (Table 1.6).

Table 1.6 Generalized Linear Mixed Model fit by the Laplace approximation for explanatory variables snag density and percent open water on *D. pileatus* cavity density.

	Estimate	Std. Error	Z value	P-value
Snag Density	0.0191	0.00107	17.891	2.00E-16*
Percent of Open Water	0.0312	0.0341	0.915	0.36

Discussion

Confirmatory Research

The majority of previous research concerning the habitat requirements of Pileated Woodpeckers was conducted in the northwestern U.S. and southwestern and eastern Canada and has found large, continuous wooded areas (> 100 ha) with large moribund or dead trees to be crucial (Morrison and Chapman, 2005; Bull and Meslow, 1977). The few studies that have been completed in the eastern and/or midwestern U.S. recognized slightly smaller woodlots (> 70 ha) containing large dying or dead trees to also be suitable as Pileated Woodpecker habitat (Kilham, 1976). No research has been done on the habitat requirements of Pileated Woodpeckers specifically in southwestern Ohio, where the landscape is dominated by agricultural fields and old forests occur mostly in small, isolated, preserved patches. My results support what previous research has found concerning the importance of snag density for Pileated Woodpecker occurrence (Bull et al., 2007; Raley and Aubry, 2006; Lemaitre and Villard, 2005; Renken and Wiggers,

1989). In all preliminary and discussed models, snag density proved to have a strong relationship with *D. pileatus* relative density suggesting that snag density plays a crucial role in habitat selection of Pileated Woodpeckers in southwestern Ohio. However, in contrast to previous studies from other areas of North America, forest size and isolation did not significantly affect *D. pileatus*' relative density in southwestern Ohio.

Previous reports concerning the habitat preferences of Pileated Woodpeckers in northwestern U.S. and along the eastern U.S. where forests are less fragmented (**Appendix C**) suggest a wooded patch size of at least 100 ha is required to be suitable habitat (Morrison and Chapman, 2005; Thomas et al., 1979; Bull and Meslow, 1977; Hoyt, 1957). Perhaps the scarcity of large forest patches in mid- to northwestern Ohio is the cause for a large gap being depicted in distributional maps (Figure 1.4). However, quite to the contrary, in this study *D. pileatus* activity was detected in the smallest forest fragment sampled, just over 1 hectare in size (**Appendix A**). Large stands of trees that contain few logs, stumps, and standing dead wood (i.e. snags) are less suitable for Pileated Woodpeckers than small, mature or old stands with an abundance of dead wood, an important resource for Pileated Woodpeckers. Although agriculture dominates western/northwestern Ohio (**Appendix C**), 10 out of 12 sites that were in immediate vicinity of the southern edge of the gap in the *D. pileatus* range map (Figure 1.4) had Pileated Woodpecker activity, all within forest stands less than 65 ha, and half of the 10 active sites were smaller than 5 ha (**Appendix A**). Supporting this finding, research on Pileated Woodpeckers in Missouri found that the territory size of these large birds decreases with the availability of log and stump volume (Renken and Wiggers, 1989). In southwestern Ohio, Pileated Woodpeckers seem to have adapted to a fragmented

landscape with more isolated woodlots that have resulted from agriculture.

Consequently, Pileated Woodpeckers may be more resilient to human development than previously thought as long as timber harvesting is abandoned or managed for retaining standing dead wood, permitting the future use of this potential keystone species.



Figure 1.4 The year-round distribution of *Dryocopus pileatus*. (Photo provided by the Cornell Lab of Ornithology (Bull and Jackson, 2011)).

Exploratory Research

Since trees, like most organisms, experience senescence, it was also important to consider if basal area significantly affects the occurrence of *D. pileatus*. Previous research in Virginia on Pileated Woodpecker nesting habitat revealed that an increase in basal area and tree density correlated with an increase in the presence of Pileated Woodpeckers since more woody substrate is available for potential excavation (Conner et al., 1975). If a forest does not provide enough standing soft-wood suitable for the creation of roosting and nesting cavities, the forest may not be able to support these large birds, which are

occasionally referred to as keystone species (Bonar, 2000; Simberloff, 1998; Remm et al., 2006). However, my results suggest that basal area is not an important habitat characteristic for Pileated Woodpeckers in southwestern Ohio, which may be due to the forest consisting mainly of hard woods relatively unsuitable for feeding and excavation before senescence. Therefore, the amount of decaying wood may be the more important factor than the abundance of all wood as expressed in basal area.

Water is well-known to cause erosion and catalyze decomposition. Forest fragments within close proximity of an open water source may thus contain softer trees or more snags than sites further away from water. Previous research has shown that Pileated Woodpeckers nest within 150 m of a water source (Conner et al., 1975; Hoyt, 1957). Consequently, it was worth exploring the percent of open water at each fragmented site and observing any potential effects it could have on *D. pileatus* density. Although there was a significant correlation between snag density and the percent of open water at each site, there was no significant relationship between the percent of open water at each site and *D. pileatus* relative abundance. While the relationship was significant, the correlation coefficient between snag density and percent of open water was relatively low (0.176) calling into question the biological significance of this relationship. Since snag density has been shown to strongly influence *D. pileatus* relative density, and the percent of open water is significantly positively correlated to snag density, it might be expected that Pileated Woodpecker relative densities would directly relate to the percent of open water within an area. However, the results showed that this was not the case which could be the result of a weak relationship between snag density and the percent of open water, as well as a large amount of nuisance variability common in ecological data.

Additionally, forests surrounding an open water source are likely older (and thus contain more snags), having been preserved for flood control or recreational purposes. Provided that Pileated Woodpeckers are able to disperse easily by flight to find water when needed, the percent of open water at a particular location is likely irrelevant to their foraging and nesting requirements in southwestern Ohio.

