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 during recent decades. We initiated this study to develop methodologies to predict the locations and monitor spatiotemporal changes in the areal extent of wood duck breeding complexes. Specifically, we want to use Light Detecting and Ranging (LiDAR) data to identify multiple habitat components and to monitor future changes in these components. 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 to accurately estimate the population variance of stems that may have suitable nesting cavities. 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 Geographic Information System (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 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 677 wetland plots during Summer 2016 and 2017, and forest plots during Fall 2016, Spring 2017, and Fall 2017. We assigned a habitat classification to 14 types of dominant emergent cover and 6 types of loafing structures during wetland surveys, and 12 cover types to forest plots during nesting habitat surveys, and measured several other habitat variables in each survey. We examined 7,357 trees during forest surveys, and classified 162 cavities as suitable and 88 as marginally suitable for nesting wood ducks. Because data were sparse for relatively large DBH trees of multiple species ($\geq$40 cm for early and mid-successional species, $\geq$50 cm for late successional species), we will survey more forest plots with the intent of obtaining sufficient data to more reliably estimate the proportion of large-DBH trees with suitable cavities.

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Flights to collect LiDAR data originally scheduled to occur during Fall 2016 were postponed until Fall 2017. Thus, we cannot begin associating ground-level aquatic and forest vegetation measurements to LiDAR data until Summer 2018.

We will begin analyzing Forest Inventory and Analysis data to ascertain the abundance and trend of trees in several species-, DBH-, and perhaps health-status classes in our study area from 1977 until the current time. We will use this trend information and empirical knowledge of the proportion of trees in each of these classes with suitable nesting cavities to make inferences about the temporal change in abundance of suitable nesting cavities.

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 during recent decades. 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, 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 Minnesota Department of Natural Resources (MNDNR) managers that harvesting relatively large-DBH trees of economically valuable species [e.g., aspen (*Populus* spp.)] 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).

Thus, there is a need 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 and precision 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 such methodologies so that long-term trends in habitat characteristics could be analyzed in the future.

It is unlikely that all of these needs can be met with a single methodology or existing dataset. 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 in Minnesota 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) and perhaps other species that use similar habitat components. 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 multiple sources of data (e.g., empirical field data, FIA, LiDAR, and associated remote sensing imagery). 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 Geographic Information System (GIS)] layers, aerial photographs). This evaluation will include determining the accuracy with which each component can be predicted with LiDAR 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

Study Area

The primary study area encompasses 254,051 ha in northeastern Cass County, Minnesota (Figure 1). Parts of Chippewa Plains, Pine Moraines-Outwash Plains, and St. Louis Moraine Ecological Subsections (Hanson and Hargrave 1996) occur within this area. This study area occurs in BCR 12.

Wetland Surveys

In 2016, we used the available wetland spatial data from NWI (Cowardin et al. 1979, MNDNR 2009) to select 260 sampling plots in the study area. We stratified wetlands contained in the NWI GIS layer by NWI system, subsystem, and class (hereafter, wetland types). Unfortunately, information about NWI subclasses was not available for many wetland types. We calculated the proportion of the wetlands in the study area composed of 9 major wetland types: Lacustrine-Littoral-Emergent Vegetation (0.004), Palustrine-Emergent Vegetation (0.102), Lacustrine-Limnetic-Unconsolidated Bottom (0.522), Lacustrine-Littoral-Unconsolidated Bottom (0.020), Palustrine-Forested (0.191), Palustrine-Shrub Scrub (0.130), Palustrine-Unconsolidated Bottom (0.026), Riverine-Upper Perennial-Unconsolidated Bottom (0.003), and Riverine-Lower Perennial-Unconsolidated Bottom (0.002). We then randomly selected 260 2- X 2-m plots from these wetland types: 60 plots from both the Lacustrine-Littoral-Emergent Vegetation and Palustrine-Emergent Vegetation types, and 20 plots each from the remaining 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 difficult to identify from LiDAR signatures. We also specified that plots had to be ≥100 m apart to reduce the likelihood of non-independence among these sampling units (i.e., sampling plots with similar vegetation structure).

Many relatively small, isolated wetlands were not delineated in the NWI GIS 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 selected wetland if it 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 plots that initially appeared accessible.

We changed our approach to selecting wetland and plot locations for the 2017 field season to reduce number of plots located in wetland habitats not likely to be used by wood duck broods and to increase sampling efficiency. Specifically, we selected wetlands classified as either inundation or intermittent water; lake, pond or reservoir; river or stream; shallow water; or wetland from the MNDNR Hydrography GIS layer (MNDNR 2015) that either (1) had a public boat access site or (2) were on public lands and ≤100 m from both a public road and water feature. From sites that met these criteria, we then randomly selected ≤5 sampling locations per wetland that were ≥4.05 ha, with these points ≥100 m apart.

Because potential loafing sites were encountered infrequently at randomly selected plots during 2016, we chose to nonrandomly select and measure a variety of these structures as encountered so that we could observe the LiDAR signature for each. We also documented and measured these structures at randomly selected points during 2017.

