ANALYZING VEGETATIVE COVER OF THE BOIS BRULE RIVER WATERSHED RE-VISITED IN NORTHWESTERN WISCONSIN, PART I: FOREST STAND CHANGES (1968 TO 2016)[1]

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ABSTRACT

The Bois Brule River flows through some of the most diverse habitats found anywhere in Wisconsin. In 2015 and 2016, our survey teams were able to collect and analyze forest strata data from 48 of the 54 forest stands surveyed by Davidson in 1968–69 using the point-centered quarter sampling method. Stands were dominated by transitional forest of northern hardwoods, while some forest types were represented by only one stand each. Average absolute tree density decreased by 25% over the 48 years, while the tree basal area did not change much with a slight decrease of 6%. These changes were indicative of a later successional stage of these forests. Species showing significant change are *Betula papyrifera*, *Abies balsamea* and *Acer rubrum*. Old growth forests have entered a later stage of maturity with some *Pinus strobus* individuals becoming snags today and *P. resinosa* trees becoming larger. Our sapling surveys in these old growth forests suggest *Acer rubrum* and *Abies balsamea* could become dominant forests in the future, with little or no recruitment from the pines. Our survey depicts a forest that is trending to a later successional stage of development and recovering from the cutover from the early 20th century. Future threats to these forests include disruptions in the natural fire regime, non-native plants (e.g., *Rhamnus cathartica*, *Lonicera* spp.), insect infestations (e.g., *Choristoneura fumiferana*, *Agrilus planipennis*), excessive fragmentation from harvesting activities and climate change. These forests may exhibit some resiliency to climate change due to the watershed's proximity to Lake Superior and the river's deep valley.

KEYWORDS: Flora of Wisconsin, land change, pre-settlement conditions, Brule River Survey, northern forest community types

INTRODUCTION

This is the first of two articles (the second of which is Hlina et al. 2020) reporting on a three-year project to re-survey and analyze vegetative and land use

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[1] Data sets used in this article are available upon request from the Lake Superior Research Institute at the University of Wisconsin-Superior, Superior, Wisconsin.

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changes in the exceptional Bois Brule River watershed in northwestern Wisconsin over the last 160 years. The original survey resulted from a call by the University of Wisconsin and the Wisconsin Conservation Department in 1942 for an extensive study and evaluation of the physical, biological and chemical characteristics of the watershed, resulting over the next several years in 11 separate monographs, featuring environmental factors that would better explain the causes of declining fish populations in the river. The study was called the Brule River Survey. Dr. Norman Fassett and Dr. John Thomson oversaw three portions of the study by assessing and describing the vegetation of the Brule River Gorge, its forest and wetland communities and provided a detailed vegetative mapping effort of the Brule River Watershed from 1852 to 1944.

In 1968, Dr. Donald W. Davidson, a plant scientist at the University of Wisconsin-Superior, started a re-survey of the Fassett and Thomson's vegetative studies by focusing on trees and saplings in 54 forest stands throughout the watershed. Though this work was never published, the original data with maps exists and contains significant information concerning the Brule River forests. The Davidson study closely follows the same study areas as the 1942–1944 study, though there were insufficient resources to complete the other stratum in the forests (e.g., shrub and herbaceous), aquatic vegetation of the river, and other wetland communities.

An Opportunity to Study Forest Change

Although we generally know about regional changes in the forest since EuroAmerican settlement through public land survey records (Schulte and Mladenoff 2001, Schulte et.al. 2002, Kronenfeld and Wang 2007), it is uncommon to have high-quality data from earlier times that could be used to make quantitative comparisons of forest change. An opportunity arose, however, in the autumn of 2014, when, during a routine office cleaning at the Brule River State Forest, Wisconsin, a cardboard box was discovered that contained hand written notes, completed raw data sheets, and topographic maps of an extensive forest survey of the Brule River watershed conducted in 1968 and 1969 by Dr. Donald W. Davidson of the University of Wisconsin-Superior. Davidson was a locally renowned botany professor who had passed away in early 2014. The lead author was made aware of this work and the materials were returned to the University of Wisconsin-Superior. The papers provided raw forest inventory data for 54 forest stands in the Brule River watershed in northwestern Wisconsin and provided the inspiration for us to undertake a re-survey of these stands. The watershed is located 48 km east of Superior, Wisconsin and the town of Brule is in the middle reaches of the river and watershed. Our objectives were to resurvey these stands using the same sampling methods used by Dr. Davidson, thereby allowing us to evaluate forest changes over the last five decades. Additionally, we quantitatively sampled shrub and ground-cover strata, which were not surveyed in 1968 and 1969, to further characterize these forests.

Brule River Watershed Forest Background

During the late 19th century and early 20th century, most of the original timber of the Brule River watershed had been harvested (Wisconsin Department of Natural Resources 2015a). The pines (*Pinus resinosa*, and *P. strobus*) were harvested first for building projects throughout the Midwest. This initial harvest was thorough, removing all trees and leaving large woody debris piles behind. Once these piles dried out, they became a catalyst for catastrophic fires, which were commonplace for decades after the initial harvest. Many of these early fires burned hot and destroyed the fragile topsoil in some areas, restricting the ability of the land to support new forest (Wisconsin Department of Natural Resources 2016b). Some of the flat upland areas in the boreal forest and the pine barrens were further cleared for agricultural purposes. Most of the pine barrens farms were short-lived and were soon abandoned. In subsequent years, the barrens were extensively converted to pine plantations by public and private interests (Wisconsin Department of Natural Resources 2015a). In the 1920s the forest industry harvested the northern hardwoods, *Quercus* spp., *Acer* spp., *Tilia americana*, *Fraxinus americana*, and *Betula papyrifera*. This harvest continued sporadically through the 1930s and early 1940s (Wisconsin Department of Natural Resources 2015a).

The Brule River State Forest (BRSF) was officially declared a state forest in 1936. The idea for a state forest on the Bois Brule River (often referred to as the Brule River) first arose in 1907 when timber baron Frederick Weyerhauser gifted over 1,619 ha to the state of Wisconsin (Wisconsin Department of Natural Resources 2015a). The BRSF is mainly located in a narrow band of the watershed from glacial ridge to glacial ridge, stretching the entire length of the river, 71 km. The Brule River spillway (glacial ridges) was a main drainage outlet for glacial Lake Duluth, 10,000 ya and flowed from north to south carving the river channel we see today. As the land rebounded and lake levels lowered the river flow reversed its direction back to modern day Lake Superior (Clayton 1984).