This study found that snags are the most crucial aspect for a forest to be suitable for Pileated Woodpeckers. Currently, Ohio is experiencing the invasion of Emerald Ash Borers, which kill off almost all ash trees and dead trees will be more abundant for years than they have been in the past. Quite possibly the increased abundance of dead trees will improve Pileated Woodpecker reproduction success since more foraging substrate and nesting sites will be available.

Conclusions

Since Pileated Woodpeckers can fly, it is reasonable to conclude that forest size, isolation, and forest structure in the form of basal area and the percent of open water are not habitat characteristics crucial to this large primary cavity excavator unless their main resource, snags, are present. Older forest stands are likely to provide the standing deadwood or trees that are vulnerable to disease and/or decomposition. Therefore, it is important for forest managers to maintain older stands, irrelevant of size or basal area, for the occupancy and use of Pileated Woodpeckers and the species that may rely on their cavities.

Chapter 2: Assessing forest vertical structure as an explanatory variable for *D. pileatus* occurrence using LiDAR

Introduction

Pileated Woodpeckers and forest complexity

Forest vertical structure and complexity are important when evaluating a habitat's suitability for a specific avian species. A variety of vegetative layers, and thus high forest complexity, provides wildlife with protection from predators, brood parasites, and adverse weather conditions (Lesak et al., 2011). The existence of a particular species may be dependent on whether there is an open understory (e.g., Ovenbirds), open midstory (e.g., Eastern Wood-pewee), or a dense amount of sub canopy foliage (e.g., Least Flycatcher) (Van Horn and Donovan, 1994; Crawford et al., 1981; Mossman and Lange, 1982). Accordingly, avian species richness has been shown to correlate with canopy and midstory height and density (Lesak et al., 2011).

Pileated Woodpeckers (*Dryocopus pileatus*) are considered a potential keystone species and ecosystem engineer because they excavate cavities and provide Secondary Cavity Users (SCUs) with shelter for roosting, resting, and nesting, aid in decomposition and nutrient cycling, and mediate insect outbreaks (Thomas et al., 2006; Adkins Geise and Cuthbert, 2003; Aubry and Raley, 2002; Bonar, 2000). *D. pileatus* occurrence is, analogously to the species previously mentioned, affected by forest vertical and horizontal complexity (Aubry and Raley, 2002). A previous study on the characteristics of Pileated Woodpecker nesting and roosting cavities in the Pacific Northwest revealed that there was a significant selection for trees greater than 27.5 meters tall and selection against trees that were less than 17.5 meters tall (Aubry and Raley, 2002). Additionally, 78% of nesting cavities were located within the canopy whereas roosting cavities were found within the canopy (58%) or below the canopy (30%). Nesting and roosting

cavities also differed in relation to nearby branches, with all nesting cavities occurring above the highest live branch and up to 35% of roosting cavities occurring below the highest live branch; however, these percentages do not consider the importance of snags to *D. pileatus* excavation sites (which contain at least 50% of cavities found for nesting and roosting) (Aubry and Raley, 2002).

The Habitat Suitability Index for Pileated Woodpeckers along with subsequent research has identified mature forest fragments as the best habitat (Bull, 2007, Savignac et al., 2000; Shroeder, 1983; Thomas et al., 1979). Mature forest fragments tend to have more senesced trees that have become vulnerable to heart-rot and insect infestations, and tend to provide taller trees better fulfilling the requirements of *D. pileatus* for roosting and nesting cavities (Aubry and Raley, 2002). Since mature forest fragments are known to encompass a greater diversity of distinct forest layers (i.e. complexity) and a higher abundance of snags (Silver et al., 2013), an important resource for Pileated Woodpeckers in the form of food and shelter (Bull et al., 2007; Raley and Aubry, 2006; Lemaitre and Villard, 2005; Renken and Wiggers, 1989), I hypothesized that *Dryocopus pileatus* relative abundance is directly related to forest complexity.

Evaluating forest complexity using LiDAR

Determining forest complexity and structure by field data collection is tedious, labor intensive and prone to observer error. Light Detection and Ranging (LiDAR) provides a method for forestry analysis without the expense of time and sampling effort put forth into field work and eliminates observer error. As a form of remote sensing through laser scanning, LiDAR can be used for the production of high resolution Digital Elevation Models (DEMs) as well as Digital Surface Models (DSMs). Light pulses released vertically from an overhead airplane or drone are reflected from objects below (buildings, tree branches, ground, etc.), transmitting an infrared signal with varying echo concentrations back to the receiver (Figure 2.1). By using a Geographic Positioning System (GPS) to determine laser positions combined with the laser range, the laser scanning angle, and the laser orientation from Inertial Gravitation Systems (INS) (Mosaic Mapping Systems Inc., 2001), LiDAR is able to record the Earth's vertical structure.

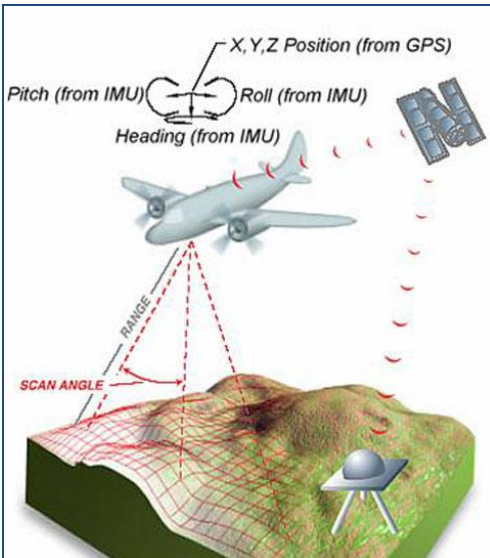


Figure 2.1 Light Detection and Ranging (LiDAR) data collection system. (Picture provided by the Ohio Department of Transportation)