We navigated to the approximate location of each plot center using a Garmin Montana Global Positioning System (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 to the nearest vegetated location within the wetland because the former habitat 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 the plot, and if so, provided a count of individuals in each cohort (male, female, brood, unknown). We did not adjust wood duck counts for detectability. 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 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 location data for each plot center using a Geneq Sx Blue II GPS unit (15–20 cm accuracy in open habitats when data were obtained at 1 reading / second for 1 minute), 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 5 habitat classes [emergent, floating leaf, ground, 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), and measured 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 closure with a spherical densiometer, 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 dm 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., forest cover type, stand age and location) of public forest lands from Cass County, State of Minnesota, and United States Department of Agriculture (USDA) Forest Service databases. There were slight differences in the manner that these agencies classified forest cover types, so we aggregated appropriate stands (i.e., likely to be used by nesting wood ducks) from each database into 5 basic cover types: aspen-birch, lowland hardwoods, mixed conifer-hardwood, northern hardwoods, and oak. We identified stands on public lands that were likely old enough to have developed cavities suitable for use by nesting wood ducks (i.e., aspen-birch ≥50 years, all other stand types ≥80 years), and constrained the potential sample to stands of these ages or greater. We then stratified stands by cover type and randomly selected 300 forest stands (60 stands of each of the 5 types) to be surveyed.

We then selected plots within these stands with the stipulations that (1) plot centers must be both ≥50 m apart and ≥30 m from the nearest stand boundary and (2) ≤2 plots per stand could be established. We used these selection criteria to increase the likelihood that plots adequately represented the diversity of vegetation structure of each forest type, thus facilitating the development of biologically realistic LiDAR models. We then randomly selected *n*=563 plots to be surveyed. It was necessary to remove 19 plots from the sample because of nearby heritage sites or scheduled timber harvests (i.e., interpretation of habitat characteristics would be confounded if 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 radius circular plots (0.126 ha) around those points. Plots located near ecotones not indicated on available GIS layers were moved sufficiently into the stand interior as to avoid potential edge effects on 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, proportion of visible sky obscured by cloud cover (0.1 increments), and proportion of tree boles covered by snow or obscured by 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 classified the stand structure following USDA Forest Service methodology (2014; 5 classes: single story, two-storied, multi-storied, mosaic, unknown/unassessable). We assigned all plots to 1 of the 5 general forest cover types (Table 2) and to an Eyre (1980) cover type.

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 the DBH to be measured (i.e., ≥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 that were not adjusted for declination) from plot center, health status (following Thomas 1979, Appendix 1), and crown class (5 classes: remnant, dominant, codominant, intermediate, overtopped; USDA Forest Service 2014).

All field crew members then used binoculars to conduct a preliminary search of each tree ≥22.0 cm DBH in the plot to identify cavities that potentially were suitable for nesting by wood ducks. During the initial search, personnel ascertained whether the entrance dimensions likely were sufficient to permit a wood duck to pass through (i.e., 6 x 6 cm; Zwicker 1999, cited in Denton et al. 2012*b*) and the bottom of cavity entrance was high enough to be used by nesting wood ducks [i.e., ≥0.6 m above ground level (Strom 1969)]. When a potentially suitable cavity was encountered, we used a Pyle Model PLCM22IR remote camera attached via a stiff, braided wire to a 15.2 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 (i.e., 6 x 6 cm) 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: horizontal depth (approximately 10 cm from inner edge 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, 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), 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 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. A cavity was classified as marginal if it was 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 was not met or if there was 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). We classified the reason that a cavity was unsuitable based on the order that structural restrictions would have been encountered as a wood duck entered a cavity (i.e., entrance dimensions, followed by horizontal depth, vertical depth, and finally, dimensions and other characteristics of the platform). 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), Leupold RX-800i rangefinder (±0.1 m), or Suunto clinometer (±0.5 m).

LiDAR Data Collection

The MNDNR Resource Assessment Program (RAP) originally planned to have LiDAR and associated remote sensing data collected during aerial flights conducted by a vendor during Fall 2016, but these efforts did not occur until Fall 2017. We anticipate the data will be available for analyses in Summer 2018.

Forest Inventory and Analysis (FIA)

We plan to conduct an analysis of FIA data to gain an understanding of temporal changes in the potential number of nest trees of common tree species (American basswood, bigtooth aspen, northern red oak, paper birch, red maple, quaking aspen, and sugar maple) that are common in our study area and the Minnesota portion of the Bird Conservation Region (BCR) 12 (Boreal Hardwood Transition, North American Bird Conservation Initiative 2018) from 1977 until the present. We will use this trend information and empirical knowledge of the proportion of trees in each species-, DBH-, and perhaps health-status class with suitable nesting cavities to make inferences about the temporal change in abundance of suitable nesting cavities.

STUDY AREA

The primary study area encompasses 254,051 ha in northeastern Cass County, Minnesota (Figure 1). Parts of Chippewa Plains, Pine Moraines-Outwash Plains, and St. Louis Moraine Ecological Subsections (Hanson and Hargrave 1996) occur within this area. This study area occurs in BCR 12.