The 2017 BRSF master plan mandated a shift towards timber production lands (27% to 58%) and away from protected natural lands. Annual harvests will remain the same, but greater disturbance will occur over time (Wisconsin Department of Natural Resources 2017). The BRSF comprises approximately 38% of the forested land in the watershed. The remaining 62% is either privately owned, part of the county forest, and /or a mixture of agricultural, residential development, rivers, lakes and wetlands. Significant areas within the BRSF with protected status include the steep sides of the Brule river valley and several state natural areas. These natural areas comprise 1,069 ha of *Thuja occidentalis* swamps in the headwaters (Figure 1), 264 ha of boreal forest approaching old growth status, 265 ha of open barrens, and a 9 ha small alkaline seepage lake with a sandy shore.

METHODS AND MATERIALS

Davidson created hand-drawn outlines on USGS topographic maps of the 54 forest stands surveyed in his study. Davidson's stands were rectangular and covered 27,600 m^2 with average dimen-

FIGURE 1. The lower reaches of the Bois Brule River at Stone's Bridge along a belt of old growth *Thuja occidentalis* swamp containing several populations of rare species. Photo by Paul Hlina.

sions of 240 m × 115 m. We georeferenced his stand boundaries with a digitizing routine in ArcMap 10.5, a geographical information system (GIS) mapping application. Using the digitized stand boundaries, we examined public forestry records from the Wisconsin Department of Natural Resources forest stand database (Wisconsin Department of Natural Resources 2016a) to evaluate the current forest community at each site. Forty-eight of Davidson's 54 forest stands (89%) were accessible for resurvey on both public and private lands. Davidson did not classify the forest stands into community types. Prior to field work and upon a cursory examination of the historical data, forest stands were classified based on the land cover data and, as defined by Wisconsin Department of Natural Resources (Epstein 2017). There are nine major forest communities in the watershed: boreal forest, northern dry forest, northern dry-mesic forest, northern hardwood forest, northern mesic hardwood forest, northern hardwood swamp, northern wet forest, northern wet-mesic forest and pine barrens. The northern hardwood forests were further separated by dominant tree species in each stand (aspen, oak-maple, or mixed). These forest types represent 58.3% of all the forests that were re-surveyed.

Davidson used the point-centered quarter sampling method developed by Cottam and Curtis (1949) to survey trees and saplings at each site, and we used the same method here. This method is one of the most frequently used distance methods employed to sample forest communities (Johnson et al. 2008). Cottam and Curtis (1956) evaluated several forestry sampling methods to quantify these forests and deemed the point-centered quarter method the best in terms of distance determinations and the amount of tree species data at each point. Bryant et.al. (2004) illustrated that the point-centered quarter method can result in biased density estimates when plant distribution deviates from random spatial patterns. We replicated the Davidson sampling design using the point-center quarter method. We used GIS to place one to five transects per stand, depending on the shape of the stand, with the criterion of a homogenous forest community. Transects were separated by at least 25 m. We distributed points along transects at 20 m intervals, and at each point the nearest tree and sapling in each of the four quarters was recorded. If no tree or sapling was present in a quarter within 12.2 m

FIGURE 2. Stephanie Glass (University of Wisconsin-Superior student) taking a dbh measurement in an old growth northern dry-mesic forest stand on the east side of the Bois Brule River on private land. Photo by Paul Hlina.

(40 ft.) of the survey point that quarter was marked as NONE. Trees are defined as individuals with stems measuring at least 10 cm diameter at breast height (dbh) while saplings were defined as individuals with stems between 2.5 cm (1 in) dbh and 10 cm dbh. as they were by Davidson in another vegetation study of the time period (Buell et. al 1966). The measurements were recorded in inches and later converted to centimeters, for all trees (Figure 2). Importance values per species were determined by calculating for relative frequency, relative density and relative dominance.

We also surveyed the groundcover (< 1 m) and shrub (ranging 1 m–3.65 m) strata in 48 forested stands using a modified method derived from the National Forest Inventory and Analysis (FIA) program developed by the U.S. Forest Service (Schulz et. al. 2009). Our modification of the FIA excluded importance values for trees and saplings, as this data was collected using the point-centered quadrat method described earlier. Each forest stand has four circular plots with a 7.32 m radius with the first identified by using the centroid of the 1968–69 stand surveys. The other three plots are located 36.58 m apart at 120°, 240° and 360° (Figure 3). For sampling of the groundcovers each plot contains three quadrats (1 m × 1 m) located at 4.57 m along each of three transects at 30°, 150° and 270° azimuths. A final modification is the addition of a circular microplot (2.07 m) east of the centroid for sampling the shrub stratum. Trees and saplings were included if they were presence in the quadrats or microplots (Figure 4).

We recorded the presence and estimated percentage cover to the nearest percentage of all species present in the quadrats and the microplot. Leaf litter and non-vegetated bare areas were recorded as percentage cover in the groundcover stratum. The shrub strata were only estimated in the microplot nested within each plot. All species, including dominant species were averaged between all stands of the same forest community type. Dominant species are those that exhibit higher frequency, density and cover values. One species list was created for each forest community by combining all species found in all the plots and microplots of that community and then removing any duplicate species.

Nomenclature follows Voss and Reznicek (2012), which includes most species found in Wiscon-

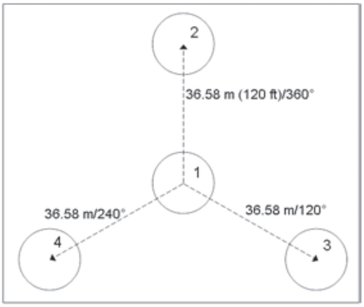

FIGURE 3. FIA plot layout. Each plot is composed of four circular plots 7.32 m in diameter; three of these are spaced 36.58 m, center to center, from a central subplot at azimuths of 120°, 240°, and 360°.

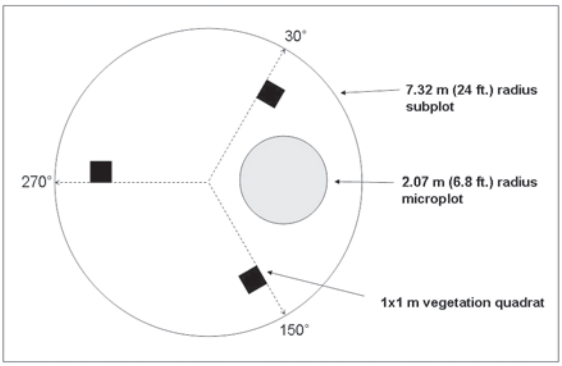

FIGURE 4. Standard FIA subplot diagram. Three quadrats are found along each transect line and quantitative data of cover values and species are recorded. A complete species list is compiled throughout for each subplot.

sin. For those species not found in Michigan Flora, Flora of North American Editorial Committee (1993+), and Judziewicz et al. (2014) were used. Difficult-to-identify plants were collected, tagged, and brought back to the herbarium for further identification.

