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## Legacy and Opportunity in Northern Hardwood Forests

Wilfred Previant

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### Recommended Citation

Previant, Wilfred, "Legacy and Opportunity in Northern Hardwood Forests", Open Access Dissertation, Michigan Technological University, 2015.  
<https://doi.org/10.37099/mtu.dc.etdr/42>

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LEGACY AND OPPORTUNITY IN NORTHERN HARDWOOD FORESTS

By

Wilfred J. Previant

A DISSERTATION

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In Forest Science

MICHIGAN TECHNOLOGICAL UNIVERSITY

2015

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This dissertation has been approved in partial fulfillment of the requirements for the Degree of DOCTOR OF PHILOSOPHY in Forest Science.

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## Preface

Chapter 1 provides an overview of three chapters that are currently in preparation for publication in a peer-reviewed journal (Chapter 2), currently in press (Chapter 3), or has been published in a peer-reviewed journal (Chapter 4). Copyright and author contributions for each chapter are listed below. Chapters in press or published in peer-reviewed journals are acknowledged in a footnote at the beginning of each chapter. Requests for permission to republish materials and corresponding permission letters from the respective publisher are included in the Appendices.

Chapter 2, Demographic change after 52 years of northern hardwood silviculture: In preparation for submission to the peer-reviewed journal *Forest Ecology and Management*. Study was conceived by Wilfred J. Previant, Linda M. Nagel, Robert E. Froese, and Christopher R. Webster. Wilfred J. Previant designed the study, collected and analyzed the data, and wrote the manuscript. Linda M. Nagel contributed to writing and editing the manuscript. Tyler Richie, Andy Beebe, Marcella-Windmuller-Campione, Charles Paulson, and Adrienne Bozic contributed to data collection and sample preparation.

Chapter 3, Vernal pool inventory and classification at Pictured Rocks National Lakeshore, Michigan, USA: © with *Natural Areas Journal* 2016 (*in press*). Documentation that includes permission to use copyright material is provided in Appendix A. Wilfred J. Previant conceived and designed the study, collected and

analyzed the data, and wrote the manuscript. Linda M. Nagel contributed to writing and editing the manuscript. Charles Olson, Steve Miceli, and Adrienne Bozic contributed to data collection.

Chapter 4, Forest diversity and structure surrounding vernal pools in Pictured Rocks

National Lakeshore, Michigan, USA: © by Springer 2014. Documentation that includes

permission to use copyright material is provided in Appendix B and Appendix D. Wilfred

J. Previant conceived and designed the study, collected and analyzed the data, and wrote

the manuscript. Linda M. Nagel contributed to writing and editing the manuscript. Dan

Hutchison and Adrienne Bozic contributed to data collection.

## Recognition

This long and wandering journey to successfully complete this dissertation work could not have been possible without the support, understanding, patience, and encouragement of several people. My advisor, Linda Nagel, gently and kindly provided guidance and advice for these and other projects, and always lent a clear and uncluttered vision while I swam in the minutia. I have become a better researcher and writer, and I thank her for allowing me the freedom to explore the scientific process. I would also like to thank my committee members, Janice Glime, Robert Froese, and Christopher Webster, for their patience, valuable feedback, and positive outlook. Robert lent a practitioner's eye to provide humour with statistics, and Chris helped me to take a step back and ponder scale.

At the earliest moments of my scholastic career, my family has been steadfast in their support, reiterating the mantra of hard work and that a “proper education is something no one can take from you.” My deepest appreciation to my grandparents for providing the chance to attend college, as without their foresight and sacrifice, I would not have started this journey. My parents, Jon and Julie, have always encouraged me to ply my talents and seek opportunity and happiness. The playful badgering by my brothers, Wes and Lee, brought laughter at the hardest crossroads. My aunt and uncle, Lynn and Dan, gave me inspiration with their compassion and stories from their worldwide motorcycle tours. I thank the Bozic family for their unwavering support. My dear friend, Charles Paulson, whose quick wit and analog view of forestry has been invaluable. Finally, I need to thank Adrienne Bozic, for challenging my “old forester ways,” editing too many of my drafts,

keeping Chinquapin fed and entertained while I was away, and believing in my research.  
May *Calypso bulbosa* and *Cypripedium arietinum* guide your path.

I would also like to thank FRES graduate students. Everyone was eager to swap research and writing tales, lending some sense of normalcy to the process. Thank you, Alex, Trevor, and Mickey! Lastly, to all the Fall Camp students, your desire to learn and gain skills in this fascinating field is an inspiration. It has been a pleasure watching your careers successfully unfold.

## Abstract

Northern hardwood management reflects a combination of historic exploitation, current efforts for sustainability, and a desired future condition that incorporates complexity, resiliency, and adaptability. Stand structure and species diversity were assessed at two study locations within Michigan (USA): (1) long-term northern hardwood cutting trials at the Ford Forestry Center (FFC; Michigan Technological University, USA); and (2) vernal pool habitat within Pictured Rocks National Lakeshore (PRNL). Following the fifth cutting entry at the FFC, age structure and pre- and post-harvest relative species abundance, stocking, and volume were compared across three diameter-limit treatments, three residual basal area treatments, and an uncut control. Results from 52 years of northern hardwood management indicate that all FFC treatments increased the dominant species, *Acer saccharum* (Marsh.), at a faster rate than the uncut control; cumulative harvested volume was partially dependent upon the initial 1957 harvest; management maintained or strengthened age-diameter linear relationships; and all treatments indicate a lack of recruitment within the past 52 years, indicating a reliance on stocking from trees prior to a region-wide 1938 high-grade. Within PRNL, vernal pool survey techniques, hydrogeomorphic classification systems, and a proposed habitat management guide were evaluated. Results suggest there are at least five subclasses of vernal pools, though nearly three-quarters were associated with just three soil series and the northern hardwoods cover type. Additionally, Nested-ANOVA and NMDS ordination indicate under-represented tree species' importance values increased closer to the vernal pool, while tree diversity and richness were positively correlated with vernal pool area. In summary,



while the FFC cutting trials indicate that stand legacy and subsequent management may create a less-diverse and simplified forest structure, vernal pools may act as refugia for under-represented species and provide an opportunity to maintain and enhance ecosystem complexity and resiliency for northern hardwoods.

## Chapter 1.      **Introduction**

### **1.1. Land-use Legacy and Long-term Cutting Trials**

The United Nations estimates that 12 percent of global forest ecosystems are protected from anthropogenic changes (Chape *et al.* 2003). Within the U.S., approximately 10 percent of forestland has statute protection that prevents conversion to non-forest lands, though less than three percent is protected within Michigan, Minnesota, and Wisconsin (Lake States; Smith *et al.* 2009). The result is a forest cover has significantly been reduced and altered from the pre-Euro-American era, placing additional pressure on sustainable management that involves protecting biodiversity, enhancing resiliency to known and unknown threats, increasing forest and stand complexity, and ensuring future adaptability to a changing climate.

For nearly two centuries, exploitation and management have profoundly altered forest ecosystems within the Lake States. Northern hardwood forests have declined in total area by 66% (Burns 1983; Frelich 1995; Frelich 2002; Shifley *et al.* 2012), with eastern hemlock (*Tsuga canadensis* (L.) Carr), eastern white pine (*Pinus strobus* L.), and yellow birch (*Betula alleghaniensis* Britt.) experiencing significant decreases in both abundance and stocking (Whitney 1987; White and Mladenoff 1994; Zhang *et al.* 2000).

Contemporary northern hardwood forests are now dominated by sugar maple (*Acer*

*saccharum* Marsh.) and red maple (*Acer rubrum* L.), and are characterized as having a uniform age, simplified size structure, lower species diversity, and lacking coarse woody debris (Tubbs 1977; Runkle 1991; Mladenoff *et al.* 1993; Goodburn and Lorimer 1999; Crow *et al.* 2002; Schwartz *et al.* 2005; Schulte *et al.* 2007; Franklin *et al.* 2007; Kenefic and Nyland 2007).

For more than five decades, management and research efforts have attempted to create sustainable second-growth forests under “near natural” uneven-aged silvicultural systems (Eyre and Zillgitt 1953; Seymour *et al.* 2006; Kern *et al.* 2014). The reliance upon the natural disturbance regime of northern hardwoods (i.e., single and group tree-fall gaps), the shade-tolerance plasticity of *Acer saccharum*, and a balanced diameter distribution created a management framework that increased growth productivity, allowed for periodic harvests, and increased the quality of high-value sawtimber. Based on Eyre and Zillgitt’s (1953) findings, Arbogast (1957) created an uneven-aged, single-tree selection marking guide for northern hardwoods that was quickly and widely adopted by federal, state, corporate, and private forest managers within the Lake States (Jacobs 1987; Erdmann and Oberg 1973; Goodburn and Lorimer 1999; Seymour *et al.* 2006; Pond *et al.* 2014). Just as importantly, both the USDA Forest Service and Ford Forestry Center (Michigan Technological University, Houghton, MI, USA) established long-term cutting trials to investigate regeneration, cutting methods, cutting cycle length, residual stocking levels, volume production, grade, diversity, and structural aesthetics (Bourdo and Johnson 1957; Rudolf 1985; Adams *et al.* 2008; Kern *et al.* 2014). These on-going

findings and techniques have been presented to forest managers, professional organizations, and academic institutions, highlighting both the sustainability of the selection system and the value of long-term research (e.g., Erickson *et al.* 1990; Reed *et al.* 1996; Bodine 2000; Gronewold *et al.* 2010; Campione *et al.* 2012; Kern *et al.* 2014). Just as critically, research results have identified that the widespread adoption of the selection system has potential drawbacks.

## **1.2. Concerns with Northern Hardwood Management**

Within northern hardwood forests, utilizing a specific silvicultural technique creates a landscape with uniform structure and composition, thus lowering beta diversity (Whittaker 1960; Nyland 2007). Frequent harvest entries promote early-successional herbaceous species (Crow *et al.* 2002; Scheller and Mladenheff 2002; Kern *et al.* 2006; Burton *et al.* 2009; Campione *et al.* 2012), eliminate intolerant and mid-tolerant tree species (Eyre and Zillgitt 1953; Metzger and Tubbs 1971; Leak and Sendak 2002; Schwartz *et al.* 2005; Neuendorff *et al.* 2007; Gronewold *et al.* 2010), remove the potential for creation of snags and dead down woody material (Gronewold *et al.* 2010), and potentially create homogenous conditions that may have the inability to adapt to unknown future climatic conditions (Evans and Perschel 2009; Puettmann 2011; Handler *et al.* 2014). Arbogast (1957) created a northern hardwood marking guide that relied on a balanced diameter distribution, while others have shown the predictive linear relationship existing between diameter and age (de Liocourt 1898; Meyer 1943, 1952; Eyre and Zillgitt 1950, 1953; Tubbs 1977; Lorimer 1980; Kenefic and Nyland 1999). This assumption that

diameter size is a proxy for age (i.e., smaller trees are younger and larger trees are older) may allocate growing space to older, shade-tolerant trees of smaller diameters.

As management attempts to balance ecological processes with societal demands, additional pressure is placed on limited forested resources to increase complexity while withstanding and adapting to projected regional climate change. Future changes in precipitation events and temperatures may negatively impact *Tsuga canadensis* and *Betula alleghaniensis*, already under-represented species (Walker *et al.* 2002; Foster *et al.* 2006). Continued or enhanced decline of these and other species alters ecological processes and limits the ability to manage for future resiliency (Ellison *et al.* 2005; Millar *et al.* 2007; Handler *et al.* 2014). Within this context, a little-known ephemeral wetland – vernal pools – may provide a unique opportunity for meeting broad management and ecological goals within the northern hardwoods forest type.

### **1.3. Vernal Pools in Northern Hardwoods**

Vernal pools occur in shallow depressions within the glaciated forests of northeastern North America (Brooks *et al.* 1998; Tiner 2003; Colburn 2004; Calhoun and deMaynadier 2008). Because these seasonal forested wetlands have a small surface area (average 800 m<sup>2</sup>) and tend to not be hydrologically connected to other wetlands, they are not federally protected (*see* Ruffolo 2002; *see* Zedler 2003). However, they are an important component in the life-cycles of amphibians and invertebrates (Ling *et al.* 1986;

Calhoun and deMaynadier 2001; Calhoun *et al.* 2003; Homan *et al.* 2004). Timing and quality of moisture availability are significant factors in determining the abundance and diversity of species utilizing vernal pools (Bliss and Zedler 1998). Vernal pools may also influence the surrounding upland northern hardwood forest diversity and structure by serving as water catchments and extending growing-season hydroperiods. This aspect may partly explain why *Betula alleghaniensis* was associated with 36% of upland vernal pools in northern Minnesota (Palik *et al.* 2007). Herein lies the epiphany- what if these known biological hotspots can be incorporated into existing management plans and provide an opportunity to maintain and enhance ecosystem complexity and resiliency?

While the majority of vernal pool assessments have been focused in the northeast USA (e.g., Brooks *et al.* 1998; Calhoun *et al.* 2003; Lathrop *et al.* 2005), the Great Lakes region has a lack of baseline information regarding locating, inventorying, and classifying vernal pools and identifying associated edaphic and forest structure characteristics. To protect the breeding, foraging, migration, and concealment habitat for a wide-range of fauna, Best Management Practices (BMPs) and habitat management guidelines (HMG) have been proposed to minimize disturbance associated with forest management practices (MDNR 2009; Calhoun and deMaynadier 2004). This voluntary protection of the vernal pool and surrounding upland forest may actually benefit two under-represented species, *Betula alleghaniensis* and *Tsuga canadensis*, providing an opportunity to increase conservation effectiveness and maintain and enhance ecosystem complexity and resiliency.

## 1.4. Summary

The goal for this dissertation work was to evaluate traditional silvicultural techniques in northern hardwoods, identify the successes and shortcomings of the long-term Ford Forestry Center Cutting Trials, and integrate those findings with the novel concept of vernal pool habitat management. Chapter Two describes 52 years of various silvicultural techniques in northern hardwood forests. An uncut control and six treatments were harvested in 2008-09, and pre- and post-harvest data was compiled and compared to the previous five decades. Relative species abundance, basal area, stocking, volume, and ages of residual and harvested *Acer saccharum* were analyzed. The following four null hypotheses were tested: (1) relative to an uncut control, all treatments result in an increase in the dominance of *Acer saccharum*; (2) all treatments increase volume productivity relative to the uncut control; (3) age structures for all treatments were younger than the uncut control; and (4) a linear relationship exists between diameter size-classes and age, indicating a balanced age structure.

Chapter Three demonstrates the techniques to identify and classify vernal pools using remote sensing and field surveys at Pictured Rocks National Lakeshore, Michigan, USA. Objectives were to: (1) locate vernal pools using true-color, spring leaf-off aerial photography at the 1:12,000-scale; (2) classify vernal pools using modified geomorphological classification systems; and (3) determine landscape associations with

soil series and cover type GIS datasets. This information helped form the baseline for collaborative research with the National Park Service (see Resh *et al.* 2013; Shrank *et al.* 2015).

In Chapter Four, using a stratified subsample of vernal pools from Chapter Three, associated edaphic and forest structure characteristics associated with vernal pools are discussed. Within the context of the Calhoun and deMaynadier (2004) HMG and its three distinct management zones, these hypotheses were tested: (1) overall tree diversity and richness would be higher within 31 m of a vernal pool's boundary compared with the surrounding 32-122 m management zone due to late-season water availability within vernal pools; (2) the relative importance of *Betula alleghaniensis* and *Tsuga canadensis* would be greater within 31 m of a vernal pool's boundary compared with the 32-122 m management zone due to mesic edaphic characteristics; and (3) tree diversity and richness would be positively correlated with the surface area of pools, indicative of higher volumes of water and late-season availability.

Long-term cutting trials are invaluable for our understanding of forest ecology and sustainable management, and serve as outdoor laboratories for practitioners, researchers, instructors, students, and the general public. These results indicate shifts in forest and stand composition and structure – namely the decline of *Betula alleghaniensis* and *Tsuga canadensis* – and require creative solutions. Incorporating vernal pools within northern hardwood management may result in locations with a higher frequency of these species



on the landscape, and may also aid in conservation efforts for at-risk flora and fauna while maintaining and enhancing ecosystem complexity and resiliency for northern hardwoods.

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## Chapter 2.      **Demographic Change after 52 Years of Northern Hardwood Silviculture**<sup>1</sup>

### **2.1. Abstract**

In 1956 Michigan Technological University established a series of silvicultural treatments and an uncut control in a northern hardwood forest to examine profitability and stand quality development. With a cutting cycle of 10 years, pre- and post-harvest stand structure data were collected on each diameter-limit (DL; 30-, 41-, and 56-cm; i.e. removal of all trees at or greater than specified diameter) and residual basal area (RBA; 11-, 16-, and 21-m<sup>2</sup> ha<sup>-1</sup>) treatment. Following the fifth entry in 2008, we investigated age structure in each treatment and an uncut control for the dominant species, *Acer saccharum* (Marsh.). Across all treatments, relative abundance of this species increased at faster rates than the uncut control. DL treatments removed more volume than RBA treatments, though the volume removed for each treatment was partially dependent upon initial 1956 conditions. Age distribution was determined from 87 harvested trees, 106 residual trees, and 71 control trees. Residual mean ages ranged from 84.9 to 121.4 years, with the uncut control being significantly older than the 41- and 56-cm DL (p-values 0.0278 and 0.0264, respectively) and the 11- and 16-m<sup>2</sup> ha<sup>-1</sup> RBA (p-values 0.0029 and 0.0393, respectively) treatments. Among the six treatments, no differences were found

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<sup>1</sup> This chapter is currently being prepared for submission to the peer-reviewed journal *Forest Ecology and Management*.

between residual mean ages. With the exception of the 30-cm DL ( $r^2 = 0.06$ ;  $p$ -value = 0.3117), all treatments exhibit a moderate to strong correlation between residual tree diameter and age (control  $r^2 = 0.57$ ; treatment  $r^2$  values between 0.43 and 0.69). All treatments indicate a lack of recruitment over 52 years of intensive management and a reliance on stocking from trees prior to a region-wide 1938 high-grade. These results raise concerns regarding species diversity and suggest it may take considerably longer than thought to convert second growth northern hardwood stands to a fully-regulated, uneven-aged condition.

## **2.2. Introduction**

The Laurentian Mixed Forest Province (Ecoprovince 212), a transition between southern deciduous and northern boreal forests, comprises 261,374 km<sup>2</sup>, or 41% of the total area of Michigan, Minnesota, and Wisconsin, USA (Lake States; Bailey 1995; Cleland *et al.* 2007). For the past 150 years, the Lake States have experienced pronounced and significant changes in forest area, composition, diversity, and structure. Relative to pre-Euro-American forests, present-day forests have been described as homogenized (Schulte *et al.* 2007), with young, even-aged forests (Frelich and Lorimer 1991; Frelich 1995) that have shifted from a diverse and conifer-dominated canopy to one now consisting of just a few deciduous species (Whitney 1987; White and Mladenoff 1994; Schulte *et al.* 2007).

For example, northern hardwood forests currently cover approximately 4-5 million ha, a substantial decline from 15.3 million ha estimated from the US General Land Office

Survey of the 1850s (Burns 1983; Frelich 1995; Frelich 2002; Shifley *et al.* 2012). The northern hardwoods forest type has experienced declines in species like eastern hemlock (*Tsuga canadensis* (L.) Carr), eastern white pine (*Pinus strobus* L.), and yellow birch (*Betula alleghaniensis* Britt.), while sugar maple (*Acer saccharum* Marsh.) and red maple (*Acer rubrum* L.) have become the dominant species (Zhang *et al.* 2000; Schwartz *et al.* 2005; Schulte *et al.* 2007). Compared to remnant and late-successional old-growth forests (e.g., Michigan's Porcupine Mountains Wilderness State Park and Sylvania Wilderness Area, USA), the majority of managed northern hardwood forests have a simplified and uniform age and size structure, lack a mixture of mid-tolerant and tolerant species, have lower species diversity, and do not exhibit the unique attributes related to downed woody debris, snags, and trees with well-developed crowns and large diameters (Tubbs 1977; Runkle 1991; Mladenoff *et al.* 1993; Goodburn and Lorimer 1999; Crow *et al.* 2002; Franklin *et al.* 2007; Kenefic and Nyland 2007). Multiple factors have contributed to the current conditions, including exploitative logging at the turn of the 20th century, and subsequent forest management practices.

Following the selective logging of eastern white pine in the mid-1800s, the ensuing removal of 20 million ha of northern hardwoods within six decades left a denuded and degraded landscape (Williams 1992; Stearns 1997). This liquidation resulted in sawmills facing stumpage shortages and public opposition to clear-cutting, culminating in management and research efforts to create sustainable second-growth forests under “near natural” uneven-aged silvicultural systems (Eyre and Zillgitt 1953; Seymour *et al.* 2006;

Kern *et al.* 2014). Based on de Liocourt (1898) and Meyer (1943, 1952), negative exponential diameter distributions using q-structures suggested that single-tree selection could be applied at the stand level to provide sustained yields. Conjointly, the USDA Forest Service established Experimental Forests to address issues related to regeneration, cutting methods, cutting cycle length, and residual stocking level (Rudolf 1985; Adams *et al.* 2008; Kern *et al.* 2014).

Within Michigan's Upper Peninsula, the USDA Forest Service established the Dukes Experimental Forest in 1926 to investigate improving quality in second-growth northern hardwood forests through the establishment of long-term silviculture studies (Eyre and Zillgit 1950; Kern *et al.* 2014). Initial results indicated that partial cuttings (i.e., selective cuttings) still degraded northern hardwood stands, but single-tree or small-group selection management provided a continuous and sustainable yield (Eyre and Zillgitt 1953). Arbogast (1957), based both on initial stand conditions and the work by Eyre and Zillgit (1953), recommended a cutting cycle of 8-15 years and a desired post-harvest basal area between 17 and 22 m<sup>2</sup> ha<sup>-1</sup> (diameter at breast height of 1.37 m, dbh > 12.6 cm). By using an empirically derived, reverse-J diameter distribution with a specified residual stocking per diameter class, Eyre and Zillgitt (1953) and Arbogast (1957) recommended that the accumulated stand growth could be harvested periodically across all size classes and thus provide a sustainable yield.

Trees selected for retention were prioritized (e.g., ability to survive to next entry, form, defect, species, crown position, and size), with the goal of the selection system retaining more vigorous trees of better form and removing those that were mature or of poor quality (Eyre and Zillgitt 1953; Arbogast 1957). By creating a balanced diameter distribution, the residual stocking forms the stand's base structure and aids in predicting growth accumulation (Eyre and Zillgitt 1950, 1953; Meyer 1952; Arbogast 1957; Leak and Smith 1996; O'Hara 2002). Hence, an uneven-aged management approach with a regulated residual stocking and size-class distribution represented the "highest potential of maximum quantity and quality growth" (Arbogast 1957).

Eyre and Zillgitt's (1953) findings also initiated replicated stocking and cutting cycle studies at both the Dukes and Argonne (Wisconsin, USA) Experimental Forests. Results from these studies supported Eyre and Zillgitt's (1953) recommendations of using a northern hardwoods selection system by maintaining a residual sawlog basal area of 16 m<sup>2</sup> ha<sup>-1</sup> (dbh > 25.4 cm) on a 10-year cutting cycle (Crow *et al.* 1981; Gronewold *et al.* 2010). The single-tree selection system within northern hardwood stands also had flexibility; maintaining higher residual basal area increased stand quality, while reducing residual basal area increased growth rates (Godman and Books 1971; Leak 1964; Erdman and Oberg 1973; Adams and Ek 1974; Crow *et al.* 1981; Nyland 1998).

Because this balanced stand structure meant an increase in productivity and quality at predictable intervals, Arbogast's (1957) "Marking Guide" was widely adopted within the

Lake States. Current estimates indicate that 85-90% of contemporary forest management is uneven-aged with single-tree selection implemented across federal, state, corporate, and private ownerships (Jacobs 1987; Johnson 1984; Minckler 1972; Erdmann and Oberg 1973; Perkey 1987; Goodburn and Lorimer 1999; Seymour *et al.* 2006; Pond *et al.* 2014). Additionally, complimentary research by Bourdo and Johnson (1957), utilizing the recommendations of Eyre and Zillgitt (1953) and Arbogast (1957), established the Ford Forestry Center (FFC) Cutting Trials at Michigan Technological University (Houghton, MI, USA) to compare volume, grade, and structural aesthetics for local woodlot owners. Relative to unmanaged second-growth forests, the selection system promotes an all-aged structure (Tubbs 1977; Kenefic and Nyland 1999; Nyland 2007), creates a more complex forest structure (Crow *et al.* 2002), concentrates forest composition into commercially-valuable species (Erickson *et al.* 1990; Crow *et al.* 2002; Schwartz *et al.* 2005; Neuendorff *et al.* 2007; Gronewold *et al.* 2010), reduces defects and cull (Tubbs 1977; Erickson *et al.* 1990; Gronewold *et al.* 2010), and improves sawlog quality while maximizing value growth (Adams and Ek 1974; Erickson *et al.* 1990; Orr *et al.* 1994; Gronewold *et al.* 2010). The selection system also allocates carbon stores to older residual trees while increasing sequestration rates via smaller and younger trees (D'Amato *et al.* 2011).

