# DEVELOPING METHODOLOGIES FOR PREDICTING THE LOCATIONS OF WOOD DUCK BREEDING HABITAT COMPONENTS IN MINNESOTA

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## SUMMARY OF FINDINGS

There have been alterations to both aquatic and terrestrial habitats used by wood duck (*Aix sponsa*) hens and broods in Minnesota and the Upper Midwest. We initiated this study to develop methodologies that can be used to predict the locations and monitor spatiotemporal changes in the areal extent of wood duck breeding complexes. Specifically, we want to develop Light Detecting and Ranging (LiDAR) as a method to identify multiple habitat components and to monitor changes in these components from the contemporary period forward. We will provide better historical context regarding spatiotemporal changes in nesting habitat by analyzing Forest Inventory and Analysis (FIA) data with a quantitative method currently being developed. Our specific objectives are to (1) develop and evaluate spatial predictive models of habitat components that are important to breeding wood ducks (i.e., tree species [alternatively deciduous v. coniferous], diameter-at-breast height [DBH], tree canopy density, stand type, wetland type, water depth) based on LiDAR-generated metrics or other sources of spatial data (e.g., National Wetland Inventory [NWI], existing GIS layers, aerial photographs), (2) ascertain the optimal pulse density of LiDAR needed to accurately measure or classify each habitat component of importance to wood ducks (3) determine the generalizability of the LiDAR method for predicting the locations of habitat components by applying algorithms developed from data collected in the main study area (Cass County, Forest Ecological Province) to other sites in the Forest, Prairie, and/or Transition Provinces at which adequate LiDAR-cloud data have been obtained, (4) estimate the species- and DBH-specific proportions of trees with suitable cavities and detection probability of suitable cavities from empirical field data, and (5) determine whether there has been a change in the number of potential nest trees since the 1970s based on changes in FIA data.

We conducted vegetation surveys at 185 wetland plots during Summer 2016 and 152 forest plots during Fall 2016 and Spring 2017. Preliminary results suggest that the proportion of trees with suitable cavities varied by species, DBH class, and health status. Flights to collect LiDAR data were scheduled to occur during Fall 2016, but were postponed until Fall 2017. Thus, we could not associate ground-level vegetation data to LiDAR data. We will collect wetland and forest surveys and analyze FIA data during much of the latter half of 2017, and associate ground-level and LiDAR data starting during late Wiinter 2018.

## INTRODUCTION

Some terrestrial and aquatic habitats used by wood duck hens and broods during the pre-nesting, nesting, and brood-rearing life-cycle phases have been altered substantially in Minnesota and the Upper Midwest. For example, there were decreases in the areal extent of some classes of aquatic habitats in northcentral Minnesota (Radomski 2006) and in the number of beaver impoundments in the forested portion of Minnesota between the early 1990s and 2002 (Dexter 2002, p. 52), both of which were used by wood duck broods (see McGilvery 1968,

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Bellrose and Holm 1994). Although the number of potential nesting trees for wood ducks was projected to increase both in Minnesota (Jaakko Pöyry Consulting, Inc. 1994) and the Upper Midwest (Denton et al. 2012*b*), there has been recent concern among MNDNR managers that harvesting relatively large-DBH trees of economically valuable species (e.g., aspen) in northern Minnesota will reduce the availability of cavity trees frequently used for nesting by some waterfowl (R. A. Norrgard and D. P. Rave, MNDNR, personal communication).

The ultimate goal of this project is to develop methodologies that can be used to predict the locations of the habitat components that compose wood duck breeding complexes (i.e., important habitats used during the pre-breeding to brood-rearing life cycle phases). These methodologies should have the (A) flexibility to identify both forested and non-forested habitat components that occur at different spatial scales, (B) accuracy to reliably quantify spatiotemporal changes in the characteristics (e.g., areal extent) of habitat components and (C) efficiency to collect habitat data over large spatial scales. It also would be beneficial to develop methodology to analyze habitat data that were collected in long-term standardized surveys that likely will be performed in the future.

Meeting all of these needs with a single methodology or existing dataset probably is not possible. Consequently, we will develop 2 methodologies for obtaining better knowledge regarding spatiotemporal changes in wood duck breeding-habitat components. We propose to develop LiDAR methodology to identify multiple habitat components and to monitor changes in these components from the contemporary period forward. This methodology also could be used to provide habitat trend information that can be used in MNDNR administrative efforts (e.g., subsection planning) and research (e.g., estimating habitat availability in resource selection studies; see Aebischer et al. [1993]).

We also propose to provide better historical context regarding spatiotemporal changes in nesting habitat by analyzing FIA data with a quantitative method currently being developed. Reliable FIA surveys have been conducted since the 1970s. We propose to conduct analyses of FIA data to identify spatiotemporal changes in nesting habitat components not characterized by LiDAR, at spatial scales smaller than those of previous investigations, and over a greater time period (i.e., since the 1970s). This methodology also will provide database queries that can be used in future monitoring efforts, and an insight of whether the predicted trend in the abundance of tree cavities (e.g., Denton et al. 2012*b*) is accurate.

## GOALS AND OBJECTIVES

The ultimate goal of this project is to develop methodologies that can be used to predict the locations and monitor spatiotemporal changes in the areal extent of wood duck breeding complexes (i.e., important habitats during the pre-breeding to brood-rearing life cycle phases). Meeting this goal will require that we (1) identify the location and areal extent of breeding-habitat components in the main study area, (2) validate the predicted locations of wood duck breeding complexes with independent, empirical data from other sites, and (3) quantify the spatiotemporal trends in potential nesting trees in Minnesota over the long term. We will meet this goal using 2 sources of data (i.e., LiDAR and FIA). Our specific objectives are to:

1. Develop and evaluate spatial predictive models of habitat components that are important to breeding wood ducks (i.e., tree species [alternatively deciduous v. coniferous], DBH, tree canopy density, stand type, wetland type, water depth) based on LiDAR-generated metrics or other sources of spatial data (e.g., NWI, existing GIS layers, aerial photographs). This evaluation will include determining the accuracy with which each component can be predicted with LiDAR-cloud data.
2. Ascertain the optimal pulse density of LiDAR needed to accurately measure or classify each habitat component of importance to wood ducks.