RESULTS

Wetland Surveys

We conducted surveys at 677 randomly selected wetland plots during the late summer and early fall of 2016 and 2017 (Table 1, Figure 2). We classified the dominant emergent cover as alder (0.7%), blue joint grass (0.6%), bur reed (0.3%), cattail *spp* (6.9%), ericaceous shrub (2.2%), floating leaf (18.0%), phragmites *spp* (2.5%), rush *spp* (20.7%), reed canary grass (2.2%), sedge *spp* (8.3%), willow (0.4%), wild rice (31.3%), other vegetation (0.9%), and none (4.9%). We also documented trees at 10 plots (1.5%), with canopy coverage ranging from 0.05 to 0.85. We observed that 12.3% of randomly selected plots were modified by beaver, wood ducks were present ≤100 m of 9.6% plots, and 4.4% of plots had potential wood duck loafing sites.

The potential loafing structures identified in randomly selected plots were 2 beaver lodges, 6 floating vegetation mats, 4 small islands or tussocks, 14 patches of bare or lightly vegetated shore, 5 logs or stumps, and 1 muskrat house in the randomly selected plots. We observed 6 beaver lodges, 2 logs or stumps, and 1 muskrat house in the 15 non-randomly selected plots.

Forest Surveys

We surveyed 213 forest plots during Fall 2016, Spring 2017, and Fall 2017 (Figure 3). The percentages of these plots located on United States Forest Service (USFS) Chippewa National Forest, Cass County, and State of Minnesota lands were 75%, 15%, and 10%, respectively. When using the Eyre (1980) approach to classify the forest cover types of surveyed plots, we observed that these units primarily were sugar maple-basswood, aspen, and northern red oak (Table 2). When assigning the more general forest-cover type to plots, the most commonly surveyed types were aspen-birch, northern hardwoods, and oak (Table 2). Interestingly, our classifications of general forest type differed from that of land-management agency classifications on 37% of plots.

A total of 7,357 trees of 27 species were measured and inspected for cavities (Table 3). We more closely examined 969 total cavities in 727 of these trees with the remote camera-system (i.e., many trees had multiple cavities). The majority of these cavities were classified as unsuitable for nesting by wood ducks (66%), and the remainder were classified as suitable (17%), marginally suitable (9%), or of unknown suitability (9%). The reasons many cavities were considered unsuitable were: insufficient vertical depth (44%), entrance dimensions too small (21%), insufficient horizontal depth (19%), insufficient platform dimensions (13%), excessive debris (3%), and too deep or hollow to the ground (1%). The primary sources of cavity creation of those structures considered suitable were: broken limb (40%), split (20%), broken top (17%), woodpecker (15%), decay or rot (2%), other (4%), and unknown (1%).

Preliminary results suggest that the proportion of trees with suitable cavities varied by species, DBH, and health status (Tables 4 and 5). It appears that the greatest proportion of suitable cavities were present in sugar maple (*Acer saccharum*), northern red oak (*Quercus rubra*) and American basswood (*Tilia americana*, Table 4). The proportion of trees with suitable cavities appeared to be generally greater in larger DBH classes (Table 3). More specifically, the average DBH of all trees sampled was 33.1 cm (range: 22.0–94.3 cm), but that of trees with suitable cavities was 42.5 cm (range: 22.8–73.6 cm). Generally, there was a lower proportion of individual trees with suitable cavities in live, healthy trees (health status 1) than in live, health impacted trees (health status 2) and dead trees (health status 3–7, Table 5). Specifically, the percentage of surveyed trees in each health status class (see Appendix 1 for criteria) was as follows: 1=64%, 2=23%, 3=1%, 4=1%, 5=1%, 6=7%, and 7=3%. In contrast, the percentage of trees with suitable cavities in each of these classes was: 1=21%, 2=42%, 3=2%, 4=2%, 5=5%, 6=19%, and 7=9%. The mean height of suitable cavities was 7.5 m (range: 1.0–15.0 m).

LiDAR Data Collection

Aerial single-photon LiDAR data and associated remote sensing imagery were collected during Fall 2017. These data were collected during peak fall color, usually at about 30 return pulses / m^2 (minimum of 12, up to 40–50; J. Corcoran, MNDNR, unpublished data). The quality of green LiDAR data was not as good as anticipated. Thus, identifying the presence/absence and density of submergent vegetation and depth of water in relatively shallow locations likely will not be discernable.

FIA Analysis

We have not yet analyzed FIA data, but plan to complete this portion of the project during the upcoming fiscal year.

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 collection that NWI classifications of some plots were incorrect, which we attribute to a combination of misclassification of wetland habitats, habitat changes since the original classification, and projection error. Further, the currently available NWI GIS layer often classifies wetlands only to the level of class, which provides little information regarding vegetation type or structure. Thus, it was not possible to select plots based on subclass or vegetation type and structure. Such limitations of available data contributed to an allocation of sampling locations that were not balanced among the 14 types of emergent covers observed. It is likely, however, that the emergent covers sampled were representative of those available in the study area.