However, the selection system is not without its drawbacks. Using the same management technique across a common and broadly-distributed forest type can create numerous stands with uniform composition and structure (Nyland 2007). Within Michigan's

corporate, nonindustrial private, and state ownerships, Arbogast's (1957) guidelines were not consistently applied, raising concerns about successful regeneration and long-term sustainability (Pond *et al.* 2014). Single-tree selection influences the richness and diversity of the herbaceous layer, including the proliferation of weedy and early-successional species (Crow *et al.* 2002; Scheller and Mladenhoff 2002; Kern *et al.* 2006; Burton *et al.* 2009; Campione *et al.* 2012). Within managed stands, while shade-tolerant *Acer saccharum* has increased in dominance, it is often to the detriment of mid-tolerant tree species (Eyre and Zillgitt 1953; Metzger and Tubbs 1971; Leak and Sendak 2002; Schwartz *et al.* 2005; Neuendorff *et al.* 2007; Gronewold *et al.* 2010). This loss of compositional, structural, and/or functional heterogeneity may result in vulnerable stand conditions, leading to an inability of Lake States northern hardwoods to be resilient or adaptable to unknown future conditions such as projected climate change (Evans and Perschel 2009; Puettmann 2011; Handler *et al.* 2014). Lastly, though a predictive linear relationship exists between diameter and age (Tubbs 1977; Lorimer 1980; Nyland 2007; Kenefic and Nyland 1999), northern hardwood management assumes diameter size classes are a proxy for age (i.e., smaller trees are younger and larger trees are older). Yet, with shade-tolerant species, suppression of trees within lower crown positions leads to older ages at smaller diameters, and subsequently, lower radial growth and poor recruitment (Tubbs 1977; Canham 1985; Seymour and Kenefic 1998; Lorimer *et al.* 1988; Kenefic and Nyland 1999). It is unclear if Arbogast's (1957) balanced size-class structure predictably and consistently creates new age classes with each cutting cycle. Long-term cutting trials are critical in addressing these concerns.

Like the Dukes and Argonne Experimental Forests, Michigan Technological University's FFC Cutting Trials have provided long-term data to evaluate the balanced stand-size structure recommended by Arbogast (1957). Similar to the cutting trials at Dukes and Argonne Experimental Forests, Bourdo and Johnson (1957) implemented a selection system of varying intensities on a regular cutting cycle. In addition, a series of diameter-limit treatments (removal of all species at and above a specified size class) were created to evaluate productivity and structure characteristics. Both the selection and diameter-limit treatments have been maintained under the original objectives, and through education, professional outreach, and peer-reviewed publications, collectively provide landowners examples of various silvicultural techniques for managing northern hardwoods (Bourdo and Johnson 1957; Reed *et al.* 1986; Erickson *et al.* 1990; Bodine 2000; Campione *et al.* 2012). Following 52 years of management, the consistency of treatments allows a unique opportunity to evaluate the composition, productivity, and relationship between size-class distribution and age structure. Thus, we hypothesize: (1) relative to an uncut control, all treatments show an increase in the dominance of *Acer saccharum*; (2) all treatments increase volume productivity relative to the uncut control; (3) age structures for all treatments would be younger than the uncut control; and (4) a linear relationship exists between diameter size-classes and age, indicating a balanced age and stand-size structure.



## 2.3. Methods

### 2.3.1. *Site description*

This study is located at Michigan Technological University's Ford Forestry Center (FFC), near the village of Alberta in Baraga County, Michigan, USA (46.66°N, 88.51°W; Figure 3-1). Similar to the historical events within the Lake States, by 1898, the majority of *Pinus strobus* had been removed from the mixed pine-hardwood forest (Bourdo and Johnson 1957). Under the ownership of the Ford Motor Company, the area was selectively logged in 1938, removing as much as 70% of the volume and nearly 90% of the merchantable value of the hardwood sawlogs (Bourdo and Johnson 1957). These two cuttings resulted in a majority of residual stocking with a dbh of < 25.4 cm and with short merchantable bole lengths, common to that of "high-graded" second-growth northern hardwood forests across the region (Reed *et al.* 1986). The research location and surrounding area was donated to Michigan Technological University in 1954 (Bourdo and Johnson 1957).

The soil at this site is classified as Allouez gravelly coarse sandy loam with slopes ranging from 0-6% (Berndt 1988). This northern temperate climate has an average summer temperature of 17.4° C and a winter temperature of -9.8° C. Annual precipitation is 87.4 cm, with a mean annual snowfall of 385.5 cm (Berndt 1988). The current overstory composition is mainly *Acer saccharum*, with minor species including *Betula*

*alleghaniensis*, white spruce (*Picea glauca* (L.)), black cherry (*Prunus virginiana* (L.)), eastern hophornbeam (*Ostrya virginia* ((Mill.) K. Koch)), American basswood (*Tilia americana* (L.)), and American elm (*Ulmus americana* (L.)). Common understory species are *Dryopteris spinulosa* (O.F. Müll.) Watt, *Carex* spp. (L.), *Rubus* spp. (L.) and *Galeopsis tetrahit* (L.). The habitat type is classified as *Acer-Tsuga-Dryopteris* (Burger and Kotar 2003; Campione *et al.* 2012).

### **2.3.2. Study design**

This demonstration woodlot was established in 1956 “to investigate the effects of subsequent treatments” following the intensive selective cut of the 1930s (Bourdo and Johnson 1957). The study tract is 22.2 ha and consists of six unreplicated cutting treatments and one uncut control, with each treatment between 1.2 and 5.7 ha (Bourdo and Johnson 1957). Treatments consist of three diameter-limit treatments (DL: 56-, 41-, 30-cm), three single-tree selection treatments with varying residual basal area (RBA; 21-, 16-, and 11-m<sup>2</sup> ha<sup>-1</sup>), and an uncut control (Figure 2-1). We did not include two additional treatments: the first having high variability between prescriptions (“light improvement”) and the second being an uncommon silvicultural prescription (13-cm DL). Following guidelines from Arbogast (1957), RBA treatments removed trees of the poorest quality and/or vigor across all diameter classes 11.4 cm and greater. Using 2.5-cm diameter-size classes, the resulting diameter distribution generally follows a *q*-factor of 1.3 (Arbogast 1957; Leak 1964; Leak and Filip 1977; Reed *et al.* 1986; Erickson *et al.* 1990; Schwartz *et al.* 2005). Additionally, trees with an upper-diameter limit of 61 cm were removed as

they were considered “economically mature” (Arbogast 1957; Bourdo and Johnson 1957; Reed *et al.* 1986; Erickson *et al.* 1990). The DL treatments removed all trees at and above the specified size class with no consideration for residual quality, vigor, composition, spacing, or stocking levels (Bourdo and Johnson 1957).

All treatments had an initial winter harvest in 1956-57, with subsequent harvests occurring on a 10-year cutting cycle, totaling five entries to date. However, if the harvest was economically infeasible at the end of a cutting cycle, that treatment was not harvested at that time (Bourdo and Johnson 1957; Reed *et al.* 1986; Erickson *et al.* 1990). The 41-cm DL, and 11- and 16 -m<sup>2</sup> ha<sup>-1</sup> RBA have been harvested at each of the five cutting cycle entries. The 21-m<sup>2</sup> ha<sup>-1</sup> RBA, 56-cm DL, and 30-cm DL were harvested four, three and two of the five cutting entries, respectively (Figure 2-1). The uncut control has not experienced any timber removals since the high-grade cutover in 1938.

### **2.3.3.      *Field and laboratory methods***

Within the center of each treatment, Bourdo and Johnson (1957) established a 0.4-ha permanent measuring block that was subdivided into ten 0.04-ha contiguous subplots (Figure 2-1). To determine basal area and sawtimber volume trends between treatments and the uncut control, we used historical data collected prior to and following each cutting cycle (e.g., 1956, 1968, 1978, 1988, and 1998; cf. Bodine 2000) and our own 2008-09 measurements pre- and post-harvest. Within each subplot, all overstory species (greater than 12.6-cm dbh) were identified to species and measured for diameter, total

height, merchantable height (to a 10.2-cm outside bark diameter), merchantable sawlog height (to a 25.4-cm outside bark diameter), gross and net volume (International ¼-in Log Rule) for trees 30.5-cm dbh and greater, cull percent, number of 2.4 m sections, and butt log tree grade (Timber Producers Association of Michigan and Wisconsin 1998). These were the same techniques used by Bourdo and Johnson (1957), Reed *et al.* (1986), Erickson *et al.* (1990), and Bodine (2000). Post-harvest basal area information is not available for the 1968 and 1978 entries. To estimate this missing data for each of the six treatments, we used the known pre- and post-harvest data for each measurement interval to create a ratio of gross volume (International ¼-in Log Rule) to basal area. These treatment-specific ratios were then averaged and applied to the known post-harvest gross volume from the 1968 and 1978 entries, respectively.

To determine tree ages within the six treatments and the uncut control, we collected both diameter increment cores of residual trees and basal cookies (horizontal chainsaw slab from the top of stump) from recently harvested trees. Within each treatment, a minimum of 10% of residual trees was randomly selected. Two increment cores at perpendicular angles to each other were extracted at dbh. If a core was unreadable (e.g., heart rot or hollow), that tree was randomly replaced with a tree of the same species and from the same 2.54-cm diameter class. For the uncut control, we attempted to core all trees within the 0.4-ha permanent block. Increment cores were then mounted on wooden planks and, along with the basal cookies, allowed to air-dry prior to sanding. Using a binocular microscope and a stage micrometer, annual rings were measured to the nearest 0.01 mm.

Each core sample was measured four times, with the average reported as the estimated minimum-maximum age. Each basal cookie was bisected and two perpendicular transects were read twice, with the average also reported as the estimated minimum-maximum age. Since we were only trying to obtain an estimated age from each sample, we did not attempt to cross-date each tree ring against a mean chronology. Potential future work exploring growth rates and release responses would incorporate cross-dating.

### **2.3.4.      *Statistical analyses***

A complete census of each treatment's structure (species, basal area, density, and volume) was measured pre- and post-harvest and reported as absolute values for each entry. Comparisons of long-term structural trends relied upon data reported in Bodine (2000). Without cross-dating, ages are reported as estimated minimums. Analysis of variance (ANOVA) was used to compare the random sampling of core ages among the treatments and control. When significant differences were detected ( $\alpha = 0.05$ ), Tukey-Kramer comparison of means (JMP 10 SAS 2012) was conducted. The diameter and age relationship of residual trees among treatments and the control was analyzed using statistical regression models, including linear, power, and polynomial (JMP 10 SAS 2012). For each treatment and control, residual plots were examined to determine homogeneous variance. Because harvested trees were the result of silvicultural prescriptions, ages taken from stumps do not represent a random sample as trees were not randomly harvested. Assumptions of normality are violated in this case, so a test of significance was not conducted on ages of harvested trees.

## 2.4. Results and Discussion

### 2.4.1. *Structure*

#### 2.4.1.1. *Relative species abundance*

To determine shifts in species composition within treatments and the uncut control, we compared the relative species abundance (i.e., percentage of one species to all species) of 1956 pre-harvest overstory species to 2008 values (Table 2-1). At the start of the study in 1956, the relative abundance of *Acer saccharum* (> 12.6-cm dbh) averaged 79.3%, and ranged between 72% (21-m<sup>2</sup> ha<sup>-1</sup> RBA) and 90% (uncut control). Four treatments (11-m<sup>2</sup> ha<sup>-1</sup> RBA, 21 m<sup>2</sup> ha<sup>-1</sup> RBA, 30-cm DL, and 56-cm DL) had *Acer saccharum* relative abundance values of 76% or less. These initial relative abundance values are comparable to the 1938 (83%) and 1952 values (75-79%) at Dukes Experimental Forest (Tubbs 1977; Gronewold *et al.* 2010). By 2008, the relative abundance of *Acer saccharum* had increased in the uncut control and all treatments, with the only exception being the 41-cm DL treatment. After 52 years, *Acer saccharum* comprised 87.7% of the study's composition for trees greater than 12.6-cm dbh, with all treatments and the uncut control greater than 80%. While *Acer saccharum* decreased in the 41-cm DL by 6% between 1956 and 2008, the range of increase for all other treatments was between six (16-m<sup>2</sup> ha<sup>-1</sup> RBA) and 16 (11-m<sup>2</sup> ha<sup>-1</sup> RBA) percent. The uncut control, both for the 1956 (90%) and

2008 (97%) measurements, had the highest pre-harvest relative species abundance of *Acer saccharum*.

For trees greater than 29.2-cm dbh (i.e., sawlog size-class), this same pattern of an increasing relative abundance of *Acer saccharum* emerged. In 1956, the pre-harvest relative abundance of *Acer saccharum* sawlogs across all treatments and the uncut control was 80.9%, with the lowest in the 21-m<sup>2</sup> ha<sup>-1</sup> RBA (68%) and highest in the 16-m<sup>2</sup> ha<sup>-1</sup> RBA (91%). By 2008, the study's average value for *Acer saccharum* sawlogs had increased to 98.4%. Compared to the treatments, the uncut control had the lowest relative abundance of *Acer saccharum* sawlogs (96%), while all the treatments had a sawlog stocking of 98% and greater. Over the 52-year period, the relative abundance of *Acer saccharum* sawlogs increased in all treatments and control, with the largest increases occurring in the 11-m<sup>2</sup> ha<sup>-1</sup> RBA (30%), 21-m<sup>2</sup> ha<sup>-1</sup> RBA (32%), and 30-cm DL (25%). The control experienced a 9% increase in *Acer saccharum* sawlogs over the same period.

Conversely, over the length of the study, the relative species abundance of *Betula alleghaniensis* has declined or this species has entirely disappeared. In 1956, *Betula alleghaniensis* relative abundance (>12.6-cm dbh) ranged between 0-14% and, by 2008, this range shifted to 0-4% (Table 2-1). For trees greater than 29.2-cm dbh, the relative abundance of *Betula alleghaniensis* declined across all treatments and the uncut control, and was eliminated in the 11-m<sup>2</sup> ha<sup>-1</sup> RBA (20% decline), 21-m<sup>2</sup> ha<sup>-1</sup> RBA (7% decline), and 30-cm DL (11% decline) treatments. For all other overstory species (e.g., some

combination of *Picea glauca*, *Prunus virginiana*, *Ostrya virginia*, *Tilia americana*, or *Ulmus americana*), only two treatments had a collective increase in relative species abundance for dbh size class 12.6 cm and greater (16-m<sup>2</sup> ha<sup>-1</sup> RBA and 41-cm DL; Table 2-1). However, between 1956 and 2008, the 29.2-cm and greater dbh class lost all other overstory species in four treatments (11-m<sup>2</sup> ha<sup>-1</sup> RBA, 16-m<sup>2</sup> ha<sup>-1</sup> RBA, 21-m<sup>2</sup> ha<sup>-1</sup> RBA, and 41-cm DL).

Table 2-1 shows how the 1956 relative species abundance values of trees with a dbh of 12.6 cm and greater represent recruitment potential. For example, the 30-cm DL 29.2-cm and greater dbh class was 73% *Acer saccharum*. Following the initial cut in 1957, all species were removed within this class, theoretically creating a recruitment slot between 12.6- and 30-cm dbh. By 1998, the 30-cm DL treatment was economically viable for its second harvest and, 10 years later, *Acer saccharum*'s relative abundance was 98%.

Across all treatments, this increase in the relative abundance of the highly valuable *Acer saccharum*, especially in trees greater than 29.2-cm dbh class, meets the major economic objective set forth by Bourdo and Johnson (1957) and corresponds with the findings of Arbogast (1957), Tubbs (1977), Crow *et al.* (2001); Schwartz *et al.* (2005); Neuendorff *et al.* (2007), and Gronewold *et al.* (2010). Each treatment, regardless of the frequency or interval of harvest entry (Figure 2-1), has experienced a decline in other species, while also successfully recruiting smaller size classes and allocating additional growing space to *Acer saccharum*. For the RBA treatments, the increased concentration of *Acer saccharum* stocking across all size classes was predicted by Eyre and Zillgit (1953) and



Arbogast (1957), and is supported across different ownership groups (Crow *et al.* 2002; Schwartz *et al.* 2005; Neuendorff *et al.* 2007) and at the Dukes Experimental Forest (Tubbs 1977; Gronewold *et al.* 2010).

The shift to nearly 100% *Acer saccharum* in the 29.2-cm and greater dbh class is reflected in the decline in *Betula alleghaniensis* and all other overstory species. These findings are consistent with other studies that indicate a decrease in mid-tolerant species in stands dominated by *Acer saccharum* (Tubbs 1977; Crow *et al.* 2002; Leak and Sendak 2002; Schwartz *et al.* 2005; Webster and Lorimer 2005; Neuendorff *et al.* 2007; Gronewold *et al.* 2010). This increase in the relative abundance of *Acer saccharum* also removes seed sources for other species, reducing not only the diversity of potential wood products, but also homogenizes the forest composition. It appears that the initial low stocking (circa 1956) of non-*Acer saccharum* species, the subsequent harvesting of non-*Acer saccharum* species (i.e., selecting against), and lack of adequate seed sources hinder advance recruitment for larger size classes of species other than *Acer saccharum*.

Compared to the control, the repeated entries (up to five harvests for some treatments) appear to have accelerated the recruitment and dominance of *Acer saccharum*. This may suggest that these harvests, intended to be a surrogate for natural disturbance (i.e., small tree-fall gaps), are not sufficient for regeneration or recruitment of non-*Acer saccharum* species (Webster and Lorimer 2005).

#### 2.4.1.2. *Basal area and density*

At the study's initiation in 1956, there was variability in basal area and stand density between the two classes of treatments (i.e., DL and RBA) and the uncut control (Figures 2-2 and 2-3). In 1956, the pre-harvest basal area for the uncut control was  $24.1 \text{ m}^2 \text{ ha}^{-1}$  and, between the two classes of treatments, the average initial basal area for the DL ( $21.5 \text{ m}^2 \text{ ha}^{-1}$ ) was not significantly different than those of the RBA ( $p\text{-value} = 0.7854$ ;  $22.6 \text{ m}^2 \text{ ha}^{-1}$ ). For the pre-harvest 1956 conditions, density for the uncut control was  $299.0 \text{ trees ha}^{-1}$  and, between the two classes of treatments, the average density for RBA ( $350.9 \text{ trees ha}^{-1}$ ) was slightly higher than those of the DL ( $p\text{-value} = 0.3289$ ;  $312.2 \text{ trees ha}^{-1}$ ).

Relative to the uncut control, the DL and RBA treatments have subsequently altered residual basal area and stocking trajectories (Figures 2-2 and 2-3). After 52 years of no treatment, the uncut control had increased its basal area by 33.3%, but its density had declined by 16.8%, a result of tree mortality and growth accumulation in fewer and larger diameter trees. When comparing pre-harvest 1956 to 2008 post-harvest basal area and densities, diameter-limit treatments increased both basal area (range between 11.5% and 31.6%) and density (range between 1% and 39.8%). This increase in stocking of smaller diameter trees comes at the detriment of larger sawlog size-classes, and may result in a lower stand value, reduced harvesting efficiency, and higher number of rare alleles potentially related to undesirable growth and quality traits (Kenefic and Nyland 2005; Hawley *et al.* 2005). In contrast to the DL treatments, RBA decreased both basal area (range between 5.7% and 51.1%) and density (range between 26.7% and 60.6%). By reducing the density (i.e., reducing resource competition) and maintaining a specific basal

area across all size classes, growth can be maximized on a per tree basis (Eyre and Zillgit 1953; Arbogast 1957; Adam and Ek 1974; Reed *et al.* 1986, Erickson *et al.* 1990, Bodine 2000, Gronewold *et al.* 2010). These respective basal area and density trends have resulted in distinctive volume accumulation and removal amounts between the DL and RBA treatments.

#### 2.4.1.3. *Sawtimber volume*

Initial standing sawtimber gross volumes ( $\text{m}^3 \text{ha}^{-1}$ ) by treatment classes and the uncut control were also not uniform (Figures 2-2 and 2-3). In 1956, the pre-harvest sawtimber volume for the uncut control was  $90.2 \text{ m}^3 \text{ha}^{-1}$  and, between the two classes of treatments, the average initial sawtimber volume for the DL ( $67.3 \text{ m}^3 \text{ha}^{-1}$ ) was not significantly different than those of the RBA ( $p\text{-value} = 0.8903$ ;  $69.6 \text{ m}^3 \text{ha}^{-1}$ ). Over the 52-year study, total net harvested sawtimber volume for all treatments was  $414.0 \text{ m}^3 \text{ha}^{-1}$ . Total net harvested sawtimber volume for each RBA treatment was approximately double the gross accumulation of the control (control's accumulation =  $30.2 \text{ m}^3 \text{ha}^{-1}$ ;  $11\text{-m}^2 \text{ha}^{-1} = 67.8$ ;  $16\text{-m}^2 \text{ha}^{-1} = 54.3$ ;  $21\text{-m}^2 \text{ha}^{-1} = 50.9 \text{ m}^3 \text{ha}^{-1}$ ), and exceeded that of the 56-cm DL ( $24.1 \text{ m}^3 \text{ha}^{-1}$ ). Moreover, total net harvested sawtimber volume for the 30-cm DL was 350% greater ( $105.7 \text{ m}^3 \text{ha}^{-1}$ ) than the uncut control's accumulation, while the 41-cm DL was even larger ( $111.2 \text{ m}^3 \text{ha}^{-1}$ ). The total net harvested sawtimber volume for both the 30-cm and 41-cm DL nearly equals the 2008 standing gross sawtimber volume in the uncut control ( $120.4 \text{ m}^3 \text{ha}^{-1}$ ).

It is important to note that the initial 1957 harvest was an influential factor in the total net harvested sawtimber volume. Across all treatments, this initial harvest provided 25.0% ( $103.7 \text{ m}^3 \text{ ha}^{-1}$ ) of the study's total volume removal. This was the largest sawtimber volume removed until 1998 (26.0% or  $107.5 \text{ m}^3 \text{ ha}^{-1}$ ). The 56-cm and 30-cm DL treatments provided inconsistent volume returns per cutting cycle (Figure 2-4). The 56-cm DL produced 80.6% ( $19.4 \text{ m}^3 \text{ ha}^{-1}$ ) of the total net harvested sawtimber volume in two harvests: 1957 (27.2%) and 1998 (53.4%). The 30-cm DL was similar, as 80.5% of the total net harvested sawtimber volume was a result of the 1957 (48.2%) and 1998 (32.2%) harvests. The 41-cm DL treatment provided sawtimber for each of the five harvests (average  $18.5 \text{ m}^3 \text{ ha}^{-1}$  per entry), with a low of  $8.6 \text{ m}^3 \text{ ha}^{-1}$  in 2008 and a high of  $25.1 \text{ m}^3 \text{ ha}^{-1}$  in 1998. Though the RBA treatments produced less total net sawtimber volume than 30-cm and 41-cm DL treatments, the RBA treatments were harvested at each entry, with the 1998 harvest being the only exception for the  $21\text{-m}^2 \text{ ha}^{-1}$  RBA.

Kenefic and Nyland (2005), from both field trials and simulations, report that diameter-limits produce higher volumes and revenues with the initial harvest. However, when compared to selection systems, the diameter-limits had a lower residual volume and did not provide consistent yields. From this FFC Cutting Trial, Erickson *et al.* (1990) state the 41-cm DL produced higher revenues and harvest volumes than the other selection system treatments, but stressed that diameter-limits did not increase tree quality (i.e., log grades). For the RBA treatments in this study, the frequency of harvests and total sawtimber volume removed are consistent with Eyre and Zillgit (1953), Arbogast (1957),

Adam and Ek (1974), Erickson *et al.* (1990), Kenefic and Nyland (2005), and Gronewold *et al.* (2010).

In summary, Bourdo and Johnson (1957) indicated a high-grade occurred in 1938, and the accumulation of growth between 1938 and 1956 resulted in non-standard initial conditions among the treatments and uncut control (Figures 2-2 and 2-3). This variation appears to have had an unknown impact on both the proportion of volume removed by treatment in 1957, but also subsequent accumulation and harvest frequency for each treatment (Figure 2-4). Following 52 years of management, the basal area and density trends of the RBA were more similar to the uncut control than the DL treatments (Figures 2-2 and 2-3). The DL treatments produced more volume per harvest and total overall volume, yet of lower quality and at more variable frequencies (Figures 3-1 and 3-4; cf. Reed *et al.* 1986; Erickson *et al.* 1990; cf. Bodine 2000). In contrast, RBA treatments produce a consistent volume for each entry of potentially higher value (cf. Reed *et al.* 1986; Erickson *et al.* 1990; Bodine 2000).

#### **2.4.2.      *Age structure***

From the tree core and basal cookies, *Acer saccharum* in the control averaged  $121.4 \pm 5.2$  years (mean  $\pm$  SE) and ranged from 38.5 to 252.5 years (Table 2-2; Figure 2-5). The maximum age of treatments ranged between 126.0 (11-m<sup>2</sup> ha<sup>-1</sup> RBA) and 216.8 years (21-m<sup>2</sup> ha<sup>-1</sup> RBA), while median ages were between 72.5 and 103.4 years. The mean age of

uncut control core samples was significantly higher than 11 m<sup>2</sup> ha<sup>-1</sup> RBA ( $77.1 \pm 6.4$ ;  $p = 0.0029$ ), 41-cm DL ( $84.9 \pm 10.1$ ;  $p = 0.0278$ ), 56-cm DL ( $85.7 \pm 7.2$ ;  $p = 0.0264$ ), and 16 m<sup>2</sup> ha<sup>-1</sup> RBA ( $90.1 \pm 7.8$ ;  $p = 0.0393$ ). No significant differences in mean ages were found between the uncut control and the 30-cm DL ( $p = 0.0634$ ) and 21-m<sup>2</sup> ha<sup>-1</sup> RBA ( $p = 0.8285$ ), nor were any significant differences found among the six treatments. A possible explanation for the lack of mean age differences between treatments appears to be related to the 1938 high-grade, resulting in stocking conditions with the majority of the trees below 25.4-cm dbh (Bourdo and Johnson 1957).