3. Determine the generalizability of the LiDAR method for predicting the locations of habitat components by applying algorithms developed from data collected in the main study area (Cass County, Forest Ecological Province) to other sites in the Forest, Prairie, and/or Transition Provinces at which adequate LiDAR-cloud data have been obtained (e.g., J. Erb's study areas, MNDNR statewide elevation measurement project).
4. Estimate the species- and DBH-specific proportions of trees with suitable cavities and detection probability of suitable cavities from empirical field data.
5. Determine whether there has been a change in the number of potential nest trees since the 1970s based on changes in FIA data.

## METHODS

### Wetland Surveys

Initially, we used the available spatial data from NWI (Cowardin et al. 1979) to select 260 sampling locations in the study area. Initially, we stratified wetlands contained in the NWI GIS layer by NWI system, subsystem, and class (hereafter, wetland types). Unfortunately, information about wetland subclasses was not available in this GIS layer. We then randomly selected 260 2- X 2-m plots from the 9 major wetland types present in the study area: 60 plots from both the Lacustrine-Littoral-Emergent Vegetation and Palustrine-Emergent Vegetation, and 20 plots each from the Lacustrine-Limnetic-Unconsolidated Bottom, Lacustrine-Littoral-Unconsolidated Bottom, Palustrine-Forested, Palustrine-Shrub Scrub, Palustrine-Unconsolidated Bottom, Riverine-Upper Perennial-Unconsolidated Bottom, and Riverine-Lower Perennial-Unconsolidated Bottom wetland types. We selected more plots from the first 2 wetland types because we surmised that these habitats were more likely to be used by wood duck broods (e.g., Grice and Rogers 1965), and that there was a greater likelihood that these habitats would be structurally diverse and thus more challenging to identify from LiDAR signatures. We also specified that plots had to be ≥100 m apart to reduce the likelihood of non-independence among plots (i.e., sampling plots with similar vegetation structure).

Many relatively small, isolated wetlands were not delineated in the NWI layer, so we later selected 50 additional plots in these habitats from the MNDNR Hydrography GIS layer (MNDNR 2015). We randomly selected 1 plot per wetland that was 0.81–8.09 ha, ≤402 m from a road, and adjacent to public land. After initially selecting plots from both layers, we examined aerial photos to assess the accessibility of these locations. We attempted to sample all plots that initially appeared potentially accessible, but not those that appeared inaccessible.

We navigated to the approximate location of each plot center using a Garmin Montana GPS unit, and established a plot center. If the plot center was difficult to access (e.g., because of soft bottom substrate that could not be traversed on foot, dense vegetation that could not be penetrated via boat) or on or near an ecotone, we moved the plot location to a site that was as close as possible to the initial location, accessible, and in the interior of a somewhat homogeneous vegetation patch. Moving plots away from ecotones reduced the likelihood of misclassifying habitats (i.e., habitat misclassifications are more likely to occur near ecotones because the exact location of a sampled plot is difficult to determine with somewhat imprecise GPS units). We also moved some plots located in open water habitats to the nearest vegetated location within the wetland because the former habitat type is simple and easily identified with LiDAR data. Instead, we chose to dedicate the greatest sampling effort to vegetated plots.

For each plot, we recorded the date, start time, observers, plot number, whether wood ducks were observed within 100 m of plot, and if so, provided a count of individuals in each cohort (male, female, brood, unknown). We ascertained whether the NWI classification (system, subsystem, class) available on our GIS layer was correct at each plot (i.e., some wetlands may have changed since the original classification, or that the original classification may have been incorrect), and recorded the appropriate NWI wetland classification to the level of subclass. We classified the types of wood duck loafing structures present within the plot (7 classes: none, rock, log or stump, muskrat lodge, beaver lodge or dam, small island or tussock, barely or lightly vegetated shoreline), as well as the type of beaver modification, if any that had some influence on the plot (6 classes: none, water level, runs, tree removal, dam or lodge, food cache). We also obtained a location data for each plot center using a Geneq Sx Blue II GPS unit (20–50 cm accuracy in open habitats when data were obtained at 1 reading / 5 seconds for 1 min), and recorded the specific GPS unit used.

At each plot, we placed a 2- X 2-m Daubenmire square (Daubenmire 1959, Gilmore et al. 2008) so its center was located at plot center, and measured several habitat variables within the device. This square had 0.2 m delineations, which facilitated the measurement of several habitat variables. Specifically, we used these delineations to estimate the % coverage (5% increments) of 4 habitat classes (emergent, floating leaf, open water, shrub [woody vegetation ≤1.37 m tall]) that were present at or above the water surface, and of submergent plants, when possible to make reliable observations (i.e., at locations in which water turbidity or sun glare did not substantially hinder observability). Within the Daubenmire square, we also documented the dominant emergent cover type (14 classes: none, alder [*Alnus spp*.], Canada bluejoint grass [*Calamagrostis canadensis*], giant bur-reed [*Sparganium eurycarpum*], cattail [*Typha spp*.], ericaceous shrub, floating-leaf, giant reed grass [*Phragmites spp*.], rush [*Scirpus spp*.], reed canary grass [*Phalaris arundinacea*], sedge [*Carex spp*.], willow [*Salix spp*.], wild rice [*Zizania aquatica*], other). Other habitat components measured inside the Daubenmire square were the minimum depth of submergent vegetation and the height of emergent vegetation and shrubs (0.1 m increments with a 3-m ruler), tree canopy height (0.1 m increments for woody vegetation >1.37 m tall with a Suunto clinometer or with a 3-m ruler), mean tree canopy cover (with a spherical densitometer), and water depth (with either a 3-m measuring pole [(0.1 m increments] at relatively shallow plots or an Eagle FishEasy 245DS depth finder [0.03 m increments] at deeper locations).