Analysis

We provide a proportional representation of each tree and sapling species by calculating relative frequency, relative density, and relative dominance in the watershed forest for 1968 and 2016 (Figure 6). Relative frequency is the presence of each species over total number of quarters. Relative density is the total number of each species in all quarters divided by total quarters. Relative dominance is the relative density × basal area over the total basal area. These three values were summed to arrive at an importance value for each species, given as a percentage in Table 1.

We used the Bray-Curtis dissimilarity index (Bray and Curtis 1957) as a numerical measure of the ecological distance or dissimilarity. The Bray-Curtis formula compares forest community types at different times (1968 and 2016). The formula is expressed as follows:

$$BC_{ij} = 1 - (2C_{ij} / (S_i + S_j)),$$

where BC_{ij} is the Bray-Curtis dissimilarity index between sites i and j; C_{ij} is the sum of only the lesser counts for each species found in both sites; S_i is the total number of species counted on site i; and S_j is the total number of species counted on site j. The result of the calculation is a number between 0 and 1. The higher the value the more dissimilarity exists between the units compared. We compared trees to trees to measure forest composition changes over time. We further compared 1968 saplings to 2016 trees to measure re-generation of saplings to mature trees and finally we compared 2016 trees to 2016 saplings to measure potential regeneration for future forests.

A modified floristic quality assessment is used to provide an ecological condition assessment based on all species in the forest. This assessment was originally developed in the late 1970's in the Chicago region to identify protection-worthy lands with a simple, repeatable, quantitative method (Swink and Wilhelm 1979). They assigned to each species in the Chicago region a Coefficient of Conservatism (C), a number from 0 to 10. In the early 2000s, Wisconsin expert botanists convened and did the same for Wisconsin's vascular plants (Bernthal 2003). This list is now maintained by Wisconsin Department of Natural Resources (Wisconsin Department of Natural Resources 2016c). Species that are relatively tolerant of anthropogenic disturbance have low C-values, whereas species that are less tolerant of anthropogenic disturbance have high C-values (Spyreas 2019). We define tolerant species as those with C-values ≤ 5, and conservative species as those having C-values ≥ 6. Non-native species and some invasive native species are assigned a C-value of zero.

We calculated a weighted Coefficient of Conservatism (*wC*) (Bourdaghs 2012), which takes abundance into account, for each forest community type using the following formula:

$$wC = \Sigma\, pC.$$

The C-value of each species in the community is multiplied by its proportional abundance (*p*), and these values are then summed for all species in the community to provide a *wC* value for the community. The proportional abundance of a species is its weighted cover value divided by the total percentage cover for all species in the community. The *wC* value represents a baseline of condition for the community during the time of the survey.

RESULTS

Status and Change of Trees and Saplings

In selecting forest stands to survey, Davidson achieved a geographic distribution throughout the watershed as well as an equitable number of private versus public stands (Figure 5). Twenty-eight stands (58.3%) were represented as northern hardwood forests, which was further categorized as aspen dominated, oak–maple dominated, or mixed conifer. Four additional forest communities included pine barrens, northern wet-mesic, northern wet and northern hardwood swamps with only one or two stands surveyed. All other forest types had three or more representative stands. Average absolute density for all trees across all community types in 1968 was 131 trees/ha with an average basal area of 10.3 m^2/ha. In 2016, our surveys found an average absolute density of 98 trees/ha with an average basal area of 9.7 m^2/ha, which represents a substantially lower tree density but a similar basal area. The sapling data indicates an increase in earlier-successional forests than during the 1968–69 time period. Five stands (11%) have been clear-cut or partially cut in the last decade. Another six stands (13%) had larger ratios of saplings to trees, indicating a recently disturbed forest (e.g., harvesting, wind damage, development). Notable changes in tree and sapling data were found between the time periods in three species: *Betula papyrifera*, *Abies balsamea*, and *Acer rubrum*. Quantitative changes in trees and sapling of each tree species is discussed below. The importance values of these tree species are provided in Table 1.

Populus tremuloides and *P. grandidentata* comprised 30.2% of the forest

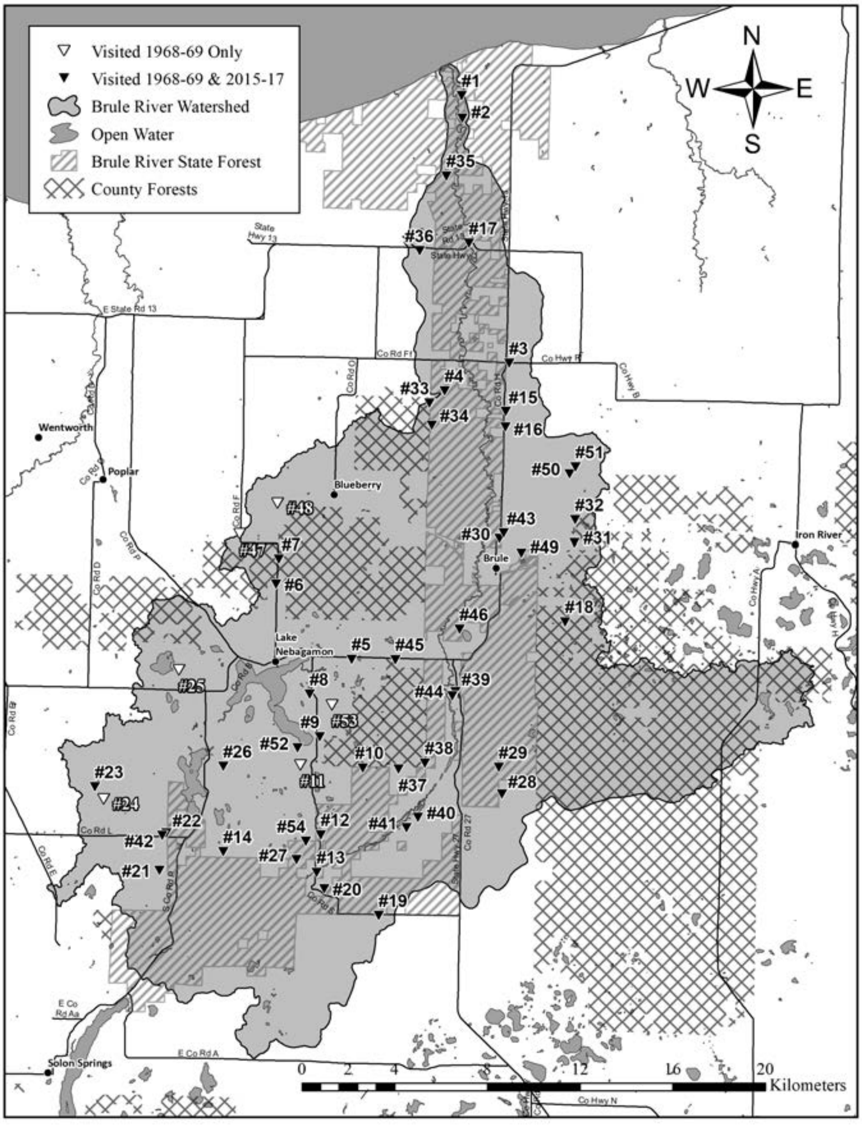

FIGURE 5. The locations of the 54 forest stands surveyed by Davidson and the 48 stands revisited in 2015 and 2016.