Accounting for the time *Acer saccharum* takes to reach 12.4-cm dbh, the median age of the uncut control and all six treatments indicate the majority of *Acer saccharum* predate the 1938 high-grade (Table 2-2). Without any management to lower tree density, the control maintained older trees while also recruiting a post-1938 age cohort. After 52 years of management, the age structure between all six treatments did not differentiate (Figure 2-5). Whether a treatment was harvested every 10 years or just twice (i.e. 30-cm DL), the age distribution was similar between treatments. Because the Arbogast (1957) Marking Guide requires stocking across all diameter size classes – only the density per size class changes with each RBA treatment – the similarity in RBA treatment mean ages was expected. The age structure was similar between the uncut control and 21-m<sup>2</sup> ha<sup>-1</sup> RBA, mainly due to similar 1956 conditions (Figures 2-2 and 2-2) and lower total volume removed ( $50.9 \text{ m}^3 \text{ ha}^{-1}$ ) relative to the other five treatments (Figure 2-3). Surprisingly, removing large diameter trees within the DL treatments did not lower the

mean age, indicating size differentiation is based on vigor, and potentially, younger trees (cf. Kenefic and Nyland 2005). The similarity between the control and 30-cm DL potentially reflects the time interval between harvests with this theory: 1) in the 20 years following the 1938 high-grade, younger and more vigorous trees captured the larger size classes; 2) the initial 1957 harvest removed this > 30-cm dbh cohort, leaving residual older trees of poorer vigor; 3) the next harvest occurred 30 years later (1998) and again removed this third cohort that was relatively vigorous and younger; and 4) future harvests may continue to remove younger trees while maintaining older and less vigorous trees.

The mean and median ages of harvested trees suggest several potential management issues of concern. Uneven-aged silviculture of *Acer saccharum* in this region typically uses a rotation age of 100-120 yr, as it coincides with the economic maturity of 61 cm dbh trees (Arbogast 1957; Tubbs 1977). After 52 years of management and differing harvesting intensities at the FFC, all treatments are still allocating considerable growing space to trees that exceed this rotation age (Table 2-2; Figure 2-5). Diameter-limit treatments within northern hardwoods attempt to maximize revenues with the first entry and give no consideration for future entries (Kenefic and Nyland 2005). This approach would indicate the 1938 high-grade and 1957 harvest had removed the vigorous and potentially younger trees, resulting in future volume growth and revenues dependent on less vigorous and/or older trees. The median (138.3 - 179.8 yr) and maximum (186.3 - 290.5 yr) age ranges for the DL treatments lend support (Table 2-2), as does the harvest frequency (Figure 2-1) and inconsistent harvest volume per entry (Figures 2-2 and 2-4).

With the selection system, Arbogast (1957) indicates that removal of both poor quality across all size classes and economically over-mature trees ( $\text{dbh} > 61 \text{ cm}$ ) will allow rapid growth of smaller size classes for stocking replacement. Harvested trees within the RBA treatment predate the 1938 high-grade (Figure 2.5; Table 3-2), including those from smaller size classes. Additionally, following this 1938 cutover and assuming the initial stand conditions were even- or two-aged, Tubbs (1977) and Nyland (2003) indicate four entries would be required to create a truly uneven-aged stand. While the selection system has removed old, poor quality, and economically mature trees, the recruitment of small diameter trees into the overstory may actually be of the same age class as those harvested. Five decades of management quickly distinguished treatments against measures of basal area, stocking, and harvested volumes (Figures 2-2; 2-3; and 2-4), yet the age structure still reflects a stand legacy that predates 1938. Of greater concern is the lack of recruitment post-1957.

### **2.4.3.      *Age-diameter relationships***

Using the same age dataset for the uncut control and residual trees for the treatments, we used linear regression to examine the relationship between tree age and the respective  $\text{dbh}$  of *Acer saccharum*. For the control,  $\text{dbh}$  explained 57% of the variation in tree age ( $n = 71$ ;  $p\text{-value} < 0.0001$ ; Table 2-3). For residual trees, the  $11\text{-m}^2 \text{ ha}^{-1}$  ( $r^2 = 0.61$ ;  $n = 15$ ;  $p\text{-value} = 0.0005$ ),  $16\text{-m}^2 \text{ ha}^{-1}$  ( $r^2 = 0.58$ ;  $n = 20$ ;  $p\text{-value} < 0.001$ ), and  $21\text{-m}^2 \text{ ha}^{-1}$  ( $r^2 = 0.69$ ;  $n = 20$ ;  $p\text{-value} < 0.0001$ ) RBA treatments have similar or slightly stronger correlations



between age and diameter than the control. With the exception of the 30-cm DL ( $r^2 = 0.06$ ;  $n = 20$ ;  $p\text{-value} = 0.3117$ ), linear regression models best fit the 41-cm ( $r^2 = 0.65$ ;  $n = 15$ ;  $p\text{-value} = 0.003$ ) and the 56-cm ( $r^2 = 0.43$ ;  $n = 16$ ;  $p\text{-value} = 0.0056$ ) DL treatments. Across all treatments and the control, systematic patterns in the residuals were not detected with linear regression. Overall, management strengthens the correlation between age and diameter across all RBA treatments and the 41-cm DL, while potentially weakening the relationship (56-cm DL) or resulting in no relationship between age and diameter (30-cm DL).

Within the control, *Acer saccharum* reached a diameter of 12.6 cm in approximately 77 years (Table 2-4). The RBA treatments achieved this diameter sooner, with a range between 56 ( $11 \text{ m}^2 \text{ ha}^{-1}$ ) and 63 ( $21 \text{ m}^2 \text{ ha}^{-1}$ ) years. The primary management objective of the FFC Cutting Trials (Bourdo and Johnson 1957) was to maximize economic value in northern hardwoods, specifically *Acer saccharum*, which translates to managing for sawtimber ( $\text{dbh} > 29.2 \text{ cm}$ ). It is at this size class that RBA management accelerates the growth relative to the control. Within the control, a tree would be an average of 118 years when it reaches sawtimber size. The  $21\text{-m}^2 \text{ ha}^{-1}$  and  $16\text{-m}^2 \text{ ha}^{-1}$  RBA accomplish this 8 and 22 years sooner, respectively, while the  $11\text{-m}^2 \text{ ha}^{-1}$  RBA achieves this in just 86 years. This compares favorably to Tubbs (1977), where after four selection cuts spanning 50 years (circa 1926-1976), a 12.6-cm dbh tree would be 55 and a 29.2-cm dbh tree would be 104 years old. These RBA treatments also appear to align with the recommendations of Arbogast (1957), Tubbs (1977), and Nyland (2003) that indicate that several entries

are required to create a fully regulated, uneven-aged northern hardwoods stand (q.v., Figures 2-3; 2-4; Table 2-4). However, if we were to assume that the control and RBA had a similar age structure following the 1938 high-grade and prior to the initial cut in 1957, then these selection treatments reinforce this legacy structure exhibited by the control. As a whole, these RBA selection treatments appear to increase light availability and reduce competition for growing space across all size classes, maintaining and increasing diameter growth relative to age.

As a group, the DL treatments did not exhibit a consistent pattern of accelerated diameter growth, with 12.6-cm dbh values ranging from 43 (41-cm DL) to 163 (30-cm DL) years (Figure 2-6; Table 2-4). While there was no relationship found between age and diameter for the 30-cm DL, it is possible to have a sawtimber tree ( $> 29.2$  cm) that is nearly 190 years old for this and, surprisingly, all other treatments. For 41-cm and 54-cm DL, management resulted in trees reaching sawtimber size ( $> 29.2$  cm dbh) approximately 10 and 22 years sooner, respectively, than the control. However, age discrepancies between these two treatments and the control were nearly indistinguishable in larger dbh classes. For example, while the 41-cm DL had younger trees at 12.6-cm dbh than the 56-cm DL (i.e., 43 vs. 67 years), the 56-DL had younger trees at 29.2 cm (96 vs. 108 years). Projecting to their respective diameter-limit harvests, the 56-cm DL would achieve a 41-cm dbh sooner (116 years) than the actual 41-cm DL treatment (154 years). In fact, a 56-cm dbh tree harvested from the 56-cm DL treatment would be younger than a 41-cm dbh tree harvested from the 41-DL (142 vs. 154 years). Additionally, the age of a 41-cm dbh

tree from the control was comparable at 147 years. The age-diameter relationships for DL treatments reflect the removal of the dominant canopy, while increasing light availability for the younger, smaller diameter, more vigorous trees. However, unlike the RBA selection system that removes trees across all diameter classes, DL treatments ignore less vigorous and older trees arbitrarily because they simply haven't reached a specific diameter-size. These "legacy trees", or trees that predate the 1938 high-grade, are allocated considerable growing space under this regime. Reliance on this age-class has potential long-term negative implications for productivity and genetic diversity (Hawley *et al.* 2005; Kenefic *et al.* 2005; Nyland 2005).

In summary, correlations between tree diameter and age help reconstruct disturbance history and allows for predictions of tree and stand growth (Gates and Nichols 1930; Tubbs 1977; Lorimer 1980; Leak 1985, Lorimer and Frelich 1989; Kenefic and Nyland 1999). Selection systems regulate diameter size classes, resulting in a predictive linear relation between diameter and age (Tubbs 1977; Lorimer 1980; Kenefic and Nyland 1999; Nyland 2007). Relative to the control, the RBA treatments at the FFC Cutting Trials improved the correlation between diameter and age and improved growth rates. Yet, for both the RBA and DL treatments, the legacy of the 1938 high-grade still influences the current age-diameter relationships.

## 2.5. Conclusion

The Ford Forestry Center Cutting Trials, like other long-term cutting trials in the Lake States, provides 52 years of perspective on various silvicultural treatments. Long-term studies can indicate whether stand structure is in compliance with Arbogast's (1957) Marking Guide, a widely accepted and practiced management style in the Lake States (Jacobs 1987; Johnson 1984; Minckler 1972; Erdmann and Oberg 1973; Perkey 1987; Goodburn and Lorimer 1999; Seymour *et al.* 2006; Pond *et al.* 2014). Additionally, while Eyre and Zillgit's (1950; 1953) recommendations and subsequent marking guidelines (Arbogast 1957) were based on 20 years of results, the FFC Cutting Trial continually adds valuable information and understanding to common silvicultural practices. The response of northern hardwoods to multiple selection and diameter-limit harvests at the FFC Cutting Trial demonstrates changes in diversity, stocking, basal area, age structure, and the relationship between age and diameter.

In this study, both RBA and DL treatments indicate that multiple harvests result in the decline and loss of mid-tolerant species, and may increase the rate of decline when compared to the uncut control. Though diameter-limit treatments tend to produce higher volumes following implementation (Reed *et al.* 1986; Erickson *et al.* 1990; Bodine 2000; Kenefic and Nyland 2005; Nyland 2005), the non-standard initial compartment conditions (i.e., basal area and stocking) may have had a disproportionate impact on the total values. Additionally, while RBA treatments produced lower sawtimber volumes per

harvest, these volumes tended to be more consistent per entry and of higher economic value (Reed *et al.* 1986; Erickson *et al.* 1990; Bodine 2000). RBA treatments strengthen the relationship between age and diameter and accelerate growth to specific size-classes relative to the control, while this relationship in DL treatments is more ambiguous. Management did not consistently remove the oldest trees across both RBA and DL treatment and, as a result, considerable growing space is still allocated to trees that pre-date the 1938 high-grade. Given the reliance on old, and potentially lower vigor, trees, it would be expected that volume accumulation in DL treatments would become even less predictable. Conversely, RBA treatments reflect the regulated size-class stocking by Arbogast (1957), with small diameter trees younger than larger diameter trees. However, caution should be used when inferring that small diameter trees are vigorous and will adequately respond to single-tree selection.

## **2.6. Acknowledgements**

The authors would like to recognize the Ford Forestry Center Committee for approval of this study; Jim Rivard, Jim Schmierer, and the FERM for pre- and post-sale data collection and implementing the sale; Dr. Robert Froese for statistical support; Tyler Ritchie for prepping the samples; Andy Beebe for dendrochronology lab work; and Dr. Marcella Windmuller-Campione, Charles Paulson, and Adrienne Bozic for logistics and field help. Funding was provided by the McIntire-Stennis program, and the Graduate School and School of Forest Resources and Environmental Science at Michigan Technological University.

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## 2.8. Figures and Tables

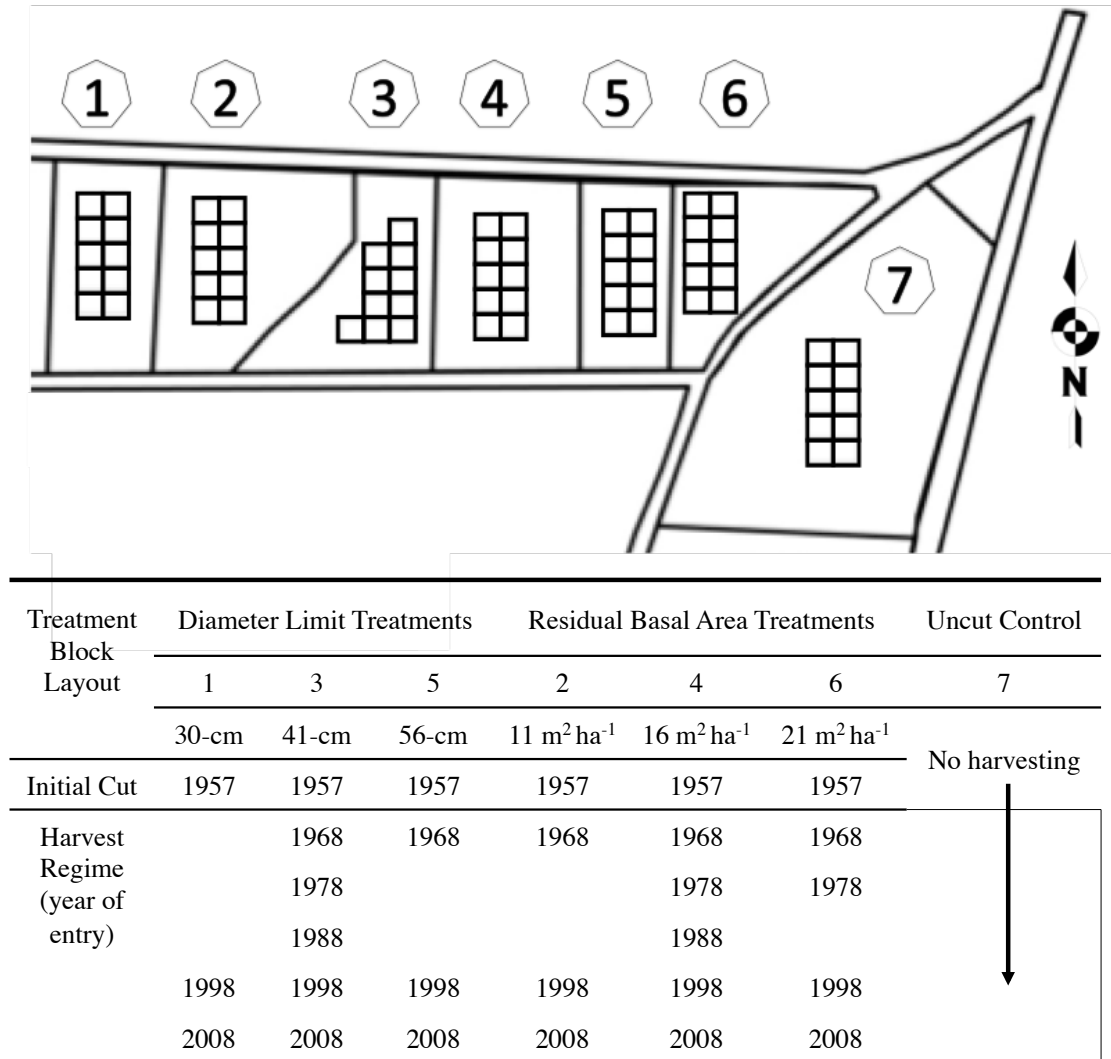


Figure 2-1: Silviculture cutting trial layout and harvest regime at Ford Forestry Center, Michigan Technological University, Alberta, MI. Diameter limit treatment indicates removal of all trees at or above specific diameter at breast height (dbh). Residual basal area is the post-harvest residual basal area (m<sup>2</sup> ha<sup>-1</sup>) for all trees greater than 12.6-cm dbh. Cutting cycle is 10 years, occurred in winter, and respective prescriptions were applied to each treatment if economically viable. Treatment block layout refers to prescription and corresponding location.

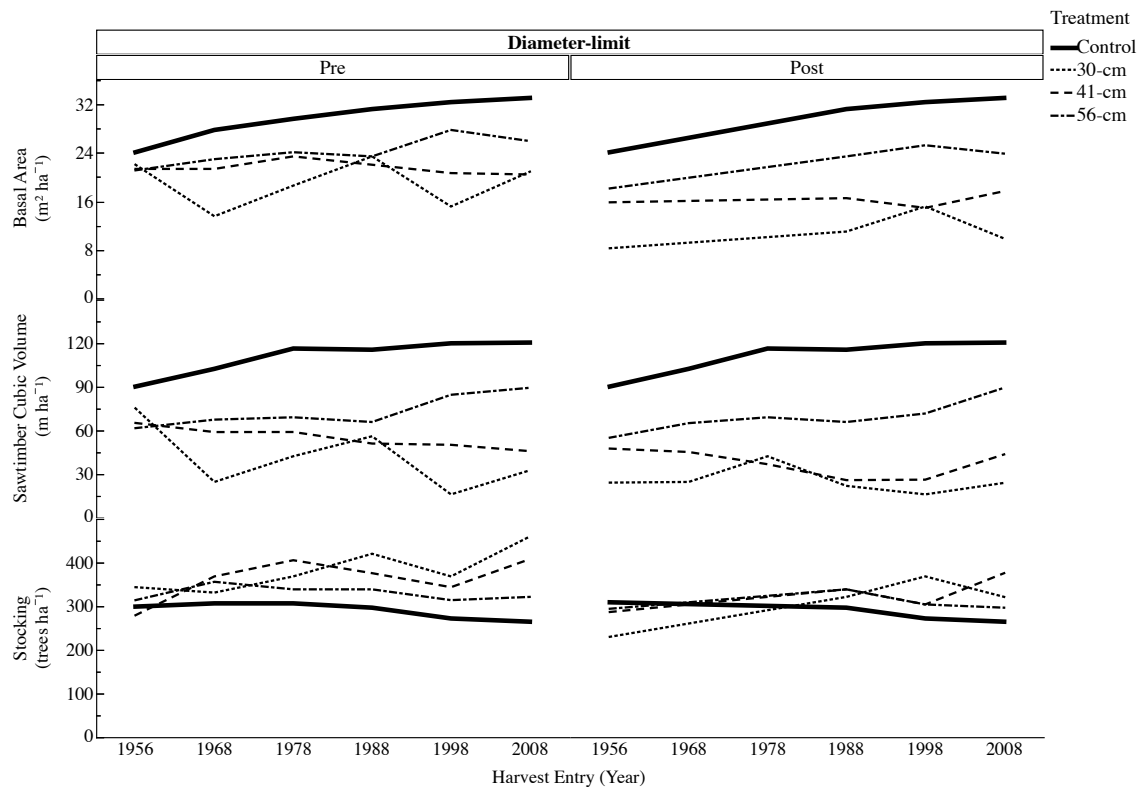


Figure 2-2: Stocking and basal area for all trees greater than 12.6-cm dbh and sawtimber volume for all trees greater than 25.4-cm dbh pre- and post-harvest at Ford Forestry Center, Michigan Technological University, Alberta, MI. Treatments displayed include uncut control and three diameter-limit (cm) techniques. Cutting cycle was 10 years, occurred during the winter, and respective prescription was applied to each treatment if economically viable. Measurements were taken pre- and post-harvest, with the exception of no post-harvest data collected in 1968 and 1978.



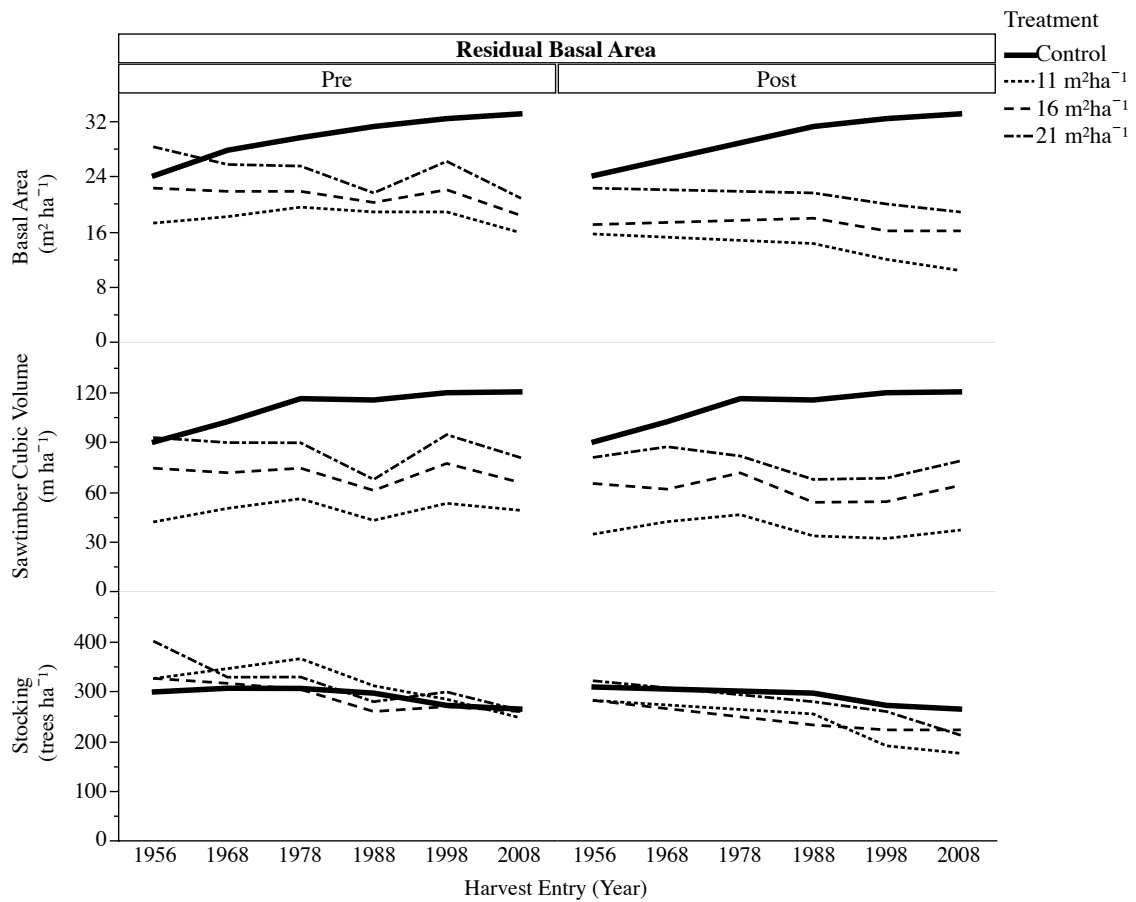


Figure 2-3: Stocking and basal area for all trees greater than 12.6-cm dbh and sawtimber volume for all trees greater than 25.4-cm dbh pre- and post-harvest Ford Forestry Center, Michigan Technological University, Alberta, MI. Treatments displayed include uncut control and three residual basal area ( $\text{m}^2 \text{ha}^{-1}$ ). Cutting cycle was 10 years, occurred during the winter, and respective prescription was applied to each treatment if economically viable. Measurements were taken pre- and post-harvest, with the exception of no post-harvest data collected in 1968 and 1978.

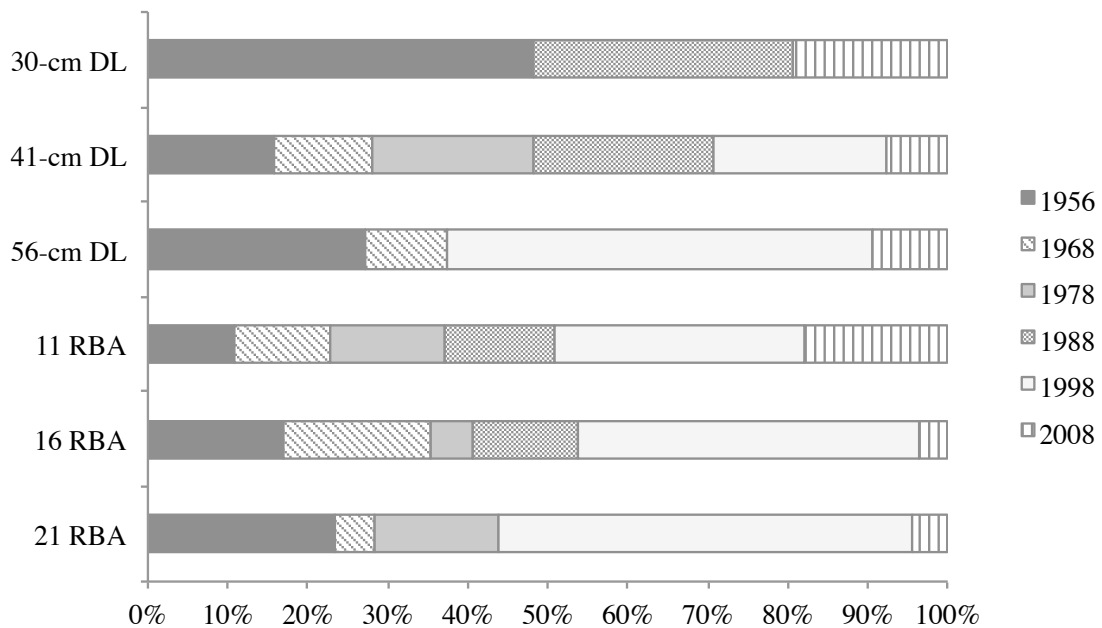


Figure 2-4: Proportion of net sawtimber volume for all trees greater than 25.4-cm dbh by treatment by harvest year Ford Forestry Center, Michigan Technological University, Alberta, MI. Cutting cycle was 10 years, occurred during the winter, and respective prescription was applied to each treatment if economically viable. Diameter-limit (DL) treatment indicates removal of all trees at or above specific diameter at breast height (dbh). Residual basal area (RBA) is the desired post-harvest retained basal area ( $\text{m}^2 \text{ha}^{-1}$ ) for all trees greater than 12.6-cm dbh.