Within the Daubenmire square, we also estimated vertical vegetation cover and structure using a round Robel pole (Robel et al. 1970) that had alternating 0.1-m white and black bands and narrow, vertical, and contrasting marks at the midpoint of each band. Because it was not possible for personnel to stand at plots in relatively deep water or where the soil substrate was soft, it was necessary to adapt this device so that it could be used by 2 people in a boat. This adaptation consisted of attaching a long wooden pole to the Robel pole in a perpendicular manner. One crew member extended the Robel pole to the corner of the Daubenmire square opposite the other crew member, and oriented this device upright to the water surface. The other crew member placed their sighting eye 0.8 and 1.6 m above the water surface with the aid of the 3-m ruler, and recorded the lowest decimeter or 0.5 decimeter mark that could be observed from diagonally across the Daubenmire square (2.8 m). Crew members switched assignments and took readings from across the opposite diagonal of the square. This approach generated 2 measurements from each observation height, all of which were averaged together.

### Forest Surveys

We first obtained forest spatial data (e.g., stand age and location, forest cover type) from Cass County, State of Minnesota, and USDA Forest Service databases. Because of slight differences among these databases regarding the classification of forest cover types, we aggregated forest composition information from these databases into 5 cover types that are likely to be used by nesting wood ducks. These cover types are aspen-birch, lowland hardwoods, mixed conifer, northern-hardwoods, and oak). We also were interested in surveying only stands likely old enough to have developed the structures likely to be used by nesting wood ducks (i.e., Aspen-Birch ≥50 years, all other stand types ≥80 years).

To reduce the likelihood of underestimating the variability of habitat structure and sampling somewhat unrepresentative habitats when selecting survey sites, we specified that ≤2 plots per stand could be established, and that these plot centers must be both ≥50 m apart and ≥30 m from the nearest stand boundary. Using these criteria, we then stratified forest stands on public lands by cover type and age class, and randomly selected 300 forest stands (60 stands of each of the 5 types, *n* = 563 plots) to be surveyed. It was necessary to remove 19 plots from the sample because of nearby heritage sites, or scheduled timber harvesting (i.e., interpretation of habitat characteristics would be problematic if timber harvesting occurred between the times forest surveys were conducted and LiDAR data were collected).

We navigated to the selected plot centers using a Garmin Montana GPS, and established 20-m circular plots (0.126 ha) around those points. Plots located near ecotones were moved sufficiently into the forest interior as to avoid apparent edge effects of vegetation structure. We first recorded the plot identification number, date, start and end times of survey, visit number to the plot (first or second), observers, cloud cover (0.1 increments), and proportion of tree boles covered by snow or leaf-out (0, 0.01–0.10, 0.11–0.33, 0.34–0.66, 0.67–1.00). We obtained location data for each plot center using Geneq Sx Blue II (0.9–1.8 m accuracy under closed forest canopy when obtaining 1 reading / 5 seconds for approximately 15 min) and Geneq Sx Blue II + GNSS (0.5–0.9 m accuracy under closed forest canopy when obtaining 1 reading / 5 seconds for approximately 15 min) GPS units, and recorded the GPS make, model, and unit number used at each plot. We also classified the stand structure following U.S.D.A. Forest Service (2014; 5 classes: single story, two-storied, multi-storied, mosaic, unknown/unassessable;) and forest cover type following Eyre (1980). We assigned these specific cover types to 5 more general types (Appendix 1).

We then examined and measured individual tree stems within each plot following an established protocol (USDA Forest Service 2014), with some exceptions. Specifically, we surveyed only trees large enough to have cavities used by nesting wood ducks (i.e., ≥22.0 cm DBH [Haramis 1975]), and tall enough for DBH to be measured (≥1.37 m). Starting at the $0^{o}$ azimuth within each plot, we proceeded clockwise, numbering each suitable tree stem, and recording the following data for each stem: species, DBH (0.1 cm increments), distance (0.1 m increments) and direction ($1^{o}$ increments) from plot center, health status (following Thomas 1979, Appendix 2), and crown class (5 classes: remnant, dominant, codominant, intermediate, overtopped; U.S.D.A. Forest Service 2014).

All field crew members then used binoculars to conduct a preliminary search of each tree in the plot to identify cavities that potentially were suitable for nesting by wood ducks. When a potentially suitable cavity was encountered, we used a Pyle Model PLCM22IR remote camera attached via a stiff, braided wire to a 15.24 m Crain CMR Series Measuring Ruler (*sensu* Waldstein 2012) to perform a more careful examination of the entrance and interior of the cavity. We first determined whether cavity entrance dimensions were suitable by attempting to pass a cardboard cut-out of the minimum usable dimensions (6 x 6 cm, Zwicker 1999, cited in Denton et al. 2012*b*) through the cavity opening. This cut-out was placed on the wire connecting the camera to the measuring ruler. We then examined cavity interiors with the camera to ascertain whether the following conditions had been met: bottom of cavity entrance was ≥0.6 m above ground level (Strom 1969), vertical depth (from the bottom of the cavity to the bottom of the entrance) was ≥10.2 cm to 4.5 m; Bellrose and Holm 1994 p. 176) and not hollow to the ground (Robb 1986, cited in Bellrose and Holm 1994, p. 178), horizontal depth (from inner bark of the entrance opening toward the back of the cavity) appeared large enough for hens to move from the entrance to the interior of the cavity, nest platform dimensions were ≥14 x 15, cm (Boyer 1974, Haramis 1975, Denton et al. 2012*a*), and the cavity did not contain standing water or excess debris (Sousa and Farmer 1983).

Field personnel ascertained whether (1) cavity dimensions were adequate to permit a wood duck to enter the cavity and access the likely nesting location and (2) structural impediments were likely to hinder nesting efforts, and used this information to classify the suitability of each examined cavity for wood duck nesting (4 levels: suitable, marginal, unsuitable, unknown). We considered a cavity to be suitable if all these conditions were met, and unsuitable if any of these conditions were not met. A cavity was classified as marginal if it were unclear whether all dimensional requirements were met (i.e, ≥1 dimensional measurement appeared to be close to some minimum or maximum value). Cavities typically were classified as unknown/unobservable if personnel were unable to completely observe the cavity, either because of cavity height or some structural attribute did not permit observation with the camera system. We considered a cavity to be unsuitable if any dimensional measurement were not met or if there were standing water or excess debris in the cavity. Field personnel also provided a cause for unsuitability (7 classes: entrance dimensions too small, insufficient horizontal depth, insufficient vertical depth, insufficient platform dimensions, too deep or hollow to the ground, standing water in the cavity, excessive debris in the cavity). Our assessment of the suitability of interior characteristics required some subjectivity because direct measurements could not be made with our camera system.