LiDAR systems are becoming more commonly used for geographic 3D modeling, providing an efficient route for the development of DEMs and DSMs. Conservationists are frequently utilizing LiDAR to evaluate landscape characteristics over broad ranges for forest management decisions and biodiversity conservation (Lesak et al., 2011; Graf et al., 2009; Hinsley et al., 2006; Hyde et al., 2006; Nelson et al., 2005). The United States Geological Survey uses The Experimental Advanced Airborne Research LiDAR (EAARL) for surveying “coral reefs, nearshore benthic habitats, coastal vegetation and sandy beaches” (Figure 2.2a) (Troche, 2013). The United States Division of Agriculture (USDA) uses LiDAR for surveying terrestrial systems such as using DEMs and DSMs in oil and gas exploration, urban development, and forestry (Figure 2.2b and 2.2c). Evaluations of the accuracy of LiDAR in determining forest attributes such as stand height, basal area, and tree density compared to field collected data are promising (Hallous et al., 2006, Zimble et al., 2003; Naesset, 2002), yet still pose potential complications and drawbacks.

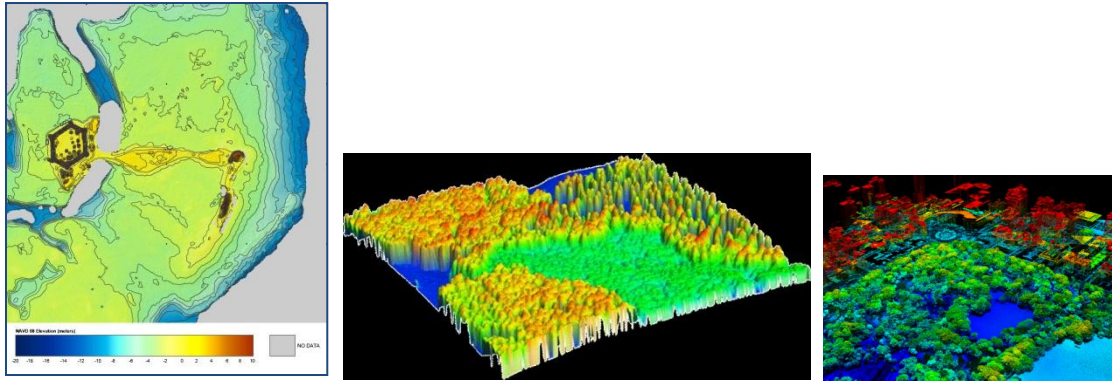


Figure 2.2 (a) Submerged Topography using EEARL (Photo provided by Troche, 2013). (b) Forestry mapping and management (Photo provided by Anderson et al., 2007). (c) Urban mapping and development (Photo provided by Rundle and Neckerman).

Due to the vast and potentially overwhelming amount of data that is received, LiDAR processing time and filtering of return data are among the most challenging aspects of its use, aside from the cost (Tattoni et al., 2012). A main concern includes the season of data collection (leaf-off versus leaf-on) since DEMs may be difficult to produce in deciduous forests during the summer when foliage is thick and the possibility of laser transmittance to the ground becomes unlikely (Hollaus, et al., 2006). Data collection throughout both seasons has been recommended for appropriate estimations of DSMs since canopy heights are likely to be more accurate in the summer and elevation (ground height) in the winter (Hollaus, et al., 2006). However, later research concerning leaf-off versus leaf-on conditions has revealed that although LiDAR data were collected during the winter when the majority of foliage was absent, reflections off of limbs and branches still provided enough valuable data to accurately assess forest structure (Hawbaker et al., 2009).

Despite some filtering problems that may be encountered during processing, LiDAR is a promising way for gaining data on fine-scale forest structure across large areas, because it has been shown to produce accurate results for many aspects of forest structure and composition (Cho et al., 2012; Lesak et al., 2011; Hawbaker et al., 2009; Hallous et al., 2006, Zimble et al., 2003; Naesset, 2002). The goal of my research was to evaluate LiDAR for its ability to determine forest height and complexity by comparing data

collected by the Ohio Statewide Imagery Program (OSIP) to data collected in the field and for its ability to explain Pileated Woodpecker habitat use.

Methods

Field data collection

I collected forest composition data across 18 sites and determined *D. pileatus* relative abundance across 37 sites (Appendix A) of varying size and isolation within southwestern - midwestern Ohio. All sites consisted mainly of deciduous hardwoods including but not limited to Maples (*Acer* spp.), Oaks (*Quercus* spp.), Ashes (*Fraxinus* spp.), Hickories (*Carya* spp.), Elms (*Ulmus* spp.), American Beeches (*Fagus grandifolia*), Black Walnuts (*Juglans nigra*), and Black Cherries (*Prunus serotina*). Terrain varied across the sites from flat agricultural areas to hilly riverines. I determined *D. pileatus* relative abundance by counting excavated cavities. To avoid confusion with cavities made by the Hairy Woodpecker (*Picoides villosus*), I considered only excavations at least 5 cm wide x 5 cm long x 5 cm deep (Lemaitre and Villard, 2005). Data collection occurred in 25 x 50 meter plots at each site (varying in number depending on site size) with forest composition sampling points at 25 meter intervals along a 50 meter transect (the length of my plot) using the Point Center Quarter Method (PCQM) for the selection of trees to measure tree height (Mitchell, 2007). I selected the location of the plots through coordinates on Google Earth using a stratified random approach. Stratification was along forest types in a fragment determined by degree of canopy homogeneity in aerial images as proxy for stand age, composition, and condition. Randomly chosen coordinates initially served as the southwest corner of a plot. I rotated each plot according to a bearing established by randomly selecting a number between 0 and 360. Data collected included tree species, basal area, and tree height. I measured tree height using a clinometer and rangefinder. Twelve trees were measured per plot in accordance with PCQM. Absolute Max Tree Heights per Site (AMTHS) were the absolute highest tree measured among all plots at a site, while Max Tree Height Averaged per Site (MTHAS) were the maximum tree heights in each plot averaged

across the site. The Standard Deviation (SDS) between plots was also calculated based on the variance of max tree height among all plots in a site.