Fortunately, we were able to collect data for a substantial number of plots (1) with structurally similar vegetation types that are difficult to distinguish from aerial photographs (i.e., wild rice v rush *spp*.; D. Dustin, MNDNR Fisheries, personal communication), (2) dominated by the types of aquatic vegetation that should begin to subside and thus change structure (e.g., floating-leaf plants, wild rice) approximately when LiDAR imagery was obtained (i.e., late September and October), (3) with vegetation types that may be sparse, and (4) with vegetation types that frequently occur in a mix of other types of vegetation (e.g., floating-leaf plants). We anticipate that a substantial amount of data will be needed to develop reliable LiDAR signatures of such sites. Presumably, wetland habitats with no surface vegetation should have a rather simple and readily identifiable LiDAR signature.

Although identifying potential loafing sites for wood ducks using LiDAR imagery was a secondary objective, we were able to locate 6 types of these structures in randomly selected plots and 3 in non-randomly selected plots. These structures likely are a somewhat important habitat component to wood ducks (McGilvery 1968).

Forest Surveys

Although sugar maple, northern red oak, and basswood have relatively high proportions of suitable cavities, aspen species (*Populus* spp.) also may be an important source of this type of structure, given the large number of stems in the contemporary landscape (Minnesota Forest Resources Council 2017) and relatively intermediate proportion of stems with suitable cavities in these species (Table 3). Interestingly, quaking aspen (*Populus tremuloides*), American elm

(*Ulmus americana*), and sugar maple were important species for nesting wood ducks in north-central Minnesota, but American basswood also was used (Gilmer et al. 1978).

Wood ducks select nesting trees that on average have a larger diameter than that observed in our study area. We observed that trees with suitable cavities had a mean DBH of 42.5 cm (range: 22.8–73.6 cm), but that of nesting trees across 12 studies conducted in eastern North America was 58.5 cm (Soulliere 1990) and 47 cm in north-central Minnesota (Gilmer et al. 1978).We plan to compare our proportions of suitable cavities in each tree species-, DBH-, and health status-class to those of other published investigations, but anticipate that there will be differences in the same classes among these studies. This variation may be attributable in-part to spatial differences in those variables (e.g., disease, insects, animal populations, soil conditions, weather patterns) that contribute to tree damage and eventually cavity formation (Morin et al. 2016).

With the exception of Lowney and Hill (1989), we have examined more trees for cavities suitable for nesting wood ducks than any other published studies of which we are aware (see Soulliere 1990, Bellrose and Holm 1994, Denton et al. 2012*a*, *b*). Despite the large sample size of stems examined, we observed relatively few large-diameter trees of all species in our plots. Such sparse data will limit our ability to develop models that reliably predict the proportion of large diameter trees with suitable cavities. It is important to obtain a sufficient sample size of large diameter trees so that models can be developed to accurately predict the proportions of such trees with suitable nesting cavities, given that wood ducks frequently use large diameter trees for nesting (e.g., Gilmer et al. 1978, Soulliere 1990, Bellrose and Holm 1994). Therefore, we will explore ways to select and survey more plots that are likely to contain relatively large diameter trees during Spring 2018.

Beyond developing or training this predictive model, we also would like to generate an additional dataset to test the predictive ability of the initial model (sensu Fortmann-Roe 2012). We are seeking additional funds to conduct further field surveys during Fall 2018 that will be used for the model-testing dataset.

It is possible that the forest and cavity properties (e.g., species composition, mean age, cavity density) we observed on the public lands that we surveyed were different than those on private land, perhaps because of differences in management practices and site characteristics. However, the use of LiDAR data, remote sensing imagery, and FIA data should permit us to discern whether such ownership-based differences in forest and cavity characteristics exist. Alternatively, we could obtain permission to conduct forest surveys on private lands within the study area to determine whether forest and cavity characteristics are similar to those on public lands, but it probably would be time consuming to obtain enough data to detect significant differences between the 2 forest ownership classes.

Forest Inventory and Analysis (FIA)

Our field crews and the databases of natural resource agencies differed in the classification of general forest type of 37% of our plots. This discrepancy may be attributed to misclassification, or changes to these stands caused by natural disturbance, logging, and forest succession that had occurred since the time of classification. Regardless, substantial misclassification of stand type in existing databases could confound our ability to estimate of the number *of suitable cavities* across the landscape (i.e., the density of cavities appears to be associated with stand type). Intuitively, a reliable estimate of the abundance of suitable nesting cavities is more likely to be generated using empirical cavity data and either FIA data or LiDAR data and associated remote imagery.

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Table 1. The National Wetland Inventory classification and sample size of plots surveyed in Cass County, Minnesota, USA during 2016–2017.