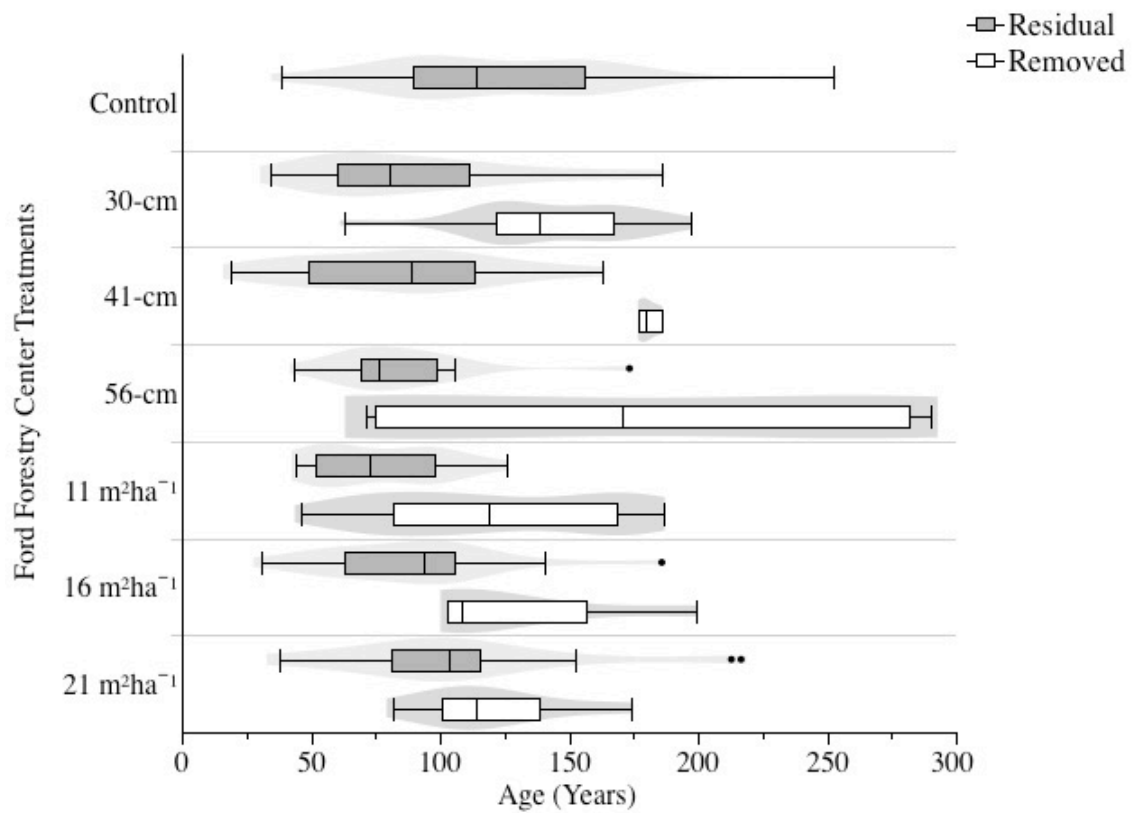


Figure 2-5: Estimated age distributions of residual trees (core height at 1.37 m) and removed trees (stump height < 0.3 m) by silvicultural treatment following the 2008-09 harvest Ford Forestry Center, Michigan Technological University, Alberta, MI. Rotated kernel density plots depict the range and distribution of *Acer saccharum*, and interior boxplots show the 25th and 75th quartiles and medians.

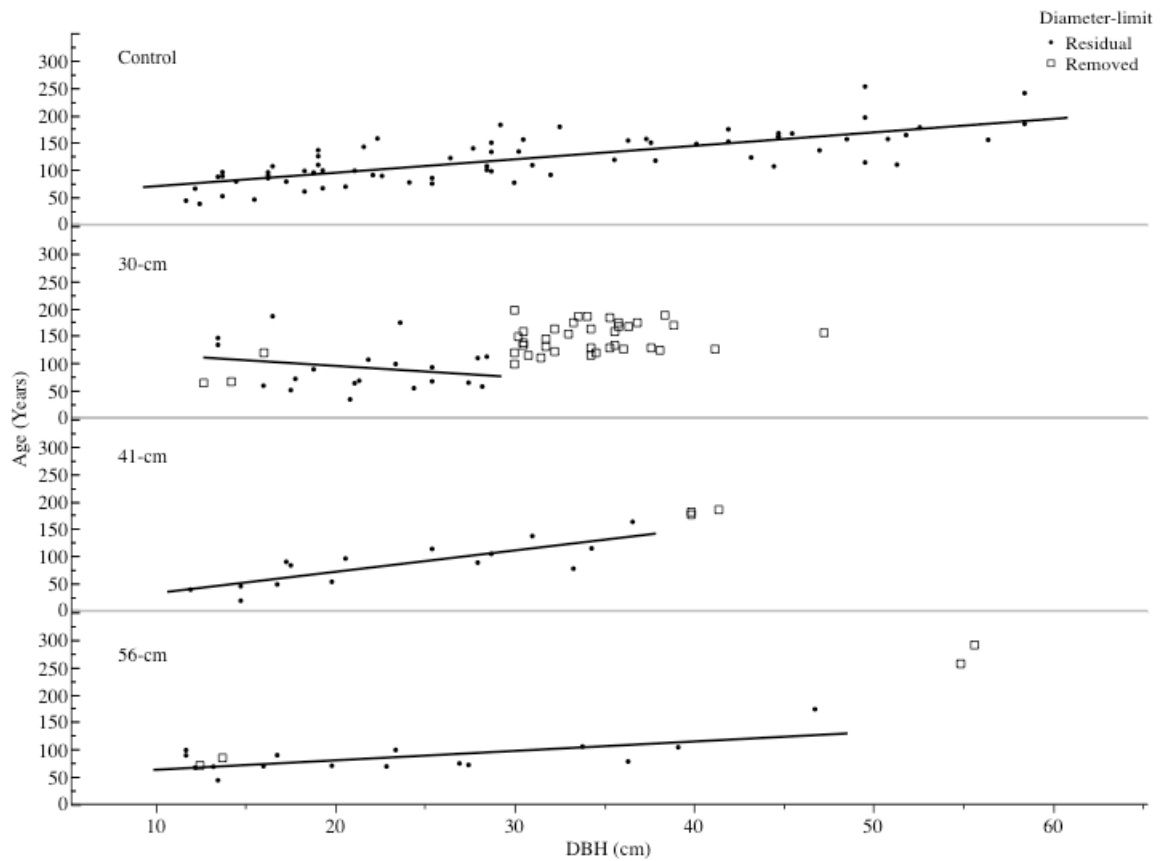


Figure 2-6: Relationship of age and diameter of residual trees (core height at 1.37 m) and scatterplot of removed trees (stump height < 0.3 m) by diameter-limit (cm) treatments following 2008-09 harvest at the Ford Forestry Center, Michigan Technological University, Alberta, MI. Data are for *Acer saccharum* with a minimum dbh of 12.6 cm.

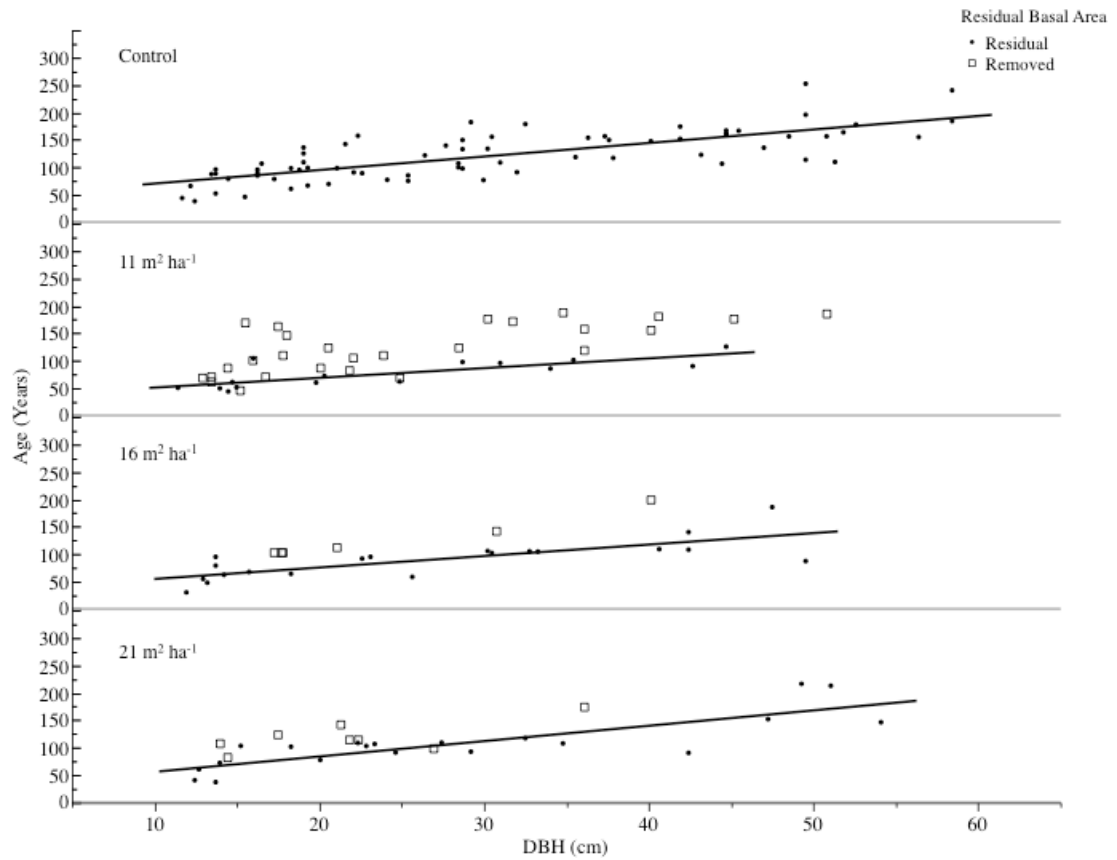


Figure 2-7: Relationship of age and diameter of residual trees (core height at 1.37 m) and scatterplot of removed trees (stump height < 0.3 m) by residual basal area ( $\text{m}^2 \text{ha}^{-1}$ ) treatments following 2008-09 harvest at the Ford Forestry Center, Michigan Technological University, Alberta, MI. Data are for *Acer saccharum* with a minimum dbh of 12.6 cm.

Table 2-1: Pre-harvest relative species abundance by treatment at Ford Forestry Center, Michigan Technological University, Alberta, MI. Diameter limit (DL) treatment indicates removal of all trees at or above specific diameter at breast height (dbh). Residual basal area is the desired post-harvest retained basal area ( $\text{m}^2 \text{ha}^{-1}$ ) for all trees greater than 12.6-cm dbh.

Treatment	Year	<u>Species</u>					
		<i>Acer saccharum</i>		<i>Betula alleghaniensis</i>		Other <sup>a</sup>	
<i>dbh classes (cm)</i>		<u><math>\geq 12.6</math></u>	<u><math>\geq 29.2</math></u>	<u><math>\geq 12.6</math></u>	<u><math>\geq 29.2</math></u>	<u><math>\geq 12.6</math></u>	<u><math>\geq 29.2</math></u>
Control	1956	0.90	0.87	0.05	0.08	0.05	0.05
	2008	0.97	0.96	0.01	0.01	0.02	0.01
11 $\text{m}^2 \text{ha}^{-1}$	1956	0.76	0.70	0.08	0.20	0.16	0.10
	2008	0.92	1.00	0.00	0.00	0.08	0.00
16 $\text{m}^2 \text{ha}^{-1}$	1956	0.80	0.91	0.14	0.04	0.06	0.06
	2008	0.86	0.98	0.04	0.02	0.10	0.00
21 $\text{m}^2 \text{ha}^{-1}$	1956	0.72	0.68	0.12	0.07	0.16	0.25 <sup>b</sup>
	2008	0.87	1.00	0.03	0.00	0.10	0.00
30-cm DL	1956	0.75	0.73	0.07	0.11	0.18	0.16
	2008	0.83	0.98	0.00	0.00	0.17	0.02
41-cm DL	1956	0.86	0.89	0.07	0.05	0.08	0.05
	2008	0.80	0.98	0.01	0.02	0.19	0.00
56-cm DL	1956	0.76	0.88	0.06	0.00	0.17	0.12
	2008	0.89	0.99	0.03	0.00	0.08	0.01

<sup>a</sup> may include one or more of the following: *Betula papyrifera*, *Picea glauca*, *Prunus virginiana*, *Ostrya virginia*, *Tilia americana*, *Tsuga canadensis*, and *Ulmus americana*.

<sup>b</sup> large component of *Tilia americana* (approximately 17%)

Table 2-2: Differences in ages of residual trees (core height at 1.37 m) and minimum ages of removed trees (stump height < 0.3 m) by silvicultural treatment following the 2008-09 harvest on the Ford Forestry Center, Michigan Technological University, Alberta, MI. Data are for *Acer saccharum* with a minimum dbh of 12.6 cm. Letters that are not the same represent significantly different means of residual trees at the  $\alpha = 0.05$ .

Treatment	<u>DBH Age of Residual Trees (years)</u>			
	Mean $\pm$ SE	Median	Maximum	Sample size
Control	121.4 $\pm$ 5.2 <i>a</i>	114	252.5	71
30-cm DL	91.9 $\pm$ 9.3 <i>ab</i>	80.2	185.8	20
41-cm DL	84.9 $\pm$ 10.1 <i>b</i>	88.5	163.0	15
56-cm DL	85.7 $\pm$ 7.2 <i>b</i>	76.3	173.5	16
11 m <sup>2</sup> ha <sup>-1</sup>	77.1 $\pm$ 6.4 <i>b</i>	72.5	126.0	15
16 m <sup>2</sup> ha <sup>-1</sup>	90.1 $\pm$ 7.8 <i>b</i>	93.9	186.0	20
21 m <sup>2</sup> ha <sup>-1</sup>	107.7 $\pm$ 10.4 <i>ab</i>	103.4	216.8	20

Treatment	<u>Stump Age of Harvested Trees (years)</u>			
	Mean $\pm$ SE	Median	Maximum	Sample size
30-cm DL	142.0 $\pm$ 5.0	138.3	197.5	39
41-cm DL	181.0 $\pm$ 2.7	179.8	186.3	3
56-cm DL	175.7 $\pm$ 56.7	170.6	290.5	4
11 m <sup>2</sup> ha <sup>-1</sup>	122.4 $\pm$ 8.6	118.8	187.0	27
16 m <sup>2</sup> ha <sup>-1</sup>	127.3 $\pm$ 15.6	108.3	199.0	6
21 m <sup>2</sup> ha <sup>-1</sup>	119.6 $\pm$ 10.1	114.0	174.3	8

Table 2-3: Relationship of ages and diameter at breast height (1.37 m) of residual trees by silvicultural treatment following the 2008-09 harvest at the Ford Forestry Center, Michigan Technological University, Alberta, MI. Data are for *Acer saccharum* with a minimum dbh of 12.6 cm.

Treatment	Equation	r <sup>2</sup>	RMSE	Sample size	p-value
Control	46.04 + 2.46*dbh	0.57	29.07	71	< 0.0001
30-cm DL	136.67 + 2.07*dbh	0.06	41.61	20	0.3117
41-cm DL	-6.27 + 3.90*dbh	0.65	23.84	15	0.0003
56-cm DL	45.73 + 1.72*dbh	0.43	22.39	16	0.0056
11 m <sup>2</sup> ha <sup>-1</sup>	33.64 + 1.78*dbh	0.61	16.03	15	0.0005
16 m <sup>2</sup> ha <sup>-1</sup>	34.29 + 2.09*dbh	0.58	23.00	20	<0.0001
21 m <sup>2</sup> ha <sup>-1</sup>	28.19 + 2.80*dbh	0.69	26.78	20	<0.0001



Table 2-4: Average number of years for *Acer saccharum* to reach specified diameter at breast height (1.37 m) by silvicultural treatment based on Table 2-3 regression equations at the Ford Forestry Center, Michigan Technological University, Alberta, MI.

DBH (cm)	Years						
	Control	Residual Basal Area (m <sup>2</sup> ha <sup>-1</sup> )			Diameter-limit (cm)		
		11	16	21	30	41	56
12.6	77.0	56.1	60.6	63.5	162.8	42.9	67.4
29.2	117.9	85.6	95.3	110.0	197.1	107.6	96.0
41	146.9	106.6	120.0	143.0	221.5	153.6	116.3
56	183.8	133.3	151.3	185.0	252.6	212.1	142.1

## Chapter 3.      **Vernal Pool Inventory and Classification at Pictured Rocks National Lakeshore, Michigan, USA<sup>2</sup>**

### **3.1. Abstract**

Vernal pools occur in the glaciated forests of northeastern North America and provide critical breeding and foraging habitat for amphibian and mammal species. Protection for these ephemeral wetlands is not federally mandated, placing them at risk for habitat fragmentation and making them more vulnerable to impacts of climate change. Unlike the northeastern US, limited information about vernal pools exists for the Great Lakes region, including a lack of information about techniques to identify and classify vernal pools using remote sensing and field surveys. At Pictured Rocks National Lakeshore, Michigan, USA, our objectives were to locate vernal pools using true-color, spring leaf-off aerial photography at the 1:12,000-scale, classify vernal pools using modified geomorphological classification systems, and determine landscape associations with soil series and cover type GIS datasets. From the 214 water features identified and categorized via aerial photography, “water with canopy” and “water without canopy” of the 12 categories accounted for 91.5% of the pools. The Park’s 51 vernal pools had a

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<sup>2</sup> This chapter is currently in press and © by *Natural Areas Journal* 2016. *Citation:* Previant, W.J. and L.M. Nagel. *In press*. Vernal pool inventory and classification at Pictured Rocks National Lakeshore, Michigan, USA. *Natural Areas Journal*. Refer to Appendix A for copyright documentation.

density of  $0.19 \text{ km}^{-2}$  and an average surface pool area of  $1,078.2 \text{ m}^2 (\pm 387.6)$ . Using basin morphology and geomorphology, vernal pools were classified into five classes: classic, complex, kettle-kame, dune-swale, and minor ponds. Vernal pools were associated with three soil series that were characterized with slopes less than 5%, poorly to very-poorly drained, and a clay content less than 10%. Nearly three-quarters of the vernal pools occurred in the hemlock-hardwood cover type. The conservation and protection of these discrete and small ephemeral wetlands should be considered within a landscape context, as subsets of vernal pools have specific geomorphology, soil series and cover type associations.

## **3.2. Introduction**

Vernal pools are ephemeral or seasonal wetlands that occur in shallow depressions within the glaciated forests of northeastern North America (Brooks *et al.* 1998; Tiner 2003; Colburn 2004; Calhoun and deMaynadier 2008). These wetland habitats have been identified as being important for the life-cycles of amphibians and invertebrates (Ling *et al.* 1986; Calhoun and deMaynadier 2001; Calhoun, Walls, *et al.* 2003; Homan *et al.* 2004); locations for numerous at-risk plant species (Comer *et al.* 2005); foraging areas for black bears (*Ursus americanus* L.) and bats (DeBrun 1997; Franci 2008); and transitions zones associated with shifts in forest structure and species importance values (Previant and Nagel 2014).

Vernal pools have been described as an essential component within forests, and recent research in these discrete wetlands has highlighted risks to the frequency, density, and overall quality of these small-scale ecosystems (*cf.* Colburn 2004; *cf.* Calhoun and deMaynadier 2008). These potential threats are related to the historical and current land-use practices of filling and draining vernal pools (Colburn 2004; Deil 2005), mercury deposition and bioaccumulation (Brooks *et al.* 2012), nonnative and invasive flora species (Comer *et al.* 2005; Deil 2005), habitat fragmentation of surrounding upland forests (Semlitsch and Bodie 2003; Zedler 2003), and unknown changes in precipitation regimes associated with climate change (Pyke 2005; Brooks 2009). Additionally, the small size and isolated locations do not meet the criteria for federal protection (*see* Ruffolo 2002; *see* Zedler 2003), requiring voluntary conservation and collaboration efforts from regional, state, and/or local land-use planners, resource managers, researchers, non-profit groups, and educational programs (e.g. Maine Audubon; Massachusetts Natural Heritage Program; Michigan Natural Features Inventory; Chadde and Flaspohler 1999; Calhoun, Reeve, *et al.* 2003; *cf.* Colburn 2004; Burne and Griffin 2005; *cf.* Calhoun and deMaynadier 2004, 2008).

The majority of vernal pool assessments have been focused in the northeast USA (e.g., Brooks *et al.* 1998; Calhoun, Walls, *et al.* 2003; Lathrop *et al.* 2005), resulting in a certification process and habitat management guidelines aimed specifically at vernal pools (e.g., Burne and Griffin 2005; Calhoun and deMaynadier 2004). While these states' (e.g., Maine and Massachusetts) guidelines are in various stages of implementation, there

is limited information regarding ephemeral depressions for the Great Lakes region of Michigan, Minnesota, and Wisconsin. Though the few vernal pool studies in the Great Lakes region explore amphibian larvae development (Ling *et al.* 1986), wetland abundance within ecological units (Palik *et al.* 2003), plant communities (Palik *et al.* 2007; Schrank *et al.* 2015), and bat feeding activities (Francl 2008), there is a paucity of information regarding hydrogeomorphic (HGM) characteristics, vernal pool basin morphology, and associations with soils and cover types.

HGM classification entails the geomorphic setting, water source, and hydrodynamics of a wetland (Brinson 1993). Vernal pool geomorphology involves the topographical location and relative landscape position (Brinson 1993), and incorporates landform, surficial geology, depression or basin shape, connectivity to groundwater, and depth to bedrock (Brooks 2005). These factors provide insight into water source and flow dynamics, landscape patterns, and habitat associations (Brooks 2005). As a result, vernal pools are identified as depression wetlands with no apparent inlet or outlet (Brinson 1993) or a Depression-Temporary HGM class (Brooks *et al.* 2011), with geomorphology that includes depressions, slopes, flats, riverine, or anthropogenic settings (Calhoun and deMaynadier 2008). Additionally, using bathymetric surveys, vernal pools can be characterized by basin morphology - maximum depth, area, volume, and perimeter length - to help provide insight into hydroperiod, precipitation inputs, storage amounts, and evapotranspiration losses (Brooks and Hayashi 2002; Brooks 2005). Brooks and Hayashi (2002) suggest that small perimeter-to-area ratios were generally correlated with longer

hydroperiods, but it was unclear the significance of the basin (i.e., perimeter) shape. Lastly, basin morphology influences amphibian species richness and vegetation community types (Schrack *et al.* 2015), but is not explicitly included or described when using HGM classification systems. The relatively small size of vernal pools, the topographical isolation from other wetlands, infrequent occurrence within a forested setting, and a lack of regional geomorphological classification makes detection and delineation difficult, potentially hindering conservation efforts and management strategies (Tiner 1990; Brooks *et al.* 1998; Colburn 2004; Lathrop *et al.* 2005; Van Meter *et al.* 2008). As such, the lack of baseline information makes comparisons between regions (i.e., Great Lakes region and northeastern US) difficult and may hinder implementation of recommended habitat management guidelines (cf. Calhoun and deMaynadier 2004).

At Pictured Rocks National Lakeshore (Pictured Rocks) in Michigan, USA, we used remote sensing, field surveys, and geographic information system (GIS) datasets to locate, assess, and classify vernal pools. This inventory was a collaborative effort between the National Park Service, Michigan Technological University, and Michigan Tech Research Institute (MTRI). Previous studies at Pictured Rocks have identified the ecological importance of vernal pools for several amphibian species (Casper 2005) and documented their forage value in the early spring for female black bears and their cubs (Debruyne 1997).

Our first objective was to identify the number of vernal pools at Pictured Rocks and determine if there was a pattern between identifying vernal pools via aerial photography and subsequent field visits and verification. Because vernal pools are seasonal wetlands and can be aggregated by “functional profile” (Brinson 1993), our second objective was to use basin morphology to modify existing vernal pool geomorphological classification systems (e.g., Brinson 1993; Brooks and Hayashi 2002; Colburn 2004; Brooks 2005; Calhoun and deMaynadier 2008; Brooks *et al.* 2011) to better suit the northern Great Lakes landscape. Our third objective investigated the association of vernal pools with soil series and cover types using GIS datasets. This vernal pool survey serves to assist land managers of both Pictured Rocks and the Great Lakes region with the identification and classification of vernal pools to aid in the protection of these aquatic habitats, while providing baseline information regarding the distribution and patterns of vernal pools within a landscape setting.