trees in 1968; today they have decreased to 21.1%. Saplings increased from 9.1% to 16.2%.

Betula papyrifera comprised 13.6% of the forest trees in 1968; recently they have decreased to 3.3%. Very few individuals of *Betula papyrifera* of any size were found. Larger individuals of *Betula papyrifera* were found only in older stands, and the relative density and relative dominance has dramatically decreased. The sapling data indicates that the relative density and relative dominance of *Betula papyrifera* saplings have decreased by 225%. As with trees, the percentage of saplings have decreased from 16.2% in 1968 to 6.3% today.

Abies balsamea comprised 5.5% of the forest trees in 1968 but has recently increased to 10.6%. Our sapling data indicates that it is germinating well across all community types and now has increased in relative density and relative dominance by 35%.

The relative density of *Picea glauca* trees has increased, while there has been a slight decrease in its relative dominance. The relative density and relative dominance of saplings have increased by 400% and 100%, respectively. Harvesting data indicates that selective cutting of larger trees has occurred in some of the boreal forest stands surveyed, potentially reducing spruce dominance (Wisconsin Department of Natural Resources 2016a).

Pinus strobus has increased in relative density by 100% and in relative dominance by 30%. Old growth pine trees cover the steep river valleys, and estimates based on landowner knowledge place these trees at 250–300 years old on two stands and 125–200 years on two other stands. The largest *Pinus strobus* trees

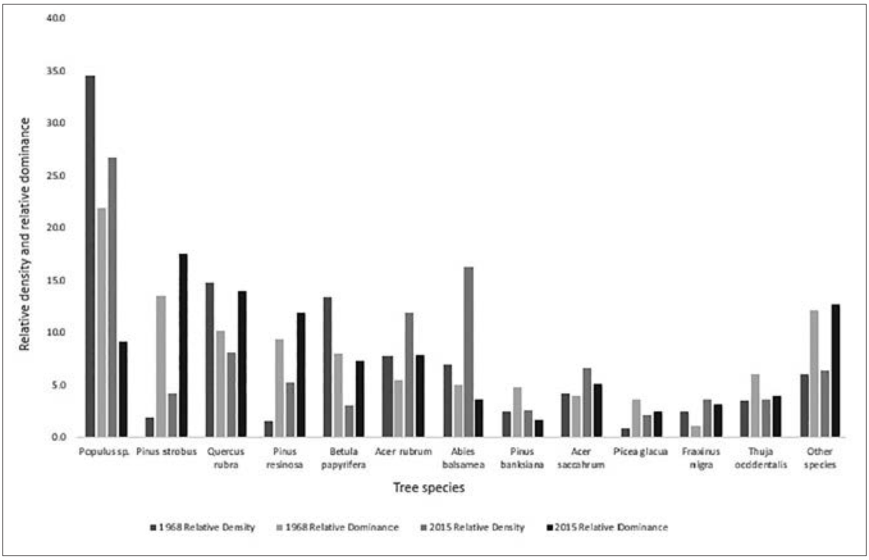

FIGURE 6. Relative density and relative dominance of forest trees in the Brule River watershed in 1968 and 2016. Tree species in the others category included species ranging from *Tsuga canadensis* to *Ulmus americana* and have a smaller influence in the forests.

TABLE 1. Importance values, expressed as a percentage, of common species in the watershed, calculated separately for trees and saplings. Because *Populus* saplings were difficult to identify to species, the entry for *Populus* sp. includes *P. tremuloides, P. grandidentata,* and *P. balsamifera*.

	Importance Values			
	Trees		Saplings	
Species	1968	2015	1968	2015
Abies balsamea	5.5	10.6	11.4	21.6
Acer rubrum	8.9	13.6	26.4	16.5
Acer saccharum	6.0	7.0	16.2	6.3
Betula alleghaniensis	0.7	0.7	0.1	0.5
Betula papyrifera	13.6	3.3	10.1	3.7
Fraxinus nigra	1.6	3.3	1.6	4.0
Pinus banksiana	4.3	3.0	2.6	7.7
Ostrya virginiana			2.6	7.7
Picea glauca	1.1	2.0	0.6	2.2
Pinus resinosa	3.0	7.5	0.2	1.7
Pinus strobus	2.8	6.4	0.7	1.1
Populus grandidentata	15.1	8.3		
Populus tremuloides	15.1	12.8		
Populus sp.			9.1	16.2
Prunus serotina			0.4	1.8
Quercus rubra	14.0	14.3	3.2	6.0
Rhamnus cathartica			0	0.1
Tilia americana	1.8	2.6		
Thuja occidentalis	1.6	0.7	0.5	0.1
Other	5.0	4.0	16.9	10.7

(>90 cm dbh) of the late 1960s exist only as snags today. The death of old trees and the absence of seedlings for regeneration will restrict the ability of these old growth forests on the Brule River watershed to be sustainable into the future. However, there are seedlings and saplings of *Pinus strobus* in the boreal forest communities, which may result in its further recovery in these forests.

Pinus banksiana was found primarily in pine plantations or as a small component of the northern dry and northern dry-mesic forest. Relative density has remained the same with a slight decrease in relative dominance.

Pinus resinosa is an important component of the old growth forest on northern dry and northern dry-mesic forest stands. In these old growth areas both relative density (300%) and relative dominance (25%) increased. Most of the increase in relative dominance can be attributed to an average increase of dbh in these sites (45 cm in 1968, 56 cm in 2016), in which the canopy trees are better represented by *Pinus resinosa* than *P. strobus.* The shade tolerant species, *Acer rubrum* and *Abies balsamea*, are abundant in the understory.