National Wetland Inventory system, subsystem, class and subclass of sampled plots [a, b]	Number of plots surveyed
Lacustrine limnetic unconsolidated bottom unknown	1
Lacustrine limnetic unconsolidated bottom sand	3
Lacustrine limnetic aquatic bed rooted vascular	1
Lacustrine littoral aquatic bed unknown	1
Lacustrine littoral aquatic bed rooted vascular	60
Lacustrine littoral aquatic bed floating vascular	5
Lacustrine littoral emergent nonpersistent	233
Lacustrine littoral unconsolidated bottom unknown	12
Lacustrine littoral unconsolidated bottom sand	1
Lacustrine littoral unconsolidated shore unknown	1
Palustrine aquatic bed floating vascular	13
Palustrine aquatic bed rooted vascular	43
Palustrine emergent nonpersistent	130
Palustrine emergent persistent	93
Palustrine emergent *Phragmites australia*	9
Palustrine forested broad-leaved deciduous	1
Palustrine scrub-shrub broad-leaved deciduous	20
Palustrine scrub-shrub broad-leaved evergreen	1
Palustrine unconsolidated bottom sand	3
Palustrine unconsolidated shore organic	1
Palustrine unconsolidated shore sand	5
Riverine lower perennial unconsolidated bottom unknown	2
Riverine lower perennial unconsolidated bottom mud	3
Riverine lower perennial rock bottom unknown	1
Riverine lower perennial emergent nonpersistent	28
Riverine upper perennial aquatic bed rooted vascular	2
Riverine upper perennial emergent nonpersistent	4

[a] Wetlands in the palustrine system are not assigned a subsystem classification in the National Wetland Inventory classification scheme.
[b] The National Wetland Inventory subclasses of some plots were classified as unknown if distinguishing characteristics were not discernable in the field.

Table 2. Crosswalk between the Forest Cover Types of Eyre (1980) and the more general forest types used to classify stands from GIS databases, and sample size of forest plots surveyed by Eyre (1980) cover types in Cass County, Minnesota, USA during 2016–2017.

General forest type	Eyre (1980) forest cover type	Number of plots surveyed
Aspen-birch	Aspen (16)	45
	Paper Birch (18)	20
Mixed conifer	Balsam fir (5)	1
	Eastern white pine (21)	3
	Red pine (15)	12
	White pine–northern red oak–red maple (20)	1
Northern hardwood	Sugar maple (27)	2
	Sugar maple–basswood (26)	59
Oak	Bur oak (42)	11
	Northern red oak (55)	32
Lowland hardwood	Black ash–American elm–red maple (39)	19
	Red maple (108)	8

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 that no trees were sampled or standard errors were not estimable for a tree species-DBH class.

	DBH class (cm)						
Tree species	22–29	30–39	40–49	50–59	60–69	70–79	≥80
American basswood (*Tilia americana*)	522 (0.006, 0.003)	381 (0.016, 0.006)	168 (0.048, 0.016)	51 (0.196, 0.056)	19 (0.105, 0.070)	1 (0,–)	1 (0,–)
American elm (*Ulmus americana*)	16 (0,–)	2 (0,–)	1 (0,–)	–	–	–	–
Balsam fir (*Abies balsamea*)	105 (0,–)	18 (0,–)	3 (0,–)	–	–	–	–
Balsam poplar (*Populus balsamifera*)	7 (0,–)	17 (0,–)	6 (0,–)	1 (0,–)	–	–	–
Bigtooth aspen (*Populus grandidentata*)	182 (0,–)	154 (0.013, 0.009)	65 (0.031, 0.021)	23 (0.043, 0.042)	11 (0.091, 0.087)	3 (0,–)	–
Black ash (*Fraxinus nigra*)	214 (0,–)	55 (0,–)	14 (0,–)	3 (0,–)	1 (0,–)	–	–
Black cherry (*Prunus serotina*)	1 (0,–)	–	–	–	–	–	–
Black spruce (*Picea mariana*)	1 (0,–)	–	–	–	–	–	–
Box elder (*Acer negundo*)	3 (0,–)	1 (0,–)	1 (0,–)	–	–	–	–
Bur oak (*Quercus macrocarpa*)	162 (0.006, 0.006)	91 (0,–)	25 (0,–)	10 (0,–)	8 (0.250, 0.153)	–	–
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*)	18 (0,–)	31 (0,–)	34 (0, –)	8 (0.056, 0.054)	14 (0,–)	4 (0.250, 0.217)	5 (0, –)
Green ash (*Fraxinus pennsylvanica*)	129 (0.008, 0.008)	63 (0,–)	27 (0,–)	8 (0,–)	1 (0,–)	–	–
Hackberry (*Celtis occidentalis*)	3 (0,–)	1 (0,–)	–	–	–	–	–
Jack pine (*Pinus banksiana*)	12 (0,–)	10 (0,–)	3 (0,–)	–	–	–	–
Northern pin oak (*Quercus ellipsoidalis*)	6 (0,–)	7 (0,–)	–	–	–	–	–
Northern red oak (*Quercus rubra*)	278 (0.007, 0.005)	315 (0.041, 0.011)	153 (0.039, 0.016)	31 (0.097, 0.053)	14 (0.143, 0.094)	1 (0,–)	–
Northern white-cedar (*Thuja occidentalis*)	14 (0,–)	15 (0,–)	4 (0,–)	2 (0,–)	–	–	–
Paper birch (*Betula papyrifera*)	444 (0.005, 0.003)	288 (0.010, 0.006)	46 (0,–)	2 (0,–)	1 (0,–)	–	–
Quaking aspen (*Populus tremuloides*)	371 (0,–)	447 (0.016, 0.006)	252 (0.060, 0.015)	51 (0.098, 0.042)	6 (0,–)	–	–
Red maple (*Acer rubrum*)	353 (0.008, 0.005)	167 (0.024, 0.012)	22 (0.091, 0.061)	3 (0.333, 0.272)	3 (0.667, 0.272)	–	–
Red pine (*Pinus resinosa*)	90 (0,–)	181 (0,–)	106 (0,–)	42 (0,–)	14 (0,–)	3 (0,–)	1 (0,–)
Sugar maple (*Acer saccharum*)	393 (0.010, 0.005)	218 (0.055, 0.015)	103 (0.175, 0.037)	35 (0.143, 0.059)	7 (0.571, 0.187)	–	1 (0,–)