For each cavity inspected, we recorded tree number, cavity entrance type (3 classes: opening on the top, side, combination of top and side openings which are joined on the exterior of the tree), primary and secondary sources of cavity formation (11 classes: split, broken limb, broken top, woodpecker, fire, lightning, insect, logging wound, decay/rot, other, unknown), evidence of animal use (9 classes: eggshell/ membrane, nesting materials, hive or other insect structure, animal present, scratching at entrance, pecking at entrance, other, unknown, none), and animal taxa. We also measured cavity height with either a 15.24 m measuring ruler (±0.1 m) or Suunto clinometer (±0.5 m).

### LiDAR Data Collection

MNDNR Resource Assessment Program (RAP) originally planned to have LiDAR and associated remote sensing data collected during aerial flights conducted by a contractor during Fall 2016. These data-collection flights were postponed until Fall 2017. This postponement will preclude us from associating LiDAR and field data until late Winter 2018.

## STUDY AREA

The primary study area encompasses 202,342 ha in northeastern Cass County, Minnesota (Figure 1), but may be expanded if additional funds become available. Parts of Chippewa Plains, Pine Moraines-Outwash Plains, and St. Louis Moraine Ecological Subsections (Hanson and Hargrave 1996) occur within this area.

## RESULTS

### Wetland Surveys

We conducted surveys at 185 wetland plots during the late summer and early fall of 2017 (Table 1, Figure 2). Of the plots sampled, 30 had no vegetation at or above the water surface but 155 had some form of vegetation growth. In the latter plots, the dominant vegetation at or above the water surface were classified as: alder ($n$ = 1), blue joint grass ($n$ = 4), bur reed ($n$ = 2), cattail *spp* ($n$ = 16), ericaceous shrub ($n$ = 5), floating leaf ($n$ = 16), phragmites *spp* ($n$ = 9), rush *spp* ($n$ = 31), reed canary grass ($n$ = 11), sedge *spp* ($n$ = 21), willow ($n$ = 2), wild rice ($n$ = 40), and other vegetation ($n$ = 1). We observed that 14 (7.6%) plots were modified by beaver, 11 (5.9%) had potential wood duck loafing sites, and wood ducks were present ≤100 m of 20 (10.8%) plots.

### Forest Surveys

We surveyed 26 forest plots during Fall 2016 and an additional 126 plots during Spring 2017 (Figure 3). The forest cover types (Eyre 1980) of plots surveyed were classified primarily as aspen, northern red oak and sugar maple-basswood (Table 2). A total of 4,931 trees of 26 species were measured and inspected for cavities (Table 3). Of these trees, 536 had potential cavities that we inspected with the remote camera-system (724 total cavities, as many trees had multiple cavities). The majority of cavities were classified as unsuitable for nesting by wood ducks ($n$ = 429; 66%), and the remainder were classified as suitable ($n$ = 126; 17%), marginally suitable ($n$ = 65; 9%), or of unknown suitability ($n$ = 54; 8%).

### FIA Analysis

We did not conduct any analyses of FIA data during FY17, but will perform analyses during FY 18.

## DISCUSSION

### Wetland Surveys

Initially, we randomly selected wetlands for sampling to obtain an adequate sample size for each NWI class, with special emphasis placed on those classes that are most likely to have diverse vegetation structure. However, these efforts were confounded in-part by limitations of the existing NWI spatial data. Specifically, we observed during field data collections that NWI classifications of some randomly selected plots were incorrect, which we attribute to a combination of misclassification of wetland habitats, habitat changes since the original classification, and projection error. Such discrepancies contributed in-part to the resultant allocation of samples (Table 1), as did our effort to sample relatively intensively in the important vegetation types within the study area so that these types could be identified with LiDAR. We chose to move some randomly selected plots that were originally located in open water habitats with no vegetative structure at or above the water surface (e.g., Unconsolidated Bottom class) to the nearest vegetated wetland location that had a relatively homogeneous structure. Presumably, wetland habitats with no surface vegetation should have a rather simple and readily identifiable LiDAR signature, whereas those with different types of vegetation will be diverse in structure and therefore will require greater sample sizes to identify with LiDAR.

During the upcoming field season, we will attempt to obtain an adequate sample size of the different vegetation types present in the study area, but this will be challenging because much of the available NWI GIS layer classifies wetlands only to the level of class, which usually provides little information about vegetation structure. However, the NWI layer for north-central Minnesota is being updated, so we will explore using any new spatial information for plot selection.

### Forest Surveys

The proportion of trees with suitable cavities varied by species, DBH and health status (Tables 4 and 5). Our preliminary results indicate that most suitable cavities were produced in sugar maple (*Acer saccharum*), northern red oak (*Quercus rubra*) and American basswood (*Tilia Americana*, Table 4). Further, the percentage of trees with suitable cavities generally increased with DBH (Table 3). The average DBH of all trees sampled was 33.3 cm (range: 22.0–94.3 cm), but the average DBH of trees with suitable cavities was 42.3 cm (range: 22.8–73.6 cm). For most species, trees that were dying or dead had a greater percentage of suitable cavities than live, healthy, trees (Table 5).

We will explore ways to select plots to be surveyed during Fall 2017 of forest cover types and tree species-DBH classes that are underrepresented in our current sample. Unfortunately, some tree species (e.g., American elm, *Ulmus americana*) and relatively large-DBH trees in general are uncommon, which challenge our ability to obtain desired sample sizes.