LiDAR data and processing

LiDAR data was collected and freely provided by the Ohio Statewide Imagery Program (OSIP) in 2007. OSIP is a collaboration among several State Agencies (ODOT, ODNR) through the Ohio Geographically Referenced Information Program (OGRIP) and was originally developed to support multi-use applications including homeland security, emergency management, economic development, and the business of government (Smith, 2007). LiDAR data were in LAS1.0 format and were based upon a 5,000' x 5,000' ortho tile layout, covering the entire land area of the southern tier of Ohio (approximately 17, 832 square miles). The remote sensing data was collected with the Leica ALS50 digital LiDAR System at a flying altitude of 7,300 feet AMT with a flight speed of 170 knots. The average point spacing between LiDAR points was 7 feet. The LAS data was prepared to be processed through ArcGIS 10.0 under the Geographic Coordinate System GCS_North_American_1983_CORS and/or Projected Coordinate System NAD_1983_CORS_Stateplane_Ohio_South_FIPS_3402. LiDAR files were split into 4 classes (Table 2.1).

Table 2.1 Classes described in LiDAR Las1.0 files

Class	Short-hand	Description
1	Default	These points are what is left of the remaining points after the ground classification. These points could contain cars, buildings, parts of vegetation, and possibly ground (not consisting of bare earth surface).
2	Ground	These are bare earth points. They are classified through an automated processing as well as manual review.
5	Non-Ground	These points consist of the first and subsequent returns from the LiDAR pulse. These are points that are most likely to signify vegetation returns or point identified to not be on the ground surface.
7	Low-Point	These are points that are below ground surface. Most of them are outliers.

LAS1.0 tiles were downloaded for all 36 sites and processed using ArcGIS 10.0 under the coordinate system specified above. LAS files were converted to Multipoint shape files using the 3D Analyst Extension. Separate Multipoint shapefiles were created to indicate ground surface for DEMs (Class 2) and all returns above the ground for DSMs (Class 5) (Table 2.1). Triangulated Irregular Network (TIN) files were created using the DEM and DSM Multipoint shapefiles. Points included in the Multipoint shapefile are point height measurements, which become the nodes in a network of polygons that make up the TIN. TINs were converted to Raster files with a cell size of 7 x 7 feet, matching the average resolution of LiDAR returns, for statistical analyses. The DEM was subtracted from the DSM to obtain raster heights (aka forest heights). Lastly, forest height statistics for each site were calculated using the Zonal Statistics as Table command under the Spatial Analyst extension within site polygons. Site statistics included the minimum (MIN), maximum (MAX), range (RANGE), mean (MEAN), and standard deviation (SD) among forest heights of all cells. One site, STUMP, was excluded in analyses because LiDAR data was unavailable for the area.

Statistical analysis

LiDAR accuracy

Forest composition data was collected across 18 sites. Since tree heights measured in the field were restricted to trees greater than 20 cm DBH, field data collection in regards to average forest heights were biased to larger trees and could not be used in the evaluation of LiDAR to determine average forest heights, which considers all received pulses from the DSM. Therefore, LiDAR accuracy was assessed by comparing the LiDAR derived maximum tree height (MAX) to the field derived measures Absolute Max Tree Height per Site (AMTHS) and the Maximum Tree Heights Averaged per Site (MTHAS) as well as the LiDAR derived standard deviation in tree heights (SD) to the field derived Standard Deviation between plots at each Site (SDS) using paired t-tests. The comparison of standard deviations between the field collected data and the LiDAR derived data were obtainable for only 17 sites, as one location, VHS, was excluded from analyses since data were collected for only one plot, preventing the standard deviation

evaluation between plots. The Null Hypothesis was that the measured max tree heights and standard deviations in the field collected data did not differ significantly from the LiDAR collected data.

Using LiDAR to predict *D. pileatus* occurrence

I used regressions to individually test the ability of all 3 LiDAR vertical forest characteristics: MAX, MEAN, and SD to explain square-root transformed Pileated Woodpecker cavity densities. Forest complexity was evaluated based on the SD - the greater the SD, the more complex the forest. Additionally, a multiple regression was implemented to evaluate all 3 LiDAR predictor variables' performance simultaneously. The null hypotheses were that *D. pileatus* density was not related to the LiDAR predictor variables.

Results

LiDAR accuracy

Evaluating the accuracy of LiDAR to predict forest max heights by using field collected data and t-tests revealed that the LiDAR predictor variables MAX and SD were not significantly different from the field collected data AMTHS and SDS, respectively. The average differences between AMTHS and MAX and SDS and SD were relatively small (Table 2.2, Figure 2.3). However, there was a rejection of the null hypothesis for MTHAS; there was a significant ($P = 5.238 \text{ E-}08$) difference in the means of the max tree heights between LiDAR collected data and field collected data (Table 2.2).