### **3.3. Methods**

#### ***3.3.1. Study site***

Pictured Rocks is located in the Upper Peninsula of Michigan in Alger County. The Park sits on the south shore of Lake Superior, with Grand Marais and Munising bookending the east and west ends, respectively. The park is approximately 296 km<sup>2</sup>, and protects 67.5 km of shoreline. Established in 1966 by the 89<sup>th</sup> U.S. Congress (Public Law 89-668), Pictured Rocks is uniquely divided into two zones: the Lakeshore Zone (LZ) and the

Inland Buffer Zone (IBZ). The LZ, at 12,000 ha, is owned and managed by the National Park Service. The IBZ, at nearly 16,000 ha, is a mix of public and private ownership that allows permanent residences and sustainable forest management (Appendix C).

The Park's name is derived from the towering and picturesque sandstone cliffs that line 19 km of the shoreline, reaching heights in excess of 60 m. The park resides within Ecoprovince 212 - Laurentian Mixed Forest, the transitional zone between the northern range of temperate and the southern range of boreal forests (Rowe 1972; Bailey 1995). The regional landscape ecosystem is classified as Grand Marais sandy end moraine and outwash, with elevations between 184 to 396 m (Albert 1995). The bedrock geology is a Cambrian-age sandstone escarpment that runs east-west, with lacustrine deposits that are either droughty sand dunes and beach ridges or poorly- and very-poorly drained glacial deposits (Albert 1995). The soils are classified as Histosols and Entisols, and while there is no mention of vernal pools, water features include emergent marshes, bogs, shrub-dominated swamps, seeps, springs, streams, rivers, and kettle lakes within pitted outwashes (Albert 1995; NRCS 2012). Average annual snowfall is 450 cm and average annual precipitation is 65 cm, although Pictured Rocks experiences dry, hot spells in the spring and fall (Albert 1995). Given the proximity to Lake Superior, the average annual temperature (4.8 °C) and average growing season (140 days) is slightly higher than those further inland (Eichenlaub *et al.* 1990).



Over 70% of Pictured Rocks is dominated by upland northern hardwoods, including *Acer rubrum* L., *Acer saccharum* Marshall, *Betula alleghaniensis* Britton, and *Fagus grandifolia* Ehrh., while the remaining forests are composed of *Pinus resinosa* Aiton, *Pinus strobus* L., *Pinus banksiana* Lamb., *Betula papyrifera* Marshall, *Populus tremuloides* Michx., *Thuja occidentalis* L., *Picea glauca* (Moench) Voss, and *Picea mariana*, (Mill.) Britton, Sterns, and Paggenb. (Woodall and Leutscher 2005; Menard *et al.* 2008).

### **3.3.2.      *Sampling methods***

For the purpose of this study, vernal pools are upland wetland depressions that are seasonally flooded and have no connection to permanent bodies of water or larger wetlands (Cowardin *et al.* 1979; Tiner 2003; Zedler 2003; cf. Colburn 2004; cf. Brooks 2005; Burne and Griffin 2005). Within the Great Lakes region, vernal pools are associated with glaciofluvial sediment, till, outwashes, end moraines, or ground moraines (Palik *et al.* 2003). Lastly, to identify vernal pools as jurisdictionally-isolated from other wetland or water features, the Michigan Wetlands Protection Part 303 of 1994 Public Act 451 defines vernal pools as having a surface area less than two hectares, located further than 152 m from inland lakes, rivers, or streams, and do not occur within 30.5 m of Lake Superior (cf. Calhoun and deMaynadier 2008).

A useful method for identifying, locating, mapping, and classifying vernal pools is a combination of remote sensing and ground-based surveys, though probabilistic sampling methods can provide vernal pool population estimates for a given region (Brooks *et al.* 1998; Lathrop *et al.* 2005; Calhoun and deMaynadier 2008; Van Meter *et al.* 2008). Starting in 2009, potential vernal pools (i.e., water features) at Pictured Rocks were first identified in aerial photography and then subsequently field visited for verification. True-color aerial photographs at 1:12,000-scale were originally collected in May of 2004, providing deciduous leaf-off viewing of the entire park. MTRI analyzed photographs for water features with a minimum surface area of 10 m<sup>2</sup> and provided a descriptive category with a digitized centroid and perimeter polygon. This imagery scale and area-size threshold were similar to methods used to study vernal pools in New Jersey (Lathrop *et al.* 2005) and several other northeastern states (summarized in Colburn 2004; Brooks *et al.* 1998). MTRI's information was then used for field verification and analysis within ESRI ArcGIS (ESRI 2011). Lastly, because residual or trapped snow and ice were still observed in the 2004 May photos, these locations were included in the 2009 field surveys. This was to include the possibility that subsequent melt water at these locations may have formed vernal pools in topographical depressions.

Using GPS locations of potential vernal pools, we surveyed these water features during the summer of 2009. Based upon the aforementioned criteria, each water feature was assessed to determine if it met the requirements of a vernal pool. By walking the perimeter of the vernal pool, we also confirmed there were no visible inflow or outflow

channels that potentially could connect to a wetland, river, or stream. Basin area, perimeter shape, maximum water depth (< 0.3 m, 0.3 – 1.0 m, and >1.0 m), surrounding upland slope, and aspect were collected for each pool (Resh *et al.* 2013; Previant and Nagel 2014; Schrank *et al.* 2015). Following Coburn (2004), each vernal pool was assigned an initial hydrological class based on when the basin was filled (spring or fall) and length of flooding duration (semi-permanent, short- or long-cycle). A geodatabase was created within ArcGIS (ESRI 2011) and spatial analysis tools were used to determine associations between vernal pools and soil series cover types. The GIS data layers used were soil series survey (NCRS 2012), land cover types (Homer *et al.* 2007) and wetland features (USFWS 1998).

### **3.3.3.      *Statistical analyses***

Chi-square test of association was used to determine vernal pool association with soil series and cover types following GIS analysis. Chi-square test was selected because vernal pools, water features, soil series, and cover types are all qualitative (categorical) datasets (Dytham 2003). To determine if vernal pools were associated with water features, soil series, and cover types, expected values within contingency tables were calculated from weighted areas of each of these landscape variables, respectively. Categories were combined if more than 20% of the contingency cells have expected values less than 5 (Dytham 2003). Statistical analysis was performed using GraphPad Prism version 6.0 for Mac OS X (GraphPad Prism 2014). A binomial exact test was used

for 2x2 contingency tables when determining significant differences between observed and expected proportions. Cramer's V was used post hoc for contingency tables greater than 2x2 to determine strength of association between row and column variables. Cramer's V provides a value between 0 and 1, with values closer to 1 indicating a stronger association (Ludbrook 2008).

## **3.4. Results**

### ***3.4.1. Vernal pool identification, density, and surface area***

Between January and July of 2009, aerial photo interpretation by MTRI of 29,637 ha determined 214 separate water features (Figure 2 -1) that were initially comprised of 12 categories (e.g., "water with no canopy," "water with canopy," "inland snow or ice"). Field surveys were then conducted at 162 of these sites during the summer of 2009. The remaining 52 water features were not visited, as they were deemed very unlikely to be vernal pools based on surveys of similar water features identified by MTRI (e.g., trapped snow and ice on the backside of beaches, rock outcroppings, or roadsides). Forty-seven of the 162 (29.0%) visited water features were verified as vernal pools during the field reconnaissance. Following the field visits, the 12 initial, photo-interpreted water feature categories were simplified to five (Table 3-1). Two water features, "water with no canopy" and "water with canopy", had a photo-interpretation accuracy rate of 35.2% (43 pools from 122 water features) and accounted for 91.5% (43 of 47) of all pools.

For analysis and to avoid violating chi-square test assumptions for small expected values, “non-pool island,” “inland snow or ice,” “road with water, snow, or ice” and “beach features with water, snow, or ice” were combined into a single category called “Other.” The frequency of observed vernal pools was significantly different than the expected frequencies of the three water feature categories ( $p < 0.0006$ ;  $X^2 = 14.81$  ;  $df = 2$ ; Cramer’s  $V = 0.3969$ ). The frequency of observed vernal pools was 33.3% and 16.3% higher than expected frequencies of “water with no canopy” and “water with canopy”, respectively. The expected frequency of the third (combined) category was 66.7% higher than the observed vernal pools. An additional four vernal pools, which were not identified in the photo-interpretation process, were located while surveying other potential vernal pools. This total of 51 vernal pools was used in the subsequent analysis and discussion.

The resulting pool density from MTRI’s aerial photography interpretation and field verification was  $0.19 \text{ km}^{-2}$  for Pictured Rocks. This average increases to  $0.25 \text{ km}^{-2}$  when non-forest cover types are removed (e.g., lakes, roads, cleared areas, beaches). The total pool surface area was  $54,990 \text{ m}^2$  and the average interpolated pool area was  $1,078.2 \text{ m}^2$  ( $\pm 387.6 \text{ m}^2$ ; Table 3-2). There was no difference in area between vernal pool classes except dune-swale ( $10.1 \text{ m}^2$ ), which just met our minimum surface area threshold (see below for description of vernal pool classes).

### **3.4.2.      *Vernal pool classes***

As a result of the field verification visits and collection of geomorphic and hydrology characteristics (e.g., perimeter shape, maximum area, water depth, slope, topographical position, microtopography, flooding timing and duration), we modified classifications of seasonal depression wetlands described by Brinson (1993), Brooks and Hayashi (2002), Colburn (2004), Brooks (2005), Calhoun and deMaynadier (2008), and Brooks *et al.* (2011). This refined classification system had five distinct classes of vernal pools: classic (n = 20), complex (n = 17), kettle-kame (n = 9), dune-swale (n = 1), and minor ponds (n = 4). Distinctions were based on basin form, maximum water depth, associated understory and overstory vegetation, and soil characteristics (Figure 3-2; Resh *et al.* 2013).

Classic vernal pools were a single depression that occurred on flat terrain with a circular or elliptical perimeter that was distinguishable with a change in the microtopography and/or understory vegetation composition. One pool had a maximum water depth between 0.3 and 1.0 m, while the remaining classic vernal pools had maximum depths less than 0.3 m. Repeated observations indicated that the hydrologic class was short-cycle, spring-filling pools (Coburn 2004). Complex vernal pools also occurred on flat terrain and were a cluster of small basins or micropools (each with a surface area ranging from 1 - 3 m<sup>2</sup>) that became interconnected following snowmelt or precipitation events. This created an irregular perimeter that lacked the distinct microtopography break of classic vernal pools, but had a similar shift in understory vegetation. All complex vernal pools had a maximum water depth of less than 0.3 m, and also were short-cycle, spring-

filling pools (Coburn 2004). Kettle-kame vernal pools, with a circular perimeter and steep basin walls, occurred on flat, sandy outwash plains. The basin walls were estimated to be 1-3 m in slope length with several having slopes greater than 45 degrees, though a few were nearly flat (Figure 3-2). Maximum water depth was estimated to be greater than 1 m with little fluctuation throughout the growing season, suggesting the hydrologic class as a semi-permanent pool (Coburn 2004). The dune-swale vernal pool was linear in shape and appeared to be a catchment between the back dune and dune crest along Lake Superior. Maximum water depth was estimated to be greater than 1 m. We were unable to determine the hydrologic class. Lastly, minor pond vernal pools had a classic basin shape, but with steeper and pronounced banks that had water depths greater than 1 m. Since the water level did not appear to fluctuate throughout the 2009-growing season, we assigned it a preliminary hydrologic class of semi-permanent pools (Coburn 2004).

### **3.4.3.      *Soil series associations***

Eight soil series occur within Pictured Rocks and vernal pools were associated with seven of these (Figure 3-3; NCRS 2012). Kalkaska-Rubicon-Duel soil series comprises 34.1% of Pictured Rocks, while 51% of vernal pools, primarily classic and complex, are associated with this soil series (Table 3-3). Munising-Onota-Deerton is the second largest soil series by area (26.6% of Pictured Rocks), but only has the fourth highest frequency of vernal pools with 5 (9.8% of total pools). Complex vernal pools (n = 17) occurred across the widest variety of soils (5 soil series), while kettle-kames (n = 9) were

exclusively found on the Rubicon-Rousseau-Ocqueoc series. While most soil series had two or fewer vernal pool classes, Shelldrake-Wallace-Roscommon was the only soil series with three different vernal pool classes. Additionally, Shelldrake-Wallace-Roscommon is the fourth smallest soil series by area (8.1%), but has the third highest density of 0.27 pools km<sup>-2</sup>. Four soil series had vernal pool densities lower than the park average: Cathro-Emmet-Onaway (no pools), Dawson-Markey-Carbondale (0.04 pools km<sup>-2</sup>), Munising-Onota-Deerton (0.07 pools km<sup>-2</sup>), and Onota-Deerton-Munising (0.11 pools km<sup>-2</sup>). The Kalkaska-Rubicon-Duel soil series is described as a flat, somewhat poorly-drained soil with an apparent shallow water table (15.2 – 45.7 cm depth), relatively high permeability rates (15.2 – 50.8 cm hr<sup>-1</sup>), low cation exchange capacity (1 – 4), somewhat acidic soils (pH 4.5 – 6), low levels of clay content (0 – 10), and little to no slope (0 – 4%). These attributes are also found in the Shelldrake-Wallace-Roscommon soil series (NRCS 2012).

Because no vernal pools were associated with Cathro-Emmet-Onaway soils series and it comprises just 0.52% of Pictured Rocks, it was not used in the statistical analysis. We combined Kalkaska-Rubicon-Duel with Karlin-Kalkaska-Blue Lake (Kalkaska) and Munising-Onota-Deerton with Onota-Deerton-Munising (Munising) to have at least 80% of expected frequency of 5 or greater (Cohran 1954; Dytham 2003). Vernal pools were associated with soils series ( $p = 0.0473$ ;  $X^2 = 9.62$ ;  $df = 4$ ; Cramer's  $V = 0.3071$ ), with observed vernal pool frequencies greater for Kalkaska (17.4%), Rubicon-Rousseau-Ocqueoc (25.0%), and Shelldrake-Wallace-Roscommon (40.0%) series than expected,



and lower for Munising (-41.7%) and Dawson-Markey-Carbondale (-66.7%). Due to expected frequencies being less than one, we were unable to test the association between vernal pool classes and soil series without violating assumptions of the chi-square test.

### ***3.4.4. Cover type associations***

Using data provided by USFWS (1998), at least eight cover types or communities were identified at Pictured Rocks (Figure 3-3). Hemlock-northern hardwoods were the predominant cover type at 70.1% and contained a corresponding 36 of 51 (70.6%) of the vernal pools. The overall vernal pool density within this cover type was 0.19 km<sup>-2</sup>. Jack, red, and/or white pine was the second largest cover type (10.0%) and had seven vernal pools identified for a density of 0.26 km<sup>-2</sup>. White cedar was the third most common cover type (9.8%), and had the lowest density of vernal pools (0.07 pools km<sup>-2</sup>) of all cover types containing vernal pools. White birch, wetlands (shrub, bog, or marsh), cleared area, beach (sand or dune plant), and water comprise the remaining 10% of the cover types at Pictured Rocks. Four vernal pools were associated with this conglomerate, resulting in a density of 0.13 km<sup>-2</sup>.

To test for association, observed vernal pool frequencies were compared to the cover type weighted expected frequencies with the following categories: hemlock-northern hardwoods, other forest (jack/red/white pine, white birch, white cedar), and wetland (water and wetland shrub, bog, or marsh). We eliminated the cover types “cleared area”

and “beach, sand, or dune plant communities” due to their relative small area. No significance was found between observed and expected frequencies of vernal pools by cover type (p-value = 0.8849;  $X^2 = 0.2445$ ; df = 2; Cramer’s V = 0.0485). No attempt was made to separate remote sensing detectability and vernal pool occurrence rates by cover type as this went beyond the scope of the project.

## **3.5. Discussion**

### ***3.5.1. Vernal pool identification, density, and surface area***

Our first objective was to identify vernal pools at Pictured Rocks, and the springtime leaf-off photography and photo scale of 1:12,000 provided great detail to detect water features with a minimum surface area of 10 m<sup>2</sup>. However, one difficulty encountered with the true-color photo interpretation was the inability to see immediately beneath conifers, resulting in at least four vernal pools eluding detection, for an omission or false negative rate of 8.5%. Conifer canopies potentially cast shadows that could either obscure a vernal pool or falsely be identified as a vernal pool (Tiner 1990; Calhoun *et al.* 2003; Dr. Olson *pers. comm.* 2009). It was estimated that once the canopy had a 10% conifer component, detection rate decreased. In the case of the four undetected vernal pools, the canopy above each pool was closed and eastern hemlock was a main canopy species (Previant *pers. obs.* 2009). This, in part, may also explain why the white cedar cover type had the lowest vernal pool density (Table 3-2). One possible solution to improve detectability is

using color-infrared (CIR) digital orthophoto quarter-quad (DOQQ) imagery. For example, Lathrop *et al.* (2005) found no discernable pattern between detection rates of mixed or conifer dominated canopies using CIR DOQQ imagery, although it was suggested that a larger validation survey was needed to examine this completely. However, this type of imagery also needs to capture the spring conditions of vernal pools under the leaf-off season of deciduous trees. Additionally, newer remote sensing techniques that use a combination of synthetic aperture RADAR and multi-spectral imagery show promise for detecting and locating vernal pools under forested canopies (<http://www.mtri.org/wetlands.html>).

Another difficulty with verifying vernal pools at Pictured Rocks was specific to the timing of the aerial imagery. Our photo interpretation approach (i.e., higher false positive rate) included all visible water features, including existing snow and ice in May. This conservative approach became apparent when over 90% of the verified vernal pools were attributed to just two categories – “water with no canopy” and “water with canopy” (Table 3-1). As a result, the majority of remote sensing and field verification visits can be focused on water features within the contiguous forest, ignoring trapped snow behind fore-dunes and beside the shoulders of active and decommissioned roads. However, the timing of the imagery is critical; field surveys in mid-summer of 2009 found that the majority of the pools were dry and required additional field time and visits following precipitation events for confirmation (cf. Tiner 1990; Calhoun, Walls, *et al.* 2003).

The density of detected vernal pools at Pictured Rocks ( $0.19 \text{ km}^{-2}$ ) is lower than those reported in northeastern states ( $0 - 13 \text{ pools km}^{-2}$ ; Brooks *et al.* 1998; Calhoun, Walls, *et al.* 2003). There may be several reasons for this difference: Pictured Rocks has a linear shape that follows and captures the Lake Superior shoreline, the shallow depth to sandstone bedrock (60 – 152 cm), the unintentional omission of vernal pools under conifer canopy, and/or our exclusion of potential vernal pools within 152 m of existing bodies of water and 30.5 m from Lake Superior.

The total surface area of the pools was  $54,989.9 \text{ m}^2$  and occupied just 0.02% of the Park, less than the estimated 1% that vernal pools occupy in the northeast US (Brooks *et al.* 1998, Brooks and Hayashi 2002; Calhoun and deMaynadier 2001; Calhoun, Walls, *et al.* 2003). From Table 3-2, the average area of  $1,078.2 \text{ m}^2$  was similar to vernal pools in the northeast US (Windmiller 1996; Brooks *et al.* 1998, Brooks and Hayashi 2002; Calhoun and deMaynadier 2001; Calhoun, Walls, *et al.* 2003), and the range at the 95% confidence interval ( $690.6 - 1465.8 \text{ m}^2$ ) is comparable to the range of maximum areas reported in Maine (Calhoun, Walls, *et al.* 2003;  $399 - 1,394 \text{ m}^2$ ), Ontario (Clark 1986;  $3 - 7,563 \text{ m}^2$ ), Minnesota (Palik *et al.* 2003;  $100 - 2,500 \text{ m}^2$ ), and Pennsylvania (Seale 1980;  $250 - 1,000 \text{ m}^2$ ). Outside of the single dune-swale vernal pool, there were no differences in average surface area among vernal pool classes. The high variability within each class is worth noting; likely a function of both sample size and working definition of ephemeral pools with surface areas between  $10 \text{ m}^2$  and  $20,000 \text{ m}^2$  (i.e., Michigan Wetlands Protection Part 303 of 1994 Public Act 451).

### **3.5.2.      *Vernal pool classes***

After identifying vernal pools, our second objective was to modify existing geomorphic classification systems based on Brinson (1993), Brooks and Hayashi (2002), Colburn (2004), Brooks (2005), Calhoun and deMaynadier (2008) and Brooks *et al.* (2011). As part of the perimeter mapping process, the catchments or basins of vernal pools were classified based upon perimeter length and relationship within the local topography (Brooks and Hayashi 2002; Brooks 2005). This modified geomorphic system proved useful for two concurrent studies at Pictured Rocks. The classes provided the initial framework to help minimize the variability in the physical characteristics of vernal pools, and proved useful in characterizing differences in surrounding forest habitat (Previant and Nagel 2014), along with hydroperiod, vegetation community type, and amphibian species richness (Resh *et al.* 2013; Shrank *et al.* 2015).

The majority of vernal pool descriptions indicate a depression with round or oblong perimeters occurring within flatwoods (e.g., Calhoun, Walls, *et al.* 2003; Brooks 2005; Calhoun and deMaynadier 2008). In this situation, our use of “classic” terminology (i.e., vernal pools with a circular perimeter that is surrounded by an upland forest) was consistent with Colburn (2004) and Calhoun and deMaynadier (2008). The “minor pond” class of vernal pools was similar to classic, but we observed the water table fluctuated

very little throughout the growing season, which may suggest a connection to groundwater.

We classified a cluster of small and interconnected micropools as a “complex” within the flat terrain of upland forests in Pictured Rocks. Calhoun and deMaynadier (2008) provide an illustrated example and description of the annual hydroperiod, which may be particularly relevant to this vernal pool type. We were unable to find published examples detailing a “complex” class of vernal pool, although the spungs of New Jersey have a similar likeness in geomorphology (French and Demitroff 2001; Lathrop *et al.* 2005). It should be noted that while spungs were created by periglacial winds (French and Demitroff 2001), complex vernal pools in this study may have been formed by a series of frost-thaw events interacting with pit-and-mound features common to hemlock-hardwood forests (Wolfe 1953; Tyrrell and Crow 1994). The dune-swale vernal pool was a linear feature near the shore of Lake Superior, with distinct vegetation on the surrounding dunes and within the swale (Cromer and Albert 1993).

Kettle-kame vernal pools were quite distinct from the other four classes, although the perimeter shapes were similar to classic vernal pools. These occurred only in the deep sands of the Kingston Plains (Rubicon-Rosseau-Ocqueoc; Figure 3-3) and are surrounded by mixed pine forests. During the late-Wisconsin glaciation, a melting glacier released an outwash of sediment (kame terrace) that then buried blocks of ice (Albert 1995). Once these blocks melted, they formed a depression, or kettle (Flint 1971). We observed that

the kettle-kame vernal pools tended to have the deepest depths and maintained water later into the growing season, supporting Calhoun and deMaynadier's (2008) assertion that these kettle depressions have groundwater sources.

### **3.5.3.      *Soil series and cover type associations***

Our last objective was to determine vernal pool associations with the soil series and cover types of Pictured Rocks via the NCRS (2012), National Land Cover Data, and the National Wetland Inventory GIS datasets (Homer *et al.* 2007; USFWS 1998). We anticipated that vernal pools would be correlated with soils that had a relatively high clay component, as this characteristic would impede percolation rates following snow melt or precipitation events. However, Munising-Onota-Deerton, with 18-35% clay content, was the second most common soil series at 26.6%, but had one of the lowest densities of vernal pools (Table 3-3). Vernal pools, with the exception of kettle-kames, tended to be associated with soils that were somewhat poorly (Kalkaska-Rubicon-Duel) or very poorly drained (Shelldrake-Wallace-Roscommon; Table 3-3), but it is unclear what factor(s) are creating and maintaining the water levels in these upland depressions. According to Calhoun and deMaynadier (2008), the Late-Wisconsin glaciation created a combination of sandstone bedrock, pitted outwash, end moraines, and outwash plains that would make vernal pools dependent upon precipitation versus groundwater as a principle source of water. Sampling of vernal pool water pH by Resh *et al.* (2013) suggested that the majority of the classic and complex vernal pools are precipitation driven. It is also

unclear if the presence of localized fragipans influences vernal pool hydrology, or what role subsurface flow after a precipitation event contributes to the water budget. We also observed that vernal pools tended to be situated closer to the boundary of a soil series rather than randomly dispersed throughout (Figure 3-3). Seasonal wetlands have a higher correlation with ground moraine landforms (Palik *et al.* 2003), and the clustering of vernal pools may imply a relationship with surficial geology (Brooks *et al.* 1998; Brooks 2005). While soil series delineation provided by NRCS (2012) isn't necessarily precise when associated with an average vernal pool area of 0.1 ha, the relationship we observed may suggest that vernal pools are more likely to occur within the transition zone between two soil series.