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Table 1. The proportion of wetlands in each National Wetland Inventory (NWI) classification (to class level), and number of plots selected to be surveyed and actually surveyed in the Cass County, Minnesota, USA study area during 2016.

| NWI wetland classification | Proportion of wetlands in study area | Number of plots selected | Number of plots surveyed |
|---|---|---|---|
| Lacustrine limnetic unconsolidated bottom | 0.522 | 20 | 4 |
| Lacustrine littoral aquatic bed | | | 7 |
| Lacustrine littoral emergent vegetation | 0.004 | 60 | 23 |
| Lacustrine littoral unconsolidated bottom | 0.020 | 20 | 13 |
| Palustrine aquatic bed | | | 13 |
| Palustrine emergent vegetation | 0.102 | 60 | 102 |
| Palustrine forested | 0.191 | 20 | 0 |
| Palustrine scrub-shrub | 0.130 | 20 | 7 |
| Palustrine unconsolidated bottom | 0.026 | 20 | 3 |
| Riverine lower perennial emergent | | | 7 |
| Riverine Lower Perennial Rock Bottom | | | 1 |
| Riverine lower perennial unconsolidated Bottom | 0.002 | 20 | 5 |
| Riverine upper perennial unconsolidated bottom | 0.003 | 20 | 0 |

Table 2. The forest cover type classification (Eyre 1980) and sample size of forest plots surveyed in Cass County, Minnesota, USA during 2016–2017.

| Forest cover-type | Number of plots surveyed |
|---|---|
| Aspen | 39 |
| Black ash–American elm–red maple | 11 |
| Bur oak | 9 |
| Eastern white pine | 3 |
| Northern red oak | 32 |
| Paper Birch | 13 |
| Red maple | 2 |
| Red pine | 7 |
| Sugar maple | 2 |
| Sugar maple–basswood | 32 |
| White pine–northern red oak–red maple | 2 |

Table 3. The number of stems counted in each tree species and diameter-at-breast-height (DBH, in centimeters) class within forest plots located in Cass County, Minnesota, USA during 2016–2017. In parentheses are the proportion of those trees with suitable cavities followed by the associated standard error. Dashed lines indicate no values for tree species-DBH classes with no trees sampled or no suitable cavities detected.

| | DBH class (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| Tree species | 22–29 | 30–39 | 40–49 | 50–59 | 60–69 | 70–79 | ≥80 |
| American basswood (*Tilia americana*) | 357 (0.008, 0.005) | 189 (0.032, 0.013) | 101 (0.069, 0.025) | 36 (0.139, 0.058) | 12 (0.083, 0.08) | 1 (0,–) | 1 (0,–) |
| American elm (*Ulmus americana*) | 15 (0,–) | 2 (0,–) | 1 (0,–) | – | – | – | – |
| Balsam fir (*Abies balsamea*) | 80 (0,–) | 13 (0,–) | 2 (0,–) | – | – | – | – |
| Balsam poplar (*Populus balsamifera*) | 7 (0,–) | 10 (0,–) | 4 (0,–) | – | – | – | – |
| Bigtooth aspen (*Populus grandidentata*) | 105 (0,–) | 118 (0.017, 0.012) | 59 (0.017, 0.017) | 23 (0.043, 0.042) | 11 (0.091, 0.087) | 3 (0,–) | – |
| Black ash (*Fraxinus nigra*) | 156 (0,–) | 29 (0,–) | 7 (0,–) | 2 (0,–) | – | – | – |
| Black cherry (*Prunus serotina*) | 1 (0,–) | – | – | – | – | – | – |
| Box elder (*Acer negundo*) | 3 (0,–) | 1 (0,–) | 1 (0,–) | – | – | – | – |
| Bur oak (*Quercus macrocarpa*) | 140 (0.007, 0.007) | 74 (0,–) | 18 (0,–) | 8 (0,–) | 6 (0.333, 0.192) | – | – |
| Eastern cottonwood (*Populus deltoides*) | 1 (0,–) | – | – | – | – | – | – |
| Eastern hophornbeam (*Ostrya virginiana*) | 1 (0,–) | – | – | – | – | – | – |
| Eastern larch (*Larix laricina*) | – | 1 (0,–) | 1 (0,–) | – | – | – | – |
| Eastern white pine (*Pinus strobus*) | 9 (0,–) | 13 (0,–) | 17 (0,-) | 8 (0.125, 0.117) | 11 (0,–) | 4 (0.250, 0.217) | 4 (0, -) |
| Green ash (*Fraxinus pennsylvanica*) | 93 (0.011, 0.011) | 47 (0,–) | 18 (0,–) | 6 (0,–) | – | – | – |
| Hackberry (*Celtis occidentalis*) | 3 (0,–) | 1 (0,–) | – | – | – | – | – |
| Jack pine (*Pinus banksiana*) | 10 (0,–) | 6 (0,–) | 1 (0,–) | – | – | – | – |
| Northern pin oak (*Quercus ellipsoidalis*) | 6 (0,–) | 7 (0,–) | – | – | – | – | – |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Northern red oak (*Quercus rubra*) | 247 (0.008, 0.006) | 287 (0.038, 0.011) | 136 (0.044, 0.018) | 26 (0.115, 0.063) | 12 (0.167, 0.108) | 1 (0,–) | – |
| Northern white-cedar (*Thuja occidentalis*) | 4 (0,–) | 1 (0,–) | 3 (0,–) | 1 (0,–) | – | – | – |
| Paper birch (*Betula papyrifera*) | 282 (0.004, 0.004) | 183 (0.005, 0.005) | 28 (0,–) | 1 (0,–) | 1 (0,–) | – | – |
| Quaking aspen (*Populus tremuloides*) | 210 (0,–) | 289 (0.010, 0.006) | 170 (0.053, 0.017) | 34 (0.118, 0.055) | 6 (0,–) | – | – |
| Red maple (*Acer rubrum*) | 243 (0.008, 0.006) | 116 (0.034, 0.017) | 17 (0.118, 0.078) | 1 (0,–) | 2 (1,0) | – | – |
| Red pine (*Pinus resinosa*) | 26 (0,–) | 59 (0,–) | 67 (0,–) | 36 (0,–) | 13 (0,–) | 2 (0,–) | 1 (0,–) |
| Sugar maple (*Acer saccharum*) | 255 (0.016, 0.008) | 138 (0.065, 0.021) | 48 (0.271, 0.064) | 18 (0.222, 0.098) | 4 (0.75, 0.217) | – | 1 (0,–) |
| White spruce (*Picea glauca*) | 6 (0,–) | 6 (0,–) | 2 (0,-) | – | – | – | – |
| Yellow birch (*Betula alleghaniensis*) | 13 (0.077, 0.074) | 9 (0.111, 0.105) | 6 (0.167, 0.152) | 1 (0,–) | – | – | – |
| Unidentified ash *spp* (*Fraxinus spp* ) | 5 (0,–) | – | – | – | – | – | – |
| Unidentified pine *spp* (*Pinus spp*) | – | 3 (0.333, 0.272) | – | – | – | – | – |
| Unidentified aspen *spp* (*Populus spp*) | 6 (0,–) | 16 (0.125, 0.083) | 9 (0, –) | 4 (0,–) | – | – | – |
| Unknown *spp* | 8 (0,–) | 2 (0,–) | – | – | 2 (1,0) | – | – |