White spruce (*Picea glauca*)	12 (0,–)	9 (0,–)	2 (0,-)	–	–	–	–
Yellow birch (*Betula alleghaniensis*)	20 (0.050, 0.049)	12 (0.083, 0.080)	16 (0.062, 0.060)	3 (0,–)	–	1 (0,–)	–
Unidentified ash *spp* (*Fraxinus spp*)	5 (0,–)	–	1 (0,–)	–	–	–	–
Unidentified pine *spp* (*Pinus spp*)	1 (0,–)	3 (0.333, 0.272)	–	–	–	–	–
Unidentified aspen *spp* (*Populus spp*)	7 (0,–)	16 (0.125, 0.083)	10 (0, –)	4 (0,–)	–	–	–
Unknown *spp*	9 (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*)	15.54	18.67	17.18
American elm (*Ulmus americana*)	0.26	–	–
Balsam fir (*Abies balsamea*)	1.71	–	–
Balsam poplar (*Populus balsamifera*)	0.42	–	–
Bigtooth aspen (*Populus grandidentata*)	5.95	4.00	3.52
Black ash (*Fraxinus nigra*)	3.90	–	0.88
Black cherry (*Prunus serotina*)	0.01	–	–
Black spruce (*Picea mariana*)	0.01	–	–
Box elder (*Acer negundo*)	0.07	–	–
Bur oak (*Quercus macrocarpa*)	4.02	1.33	1.76
Eastern cottonwood (*Populus deltoides*)	0.01	–	–
Eastern hophornbeam (*Ostrya virginiana*)	0.01	–	–
Eastern larch (*Larix laricina*)	0.03	–	–
Eastern white pine (*Pinus strobus*)	1.69	1.33	1.76
Green ash (*Fraxinus pennsylvanica*)	3.10	0.67	0.44
Hackberry (*Celtis occidentalis*)	0.05	–	–
Jack pine (*Pinus banksiana*)	0.34	–	–
Northern pin oak (*Quercus ellipsoidalis*)	0.18	–	–
Northern red oak (*Quercus rubra*)	10.77	16.00	13.22
Northern white-cedar (*Thuja occidentalis*)	0.48	–	–
Paper birch (*Betula papyrifera*)	10.62	3.33	4.41
Quaking aspen (*Populus tremuloides*)	15.32	16.00	17.18
Red maple (*Acer rubrum*)	7.45	6.67	9.25
Red pine (*Pinus resinosa*)	5.94	–	–
Sugar maple (*Acer saccharum*)	10.29	27.33	25.11
White spruce (*Picea glauca*)	0.31	–	–
Yellow birch (*Betula alleghaniensis*)	0.71	2.00	2.20
Unidentified ash *spp* (*Fraxinus spp*)	0.08	–	–
Unidentified pine *spp* (*Pinus spp*)	0.05	0.67	0.44
Unidentified aspen *spp*. (*Populus spp*)	0.50	1.33	2.20
Unknown spp	0.18	0.67	0.44

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 (described in Appendix 1) were assigned to broader classifications as follows: healthy (1), health-impacted (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 healthy trees (%)	Healthy trees (%)	Cavities in health-impacted trees (%)	Health-impacted trees (%)	Cavities in dead trees (%)	Dead trees (%)
American basswood (*Tilia americana*)	29	41.38	85.48	37.93	10.24	20.69	4.29
Bigtooth aspen (*Populus grandidentata*)	6	-–	60.27	16.67	23.29	83.33	16.44
Bur oak (*Quercus macrocarpa*)	3	66.67	84.80	33.33	13.51	-–	1.69
Eastern white pine (*Pinus strobus*)	2	-–	65.32	-–	16.13	100.00	18.55
Green ash (*Fraxinus pennsylvanica*)	1	-–	81.14	-–	14.91	100.00	3.95
Northern red oak (*Quercus rubra*)	26	26.92	66.54	42.31	23.36	30.77	10.10
Paper birch (*Betula papyrifera*)	5	-–	60.82	40.0	19.97	60.00	19.21
Quaking aspen (*Populus tremuloides*)	27	3.70	34.07	40.74	37.53	55.56	28.39
Red maple (*Acer rubrum*)	12	8.33	50.73	66.67	39.23	25.00	10.04
Sugar maple (*Acer saccharum*)	43	9.30	61.03	76.74	32.50	13.95	6.47
Yellow birch (*Betula alleghaniensis*)	3	33.33	59.62	33.33	32.69	33.33	7.69
Unidentified pine *spp* (*Pinus spp*)	1	-–	-–	-–	-–	100.00	100.00
Unidentified aspen *spp* (*Populus spp*)	2	-–	5.41	-–	-–	100.00	94.59
Unknown *spp*	2	-–	38.46	-–	-–	100.00	61.54