Vernal pools are commonly associated with upland forests (*cf.* Massachusetts Division of Fisheries and Wildlife 1988; Palik *et al.* 2003; Tiner 2003; Calhoun and deMaynadier 2004; Calhoun and deMaynadier 2008), although accepted definitions do not include this qualifier. Many northeastern USA surveys of vernal pools are conducted for individual watersheds or even for the entire state, but cover types associated with vernal pools are divided into upland or lowland, deciduous or conifer categories (Brooks *et al.* 1998; Lathrop *et al.* 2005; Van Meter *et al.* 2008). At Pictured Rocks, approximately 81% of the area is upland forest, and 86.2% of vernal pools were found in this broad cover type (Figure 3-3; Tables 3-1 and 3-2). This rate of vernal pool occurrence within upland forests is similar to the Quabbin Reservoir watershed, MA (Brooks *et al.* 1998). Yet, given this pattern, the vast majority of vernal pool habitat descriptions quantify only what



occurs within the vernal pool perimeter and not the surrounding forest (Schiller *et al.* 2000; Palik *et al.* 2007), although Franci (2008) and Previant and Nagel (2014) are notable exceptions. A limitation to the GIS cover type association analysis is that land cover types are based upon imagery and not forest structure data. Having better quality information, specifically for the hemlock-hardwood cover type, may help guide conservation and preservation efforts within the mixed management zones of Pictured Rocks.

### **3.6. Conclusions**

This collaborative work at Pictured Rocks required both remote sensing and field surveys to identify and classify 51 vernal pools. Although the rate of omission was less than 10%, detecting water features under canopies with a conifer component was difficult with true-color aerial photography. Field surveys confirmed 29.0% of the water features as vernal pools, although this accuracy could potentially increase with a more discriminate identification of water features and CIR DOQQ imagery. The vernal pool density at Pictured Rocks was on the low end of those reported in the northeast, but several factors could have contributed to this result: linear shape of the Park, limitations of true-color aerial photography, restrictive definition of vernal pools, and difficulty of detectability under conifers. The average vernal pool surface area and discrete location within upland forests was not only similar to other vernal pool studies, it also allowed us to refine

existing classification systems based on catchment profile and surrounding upland vegetation.

The available GIS datasets and our study's small sample size limited investigation into various associations among vernal pools and soil series and cover types. A need exists for field soil profiles and more detailed descriptions of the hydrogeomorphic setting in and around a vernal pool, as these may be useful in identifying the agents that are impeding the drying out process. Additionally, spatial analysis of vernal pool proximity to specific wetland types may help identify habitat corridors for migratory amphibians. Nearly all the vernal pools we observed occurred in a hemlock-hardwood cover type, yet the majority of vernal pools were associated with either an open or closed canopy, indicating a difference in forest structure within that forest type. This raises the question of how soil properties and the hydrologic dynamics of vernal pools might influence the surrounding forest structure and diversity given that temperate tree species vary in their site requirements and ecological amplitudes, especially as related to nutrient and moisture availability in this region.

### **3.7. Acknowledgements**

Many thanks and appreciation to Bruce Leutscher and Lora Loope of Pictured Rocks National Lakeshore for their logistic support, comments, and sharing of information; Dr. Charles Olson of Michigan Tech Research Institute for aerial photography interpretation; Dr. Rod Chimner, Dr. Sigrid Resh, and Dr. Amy Schrank of Michigan Technological

University for collaboration; and Steve Miceli and Adrienne Bozic for field help.

Funding was provided by McIntire-Stennis program, and the Graduate School and School of Forest Resources and Environmental Science at Michigan Technological University.

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### 3.9. Figures and Tables

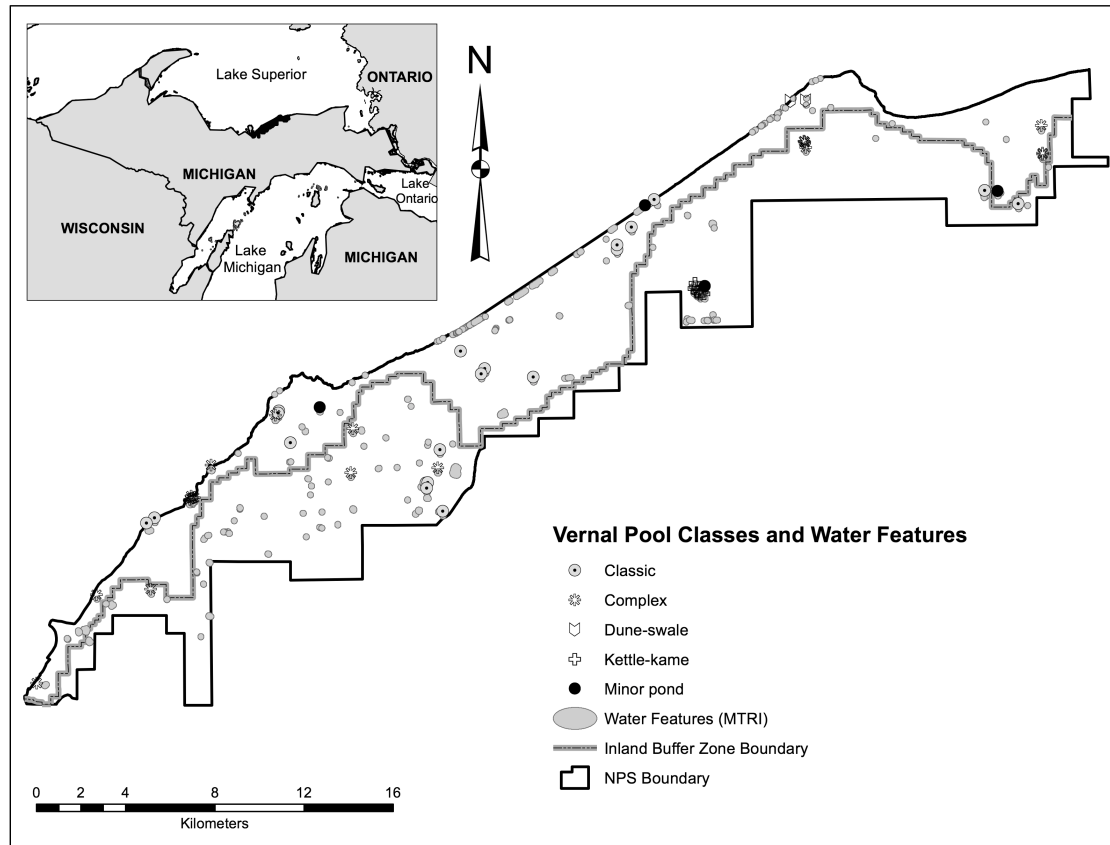


Figure 3-1: Location of water features from aerial photo interpretation and resulting vernal pool classes at Pictured Rocks National Lakeshore, Michigan, USA.

Table 3-1: Water feature types identified with resulting vernal pool classes at Pictured Rocks National Lakeshore, Michigan, USA. Four additional vernal pools were found through field surveys that were not detected by aerial photography interpretation.

Water Feature Type	Water Features Identified	Vernal Pool Classes				
		Classic	Complex	Dune-swale	Kettle-kame	Minor pond
Non-pool island	1	-	-	-	-	-
Inland snow or ice	3	-	1	-	-	-
Road with water, snow, or ice	33	-	1	-	-	-
Water with no canopy	39	7	1	-	9	1
Beach features with water, snow, or ice	55	-	-	1	-	1
Water with canopy	83	10	13	-	-	2
Field survey - no photo	-	3	1	-	-	2
Totals	214	20	17	1	9	4



Figure 3-2: Field examples of vernal pools at Pictured Rocks National Lakeshore, Michigan, USA. Vernal pool classes are classic (upper left), complex (center), kettle-kame (upper right), minor pond (lower left), and dune-swale (lower right). Photos by W. Previant.

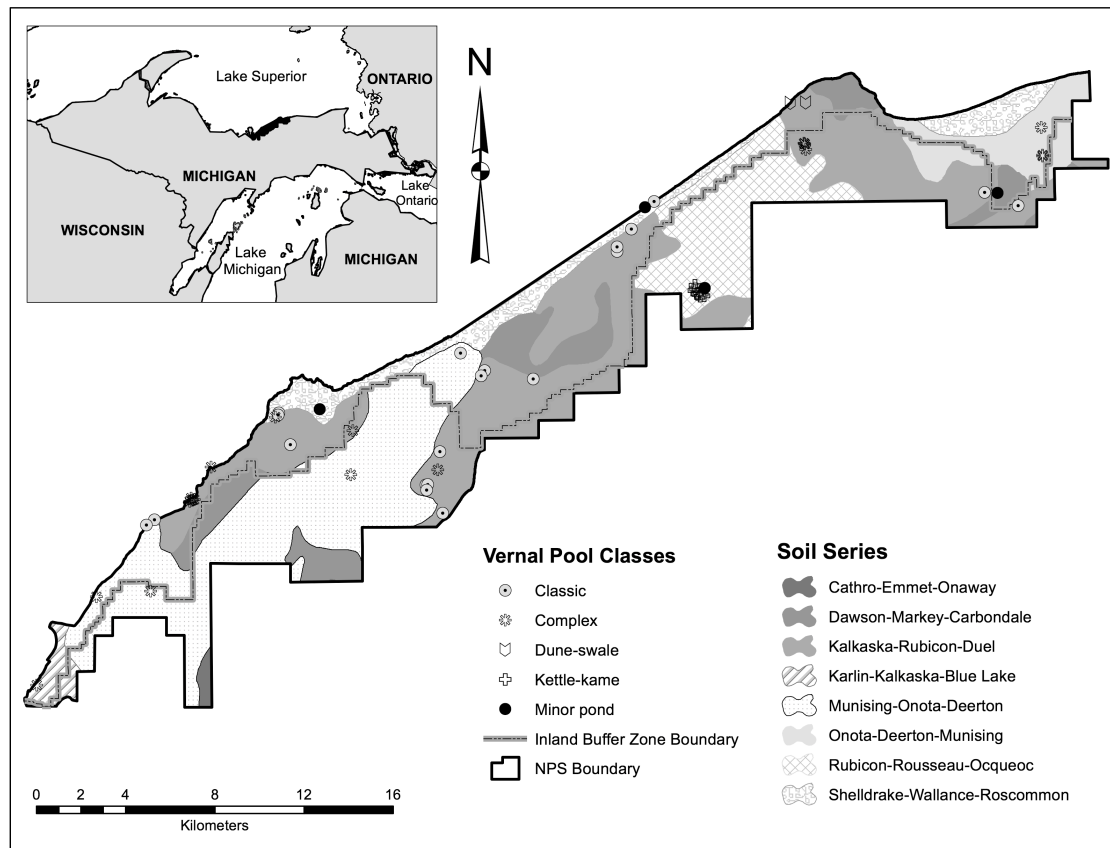


Figure 3-3: Soil series and associated vernal pools classes at Pictured Rocks National Lakeshore, Michigan, USA.

Table 3-2: Interpolated maximum vernal pool area and vernal pool density by cover type at Pictured Rocks National Lakeshore, Michigan, USA.

Vernal pool class	Vernal pool total area (m <sup>2</sup> )	Vernal pool average area (m <sup>2</sup> )	Confidence interval (95%) Lower, Upper		Park density (pool km <sup>-2</sup> )	Cover type density (pool km <sup>-2</sup> )
Classic <sup>NH</sup>	19,239.0	961.9	349.8	1574.0	0.07	0.10
Complex <sup>NH</sup>	20,172.4	1186.6	383.4	1989.8	0.06	0.08
Dune-swale <sup>1</sup>	10.1	10.1	-	-	0.00	0.03
Kettle-kame	12,606.2	1400.7	539.4	2262.0	0.03	0.30
Minor pond <sup>1</sup>	2,962.1	740.5	598.9	882.1	0.01	0.02
Total <sup>NH</sup>	54,989.8	1078.2	690.6	1465.8	0.17	0.25
<sup>NH</sup> - Hemlock-northern hardwoods <sup>P</sup> - Jack, red, and/or white pine <sup>WC</sup> - White cedar						

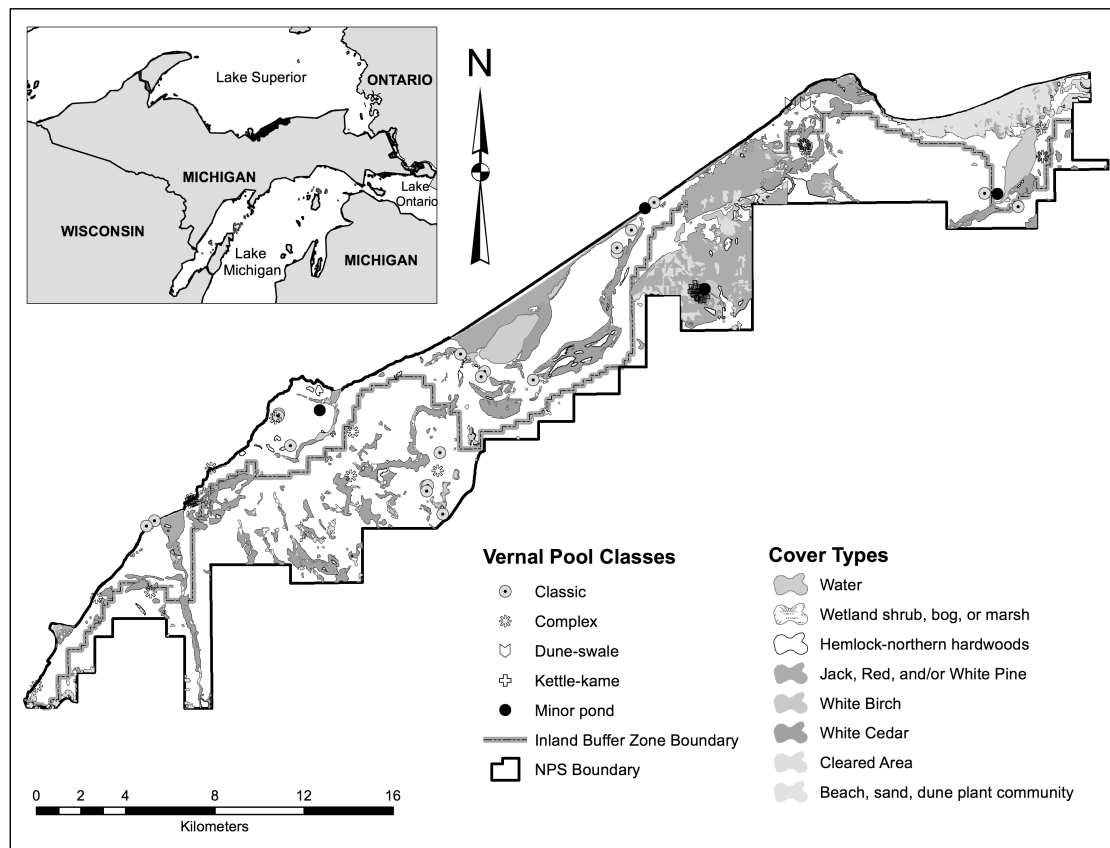


Figure 3-4: Cover type and wetland association with vernal pool classes at Pictured Rocks National Lakeshore, Michigan, USA.

Table 3-3: Vernal pool association with soil series at Pictured Rocks National Lakeshore, Michigan, USA (Homer *et al.* 2007; NCRS 2012).

Vernal Pool Class Association <sup>1</sup>								
Soil Series <sup>2</sup>	Soil Series Proportion of Park area	Classic	Complex	Dune- swale	Kettle- kame	Minor pond	Total	Vernal Pool Density by Soil Series (pool km <sup>-2</sup> )
Cathro	0.01	-	-	-	-	-	-	-
Karlin	0.02	-	0.06	-	-	-	0.02	0.22
Onota	0.07	-	0.12	-	-	-	0.04	0.11
Shelldrake	0.08	0.15	0.06	-	-	0.50	0.12	0.27
Dawson	0.10	-	-	-	-	0.25	0.02	0.04
Rubicon	0.12	-	-	-	1.00	0.25	0.20	0.30
Munising	0.27	0.15	0.12	-	-	-	0.10	0.07
Kalkaska	0.34	0.70	0.65	1.00	-	-	0.51	0.28
Total <sup>3</sup>	100%	20	17	1	9	4	51	0.19

<sup>1</sup> Proportion of vernal pool classes by soil series

<sup>2</sup> Soil series abbreviations: Cathro-Emmet-Onaway; Karlin-Kalkaska-Blue Lake; Onota-Deerton-Munising; Shelldrake-Wallace-Roscommon; Dawson-Markey-Carbondale; Rubicon-Rousseau-Ocqueoc; Munising-Onota-Deerton; and Kalkaska-

<sup>3</sup> Total number of surveyed vernal pools by class



## Chapter 4.      **Forest Diversity and Structure**

### **Surrounding Vernal Pools in Pictured Rocks National Lakeshore, Michigan, USA<sup>3</sup>**

#### **4.1. Abstract**

Vernal pools have been identified as unique contributors to forest biodiversity, with habitat management guidelines commonly recommending concentric zones of varying conservation intensity. However, little is known about the associated edaphic and forest structure characteristics associated with vernal pools. At Pictured Rocks National Lakeshore (Michigan, USA), we measured a stratified-random sample of 18 of 51 vernal pools to investigate soil pH, down dead wood, tree stocking, species richness, species evenness, species diversity, and species importance values within and across these zones. Within the pool zone, live tree basal area and live tree density was significantly lower and down dead wood volume was significantly higher than either the buffer or matrix zones. Nested-ANOVA and NMDS ordination indicated that importance values of under-represented species increased closer to the vernal pool. Tree diversity and richness were positively correlated with vernal pool area. These findings suggest the buffer zone serves as a transition zone between vernal pools and the surrounding forest, complementing the

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<sup>3</sup> This chapter © by Springer 2014. Citation: Previant, W.J. and L.M. Nagel. 2014. Forest diversity and structure surrounding vernal pools in Pictured Rocks National Lakeshore, Michigan, USA. *Wetlands* 34(6): 1073-1083. Refer to Appendix B and Appendix D for copyright documentation.

proposed guideline goals of reducing impacts of forest management. Vernal pools are unique forested wetlands and may provide an opportunity to maintain and enhance ecosystem complexity and resiliency.

## **4.2. Introduction**

Vernal pools are small and occur in low densities, with an average surface area of 800 m<sup>2</sup> and a frequency between one and 13.5 km<sup>-2</sup> (Brooks *et al.* 1998; Brooks and Hayashi 2002; Calhoun *et al.* 2003; Franci 2008). Vernal pools are estimated to occupy approximately 1% of the northeastern U.S. landscape and are associated with glacial features including outwash, end moraines, and ground moraines (Calhoun *et al.* 2003; Palik *et al.* 2003). The ecological role of vernal pools within upland forests include providing critical sites for reproduction, development, and survival of amphibians and invertebrates (Ling *et al.* 1986; Calhoun *et al.* 2003; Homan *et al.* 2004), feeding areas for bats (Franci 2008), and habitat for numerous threatened and endangered species (Schiller *et al.* 2000). These ephemeral forested wetlands occur in small basins, exhibiting annual wet and dry periods that are precipitation-driven (Cowardin *et al.* 1979; Brooks 2005). The timing and quality of moisture availability are important factors in determining the abundance and diversity of species utilizing these vernal pools (Bliss and Zedler 1998).

Vernal pools may influence the surrounding upland forest diversity and structure, as they serve as water catchments and have extended growing-season hydroperiods. For example, *Betula alleghaniensis* (Britton) was associated with 36% of upland vernal pools in northern Minnesota (Palik *et al.* 2007). This is notable for several reasons. First, land management practices in the Great Lakes have significantly altered forest composition over the past 150 years, resulting in decreased diversity and simplified forest structure (Whitney 1987; Schulte *et al.* 2007). Between 1850 and 1990, maximum relative dominance of *Betula* spp. and *Tsuga canadensis* ((L.) Carrière)) has declined by 25.3% and 34.3%, respectively (Schulte *et al.* 2007). Within Michigan, *Betula alleghaniensis* and *Tsuga canadensis* growing stock and volume have decreased 5-71% (Godman 1992; Zhang *et al.* 2000; Pugh *et al.* 2012), while *Tsuga canadensis* has been reduced to just 0.5% stocking of Wisconsin forests (Eckstein 1980). In contrast, *Acer saccharum* (Michx.) maximum relative dominance has increased by 28.4%, while *Acer rubrum* (L.) coverage has increased by 14% (Zhang *et al.* 2000; Schulte *et al.* 2007). Secondly, this trend is predicted to continue; both *Betula alleghaniensis* and *Tsuga canadensis* are expected to decline in managed northern hardwood stands due in part to poor regeneration success and browsing pressure (Schwartz *et al.* 2005; Schulte *et al.* 2007; Witt and Webster 2010; Kern *et al.* 2012). Lastly, fluctuations in precipitation and temperature resulting from regional and global climate change have and will continue to negatively impact these two species (Walker *et al.* 2002; Foster *et al.* 2006). The decrease in abundance of these and other species reduces landscape diversity (Schulte *et al.* 2007; Schwartz *et al.* 2005), alters known and unknown ecological processes (Ellison *et al.*

2005), and may ultimately limit the ability to manage for future resiliency in the face of climate change (Millar *et al.* 2007). The projected result of a homogenous forest (i.e., fewer tree species and simplified structure) has an unknown impact on ecological processes related to productivity, biochemical cycling, and hydrology of vernal pools.

Though vernal pools occur at low frequencies across the landscape, their forested setting consistently exposes them to potentially damaging land management practices. These isolated forested wetlands receive no legal protection (*see* Ruffolo; *see* Zedler 2003), and management guidelines, such as Best Management Practices (BMPs), are typically only recommendations to minimize canopy disturbance within 30 m of a vernal pool (MDNR 2009). Calhoun and deMaynadier (2004) propose a habitat management guideline (HMG) based on habitat values for a wide variety of amphibians, arthropods, mammals, and birds that are dependent upon vernal pools and surrounding uplands for breeding, foraging, migration, and concealment. This HMG encompasses 5.3 ha and is comprised of three zones: the vernal pool itself, 0-31 m from the vernal pool boundary, and an additional 32-122 m beyond this same boundary (Calhoun and deMaynadier 2004; Figure 4-1A). This HMG is designed to mitigate disturbance by protecting and maintaining the physical integrity of the vernal pool, aboveground and subsurface hydrology, water quality, canopy closure, and forest floor structure (Calhoun and deMaynadier 2008). It may also identify suitable habitat with higher occurrence rates of under-represented species, such as *Betula alleghaniensis* and *Tsuga canadensis*, thereby increasing conservation effectiveness for vernal pools across landscapes when protected.

Using the Calhoun and deMaynadier (2004) habitat management guidelines, we evaluated forest overstory diversity and structure of vernal pools and surrounding forest within Pictured Rocks National Lakeshore (Pictured Rocks), Michigan. Because of late-season water availability within vernal pools, we hypothesized that overall tree diversity and richness would be higher within 31 m of a vernal pool's boundary compared with the surrounding 32-122 m management zone. Additionally, since *Betula alleghaniensis* and *Tsuga canadensis* prefer mesic sites, we hypothesized the relative importance of each species would be greater within 31 m of a vernal pool's boundary compared with the 32-122 m management zone. Lastly, given the relationship between area and volume, vernal pools with greater surface area collect more water in spring, which in turn, will be retained longer into the growing season. Thus, we hypothesize that tree diversity and richness would be positively correlated with the surface area of pools. This data will provide critical information that is currently lacking on the relationship between vernal pools and upland forest structure and diversity, and will further inform conservation aimed at maintaining, conserving, and promoting forest diversity within the context of the Calhoun and deMaynadier (2004) guidelines.

### **4.3. Study Location**

We chose Pictured Rocks as a study location for several reasons: 1) the availability of high-quality aerial imagery; 2) Pictured Rocks permits forest management in defined

areas; and 3) this research was complementary and collaborative to Pictured Rock's investigation into the relationship between vernal pools and amphibians, macro-invertebrates, understory vegetation, and carbon (Resh *et al.* 2013). Located in the Upper Peninsula of Michigan, Pictured Rocks sits on the south shore of Lake Superior (Figure 4-2). Established in 1966, the park is approximately 296 km<sup>2</sup> and protects 67.5 km of shoreline. A unique feature of Pictured Rocks is the delineation of two management areas: Lakeshore Zone (LZ) and Inland Buffer Zone (IBZ). The LZ is over 12,000 ha and is owned and managed by the National Park Service. The IBZ is nearly 16,000 ha and is a patchwork of federal, state, and private ownership that allows sustainable forest management (PL 89-668 Section 9a – 10a).

The average annual precipitation is 65 cm at Pictured Rocks, with an average annual temperature of 4.8° C (Eichenlaub *et al.* 1990). Bedrock geology is a Cambrian-age sandstone escarpment with either lacustrine or poorly and very poorly drained glacial deposits (Albert 1995). Soils are classified as Histosols and Entisols (NRCS 2012). Pictured Rocks vegetation reflects the transition zone between the northern range of temperate and the southern range of boreal forests (Bailey 1995), and is dominated by *Acer rubrum*, *Acer saccharum*, *Betula alleghaniensis*, and *Fagus grandifolia* (Marshall). Other common species found within the park include *Pinus resinosa* (Aiton), *Pinus strobus* (L.), *Pinus banksiana* (Lamb.), *Betula papyrifera* (Marshall), *Populus tremuloides* (Michx.), and *Thuja occidentalis* (L.) (Woodall and Leutscher 2005; Menard *et al.* 2008).

## 4.4. Methodology

### 4.4.1. *Selection of vernal pools*

In 2009, Michigan Tech Research Institute (MTRI) delineated potential Pictured Rocks vernal pools using true-color leaf-off aerial photographs (1:12,000) from May 2004.