Table 2.2 Paired t-test results for field collected data compared to LiDAR MAX. A negative effect size indicates that the LiDAR values were smaller.

	t	df	Effect Size (m)	p-value
AMTHS	0.422	17	0.728	0.6784
MTHAS	-9.193	17	-8.178	5.238E-08**
SDS	-0.696	16	-0.495	0.4967

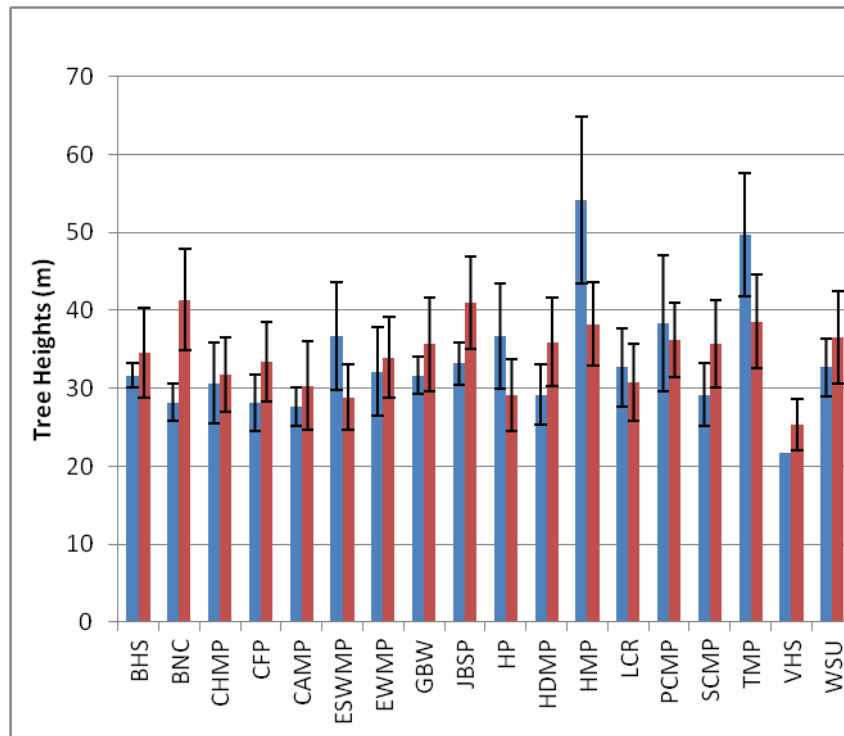


Figure 2.3 Comparison of the Absolute Maximum Tree Height (AMTHS, blue) collected in the field and the maximum tree heights recorded in the LiDAR data (red) for each site. Error bars are each site’s standard deviation in tree heights.

Using LiDAR to predict *D. pileatus* occurrence

Simple linear regressions rejected the null hypothesis, revealing a nearly significant ($P = 0.0763$) relationship with the mean forest heights and a significant ($P = 0.004$ and 0.0200) relationship between *D. pileatus* cavity abundance and MAX and SD, respectively (Table 2.3, Figure 2.4). The residuals versus fitted values graphs for the three explanatory variables showed curved smoother fits (Figure 2.4b). The residuals for both the standard deviation and the max tree heights both showed a unimodal relationship while the mean tree heights were smoother and mostly flat with minor outliers (Figure 2.4b).

Table 2.3 Regression statistics between *D. pileatus* relative cavity density and 3 LiDAR predictor variables.

	df	Multiple R-squared	F-statistic	Regression coefficient	p-value
SD	34	0.149	5.955	0.431	0.0200*
MAX	34	0.219	9.538	0.098	0.004*
MEAN	34	0.09	3.344	0.088	0.0763

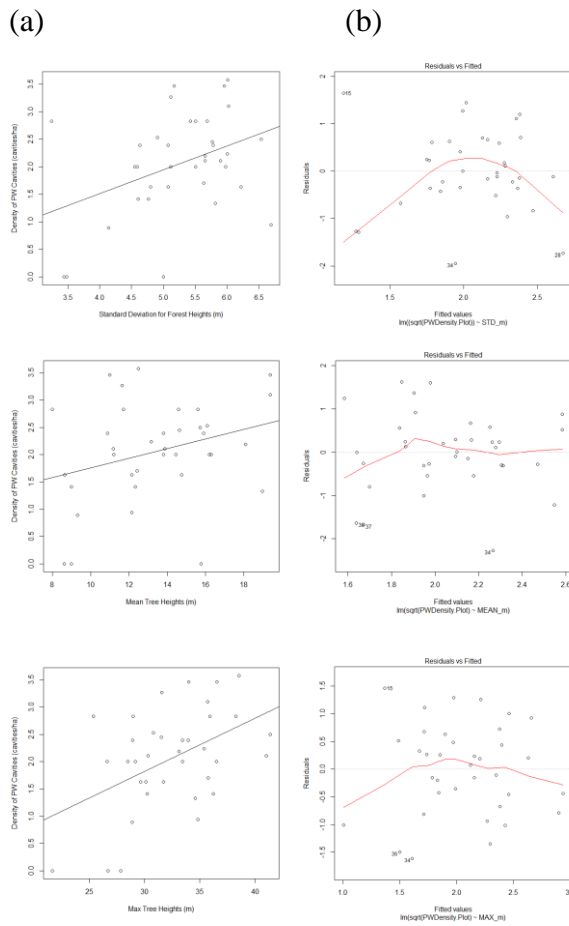


Figure 2.4 (a) Linear regressions for Max and SD on *D. pileatus* cavity density. Graph statistics can be found in Table 2.5 **(b)** Residuals versus fitted graph including a smoother line.

When all three LiDAR variables were included in a multiple linear regression, only MAX significantly ($P = 0.0494$) affected *D. pileatus* cavity density (Table 2.4).

Table 2.4 Multiple regression statistics for all the LiDAR predictor variables on *D. pileated* relative cavity density. $R^2 = 0.254$, $DF = 32$, F-statistic = 3.638, P-value = 0.0230.