Acer rubrum trees comprised 8.9% of the forest in 1968; today they have increased to 13.6%. *Acer rubrum* has increased in presence and size. The relative density of *Acer rubrum* saplings has decreased from 26.4% to 16.5%, but its relative dominance has remained constant.

TABLE 2. Bray-Curtis dissimilarity index values for forest communities in the Brule River watershed, showing comparisons between trees (T) in 1968 and 2016, between saplings (S) in 1968 and trees in 2016, and between trees and saplings in 2016. The higher the values the more dissimilar the communities. The pine barrens, northern hardwood swamp, northern wet-mesic forest, and northern wet forest community types are poorly represented in the Davidson data and are therefore not analyzed under Bray-Curtis.

Forest Community Type	1968T_2016T	1968S_2016T	2016T_2016S
Boreal forest	.26	.31	.31
Northern dry-mesic (old growth)	.28	.45	.28
Northern hardwood–aspen	.36	.33	.37
Northern hardwood–oak/maple	.37	.42	.26
Northern hardwood–mixed conifer	.29	.31	.27
Northern mesic	.31	.37	.24

Quercus rubra comprised 14.0% of the forest trees in 1968 and has slightly increased to 14.3%. The percentage of saplings has increased from 3.2% to 6%.

Acer saccharum trees comprised 6.0% of individuals in 1968 and has increased to 7.0%. *Acer saccharum* also experienced an increase in relative density and relative dominance between the two surveys. Sapling numbers have declined from 16.2% to 6.3%.

Forest Community Composition and Change

Our findings with respect to these forests are consistent with those reported in earlier publications (Epstein et al 1999; O'Connor, 2016). Early successional forest remains the dominant forest type throughout the watershed, often consisting of *Populus* spp. and *Pinus* spp. There remain pockets of old growth forest with large diameter trees of *Thuja occidentalis*, *Pinus strobus, Pinus resinosa*, and *Picea glauca*, which indicates a larger and older forest that supports higher levels of species richness. Sapling numbers have increased with changes for individual species differing in relation to natural succession, harvesting, fire, and/or wind damage between the two time periods.

The Bray-Curtis dissimilarity index was used to depict differences in tree and sapling composition between the time periods (Bray and Curtis 1957). In comparing trees and saplings in the northern hardwoods forest community type between 1968 and 2016, there is a smaller difference in species composition than in that of the other forest communities, which suggests that the sapling layer is more similar in these northern hardwoods (Table 2). Eight to ten tree species rotate dominance at any one-time period across even-age and multi-age stands. Analysis of tree and sapling data showed a dramatic disappearance of *Betula papyrifera* across all northern hardwood forest community types, thereby widening the ecological distance between the two time periods. The most notable species with increased importance values were *Acer rubrum* and *Abies balsamea.* The remaining species in the northern hardwoods exhibited both rising and declining importance values equitably. The northern mesic forest tree composition has remained consistent between the two time periods with *Acer saccharum* remaining dominate with *Betula allegheniensis, Tilia americana*, and *Acer rubrum* as common associates. Successional stage and stand location influence which species dominates in each stand. Boreal forest and northern dry-mesic forest have the smallest differences in species composition between the two time periods. In 60% of the northern dry-mesic stands, the largest living individuals of *Betula papyrifera* were recorded as a subcanopy tree in old growth forest. The comparison of saplings in 1968 to trees in 2016 indicates that many forest community types are widening their ecological distance, suggesting a greater change in species composition in the forest today than would be expected from the sapling data of 1968. The comparison of saplings to trees in 2016 in all forest community types depicts a future forest with a similar species composition, except in old growth forest. Sapling species composition in old growth forest suggests a departure from old growth pine to mixed conifer-hardwood forest (Table 2).

Old growth northern dry-mesic forest had the highest *wC* value of 5.2, while the northern hardwood–aspen had the lowest *wC* value at 3.9. The boreal forest and the northern hardwood–aspen had the highest average number of species richness at 71; however, the northern hardwood mixed conifer had the greatest species richness at 190. The northern hardwood–oak/maple forest had the highest percentage of non-native species at 16%, followed closely by the boreal forest, which had 14%. The lowest percentage of non-native species was recorded for the northern mesic forest at 5% and the northern dry-mesic forest at 7% (Table 3).

Groundcover and Shrub Strata by Forest Community Type

Boreal forest

The dominant groundcover species are *Eurybia macrophylla*, *Rubus pubescens*, *Rubus parviflorus* and *Cornus canadensis*; the first of which has a substantially greater abundance than the others. *Rubus parviflorus* is ranked third, as it was found on north and west facing slopes in only ten quadrats but is a sprawling vine-like shrub with large leaves often with high cover values. The shrub stratum is dominated by seedlings of *Abies balsamea* and mature *Alnus incana.* Other species of importance in this stratum are seedlings of *Fraxinus pennsylvanica* and *F. nigra.* Associated species include *Populus tremuloides*, *Amelanchier arborea*, *A. sanguinea*, and *Rubus parviflorus.*

The boreal forest is found north of the town of Brule to the mouth of the river. These forest stands exhibit an increase in species richness from the 1940s to present day as a result of increases in non-native plants from 5% in 1940s to 14% today. Native plants across all forest strata continue to dominate the floristic character of this forest. In some stands, conservative species remain strong: *Acer spicatum*, *Clintonia borealis*, *Dryopteris carthusiana*, *Dryopteris intermedia*, *Cynoglossum boreale*, and *Petasites frigidus* var. *frigidus*.

Northern dry-mesic forest

The dominant groundcover species are *Maianthemum canadense*, *Acer rubrum*, and *Cornus canadensis.* Subdominant species include *Abies balsamea*

TABLE 3. Several metrics for seven forest community types in the Brule River watershed. The northern wet, northern wet mesic, and northern hardwood swamp forest community types lacked a sufficient number of plots surveyed to conduct a meaningful analysis. Species richness is the number of species recorded in all plots in each community type and is the sum of the native and non-native species totals. Mean richness is the average number of species per 4 plots/1 stand. The weighted mean coefficient of conservatism (*wC*) is calculated for all species (native and non-native) and for only native species in each community type.