Parameters used to identify potential vernal pools were the inclusion of residual snow and ice, minimum size of 10 m<sup>2</sup> in area, and maximum size of two hectares. Potential vernal pools were to be located further than 152 m from inland lakes, rivers, or streams and not to occur within 30.5 m of Lake Superior (Michigan Wetlands Protection Part 303 of 1994 Public Act 451). Field visits were conducted at 162 sites during the summer of 2009, resulting in 47 confirmed vernal pools (Previant and Nagel *in press*; Figure 4-2). An additional four vernal pools were located that were not originally detected from the photo interpretation. A hydrogeomorphic classification system based upon Colburn (2004) and Calhoun and deMaynadier (2008) was developed, creating five categories of vernal pools: classic, complex, kettle-kame, dune-swale, and minor ponds (Previant and Nagel *in press*). A stratified-random sample of 18 vernal pools was selected (classic = 14; complex = 4), as these two types are exclusive to upland northern hardwood forests of Pictured Rocks. Classic vernal pools were basins on flat terrain, with no inlets or outlets, and a definable pool boundary that was circular or oblong. Complex vernal pools also occurred on flat terrain, consisted of small, interconnected depressions with no inlets or

outlets, and with an irregular boundary best delineated using wetland obligate herbaceous species.

#### **4.4.2.      *Plot design***

We sampled 18 vernal pools using a distance-gradient nested-plot design based on the habitat management zones from Calhoun and deMaynadier (2004), using pool, buffer, and matrix zones (Figure 4-1B). The pool zone was the basin that contained water, the buffer zone was 0 - 31 m from the pool zone perimeter, and the matrix zone was the area 32 - 122 m from the same perimeter. Collectively, these zones were known as a vernal pool management zone (VPZ). Each VPZ was considered a macroplot and consisted of seven nested subplots. Macroplot center was established within the pool zone at the intersection of the longest perpendicular axis. All subplots radiated outwards from this center point at 0°, 120°, and 240°. The first subplot (pool zone) was defined by each vernal pool perimeter and was a complete census of the variables of interest (see below). The remaining six circular subplots were each 0.08 ha with a radius of 15.96 m. Plot size was determined from the accepted average value of 0.08 ha of northeastern vernal pools (Brooks *et al.* 1998; Calhoun *et al.* 2003; Franci 2008; Calhoun and deMaynadier 2008). Three subplots were located at the midpoint of the buffer zone (0 - 31 m), and the remaining three were randomly installed between 48 - 106 m within the matrix zone. In a few instances, a buffer or matrix subplot landed within a non-forest opening (i.e., road, water, or bog). These were not sampled and no replacement subplots were installed to



ensure that this sampling approach best reflected the variability of landscape features associated with vernal pools.

#### **4.4.3.      *Variables collected***

The maximum area of each vernal pool was determined by first delineating the perimeter along either a micro-topography break (i.e., bank) or an abrupt shift in the herbaceous layer (e.g., presence/absence of *Osmunda* spp.). Next, at cardinal and sub-cardinal directions, horizontal distances from the center point to the pool perimeter were measured with a Suunto Kb-14 Compass and Hagl f Vertex III Hypsometer, creating eight triangles. The area of each triangle was then combined to determine total vernal pool area. However, this technique did not work for two of the vernal pools (water depth > 1 m or dense vegetation). In these cases, the perimeter was traversed while a DeLorme PN-30 GPS (WAAS enabled) tracked the waypoints. This series of waypoints were later converted into a polygon within ESRI ArcMap 10.1 (ESRI 2011).

At each subplot, species and diameter at breast height (dbh, 1.37 m) was measured for all live and dead trees > 12.6-cm dbh. A total of four circular regeneration microplots (2.1 m radius) were installed 3.7 m from each subplot center along cardinal directions. At each microplot, saplings with a dbh between 2.5 and 9.9 cm were measured. Seedlings less than 2.5 cm at dbh, with a minimum height threshold of 15 cm for conifers and 30.5 cm for hardwoods. Species richness, evenness, and diversity (Shannon-Wiener Index) were

standardized for both the VPZ and by pool, buffer, and matrix zones (Simpson 1949; MacArthur and MacArthur 1961). To detect subtle changes in composition and abundance, individual species were ranked according to relative importance by frequency, density, and dominance. To determine importance values (IV), we used the following equations:

$$[S_N / \sum S_A] * 100 \quad (1.1)$$

$$[S_{N_{tpha}} / \sum S_{A_{tpha}}] * 100 \quad (1.2)$$

$$[S_{N_{ba}} / \sum S_{A_{ba}}] * 100 \quad (1.3)$$

Relative frequency (1.1) is a function of a specific species count ( $S_N$ ) and count of all species ( $S_A$ ); relative density (1.2) is a function of a specific species density per ha ( $S_{N_{tpha}}$ ) and total tree density ( $S_{A_{tpha}}$ ); and relative dominance (1.3) is a function of a specific species basal area ( $S_{N_{ba}}$ ;  $m^2 ha^{-1}$ ) and total basal area of all species ( $S_{A_{ba}}$ ;  $m^2 ha^{-1}$ ). Basal area, the cross-sectional area occupied by tree stems, is correlated with leaf area index and is a predictor for competition, growth rates, horizontal structure, and amount of light reaching the forest floor (Crow *et al.* 2002; Woodall *et al.* 2003). Summing these three values created an IV for each species by subplot, which were then standardized across each zone. The magnitude of IV is an integrative indicator of overall ecological importance of a given species, allows for ranking among species, and identifies species associations within communities of interest (Curtis and McIntosh 1951).

Down dead wood (DDW) was recorded using the line-intercept method along cardinal transects of each subplot (LIS; Brown 1974; de Vries 1986; Woodall and Monleon-Moscardo 2007). Minimum diameter at intercept location was 12.7 cm. Large- and small-end diameters were recorded to the nearest 2.54 cm, and total length was recorded to the nearest 0.3 m. Height and cross-section were recorded for stumps with a height > 30.5 cm and minimum diameter of 12.7 cm. Each piece was rated using a 5 decay-class scale (Maser *et al.* 1979; Sollins 1982). Volume was estimated using Smalian's formula (Husch *et al.* 1972).

For each subplot and within the top 10 cm of soil, we averaged eight pH readings from a Kelway HB-2 probe. Vernal pools were assigned a soil series by overlaying GPS locations with a GIS data layer within ArcMap 10.1 (ESRI 2011; NRCS 2012). Finally, because trees can tolerate a range of site qualities, habitat types (Burger and Kotar 2003) were determined for each subplot.

#### **4.4.4.      *Statistical analyses***

The association between different zones (i.e., pool, buffer, and matrix) and measurement variables (see above) were evaluated using one-way two-level nested analysis of variance (ANOVA). ANOVA was also used to compare vernal pool classes (classic and complex) and legislative management type (LZ and IBZ) across the same variables. When

significant differences were detected, Tukey-Kramer comparison of means (JMP 10 SAS 2012) was conducted.

To explore how IV along a distance gradient related to the environmental variables of soil pH, pool area, soil series, and habitat type, we used nonmetric multidimensional scaling ordination (NMDS) within PC-ORD ver. 5.1 (McCune and Mefford 2006). We chose the Sørensen (Bray-Curtis) distance, six dimensions, and used 250 runs of real data and 250 runs of randomized (Monte Carlo) data. Model stress was reduced by re-running the data in 3-dimensional space, with a final instability of zero. The primary (species abundance) and secondary matrices (environmental variables) were not transformed.

We tested the null hypothesis that no differences in species importance values exist between VPZs by using a Multiple Permutation Procedure (MRPP). MRPP used the Sørensen distance measure to be consistent with NMDS ordination. Indicator species analysis (ISA) was applied to the vernal pool zones to describe differences in individual IV among zones and to help identify species that had higher IV within one or more zones. A Monte Carlo test of significance (4999 permutations) was used to identify species with alpha levels less than 0.05.

## 4.5. Results

### 4.5.1. *Edaphic and habitat characteristics*

Within the upland forest of Pictured Rocks, the total vernal pool density was 0.19 pools  $\text{km}^{-2}$ . The average surface area was 1280.2  $\text{m}^2$  ( $\pm 313.1$ ), with classic ( $772.0 \pm 127.2 \text{ m}^2$ ) being significantly smaller than complex vernal pools ( $3059.0 \pm 948.2 \text{ m}^2$ ;  $p = 0.0470$ ). There was no difference in vernal pool surface area between LZ and IBZ ownership ( $p = 0.5482$ ). Vernal pools occur on seven of the eight soil series, and the 18 sampled vernal pools occur on four of these seven (Figure 4-2). Nine of the 18 vernal pools (all classic) were associated with Kalkaska-Rubicon-Duel. The average sampled soil pH was  $6.0 \pm 0.1$  (Table 4-1). Soil pH of the classic ( $6.1 \pm 0.04$ ) was higher than for complex VPZs ( $5.9 \pm 0.09$ ;  $p = 0.0329$ ). There was no difference in soil pH between the matrix ( $6.1 \pm 0.1$ ), buffer ( $6.0 \pm 0.1$ ) or pool zones ( $5.8 \pm 0.1$ ). No difference was found between IBZ and LZ ownership ( $p = 0.2440$ ).

VPZs were most often classified as *Acer saccharum-Tsuga canadensis-Fagus grandifolia* / *Dryopteris spinulosa* (ATFD) habitat type (64.9%), and was consistent across the buffer (72.5%) and matrix (56.5%) zones (Table 4-1). Classic VPZs were frequently classified as ATFD (68.4%), while complex VPZs were almost equally split between ATFD (52.4%) and *Acer saccharum-Fagus grandifolia* / *Osmorhiza claytonii-Arisaema triphyllum* (AFOAs; 47.6%).

#### **4.5.2.      *Forest structure***

The average live tree (dbh > 12.7 cm) density was 315.8 ( $\pm 23.5$ ) trees ha<sup>-1</sup> with an average basal area of 23.6 m<sup>2</sup> ha<sup>-1</sup> ( $\pm 2.1$ ) across all VPZs (Table 4-2). Dead tree density was 27.2 trees ha<sup>-1</sup> ( $\pm 3.8$ ) and average basal area of 1.8 m<sup>2</sup> ha<sup>-1</sup> ( $\pm 0.3$ ). Down dead wood volume for classes 1-4 averaged 98.6 m<sup>3</sup> ha<sup>-1</sup> ( $\pm 21.4$ ) while class 5 was 58.4 ( $\pm 13.1$ ) m<sup>3</sup> ha<sup>-1</sup>. Across these same structural attributes, no significant differences were found between complex and classic VPZs, with one exception: dead tree basal area in complex VPZs ( $3.2 \pm 0.6$  trees ha<sup>-1</sup>) was significantly higher than classic ( $1.4 \pm 0.3$  trees ha<sup>-1</sup>;  $p = 0.0146$ ). Lastly, when comparing the LZ to the IBZ, no significant differences were found between the VPZs.

The matrix zone had higher live basal area ( $38.3 \pm 1.3$  m<sup>2</sup> ha<sup>-1</sup>) than the buffer ( $27.4 \pm 1.2$  m<sup>2</sup> ha<sup>-1</sup>;  $p = 0.0429$ ) and the pool ( $5.1 \pm 1.2$  m<sup>2</sup> ha<sup>-1</sup>;  $p < 0.0001$ ) zones, and the buffer was higher than the pool zone ( $p < 0.001$ ). There were no differences in dead basal area between zones ( $p = 0.0513$ ). The pool zone had significantly lower average live tree density than both buffer and matrix zones ( $105.0 \pm 22.3$  pool vs.  $436.6 \pm 18.9$  buffer vs.  $406.0 \pm 19.3$  matrix trees ha<sup>-1</sup>;  $p < 0.0001$ ). Standing dead tree density in the buffer ( $40.6 \pm 6.7$  trees ha<sup>-1</sup>) was significantly higher than the pool zone ( $12.2 \pm 6.2$  trees ha<sup>-1</sup>;  $p = .0065$ ), but there was no difference between buffer and matrix ( $28.8 \pm 5.1$  trees ha<sup>-1</sup>;  $p = 0.2351$ ) or matrix and pool zones ( $p = 0.1509$ ). Pool DDW class 1-4 volume ( $201.8 \pm$

56.1 m<sup>3</sup> ha<sup>-1</sup>) was higher than buffer (31.9 ± 5.3 m<sup>3</sup> ha<sup>-1</sup>; p < 0.0001) and matrix (62.0 ± 12.7 m<sup>3</sup> ha<sup>-1</sup>; p < 0.0001), although there was no difference between buffer and matrix zones (p = 0.4572). Class 5 DDW volume exhibited the same pattern, with the pool (117.8 ± 29.7 m<sup>3</sup> ha<sup>-1</sup>) showing higher amounts than buffer (21.6 ± 10.0 m<sup>3</sup> ha<sup>-1</sup>; p = 0.0011) and matrix zones (34.6 ± 17.5 m<sup>3</sup> ha<sup>-1</sup>; p = 0.0062). There was no difference in average DDW volumes between buffer and matrix zones (p = 0.8024).

#### 4.5.2.1. *Species richness, evenness, diversity, and importance values*

A total of 22 tree species were encountered within the 18 VPZs (Table 4-3). Using the NRCS (2012) northcentral and northeastern wetland indicator status, species were classified as one of three groups: facultative (FAC); facultative upland (FACU); or facultative wetland (FACW). The majority of species (63.6%) are considered FACU, with the balance evenly divided between FAC (18.2%) and FACW (18.2%). There were no obligate upland or obligate wetland tree species sampled.

There were no differences in richness, evenness, or diversity between classic and complex VPZs (p = 0.8149; p = 0.9674; p = 0.8384, respectively), or between LZ and IBZ ownerships (p = 0.7506; p = 0.0626; p = 0.3241, respectively). When we compared richness, evenness, and diversity between pool, buffer, and matrix, the only significant difference was buffer species richness (4.5 ± 0.4), which was greater than the pool zone (2.9 ± 0.5; p = 0.0193; Table 4-1).

Over 96% of the basal area and 95% of live tree stocking (dbh > 12.7 cm) were comprised of six species: *Acer saccharum*, *Acer rubrum*, *Fagus americana*, *Betula alleghaniensis*, *Betula papyrifera*, and *Tsuga canadensis*. Across all VPZs, *Acer saccharum* average IV was highest at  $122.5 \pm 7.9$ , followed by *Acer rubrum* ( $46.3 \pm 5.6$ ), *Fagus americana* ( $34.7 \pm 3.9$ ), *Betula alleghaniensis* ( $14.2 \pm 2.3$ ), *Tsuga canadensis* ( $5.6 \pm 1.3$ ), and *Betula papyrifera* ( $5.1 \pm 2.3$ ). The other 16 species combined had an average IV of  $14.6 \pm 3.1$ . Two patterns emerged when IV was separated among the vernal pool zones (Figure 4-3). The respective IV for *Acer saccharum*, *Fagus americana*, and *Betula papyrifera* decreased consistently when moving inward from the matrix to buffer to pool, while IV increased for *Acer rubrum*, *Betula alleghaniensis*, and *Tsuga canadensis* along this same distance-gradient. Significant differences in IV were found between matrix and buffer (*Acer saccharum*  $p = 0.0169$ ), buffer and pool (*Acer saccharum*  $p < 0.0001$ ; *Betula alleghaniensis*  $p = 0.0294$ ), and matrix and pool zones (*Acer saccharum*  $p < 0.0001$ ; *Acer rubrum*  $p = 0.0002$ ; *Betula alleghaniensis*  $p = 0.0012$ ). There were no significant differences in individual IV by zone for the following species: *Betula papyrifera*, *Fagus americana*, and *Tsuga canadensis*. No differences in average species IV were found between classic and complex vernal pools. Average *Betula alleghaniensis* IV in the IBZ ( $32.7 \pm 10.2$ ) was significantly higher than LZ ownership ( $11.8 \pm 2.2$ ;  $p = 0.0388$ ).

#### **4.5.3.      *Multidimensional analysis of species composition***



NMDS ordination of IV by vernal pool zones was best described by a two-dimension solution that explained 91.4% of the variation (Figure 4-4). The ordination had a final stress test of 13.15 and instability of 0.00, which is considered a reliable representation with a low risk of false inferences (McCune and Grace 2002). Axis 1, which explained 61.6% of the data variation, was most positively correlated with *Acer rubrum* ( $\tau = 0.572$ ), *Betula alleghaniensis* ( $\tau = 0.285$ ), *Tsuga canadensis* ( $\tau = 0.143$ ), the other 16 species ( $\tau = 0.311$ ), and pool area ( $\tau = 0.042$ ). This axis was most negatively correlated with *Acer saccharum* ( $\tau = -0.725$ ), *Fagus americana* ( $\tau = -0.404$ ), *Betula papyrifera* ( $\tau = -0.088$ ), and soil pH ( $\tau = -0.478$ ). The positive correlations with Axis 2 were *Acer rubrum* ( $\tau = 0.675$ ), *Fagus americana* ( $\tau = 0.175$ ), *Tsuga canadensis* ( $\tau = 0.159$ ), *Betula alleghaniensis* ( $\tau = 0.142$ ), *Betula papyrifera* ( $\tau = 0.131$ ), and pool area ( $\tau = 0.038$ ). Axis 2 was negatively correlated with *Acer saccharum* ( $\tau = -0.550$ ), the other 16 species ( $\tau = -0.012$ ), and soil pH ( $\tau = -0.112$ ). Figure 4-4 shows strong differentiation between pool, buffer, and matrix zones, although the separation between the buffer and matrix zones isn't as pronounced. *Acer rubrum*, *Betula alleghaniensis*, *Tsuga canadensis*, and the other 16 species are correlated with both buffer and pool zones, while *Acer saccharum*, *Fagus americana*, and *Betula papyrifera* are associated with matrix and buffer zones.

The MRPP procedure indicated a significant difference in IV between zones ( $p < 0.0001$ ,  $T = -15.01$ ,  $A = 0.197$ ), supported by ISA pairwise comparison of *Acer saccharum* and the matrix ( $p = 0.0002$ ). The ISA found no significance between *Fagus americana* and the matrix ( $p = 0.1064$ ), between *Acer rubrum* and pools ( $p = 0.1076$ ), *Betula*

*alleghaniensis* and pools ( $p = 0.2741$ ), *Betula papyrifera* and buffers ( $p = 0.3333$ ), and *Tsuga canadensis* and the buffer ( $p = 0.5735$ ).

## 4.6. Discussion

### 4.6.1. *Edaphic and habitat characteristics*

Average vernal pool surface area at Pictured Rocks (772.0 m<sup>2</sup> classic; 3059.0 m<sup>2</sup> complex; 1280.2 m<sup>2</sup> overall average) is similar to values reported for the northeastern USA (800 m<sup>2</sup>), although density (0.19 pool km<sup>-2</sup>) was lower than the reported frequency of 1.0-13.5 per km<sup>2</sup> (Brooks *et al.* 1998; Brooks and Hayashi 2002; Calhoun *et al.* 2003; Franci 2008). This lower density may have been a result of several factors. First, high omission rates may be associated with true-color aerial photography once the canopy contained a minimum of 10% conifer cover (Dr. Olson *pers. comm.* 2009). Second, the linear shape of Pictured Rocks may reflect a landscape system not particularly suitable to vernal pools (Figure 4-2). Lastly, our working definition for vernal pools may have been too restrictive as we eliminated any water feature within 152 m of wetlands, rivers, or lakes, or within 30.5 m of Lake Superior.

VPZs were predominately associated with well- to excessively-drained soils (series Kalkaska-Rubicon-Duel; Figure 4-2) and a poor- to medium-nutrient regime, best characterized by ATFD habitat type (Table 4-1; Burger and Kotar 2003; NRCS 2012).

This type of soil drainage class is consistent with other northeastern vernal pool studies (c.f. Colburn 2004). The ATFD was more commonly associated with the buffer zone (72.5%) than the more nutrient-rich AFOAs (21.6%), while the matrix zone was slightly more balanced (ATFD 56.5%; AFOAs 30.4%). A possible explanation may be the difficulty of using soil series designed for large-scale delineation and habitat typing on a fine scale (< 0.2 ha). Given the basin depression, it is unclear what soil characteristics (i.e., clay fragipan) may be potentially contributing to the ponding, and further investigation is warranted. If anoxic soils were present, this would suggest that seed germination is inhibited and seedling survivability is hindered. Additionally, higher amounts of soil carbon may indicate a longer hydroperiod, potentially limiting establishment (Resh *et al.* 2013). Though the ATFD has the lowest nutrient and soil moisture regime of *Acer saccharum* habitat types in the eastern Upper Peninsula, the extended hydroperiod regime of vernal pools provides variation to these well-drained soils. These qualities, plus the uncommon frequency within Pictured Rocks, make VPZs a unique localized feature within the landscape.

#### **4.6.2.      *Forest structure***

Seedling, sapling, live tree density, and live basal area were lowest in the pool zone (Table 4-2), which is probably attributed to the presence and depth of water. Standing dead density was higher in the buffer and matrix than the pool zone, reflecting mortality from competition due to higher densities in those zones. However, DDW volume (all

classes) was lowest in the buffer and highest in the pool zone. The following process may explain this pattern: 1) low stocking in the pool zone has a correspondingly low canopy cover, creating a canopy gap; 2) trees in the buffer zone grew into this gap, creating a bole with a lean angle and a crown with its volume and mass concentrated towards the gap area; 3) leaning trees along the buffer-pool boundary eventually die and subsequently fall into the pool zone, increasing all classes of DDW volume while removing this volume from the buffer zone; and 4) DDW decay rates are lower in the pool zone as a function of moisture.

#### 4.6.2.1. *Species richness, evenness, diversity, and importance values*

Species diversity and richness in the buffer was not significantly higher than either the pool or matrix zone, which did not support our first hypothesis (Table 4-1). It should be noted that the buffer zone average richness, evenness, and diversity were higher than the other two zones if the type 1 error was 10% ( $\alpha = 0.10$ ). Pool zone richness was lower than in the buffer and matrix, a likely function of ephemeral wetness of pool area that may prevent the survivorship of certain tree species.

Results from this study partially support our second hypothesis that importance values of *Betula alleghaniensis* and *Tsuga canadensis* will be higher in the buffer zone compared to pool or matrix zones. *Betula alleghaniensis* IV was higher in the pool than either buffer or matrix zones, although there was no difference in *Tsuga canadensis* IV among

the zones ( $p = 0.059$ ; Figure 4-3). However, Figure 4-3 demonstrates IV trends in the prominent species among the habitat management zones, with the post-hoc pairwise procedure (MRPP) indicating this was mostly attributed to *Acer saccharum*. The IV of *Betula alleghaniensis*, *Tsuga canadensis*, and *Acer rubrum* decrease with an increasing distance from the pool, while the IV of *Acer saccharum*, *Fagus americana*, and *Betula papyrifera* increase. There were also shifts in species relative IV rankings among the management zones. For example, within the matrix zone, *Acer saccharum* IV is nearly 600% greater than *Fagus americana*, but is only approximately three times greater within the buffer zone. Within the pool zone, *Acer rubrum* has the highest IV, with *Betula alleghaniensis* second and *Acer saccharum* third. *Tsuga canadensis* has the lowest matrix zone IV of the six prominent species, but, within both the pool and buffer zones, it has the fourth highest IV ranking. This ecological shift in importance of *Betula alleghaniensis* and *Tsuga canadensis* can be partially explained by the National Wetlands Inventory's wetland index (Table 4-3), a reduction in *Acer saccharum* competition, an increase in light availability associated with canopy gaps above the pool zone, seedbed quality, or some combination of these and other factors (Curtis and McIntosh 1951).

Results support our third hypothesis that diversity and richness are associated with vernal pool area (Figure 4-4). Over 86% of the species (*Acer rubrum*, *Betula alleghaniensis*, *Tsuga canadensis*, and 16 others) and pool area were positively correlated with Axis 1, which explained 61.6% of the data's variation. Vernal pools that have larger surface area will have a longer drying period, influencing the germination and survivability of certain

species (c.f., Colburn 2004; Calhoun and deMaynadier 2008). Additionally, vernal pools will have a greater perimeter, increasing the potential area of the buffer zone and the probability of these species occurring. *Acer saccharum*, *Fagus americana*, and *Betula papyrifera* tended to group with soil pH more so than pool area.

The management zones put forth by Calhoun and deMaynadier (2004) to protect pool-breeding amphibians also demonstrate that each zone has distinct and unique tree species assemblages and structures. Buffer zones represent a transition between the matrix and the pool, and may be areas where under-represented species (i.e., *Betula alleghaniensis* and *Tsuga canadensis*) take advantage of both increased light availability (i.e., lower stocking within the pool zone) and late-season water availability. Absent the link to other wetlands or riparian areas, this transition zone provides unique connectivity between vernal pools and upland forests. Vernal pools are species-rich and area-poor, functioning as important refugia for herpetofauna and other species of conservation concern. Forest management, regional climate change, and invasive species have great potential to negatively impact these fragile biological hotspots.

## **4.7. Management Implications**

Vernal pools occupy approximately 1% of the landscape, and the Calhoun and deMaynadier (2004) habitat management guide recommends 5.3 ha of modified forest management around each pool. However, these and other guidelines like BMPs are

focused on minimizing disruption to the vernal pool, forest floor, and canopy cover. The surrounding upland forest contributes to the uniqueness of these forest wetlands, and tree species importance values and pool surface area may be additional criteria to include in forest management plans. In this study, buffer zones had higher live tree densities and lower basal area than the matrix. Removing up to 25% of the tree canopy within the buffer zone (as suggested by Calhoun and deMaynadier 2004) would actually remove more trees per unit area than the matrix, potentially selecting against those trees that occur at lower frequencies on the landscape but at higher frequencies near vernal pools (i.e., *Betula alleghaniensis* and *Tsuga canadensis*). The composition of upland forests influences the richness, evenness, diversity, and juvenile behavior patterns of herptofauna (Degraff and Rudis 1990; deMaynadier and Hunter 1999). Maintaining tree diversity in these areas may further be key to increasing the adaptive capacity of forests to climate change (Duveneck *et al.* 2014). By acknowledging vernal pools and the surrounding forest as a critical landscape component, not only is protection afforded to known threatened and endangered fauna, but local and regional biodiversity may be conserved and ecosystems may be better able to adapt.