Table 4. The percentage of trees by tree species that were sampled, the percentage of trees of each species with suitable cavities, and the percentage of trees of each species with suitable or marginal cavities that were detected within forest plots located in Cass County, Minnesota, USA during 2016–2017.

| Tree species | % of all trees sampled | % of all trees with suitable cavities | % of all trees with suitable or marginal cavities |
|---|---|---|---|
| American basswood *(Tilia americana*) | 14.14 | 18.97 | 16.28 |
| American elm (*Ulmus americana*) | 0.37 | – | – |
| Balsam fir (*Abies balsamea*) | 1.93 | – | – |
| Balsam poplar (*Populus balsamifera*) | 0.43 | – | – |
| Bigtooth aspen (*Populus grandidentata*) | 6.47 | 4.31 | 4.07 |
| Black ash (*Fraxinus nigra*) | 3.93 | – | 0.58 |
| Black cherry (*Prunus serotina*) | 0.02 | – | – |
| Box elder (*Acer negundo*) | 0.10 | – | – |
| Bur oak (*Quercus macrocarpa*) | 4.99 | 1.72 | 1.74 |
| Eastern cottonwood (*Populus deltoides*) | 0.02 | – | – |
| Eastern hophornbeam (*Ostrya virginiana*) | 0.02 | – | – |
| Eastern larch (*Larix laricina*) | 0.04 | – | – |
| Eastern white pine (*Pinus strobus*) | 1.34 | 1.72 | 2.33 |
| Green ash (*Fraxinus pennsylvanica*) | 3.33 | 0.86 | 0.58 |
| Hackberry (*Celtis occidentalis*) | 0.08 | – | – |
| Jack pine (*Pinus banksiana*) | 0.34 | – | – |
| Northern pin oak (*Quercus ellipsoidalis*) | 0.26 | – | – |
| Northern red oak (*Quercus rubra*) | 14.38 | 18.97 | 15.12 |
| Northern white-cedar (*Thuja occidentalis*) | 0.18 | – | – |
| Paper birch (*Betula papyrifera*) | 10.04 | 1.72 | 3.49 |
| Quaking aspen (*Populus tremuloides*) | 14.38 | 12.07 | 14.53 |
| Red maple (*Acer rubrum*) | 7.69 | 6.90 | 9.88 |
| Red pine (*Pinus resinosa*) | 4.14 | – | – |
| Sugar maple (*Acer saccharum*) | 9.41 | 26.72 | 25.58 |
| White spruce (*Picea glauca*) | 0.28 | – | – |
| Yellow birch (*Betula alleghaniensis*) | 0.59 | 2.59 | 1.74 |
| Unidentified ash *spp* (*Fraxinus spp*) | 0.10 | – | – |
| Unidentified pine *spp* (*Pinus spp*) | 0.06 | 0.86 | 0.58 |
| Unidentified aspen *spp*. (*Populus spp*) | 0.71 | 1.72 | 2.91 |
| Unknown spp | 0.24 | 0.86 | 0.58 |

Table 5. The species-specific number of suitable cavities detected; percentage of cavities in live, dying, and dead trees; and percentage of trees examined in the live, dying and dead classes in Cass County, Minnesota, USA during 2016–2017. Health status classifications (1–7 described in Appendix 2) were assigned to broader classifications as follows: live (1), dying (2), and dead trees (3–7). Tree species were included only if at least one suitable cavity was found.

| Tree species | Number of suitable cavities | Cavities in live trees (%) | Live trees (%) | Cavities in dying trees (%) | Dying trees (%) | Cavities in dead trees (%) | Dead trees (%) |
|---|---|---|---|---|---|---|---|
| American basswood (*Tilia americana*) | 22 | 50.00 | 85.22 | 27.27 | 9.90 | 22.73 | 4.88 |
| Bigtooth aspen (*Populus grandidentata*) | 5 | – | 51.41 | 20.00 | 27.90 | 80.00 | 20.69 |
| Bur oak (*Quercus macrocarpa*) | 2 | 66.67 | 86.59 | 33.33 | 12.20 | – | 1.22 |
| Eastern white pine (*Pinus strobus*) | 2 | – | 63.64 | – | 10.61 | 100.00 | 25.76 |
| Green ash (*Fraxinus pennsylvanica*) | 1 | - | 83.54 | – | 11.59 | 100.00 | 4.88 |
| Northern red oak (*Quercus rubra*) | 22 | 29.17 | 67.28 | 41.67 | 22.57 | 29.17 | 10.16 |
| Paper birch (*Betula papyrifera*) | 2 | - | 60.00 | - | 18.18 | 100.00 | 21.82 |
| Quaking aspen (*Populus tremuloides*) | 14 | 6.25 | 36.81 | 25.00 | 33.57 | 68.75 | 29.62 |
| Red maple (*Acer rubrum*) | 8 | 10.00 | 50.40 | 70.00 | 39.58 | 20.00 | 10.03 |
| Sugar maple (*Acer saccharum*) | 31 | 6.06 | 57.54 | 84.85 | 35.99 | 9.09 | 6.47 |
| Yellow birch (*Betula alleghaniensis*) | 3 | 33.33 | 55.17 | 33.33 | 37.93 | 33.33 | 6.90 |
| Unidentified pine *spp* (*Pinus spp*) | 1 | - | | - | - | 100.00 | 100.00 |
| Unidentified aspen *spp* (*Populus spp*) | 2 | – | 5.71 | – | – | 100.00 | 94.29 |
| Unknown *spp* | 1 | – | 33.33 | – | – | 100.00 | 66.67 |