	Std.			
	Estimate	Error	t value	P-value
MAX	0.102	0.050	2.043	0.0494*
MEAN	0.0681	0.058	1.173	0.249
SD	-0.127	0.318	-0.401	0.691

Discussion

LiDAR accuracy

Previous research has shown LiDAR to be a novel and accurate approach for evaluating forest structural characteristics across broad landscapes (Cho et al., 2012; Lesak et al., 2011; Hawbaker et al., 2009; Hallous et al., 2006; Zimble et al., 2003; Naesset, 2002). Aside from using LiDAR to evaluate vertical forest composition, scientists have started using LiDAR as an effective tool for mapping more complex and fine-scaled forest characteristics such as species, snag, and understory composition (Cho et al., 2012; Martinuzzi et al., 2009).

While the overall agreement between LiDAR and field data was impressive, slight deviations occurred (Figure 2.3). Such deviations were expected given the very different data collection and processing methods of field and remote measurements. For example, the maximum height found by LiDAR consisted of a single value captured from a raster file, while the maximum height from the field - collected data included an average among the tallest tree heights captured within each plot. The standard deviation calculated from the statistics in the LiDAR data was interpreted between pixels and did not significantly differ from the standard deviation found between plots, lending support to the usefulness of this remote sensing technique for broad-scale data collection.

Both the LiDAR and field collected data were acquired during leaf-off conditions, allowing for more accurate measurements from the ground (field-collected) and to the

ground (LiDAR). Foliage can obscure the view of a tree, leading to inaccurate measurements of tree heights in the field. Similarly, ground measurements captured by remote sensing are important for estimating tree heights by remote sensing because the forest heights were estimated as the differential between canopy and ground elevation (DEMs); tree foliage could cause poor estimates of ground elevation DEMs, ultimately skewing height results. The ability of the LiDAR system to collect accurate measurements during leaf-off conditions confirms what previous research has found regarding the difference in seasons; tree branches and limbs provided enough reflectivity to achieve useful LiDAR accuracy (Hawbaker et al., 2009).

Results regarding LiDAR vertical accuracy in this study confirmed previous research (Cho et al., 2012; Lesak et al., 2011; Hawbaker et al., 2009; Hallous et al., 2006, Zimble et al., 2003; Naesset, 2002). Both LiDAR variables, maximum tree height (MAX) and standard deviation in tree height (SD), did not show significant deviations from field data with the AMTHS and SD being on average only less than a meter higher than the LiDAR derived estimates. However, MTHAS differed significantly ($P = 5.24E-08$) from the maximum tree height collected by the LiDAR system, averaging over eight meters below the maximum tree height found by LiDAR. Since the maximum tree height captured by LiDAR contained only one value, it is not representative of the average maximum tree heights. Heights that have been averaged are influenced by low tree height plots, which reduce their values, and therefore a single maximum height found by remote sensing data can be expected to be higher than the averages.

Given that measurements were recorded across the site, it is possible that forest characteristics such as complexity (measured by standard deviation in this study) may have been influenced by forest age variations across the site. Some of the sites sampled contained a variety of forest types from younger stands experiencing succession resulting from recent conservation efforts to older, mature stands that were the nucleus of the conservation area. An improvement could be analyzing the LiDAR data at the plot level, where such variations are less likely. Additionally, it is also possible the standard deviation was a measure of the differences measured within canopy height rather than overall forest heights (i.e. including mid-story trees and shrubs) since the data consisted

of large footprint, low density sampling . The data freely provided by OSIP were of relatively low-resolution (1.0 return / 2 m²), making it infeasible to accurately assess mid-story structure (Figure 2.5) since the probability of emitted light reaching the mid-story is low and the returns collected likely mostly consisted of points returned from the upper canopy. Nevertheless, further research comparing other characteristics such as basal area, canopy coverage, and tree density might be useful for more in-depth evaluation of LiDAR accuracy, provided that higher resolution data are obtainable.

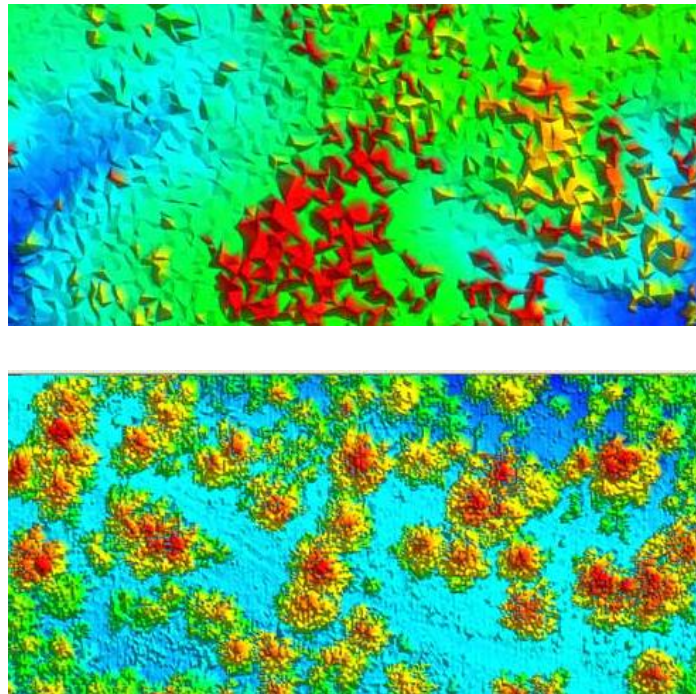


Figure 2.5 Effects of difference in data resolution. The top image was collected at low-resolution (1 return / 5 m²) while the bottom photograph was collected at high-resolution (4 returns / m²). Although the data freely provided by OSIP are of higher resolution than the top image, they are still not adequate for the analysis of understory composition (Images are from Tweddale and Newcomb, 2011).

Higher resolution data are becoming available by county throughout Ohio but are costly. Although the data used in this study were not intended for use in forestry analysis, exploratory investigations of statewide surveys turned out to be feasible.