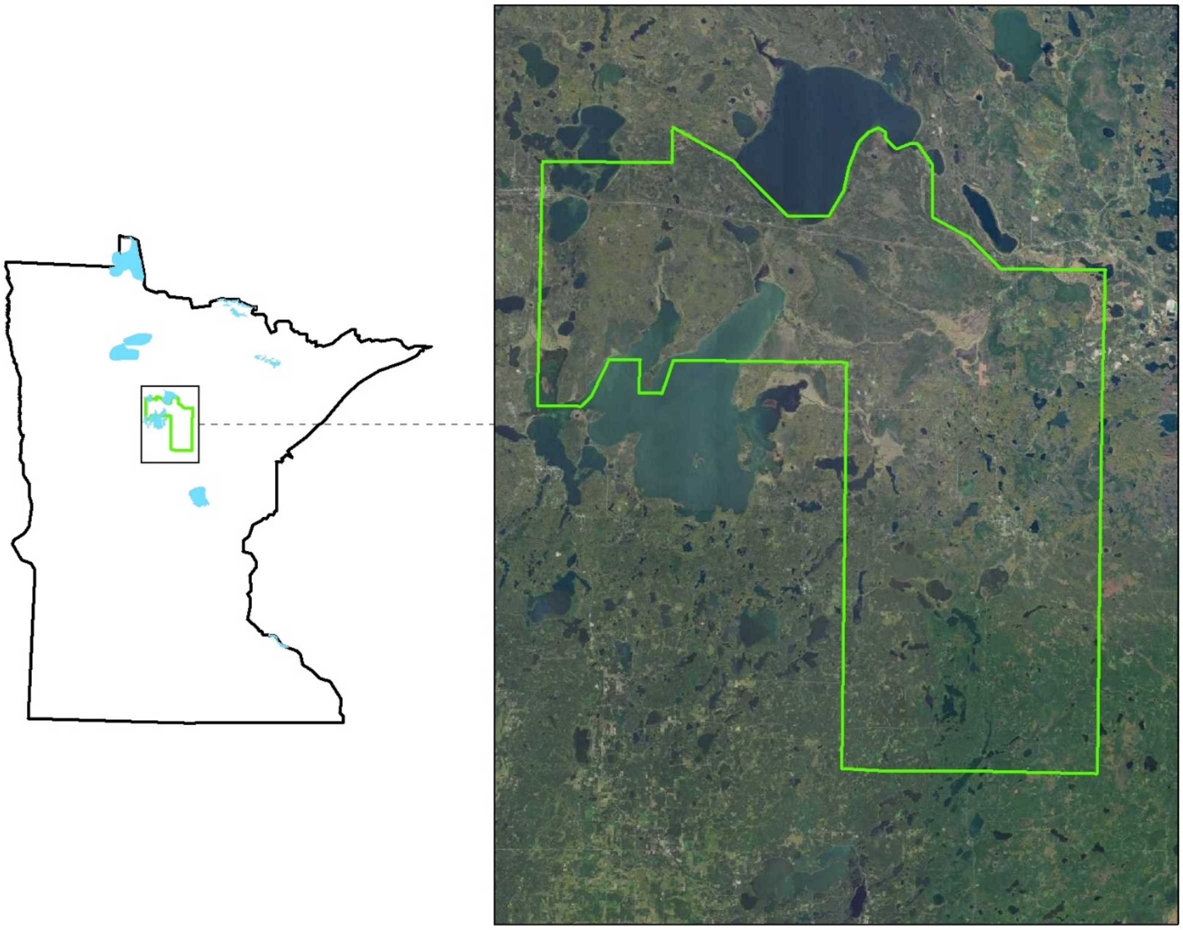

Figure 1. Location of the wood duck-LiDAR project in Cass County, Minnesota, USA.