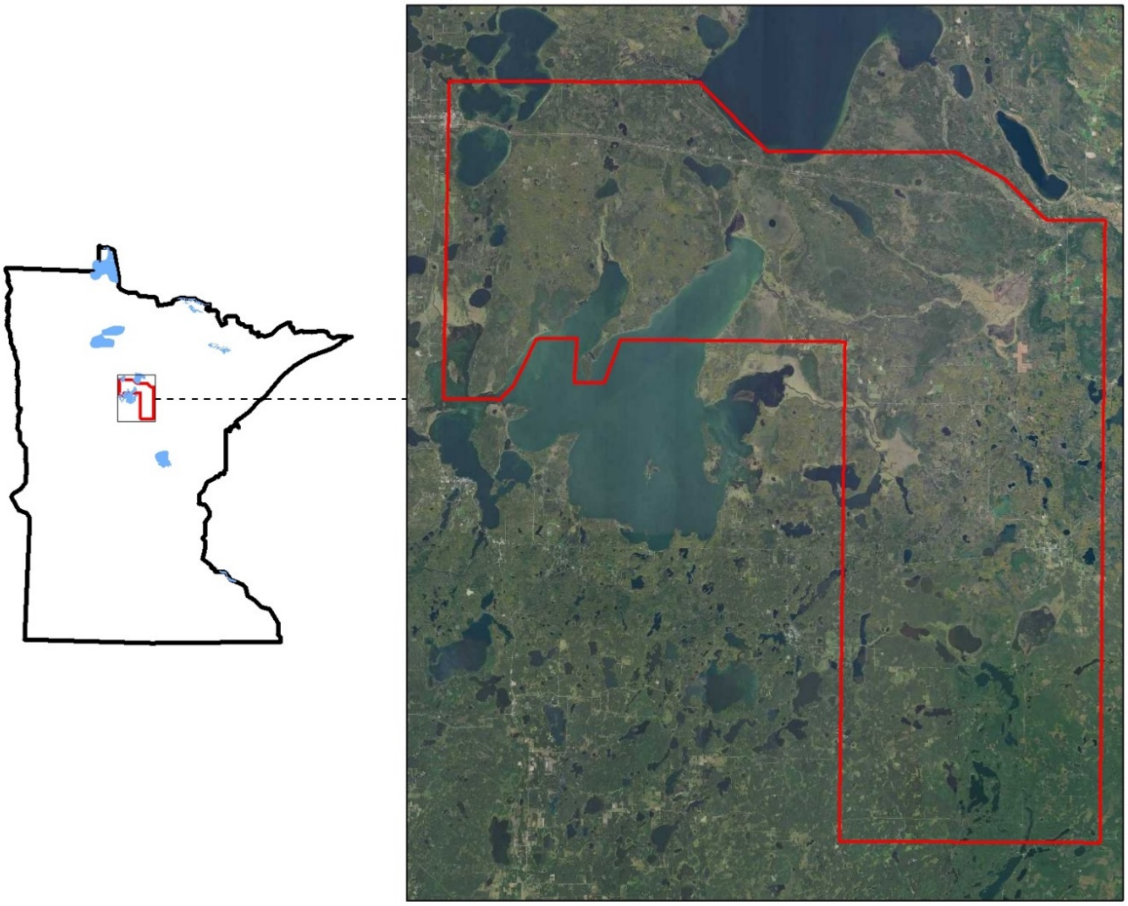

Figure 1. Location of the wood duck-LiDAR project in Cass County, Minnesota, USA.