Using LiDAR to predict *D. pileatus* occurrence

Vertical forest structure is important for many woodland dwelling species. Preference for a shrubby understory or an open sub-canopy can be the ultimate determinant for a species' persistence at a certain location. As previously mentioned, Pileated Woodpeckers have a preference for certain types of vertical forest composition, in particular related to nesting and roosting cavities, preferring to excavate these in tall trees (Aubry and Raley, 2002). However, southwestern Ohio has experienced many anthropogenic changes in the landscape and wildlife, to which Pileated Woodpeckers may need to adjust for survival.

Since older forests are more likely to contain snags (standing deadwood) (Silver et al., 2013), an important resource for Pileated Woodpeckers in the form of food and shelter (Bull et al., 2007; Raley and Aubry, 2006; Lemaitre and Villard, 2005; Renken and Wiggers, 1989), they are prime habitat for these large birds. The level of forest complexity has been shown to be a useful characteristic when determining the age of a forested area, with forest complexity increasing with age (Silver et al., 2013). Relating forest complexity to Pileated Woodpecker relative abundance using LiDAR may be a useful new way for evaluating habitat suitability without the need for extensive field work since LiDAR has been shown to accurately assess forest characteristics over broad ranges (Cho et al., 2012; Lesak et al., 2011; Hawbaker et al., 2009; Hallous et al., 2006, Zimble et al., 2003; Naesset, 2002). In this study, forest complexity, evaluated by the standard deviation, did reveal a significant correlation ($P = 0.0200$) with cavities excavated by Pileated Woodpeckers supporting the hypothesis that *D. pileatus* occurrence increases with a more complex forest. Additionally, a unimodal pattern in the residuals suggest that the density of cavities were highest at sites that had an intermediate standard deviation, most likely representing an older, mature forest site. Sites that have the highest standard deviations are likely to include both mature and immature forests across the landscape resulting in higher variability in tree heights than a site fully covered in mature forest, while standard deviations at the lower end would indicate a homogenous forest stand with low vertical complexity consisting of even aged, younger trees.

Older forests typically harbor larger and taller trees than younger forests given the extended period trees had for growing. Therefore, relating maximum forest heights to *D. pileatus* relative abundance could work well for determining Pileated Woodpecker's potential habitat. The maximum forest height revealed a significant ($P = 0.004$) relationship with *D. pileatus* occurrence; this relationship is supported in previous studies since Pileated Woodpeckers have been shown to use large trees for nesting and roosting (Hartwig et al., 2004; Adkins Giese and Cuthbert, 2003). Although the maximum forest height found by LiDAR was a single measurement, it is likely that a tall tree does not exist in isolation and that some of the neighboring trees are relatively tall as well. However, including statistics such as upper quantiles of tree heights in LiDAR data might be even better suited for explaining the occurrence of *D. pileatus* since it was previously found that this woodpecker prefers to nest within the canopy (Aubry and Raley, 2002). Upper quantiles could be useful for finding average tree heights within the canopy layer (rather than across all height classes) of the forest across sites and may thus work well for predicting *D. pileatus* occurrence.

Average forest heights may be a plausible proxy for forest age, as older forests tend to have taller trees. Therefore, average tree height may be a useful factor for determining *D. pileatus* relative abundance. Average forest heights nearly significantly ($P = 0.07$) predicted *D. pileatus* cavity density. Since averages incorporated all captured vegetation heights (potentially including understory plants), this variable may have underperformed due to reflecting the availability of mature forest poorly by representing heights somewhere between the canopy and mid-story stratum, depending on how many LiDAR returns captured the lower layer. However, higher resolution data could capture mean tree heights that represent the mean canopy layer, allowing this variable to be an important predictor for *D. pileatus* occurrence since they prefer to nest in tall trees within the canopy.

When the three variables (maximum tree height, mean tree height, and standard deviation) were included in a single model to predict *D. pileatus* relative abundance, only maximum tree height was significant ($P = 0.0494$). Intercorrelations were present among maximum and mean tree heights, and standard deviation. When processed as covariates

to explain *D. pileatus* relative abundance, the intercorrelation between the explanatory variables MAX, MEAN, and SD could result in misleading coefficient estimates. Therefore, in these analyses, the use of individual models worked best for explaining Pileated Woodpecker relative abundance.

Determining forest characteristics important to *D. pileatus* preferences may be challenging across broad landscapes without high resolution remotely-sensed data. Although expensive, using higher resolution data could cause a significant change in results and would be worth looking into.

In this study, LiDAR has proven to be a valuable tool for evaluating vertical habitat characteristics of Pileated Woodpecker habitat. LiDAR has a promising future for use by scientists and conservationists, alike. This form of remote sensing could provide for more efficient data collection than field work for forest management as it can cover landscape characteristics over a large extent across rugged landscapes that may otherwise be difficult to reach and evaluate by foot.