Forest Community Type	Number of plots	Number of quadrats	Number of mini-plots	Mean richness	Species richness	Species Totals		*wC*	
						Native	Non-native (%)	Native species	All species
Boreal forest	16	48	16	71	134	118	16(14%)	5.2	5.1
Northern dry-mesic	16	48	16	57	113	105	8(7%)	5.4	5.2
Northern hardwoods–aspen dominated	36	108	36	71	172	153	19(11%)	4.1	3.9
Northern hardwoods–oak–maple	48	120	48	58	185	156	29(16%)	5.2	4.8
Northern hardwoods–mixed conifer	28	84	28	63	190	170	20(11%)	4.2	4.0
Northern mesic hardwoods	24	72	24	66	159	151	8(5%)	5.2	5.0
Pine barrens	8	24	8	63	116	105	11(9%)	4.6	4.3

and *Oryzopsis asperifolia*. This forest type is rare in the watershed, and most stands are in private landholdings. The shrub stratum is dominated by seedlings of *Abies balsamea* and *Acer rubrum*, but *Corylus cornuta*, *C. americana*, and *Ostrya virginiana* have a significant role in this stratum. Associated species include *Pteridium aquilinum*, *Quercus rubra*, and, in one stand, *Pinus strobus*. *Pinus resinosa* has the highest importance value, and *P. strobus*, *Betula papyrifera*, and *Abies balsamea* are associated species.

The northern dry-mesic forest represents climax successional conditions and exhibit stability. Species are equally made up of tolerant species (41%) and conservative species (42%). Some of the conservative species are: *Dirca palustris*, *Pyrola americana*, *Moneses uniflora*, *Lonicera villosa*, and *Linnaea borealis*.

Northern hardwood forest

We have divided the northern hardwood forest into three categories: aspen dominated, oak/maple dominated, and mixed conifer dominated. These transitional forests fluctuate between one another over a relatively short time period (40–80 years).

Aspen dominated

The dominant species in the groundcover stratum are *Pteridium aquilinum*, *Eurybia macrophylla*, and *Rubus pubescens*. Interestingly, *Diervilla lonicera*, dominant in Thomson's 1940's surveys, was rarely encountered in our surveys. The shrub stratum is dominated by *Ilex verticillata*, *Fraxinus pensylvanica*, and *Viburnum rafinesquianum*. Other species of importance in this stratum are seedlings of *Populus grandidentata*, *Quercus rubra*, and *Acer rubrum.* Associated species include *Amelanchier arborea*, *Ostrya virginiana*, *Corylus americana*, *C. cornuta*, *Prunus pensylvanica*, and *P. serotina*.

Mixed conifer

The dominant species in the groundcover stratum are *Pteridium aquilinum*, *Eurybia macrophylla*, *Carex pensylvanica*, and *Acer rubrum* seedlings. These stands were all early to mid-successional forest. The shrub stratum is dominated by seedlings of *Acer rubrum*, *Populus tremuloides*, and *P. grandidentata* and mature *Ostrya virginiana*, *Corylus americana*, and *C. cornuta.* Surprisingly, *Quercus rubra* and *Acer saccharum* were of less importance in the shrub stratum. Associated species include *Betula papyrifera*, *Pinus strobus*, *Prunus serotina*, *and Dirca palustris.*

Oak/maple dominated

The dominant species in the groundcover stratum are *Eurybia macrophylla*, *Maianthemum canadense*, *Carex pensylvanica*, *Pteridium aquilinum*, and *Acer rubrum* seedlings. Dominance in the groundcover stratum fluctuates between these five species in all the hardwoods as these communities are all second growth forest spanning early-, mid-, and late-successional stage forest. The shrub stratum is dominated by seedlings of *Abies balsamea*, *Populus grandidentata* and *Acer rubrum* and mature *Corylus americana* and *C. cornuta.* The species richness as in other hardwood forest, is high with the following associates: *Picea glauca*, *Rubus alleghaniensis*, *Alnus incana*, *Viburnum lentago*, *Betula papyrifera*, *Populus tremuloides*, *Quercus rubra*, *Acer saccharum*, *Pteridium aquilinum*, *Pinus strobus*, *Prunus pensylvanica*, *P. serotina*, *Tilia americana*, *and Carpinus caroliniana*. Species richness is 185 species, and these seven-species represent 31.2% of the groundcover stratum in the forest. Tolerant species (57%) have a 2:1 ratio over conservative species (28%).

In these northern hardwood forests, species richness is 185 species, and the seven dominant species represent 31.2% in the groundcover stratum of these forests. Tolerant species (57%) have a 2:1 ratio over conservative species (28%).

Northern mesic hardwoods

The dominant groundcover species are *Rubus pubescens* and tree seedlings of *Acer saccharum*, *A. rubrum*, and *Fraxinus pennsylvanica* followed by *Maianthemum canadense* and *Trientalis borealis* which had lower frequency and cover values. The shrub stratum is dominated by seedlings of *Acer saccharum*, *Acer rubrum*, and *Abies balsamea,* with *Corylus cornuta* and *Ostrya virginiana*. Associated species include *Acer spicatum*, *Fraxinus americana*, *Betula papyrifera*, and *Carpinus caroliniana.*

The northern mesic forest is comprised of *Acer saccharum*, *Betula alleghaniensis*, *Tilia americana*, and *Tsuga canadensis*. Northern mesic forest represents only 2% of the forest in the watershed and are the most western forest of its type in Wisconsin. The forest type is best represented in the Brule River watershed at the Sugar Camp Hill stand area, north of the town of Brule. One *Tsuga canadensis* stand supported the largest patch (approximately 2m × 7m) of *Adiantum pedatum* in the watershed at the bottom of a ravine. Two other observations of this species were made, but only of individual plants. Species richness is high, and conservative species (52%) have a slightly higher representation than tolerant species (48%). Conservative species are: *Carex disperma*, *Woodsia ilvensis*, *Chrysosplenium americanum*, *Panax trifolius*, *Dirca palustris*, and *Carex backii* (a state special concern species).

Pine barrens

One site had been clear cut in the recent past resulting in an open barrens-like community. Groundcover and shrub data from this site were added to the analysis. The dominant groundcover species are *Pteridium aquilinum*, *Corylus americana*, *Vaccinium angustifolium*, *Quercus macrocarpa*, and *Carex pensylvanica*. The shrub stratum is dominated by *Corylus americana*, *Quercus ellipsoidalis*, *Quercus macrocarpa*, and *Pinus banksiana*. Associated species with lower importance values include *Amelanchier spicata*, *Prunus pensylvanica*, and *Pinus strobus*. Non-native species have been well represented in the floral record for the pine barrens community. Thomson (1944) observed that 17% of the flora was non-native, while our surveys found 13.4%.

Northern hardwood swamp

One northern hardwood swamp stand was revisited, representing only 2% of the forest surveyed in 2015. With only one sample in the survey, there are no trends we can point to with any level of confidence. There were only four plots for groundcover species and the data was too sparse to analyze. Furthermore, species composition and total species richness differed between the two surveys, as geo-referencing was less accurate because of the large expanse of this forested wetland mosaic.