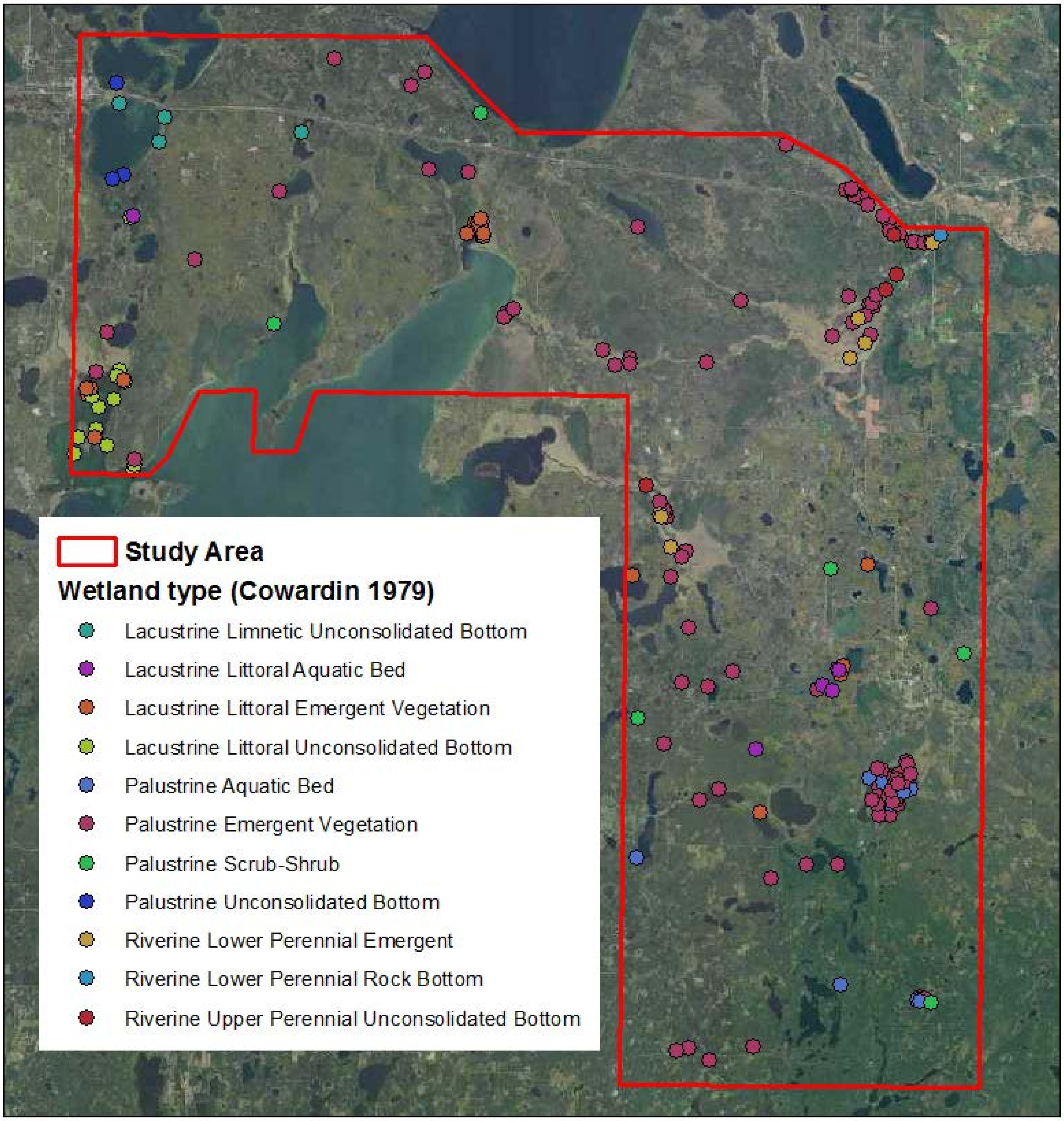


Figure 2. Location of wetland plots of different National Wetland Inventory classes (Cowardin et al. 1979) surveyed in in Cass County, Minnesota, USA during Summer and Fall 2016.

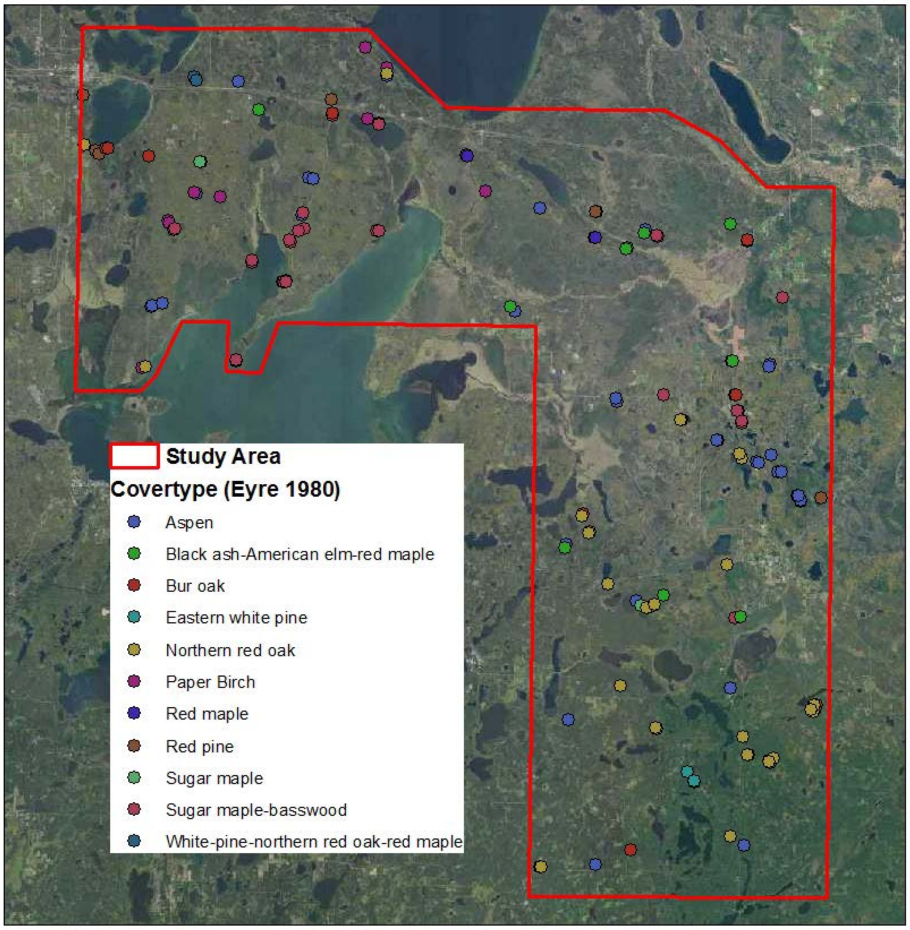


Figure 3. Location of forest plots of different cover types (Eyre 1980) that were surveyed in Cass County, Minnesota, USA during Fall 2016 and Spring 2017.

Appendix 1. Crosswalk between the Forest Cover Types of Eyre (1980) and the more general forest types used to classify stands from GIS databases.

| General forest type | Eyre (1980) forest cover type |
|---|---|
| Aspen – birch | Aspen (16) |
| | Paper birch (18) |
| Mixed conifer | Red pine (15) |
| | White pine – northern red oak – Red maple (20) |
| | Eastern white pine (21) |
| Northern hardwood | Sugar maple – basswood (26) |
| | Sugar maple (27) |
| Oak | Norther pin oak (14) |
| | Bur oak (42) |
| | White oak (53) |
| | Northern red oak (55) |
| | Black oak (110) |
| Lowland hardwood | Black ash – American elm – red maple (39) |
| | Silver maple – American elm (62) |
| | Red Maple (108) |

Appendix 2. Numerical codes used to classify the health status of trees (from Thomas 1979).

| Health status | Description |
|---|---|
| 1 | Live tree that has no defects or injuries that will threaten its long-term health. |
| 2 | Live tree with defects that contribute to a decline in health. Indicators may include decay on the bole, fungi, large dead limbs, and substantial cracks. |
| 3 | Recently dead tree with bark, limbs, and twigs substantially intact. |
| 4 | Dead tree that has lost some limbs and almost all twigs. |
| 5 | Dead tree that has lost most limbs and all twigs... |
| 6 | Dead tree with a broken top and hard bole wood. |
| 7 | Dead tree with a broken top and soft bole wood. |