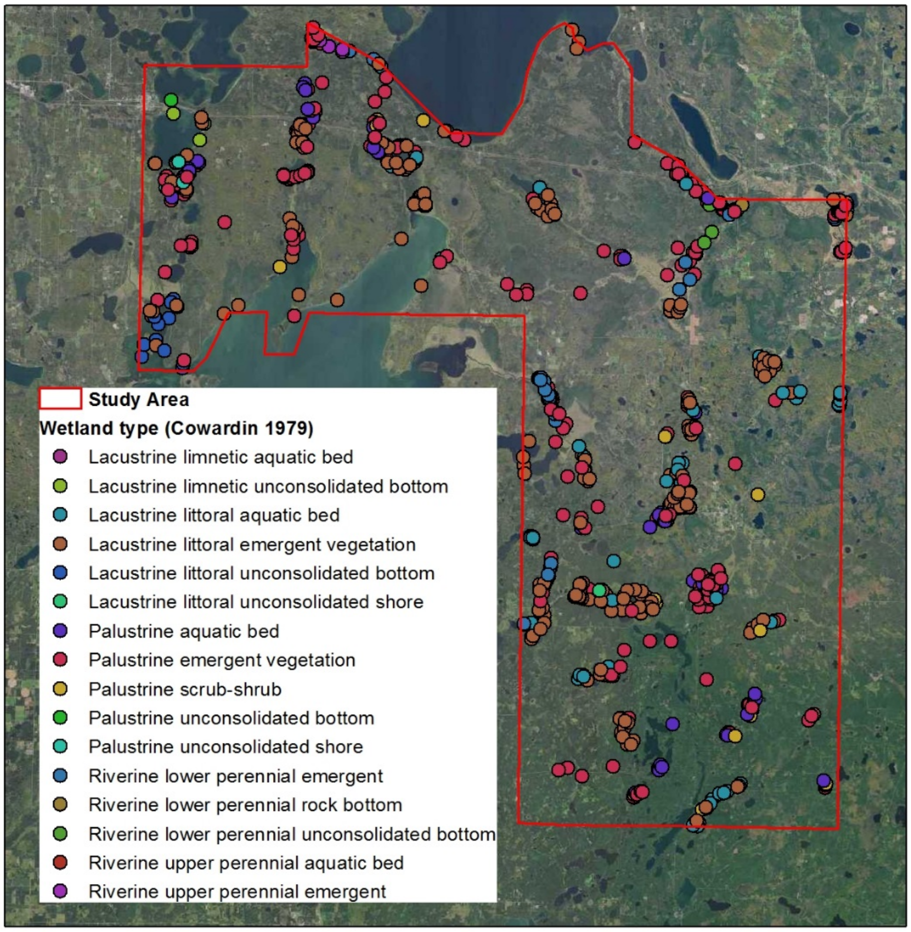

Figure 2. Location of wetland plots of different National Wetland Inventory classes (Cowardin et al. 1979) surveyed in in Cass County, Minnesota, USA during Summer and Fall 2016 and 2017.

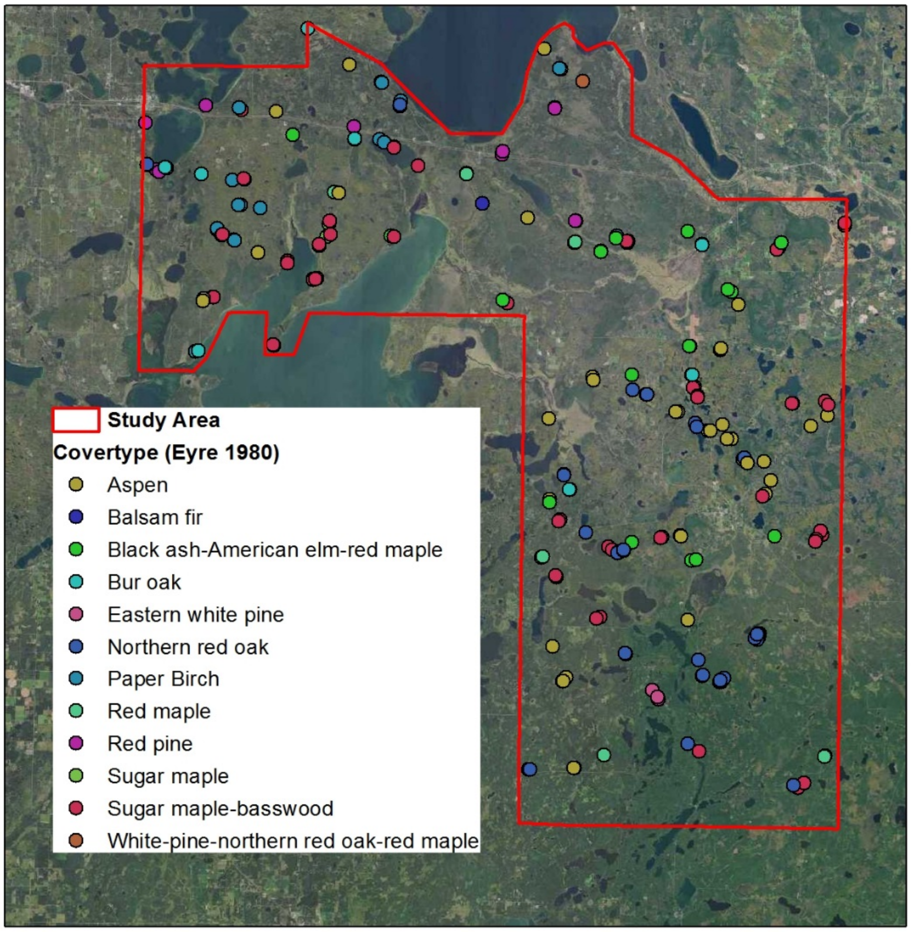

Figure 3. Location of forest plots of different cover types (Eyre 1980) that were surveyed in Cass County, Minnesota, USA during Fall 2016, Spring 2017, and Fall 2017.

Appendix 1. Numerical codes used in the classification of 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.