Northern wet forest

One northern wet forest was re-visited, representing 2% of the forest surveyed. Within the Brule river watershed, this community is relatively rare. Stands are small and, when away from the river corridor, often isolated. These stands are dominated by either *Picea mariana* or *Larix laricina* growing in a thick layer of sphagnum moss and ericaceous shrubs. Davidson had visited only one stand, and we are unable to identify trends in this community. Analysis was not conducted as only one stand/four plots were surveyed.

Northern wet-mesic forest

One *Thuja occidentalis* swamp was revisited representing 2% of the forest surveyed in 2015. Analysis was not conducted as only four plots were surveyed.

DISCUSSION

As is noted in the results section, significant changes are evident in individual tree species, as well as forest communities. *Betula papyrifera* is declining rapidly everywhere we surveyed. In our observations only mature trees and young saplings are present, with most middle-aged trees fallen or upright dead snags. Since 1983, the mortality rate of *Betula papyrifera* has exceeded its annual growth in Wisconsin (Wisconsin Department of Natural Resources 2016b). As climate change models illustrate (Scheller and Mladenoff 2005), it is predicted that by the end of the 21st century, *Betula papyrifera* may become extirpated from northern Wisconsin. The death of old pines *(Pinus resinosa* and *P. strobus*) and cedars (*Thuja occidentalis*) and the absence of seedlings for regeneration will restrict the ability of these old growth forests on the Brule River watershed to be sustainable into the future. However, there are some seedlings and saplings of *Pinus strobus* in the boreal forest communities, which may result in further recovery in these forests.

Two trees that are having a greater influence across several forest community types are *Acer rubrum* and *Abies balsamea.* These two species threaten the viability of the old growth northern dry-mesic forest, as well as other northern forest communities. Fire, at frequent intervals, remains evident on *Pinus resinosa* trunks and was the primary disturbance responsible for regenerating these stands (Meunier et. al. 2019). Today, these old growth stands represent less than 1% of all forest in the watershed.

Though these stands are climax communities, they are not without threats. Without ground fires to reduce the groundcover and shrub layers (e.g., *Acer rubrum* and *Abies balsamea* saplings) *Pinus resinosa and P. strobus* recruitment will remain low (Meunier et. al. 2019). A large storm in the summer of 2016 created several gaps in the forest canopy. Active pine plantings in naturally occurring openings today and in the future may benefit the old growth forest. Absent of natural or human re-planting activities, these gaps provide invasive non-native plants an opportunity to get a stronger foothold. Several small scattered populations of a few non-native species are already present (e.g., *Hieracium aurantiacum* and *Ranunculus acris*), an indicator of earlier disturbances.

By the 1940's logging activities greatly expanded on the narrowing boreal forest at the mouth of the watershed. These activities contributed to further fragmentation of the forest, along with new roads, cleared areas for development, and agricultural conversion. These disturbances serve as a conduit for non-native plants to expand their presence adjacent to and in the forest. Instead of tree seedlings germinating in gaps from natural causes, we now find opportunistic wind-pollinated non-native species out-competing the native species.

The 2003 Brule River State Forest master plan and environmental impact statement outlined a 100-year conservation plan to restore the boreal forest by reducing the amount of *Populus tremuloides* density and dominance, while increasing *Pinus strobus, Picea glauca* and *Betula papyrifera* north of the Town of Brule to the mouth of the river (Van Horn et al. 2003). Data from the boreal forest depicts a forest in recovery from the initial harvest in the 1880's, with later successional to mature old growth forest present in some stands. Analyzing our data from the boreal forest stands indicates that since 2003, the boreal forest has higher tree importance values for *Abies balsamea, Picea glauca* and higher sapling importance values for *Pinus strobus,* but a declining presence of *Betula papyrifera* as discussed earlier. This report illustrates that the forest communities are multi-aged with high biodiversity of tree and sapling species, sustaining the plant and animal species that are dependent on these communities, as well as the human community.

The northern mesic forest communities are expansive in northeastern and north central Wisconsin but are rare in the watershed. The Sugar Camp Hill stand is the best example of this forest community type. It is managed as a shelter wood forest by the Brule River State Forest and was last harvested in 1933 (Wisconsin Department of Natural Resources 2016a). Between now and the next harvest in 2033, the forest will be thinned to allow new seedling to grow and thrive. At that time, the canopy of older trees will be removed, and a younger forest will then stand in its place. The stands near Lake Minnesuing consist of *Tsuga canadensis*, a frequent associate in the northern mesic forest. Davidson et al. (1973) reported *Tsuga canadensis* in these stands as the westernmost record for this species in Wisconsin at that time. Subsequent reports (e.g., Fryer 2018) now extend the range of this species into northeastern Minnesota. Future harvesting activities should strive to protect and sustain these rare stands in the watershed representing the westernmost northern mesic forest in the upper Midwest.

Northern hardwood swamp is lowland forest dominated by *Fraxinus nigra* (Figure 7). In the Davidson data there was only one stand represented, and trees were alive and healthy. However, today, northern hardwood swamp is threatened by a non-native insect pest, the emerald ash borer (*Agrilus planipennis*), which was discovered in 2014 in our region, 35 miles to the west in Superior, Wisconsin. In the summer of 2016, Schulz (personal communication), stated that *Agrilus planipennis* had not been found in the watershed. Our data along with other studies suggest that *Acer rubrum*, *Abies balsamea*, and *Alnus incana* may be the best adapted species to take advantage of the demise of the northern hardwood swamp (United States Forest Service 2014, Chaffin 2019).

More than 2,630 ha spanning the upper reaches of the watershed consists of the northern wet-mesic forest. The conifer swamp stands of the upper Brule River are generally mature, with some stands in or approaching old-growth condition. The forest understory is floristically rich, especially in orchids and sedges. The northern wet mesic forest is dominated by *Thuja occidentalis* with *Abies balsamea*, *Picea mariana*, *Fraxinus nigra*, and *Larix laricina* being common associates. Davidson recorded one stand in this forestry community type. This stand is an old growth forest dating back to 1838. Deer herbivory is a major problem affecting forest regeneration in these important wet-mesic forest on the Brule River. *Thuja occidentalis* seedlings are rare, and reproductive success has

FIGURE 7. A northern hardwood swamp forest of *Fraxinus nigra* on a perched ledge about 9 m above the Bois Brule River. These unique forests were created in a cut-off ox-bow meander of an earlier period of the river's history. These lowland forests remain free of the emerald ash borer, but are likely to be threatened in future years, as the pest has been found to the west in Superior, Wisconsin. Photo by Paul Hlina.

been low. These unique forest stands at the headwater areas of the Brule River have been recognized for their significance for decades (Fassett 1944, Thomson 1945). In 1945, the area was purchased by the Wisconsin Conservation Commission following recommendations by Thomson (1945) to halt all harvesting activity here. The same area received further protective status in the 1980s, and it was designated as a State Natural Area in 2003.