Appendix A

Site Name	Site Size (ha)	Sample Size (n)	Cavity Density (cavities/ha)	Snag Density (snags/ha)	Basal Area (m ² /ha)	Isolation Index (m)	Percent of Open Water (%)
Vandalia Historical Society	1.11	1	8	64	6640.0	9392.0	0.00
Garber Property	1.98	2	0	8	NA	17722.0	0.00
Merlin Property	2.15	2	4	8	NA	17103.0	0.88
Weaver Property	1.58	2	4	17	NA	38069.0	0.00
Kretch Property	1.67	1	0	32	NA	13420.0	0.00
Silvercreek Preserve	1.80	2	0	24	NA	5306.0	0.00
Stump Property	3.22	4	8	12	NA	10470.0	0.00
Charlie and Merlin Property	4.36	3	2.67	13.33	NA	18038.0	0.22
Warner Property	3.51	2	8	20	NA	25906.0	0.00
Pondview Park	4.78	4	6	8	NA	9214.0	0.00
Helke Park	5.51	4	4	8	2194.0	7596.0	0.00
Indian Rifle Park	7.95	4	2	30	NA	18401.0	0.00
Lavy Property	10.18	7	5.71	10.28	NA	5573.0	0.00
Lost Creek Reserve	12.16	10	6.4	14.4	2130.0	4825.0	0.25
Keuther Property	13.13	8	4	10	NA	5868.0	0.00
Coppess Nature Sanctuary	13.40	3	2.66	10.67	NA	23930.0	0.00
Routzong Preserve	15.21	5	4.8	6.4	NA	36009.0	0.00
Beavercreek Highschool	19.17	9	1.78	15.11	2021.0	7150.0	0.12
Waldruhe Park	21.47	7	5.71	19.4	NA	2600.0	0.41
Shawnee Prairie Preserve	26.15	4	10.67	58.67	NA	5299.0	0.36
Eastwood Metropark	25.66	10	0.8	24.4	1658.0	16972.0	4.87
Cox Arboretum Metropark	45.33	9	4.44	22.22	1755.0	5594.0	0.06
Dudley Woods Metropark	58.87	8	5	15	NA	0.00	0.18
Garbry Big Woods	66.42	10	9.6	17.6	2896.0	0.00	0.00
Grant Park	69.94	9	0.89	8	NA	0.00	0.63
Wright State University	80.68	10	12	21.6	2749.0	0.00	0.43
Possum Creek Metropark	106.47	10	2	25	1417.0	0.00	1.34
Brukner Nature Center	111.97	8	6.22	20.44	2262.0	0.00	1.87
Charleston Falls Preserve	122.73	7	5.71	21.71	1593.0	0.00	1.16
Hills and Dales Metropark	133.89	4	8	22	2488.0	0.00	1.77
Rentschler Forest Preserve	227.48	10	4	12	NA	0.00	4.05
Sugar Creek Metropark	275.42	10	2.91	18.2	2415.0	0.00	0.25
Carriage Hill Metropark	290.60	9	2.67	19.55	2017.0	0.00	0.39
Huffman Metropark	310.47	10	8	24.8	1837.0	0.00	4.08
Englewood Metropark	488.25	10	12	41	2822.0	0.00	19.48
Taylorville Metropark	574.83	10	12.8	49.6	2586.0	0.00	2.57
John Bryan State Park	856.63	27	4.44	30.5	2538.0	0.00	0.36

Appendix B

NLCD Classes

Open Water
Developed Open Space (imperviousness < 20%)
Low Intensity Developed (imperviousness from 20 – 49%)
Medium Intensity Developed (imperviousness from 50 - 79%)
High Intensity Developed (imperviousness > 79%)
Barren Land (lacking useful vegetation)
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrubs
Herbaceous
Hay Pastures
Cultivated Crops
Woody Wetlands
Emergent Herbaceous

Appendix C



The National Land Cover Database

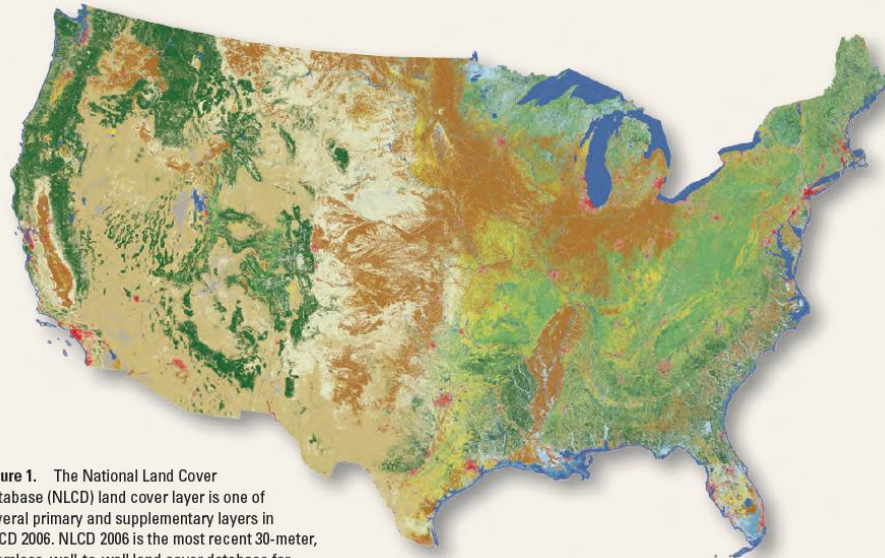


Figure 1. The National Land Cover Database (NLCD) land cover layer is one of several primary and supplementary layers in NLCD 2006. NLCD 2006 is the most recent 30-meter, seamless, wall-to-wall land cover database for the conterminous United States.



The National Land Cover Database (NLCD) serves as the definitive Landsat-based, 30-meter resolution, land cover database for the Nation. NLCD provides spatial reference and descriptive data for characteristics of the land surface such as thematic class (for example, urban, agriculture, and forest), percent impervious surface, and percent tree canopy cover. NLCD supports a wide variety of Federal, State, local, and nongovernmental applications that seek to assess ecosystem status and health, understand the spatial patterns of biodiversity, predict effects of climate change, and develop land management policy. NLCD products are created by the Multi-Resolution Land Characteristics (MRLC) Consortium, a partnership of Federal agencies (see logos below) led by the U.S. Geological Survey. All NLCD data products are available for download at no charge to the public from the MRLC Web site: <http://www.mrlc.gov>.

EXPLANATION

NLCD 2006 class legend

Open water	Evergreen forest
Perennial ice/snow	Mixed forest
Developed, open space	Shrub/scrub
Developed, low intensity	Grassland/herbaceous
Developed, medium intensity	Hay/pasture
Developed, high intensity	Cultivated crops
Barren land	Woody wetlands
Deciduous forest	Herbaceous wetlands



U.S. Department of the Interior
U.S. Geological Survey

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