Northern dry forest has declined greatly due to post-EuroAmerican settlement harvesting and the replacement of these forest with pine plantations over the past century. These communities are fire dependent for seed release and growth and do not exist as pure stands today.

Pine barrens were once widespread throughout northwestern Wisconsin covering 9.3 million ha. Today, only two percent remain in heavily managed and protected areas (United States Forest Service 2001). Pine barrens is considered an endangered community type in Wisconsin (Wisconsin Department of Natural Resources 2015b). Vast hectares of the pine barrens landscape were converted to *Pinus resinosa* and *P. banksiana* plantations by both private and public interests. During this time and continuing today, many pioneer species, especially non-native species, occur in the sandy soils of the pine barrens due to frequent disturbances past and present, such as fires, logging, road building, agriculture, and harvesting and planting of tree plantations. Prior to EuroAmerican settlement, pine barrens was characterized by scattered *Pinus banksiana* or less commonly *P. resinosa* sometimes mixed with *Quercus ellipsoidalis* and *Quercus macrocarpa* (Radeloff et al. 2000). The scattered trees or groves are interspersed with openings in which shrubs, such as *Corylus americana*, and grass dominated prairies are the common cover types. These species benefit from periodic episodes of fire in creating and sustaining this mosaic of forest, openings, and prairies (Radeloff et. al. 1999). The best example in the watershed of an early successional pine barrens community is Mott's Ravine State Natural Area, designated in 2003, which is managed through prescribed fire treatments and shrub and tree removal. Examples of high quality pine barrens are also found nearby at Crex Meadows State Wildlife Area (Burnett County), Namekagon Barrens (Burnett County), Solon Springs Sharp-tail Barrens State Natural Area (Douglas County), and the Moquah Barrens (Bayfield County) (Wisconsin Department of Natural Resources 2015b). One of the most notable finds in the pine barrens was more than 200 stems of the threatened *Asclepias ovalifolia* (dwarf milkweed) at the outer edge of a 6-year old pine plantation. This is one of the most northern locations in Wisconsin for this species, which is more frequent in the southern prairies of the state. It appears that these plants and seeds remained dormant during the period prior to harvesting. Once the canopy was removed, these plants were able to rebound, but will likely disappear again as the young forest shades them out in the years to come.

Northern hardwood communities have seen the greatest disturbance in the past century, and some are second and third growth stands. In our re-survey of these three types of northern hardwood forest we found dominant species composition of only seven species: *Pteridium aquilinum*, *Eurybia macrophylla*, *Maianthemum canadense*, *Carex pensylvanica*, *Rubus pubescens*, *Vaccinium angustifolium*, and *Acer rubrum*. Rooney et al. (2004), conducting a re-survey of Brown and Curtis (1952) northern forest stands in Wisconsin, found that the understory diversity had become biotically impoverished. Rooney et al. (2004) note that species composition was becoming homogenized and that tolerant and non-native species were on the rise, threatening the ecological integrity of the forest. The baseline data represented in these hardwoods indicates a similar response. Future research projects could focus on one or more of the following potential threats. Are frequent disturbances having a negative or positive effect on the species richness of the northern hardwoods? Are we seeing the beginning stages of biotic impoverishment in the Brule River watershed? Are animal-dispersed and animal-pollinated species showing a decline, while wind dispersed species are rising? Are deer populations causing a shift in the floral composition? Are earthworm invasions having an impact on the duff or humus layer of the forest? Are climate resistant species increasing, decreasing, or staying the same?

CONCLUSION

The Bois Brule River flows through some of the most diverse habitats found anywhere in the state of Wisconsin. In 2015 and 2016, our survey teams were able to collect and analyze forest strata data from 48 of Davidson's 54 original forest stands from 1968 and 1969. A major finding here is that *Betula papyrifera* has declined throughout all the forest types of the region over the last 50 years. Our data confirm the continuing trend of the steep decline of *Betula papyrifera* statewide (Wisconsin Department of Natural Resources 2016b). A second group of tree species of concern in the watershed are *Fraxinus* spp. These trees are seriously threatened by the accidental introduction of *Agrilus planipennis* in shipping crates from Asia (Emerald Ash Borer Network 2015). Though not present in the stands we surveyed, *Agrilus planipennis* is creeping closer to the Brule River watershed, as indicated by the discovery of the pest 35 miles to the west in Superior, Wisconsin in 2013. What will replace these species? From our data, we can postulate that *Acer rubrum* and *Abies balsamea* are likely to be the future forest benefactors (United States Forest Service 2014; Chaffin 2019). The densities of these two species continue to be strong across several forest community types and has increased in importance in others that are adjacent to northern hardwood swamp. Both species have a high tolerance of shade, moisture, and soil conditions, which provides an advantage for these trees over other species.

In the Davidson data, we found a low number of stands in some forest community types. This factor, along with the lack of access to some privately held stands, restricted our ability to provide quantitative analysis of northern hardwood swamp, northern dry forest, northern wet-mesic forest and northern wet forest. In 1968 and 1969, Davidson identified five old growth forest stands (numbers 13, 39, 40, 41, and 44 in Figure 5). These virgin forests remain today. There are also stands (4 and 35 in Figure 5) that will soon achieve old growth status in the boreal forest region of the watershed.

Over the years, a balance has been successfully achieved between the multiple uses of this dynamic landscape (e.g., timber production, sensitive area protection, river and recreation, ecological health, and residential development), and the forests of the watershed are in good to fair condition. Non-native plants are ubiquitous across almost all community types, but in most communities at a low abundance and a high frequency. Still, other threats today and into the future challenge maintaining the balance, such as the expansion of non-native plants, insect infestations, forest fragmentation by roads and development, climate change (United States Forest Service 2014; Chaffin 2019), deer herbivory, catastrophic extreme climate events (e.g., wind throw and flooding), fire or lack of fire (Radeloff et. al. 1999; Meunier et. al. 2019) and potential increases in overharvesting for quicker financial returns (Rooney et al. 2004; Harper et al. 2005; Scheller and Mlandoff 2005; Stueve et al. 2011; Rooney et al. 2015). Informed land managers, community decision-makers, citizen conservation groups, and others will need to work in partnership to develop and implement strategies of sustainable practices that will guarantee a healthy and thriving forest for future generations. Future studies should evaluate whether the delicate balance between ecological health and human impact has been successfully maintained.

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