## **4.8. Acknowledgements**

Heartfelt appreciation to Bruce Leutscher and Lora Loope of Pictured Rocks National Lakeshore for their logistic support, comments, and sharing of information; Dr. Charles Olson of Michigan Tech Research Institute for aerial photography interpretation; Dr. Rod Chimner, Dr. Sigrid Resh, and Dr. Amy Schrank of Michigan Technological University for collaboration; Dr. Christopher Webster of Michigan Technological University for help with statistical analysis; Janet Marr for botanical identification; and Steve Miceli, Dan Hutchison, and Adrienne Bozic for field help. Funding was provided by the USDA McIntire-Stennis Cooperative Forestry Program and the School of Forest Resources and Environmental Science at Michigan Technological University.



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## 4.10. Figures and Tables

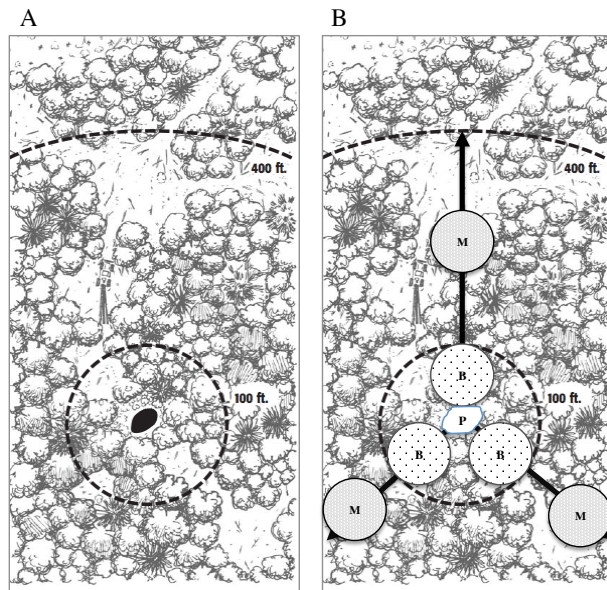


Figure 4-1: A) Calhoun and deMaynadier (2004; 2008) proposed vernal pool management zones. B) Sampling design of pool, buffer, and matrix zones at Pictured Rocks National Lakeshore, MI, USA. Pool zone (P) is the basin area, buffer zone (B) is 0-31 m from pool perimeter, and matrix zone (M) is 32-122 m from pool perimeter. Each buffer and matrix plot size was 0.08 ha with a radius of 15.96 m. Buffer zone plot centers were installed 16 m from pool perimeter. Matrix zone plot centers were randomly installed between 48 and 106 m from pool perimeter. Reprinted and modified by permission of the copyright holder: Dr. Michael W. Klemens, Metropolitan Conservation Alliance, POB 506, Salisbury, CT 06068. See Appendix D for documentation of permission to republish this material.

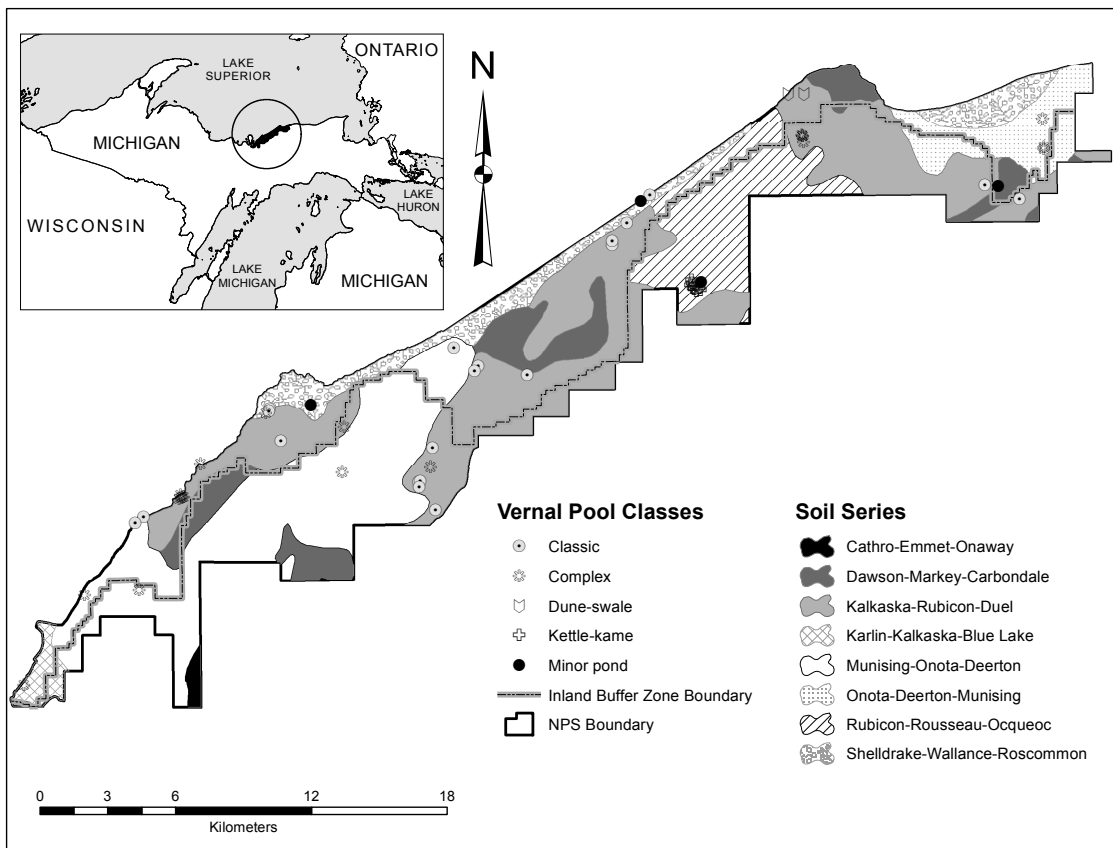


Figure 4-2: Vernal pool classes and soil series at Pictured Rocks National Lakeshore, MI, USA.



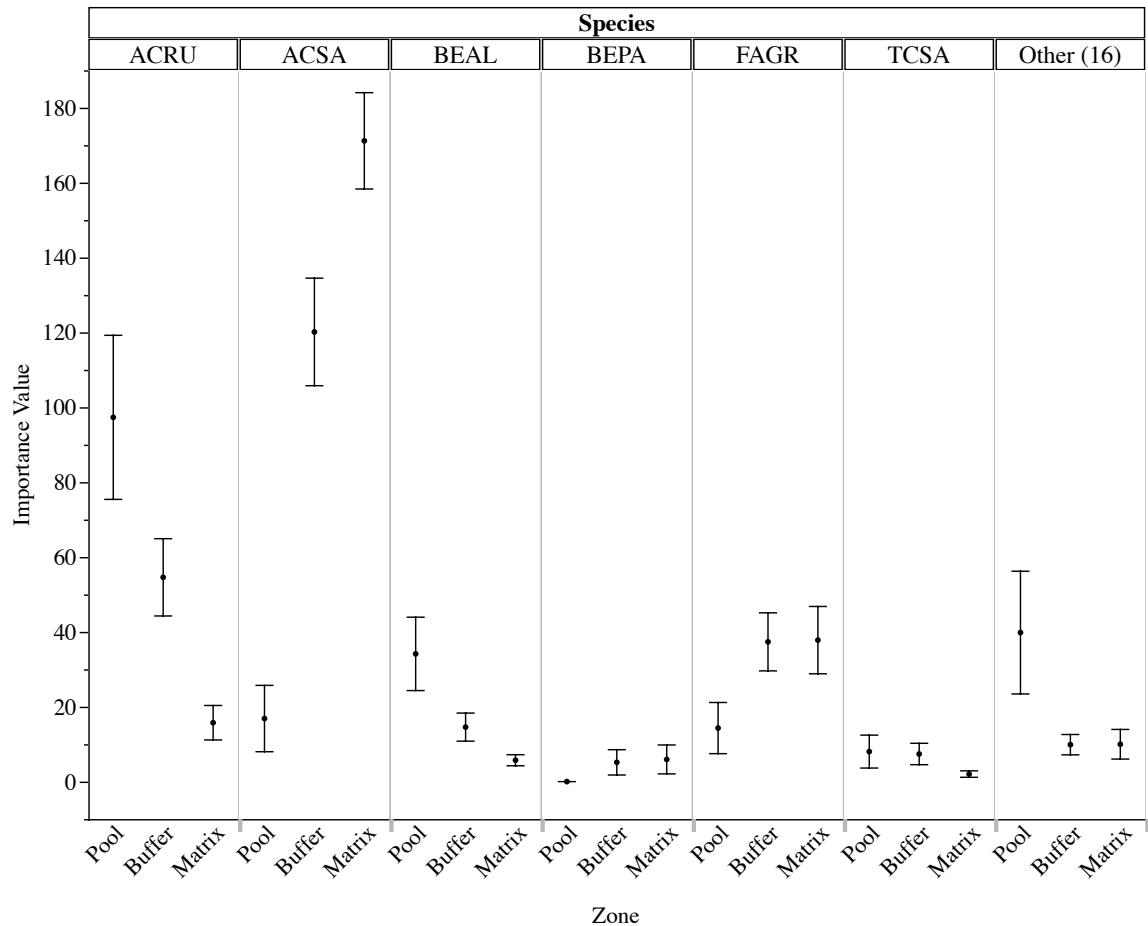


Figure 4-3: Mean importance values of six prominent species by vernal pool management zones at Pictured Rocks National Lakeshore, MI, USA. Importance values are the cumulative score of each species based upon relative dominance (basal area), relative frequency, and relative density. Maximum score is 300. Pool zone is the basin area, buffer zone is 0-31 m from pool perimeter, and matrix zone is 32-22 m from pool perimeter (Calhoun deMaynadier 2004; 2008). Error bars reflect one standard error of the mean. Acronyms are: ACRU (*Acer rubrum*), ACSA (*Acer saccharum*), BEAL (*Betula alleghaniensis*), BEPA (*Betula papyrifera*), FAGR (*Fagus grandifolia*), and TCSA (*Tsuga canadensis*). OTHER refers to 16 species that comprised less than 5% of the stocking (see Table 4-3).

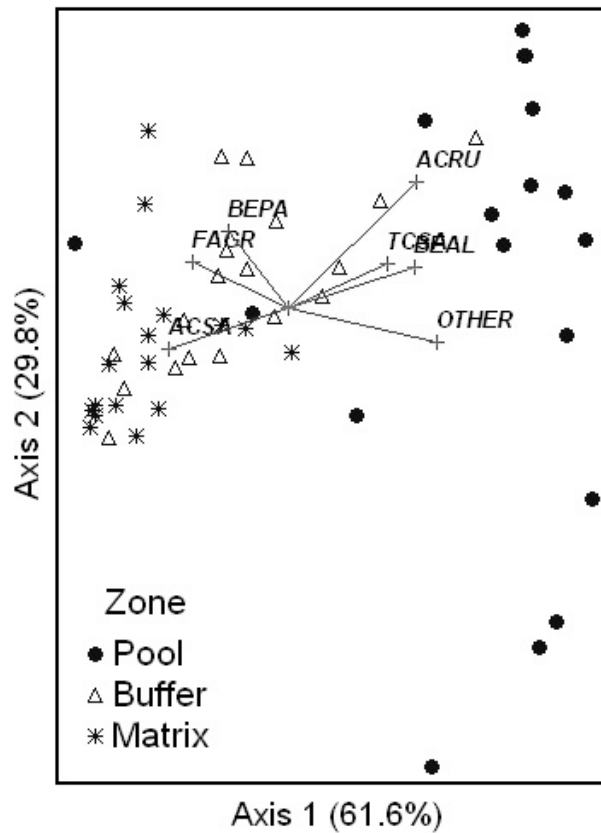


Figure 4-4: Nonmetric multidimensional scaling ordination for importance values (relative density, relative frequency, and relative dominance) of tree species in pool, buffer, and matrix management zones of vernal pools at Pictured Rocks National Lakeshore, MI, USA, as proposed by Calhoun and deMaynadier (2004; 2008). Axis 1-2 had a cumulative  $R^2$  of 0.914 (0.616 and 0.298, respectively) for pool, buffer, and matrix vernal pool zones. Acronyms are: ACRU (*Acer rubrum*), ACSA (*Acer saccharum*), BEAL (*Betula alleghaniensis*), BEPA (*Betula papyrifera*), FAGR (*Fagus grandifolia*), and TSCA (*Tsuga canadensis*). OTHER refers to 16 species that comprised less than 5% of the stocking (see Table 4-3).

Table 4-1: Relationship between vernal pool zones and soil pH within the top 10 cm; richness, evenness, and diversity of trees greater than 12.7 cm diameter at breast height; and community and habitat frequency at Pictured Rocks National Lakeshore, MI, USA. Letters that are different indicate significant differences between zones. Pool zone is the basin area, buffer zone is 0-31 m from pool perimeter, and matrix zone is 32-122 m from pool perimeter (Calhoun deMaynadier 2004; 2008). Acronyms are from Burger and Kotar (2003): AFTD (*Acer saccharum* - *Tsuga canadensis* - *Fagus grandifolia* / *Dryopteris spinulosa*); AFPO (*Acer saccharum* - *Tsuga canadensis* - *Fagus grandifolia* / *Polygonatum pubescens*); AFOAs (*Acer saccharum* - *Fagus grandifolia* / *Osmorhiza claytonii* – *Arisaema triphyllum*).

Vernal Pool Zone	Soil pH (± SE)	Richness (± SE)	Evenness (± SE)	Diversity (± SE)	Community and Habitat Type Frequency (%)		
					AFTD	AFPO	AFOAs
Pool	5.8 ± 0.1 <sup>A</sup>	2.9 ± 0.5 <sup>A</sup>	0.57 ± 10 <sup>A</sup>	0.71 ± 0.14 <sup>A</sup>	-	-	-
Buffer	6.0 ± 0.1 <sup>A</sup>	4.5 ± 0.4 <sup>B</sup>	0.69 ± 0.03 <sup>A</sup>	1.01 ± 0.08 <sup>A</sup>	72.50%	5.90%	21.60%
Matrix	6.1 ± 0.1 <sup>A</sup>	3.5 ± 0.5 <sup>AB</sup>	0.55 ± 0.04 <sup>A</sup>	0.68 ± 0.07 <sup>A</sup>	56.50%	13.00%	30.40%
Average	6.0 ± 0.1	3.6 ± 0.2	0.60 ± 0.04	0.08 ± 0.06	64.90%	9.30%	25.80%

Table 4-2: Basal area (BA), live and dead tree density (dbh greater than 12.7 cm), down dead wood (DDW) volumes by class, live seedling density of trees taller than 15.2 cm and less than 2.54 dbh, and live sapling density (dbh between 2.54 and 12.69 cm) at Pictured Rocks National Lakeshore, MI, USA. Letters that are different indicate significant differences between zones. Pool zone is the basin area, buffer zone is 0-31 m from pool perimeter, and matrix zone is 32-122 m from pool perimeter (Calhoun deMaynadier 2004; 2008).

Forest Structure	Vernal Pool Zone			
Variables	Pool	Buffer	Matrix	Average
Live BA (m <sup>2</sup> ha <sup>-1</sup> ± SE)	5.1 ± 1.2 <sup>A</sup>	27.4 ± 1.2 <sup>B</sup>	38.3 ± 1.8 <sup>C</sup>	23.6 ± 2.1
Snag BA (m <sup>2</sup> ha <sup>-1</sup> ± SE)	0.7 ± 0.4 <sup>A</sup>	2.5 ± 0.5 <sup>A</sup>	2.1 ± 0.6 <sup>A</sup>	1.8 ± 0.3
Live Density (trees ha <sup>-1</sup> ± SE)	105.0 ± 22.3 <sup>A</sup>	436.6 ± 18.9 <sup>B</sup>	406.0 ± 19.3 <sup>B</sup>	315.8 ± 23.5
Snag Density (trees ha <sup>-1</sup> ± SE)	12.2 ± 6.2 <sup>A</sup>	40.6 ± 6.7 <sup>B</sup>	28.8 ± 5.1 <sup>AB</sup>	27.2 ± 3.8
DDW Class 1-4 (m <sup>2</sup> ha <sup>-1</sup> ± SE)	201.8 ± 56.1 <sup>A</sup>	31.9 ± 5.3 <sup>B</sup>	62.0 ± 12.7 <sup>B</sup>	98.6 ± 21.4
DDW Class 5 (m <sup>2</sup> ha <sup>-1</sup> ± SE)	117.8 ± 29.7 <sup>A</sup>	21.6 ± 10.0 <sup>B</sup>	35.7 ± 17.5 <sup>B</sup>	58.4 ± 13.1
Seedling Density (trees ha <sup>-1</sup> ± SE)	905.2 ± 623.9 <sup>A</sup>	19,257.0 ± 3,044.4 <sup>B</sup>	15,889.0 ± 4437.6 <sup>B</sup>	12,015.1 ± 2082.8
Sapling Density (trees ha <sup>-1</sup> ± SE)	246.9 ± 179.6 <sup>A</sup>	2,180.8 ± 433.7 <sup>B</sup>	1,440.2 ± 335.9 <sup>B</sup>	1,289.2 ± 218.2

Table 4-3: Tree species classified by wetland indicator status at Pictured Rocks National Lakeshore, MI, USA (NRCS 2012). Facultative species are designated as hydrophytes and occur in both wetlands and non-wetlands. Facultative wetland species are also hydrophytes and usually occur in wetlands and occasionally in non-wetlands. Facultative upland species are nonhydrophyte and usually occur in non-wetlands and occasionally in wetlands.

Facultative (FAC)	Facultative Wetland (FACW)	Facultative Upland (FACU)	
<i>Abies balsamea</i>	<i>Fraxinus nigra</i>	<i>Acer saccharum</i>	<i>Pinus strobus</i>
<i>Acer rubrum</i>	<i>Picea mariana</i>	<i>Betula papyrifera</i>	<i>Populus grandidentata</i>
<i>Betula alleghaniensis</i>	<i>Thuja occidentalis</i>	<i>Fagus grandifolia</i>	<i>Populus tremuloides</i>
<i>Sorbus americana</i>	<i>Ulmaceae americana</i>	<i>Acer pensylvanicum</i>	<i>Prunus pensylvanica</i>
		<i>Fraxinus americana</i>	<i>Prunus serotina</i>
		<i>Ostrya virginiana</i>	<i>Tilia americana</i>
		<i>Picea glauca</i>	<i>Tsuga canadensis</i>

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# Appendix C: Chapter 3 trespass email and police report.

FORM 10-343

## UNITED STATES DEPARTMENT OF THE INTERIOR NATIONAL PARK SERVICE

### CASE INCIDENT RECORD

1. ORGANIZATION CODE 6320		2. ORGANIZATIONAL (PARK) NAME Pictured Rocks National Lakeshore		3. LOCATION CODE 0270		4. CASE / INCIDENT NUMBER 09-117	
5. LOCATION OF INCIDENT Inland Buffer Zone – Private property (Coggins Property)				6. DATE OCCURRED 07/22/2009		7. TIME OCCURRED 1530 approx	
8. DAY OF WEEK Wednesday							
9. OFFENSE INCIDENT CODE 33-20-00 / 02-20-00		10. NATURE OF INCIDENT Threatening email resulting from researcher trespass on private property				11. HOW REPORTED Email / phone	
12. REPORTED BY Lora Loope		13. ADDRESS P.O. Box 40, Munising, MI 49862				14. HOME PHONE 906-387-2680	
15. RECEIVED BY Tim Colyer		16. DATE RECEIVED 07/23/2009		17. TIME BROADCAST n/a		18. WHEN INVESTIGATED - DATE / TIME 07/23/09 1400	
19. INVESTIGATED BY Tim Colyer				20. COMMISSION NUMBER 142		21. WHEN CLEARED 1800	
22. DISPOSITION Closed							
23. INVOLVED PERSONS		24. ADDRESS		25. PHONE		26. SEX	
27. RACE		28. AGE		29. DATE OF BIRTH			
1	Steve Miceli	MTU			M	W	---
2	John Coggins				M		
3	Wilf Previant	MTU			M	W	---
4	Lora Loope	P.O. Box 40, Munising			F	W	---
29. DETAILS OF INCIDENT							
<p>On Thursday July 23, 2009 at approximately 1115 I received a call from Lora LOOPE on my cell phone. LOOPE advised that she had been contacted by Sherry STANLEY, a professor at Michigan State University, regarding a very threatening email she had received regarding researchers trespassing on private property. STANLEY stated she did not have any researchers working in the area but forwarded the message to LOOPE because she was concerned for the safety of other researchers in the area due to the very threatening tone of the email. (The entire thread of emails including the original message from the property owner is listed at the bottom of this report.)</p> <p>The email claims that a researcher walked onto private property owned by John Coggins of *****. COGGINS states in his letter that his property is heavily posted and that someone may get hurt if they come on to his property because he shoots guns on his property. COGGINS requested someone to contact him and ended his correspondence with, "It may save a life." LOOPE advised that she has not yet been able to determine what researcher was involved in the incident but that she had determined that it was Michigan Tech, not Michigan State University that had a research permit for vernal ponds in the area. LOOPE stated she would continue to try to contact the researcher. LOOPE is an Aquatic Ecologist with the Lakeshore and is the National Park Service point of contact for the research permit issued for this project.</p> <p>LOOPE forwarded the threatening message to me which I received via Blackberry. I studied the content of the letter and found it to have a very threatening tone and offensive language. Despite the threatening tone there was no specific threat to any individual or reference to a specific act of violence. COGGINS referenced shooting weapons on his property and implied that he could not be held responsible for anything that may happen to persons who are there illegally. I did not view it as an imminent threat to safety but felt that keeping any additional researchers well clear of the area would be a prudent response until the issue could be sorted out. LOOPE had already spoken with advisors at Michigan Tech to ensure that would happen.</p> <p>I was unable to turn up any evidence of prior incidents on the property or with COGGINS. No park staff or local law enforcement were aware of any problems or issues that may precipitate such a hostile response from the property owner.</p> <p>LOOPE contacted me again at approximately 1530 hours and stated that she was in contact with the researcher who had encountered COGGINS and his project supervisor. I met with LOOPE, acting superintendent Chris CASE, researcher Steve MICELI, and project lead, Wilf Previant. MICELI was the researcher who encountered COGGINS on his property on July 22 at approximately 1530 – 1600 hours. He was by himself at the time of the contact and no other researchers were in the area.</p>							
31. QUANTITY		32. PROPERTY STOLEN OR DAMAGED		33. ESTIMATED VALUE		34. IF RECOVERED LIST DATE AND VALUE	
35. PROPERTY CODE OF HIGHEST VALUE *		36. TOTAL		37. TOTAL			
INVESTIGATED BY (SIGNATURE AND DATE)				APPROVED BY (SIGNATURE AND DATE)			
							



SUPPLEMENTAL CASE / INCIDENT RECORD

ORGANIZATIONAL (PARK) NAME <b>Pictured Rocks National Lakeshore</b>	CASE INCIDENT NUMBER 09-117
LOCATION OF INCIDENT <b>Inland Buffer Zone – Coggins Property near Shoe Lake</b>	DATE OF INCIDENT July 22, 2009
NATURE OF INCIDENT <b>Trespass on Private Property / Threatening email</b>	

I asked MICELI and PREVIANT what their roles were with the research project and how they were involved in this incident. Both are students at Michigan Tech. The vernal pool research project is PREVIANT's project. He orchestrates the research being done and provides oversight to other researchers working on the project. He was not present on July 22 when MICELI encountered COGGINS.

MICELI takes his project assignments directly from PREVIANT. They showed me a copy of Scientific Research and Collection Permit #PIRO-2009-SCI-0001 which had been issued to Rod CHIMNER by Lora LOOPE. CHIMNER is a professor at Michigan Tech University.

PREVIANT and MICELI both state they are absolutely aware that they are not allowed to function on private property unless they have the expressed consent of the property owner. They did not have permission or any other contact with COGGINS prior to July 22, 2009. Private land is not referenced in the permit but PREVIANT and MICELI stated that it was made abundantly clear to them by LOOPE, their professors, and Bruce LEUTSCHER the acting chief of the Science and Natural Resources division at the Lakeshore. They state they make every effort to stay clear of private property but MICELI did not have a copy of the property owner plat map with him while doing his research. He knew there was private property in the vicinity. LOOPE claimed responsibility for not making sure the researchers had a plat map with them.

MICELI stated that on July 22, 2009 at approximately 1530 hours he was walking along a two-track road in the Inland Buffer Zone (IBZ) near COGGINS property. He remembered seeing one No Trespassing sign but stated that he was walking parallel with the direction the sign was facing and did not believe he crossed the posted property line. Shortly thereafter, he heard someone chopping wood and saw a structure. MICELI recognized that he was wearing dark clothing and decided it would be prudent for him to approach the individual and identify himself and his purpose for being there. This contact was aimed at preventing the individual from seeing someone in dark clothing lurking in the woods and becoming alarmed. MICELI stated that he walked towards the noise and saw a man standing in his garage. He called out to the man and was not heard. He called out again and states that the man turned around and spoke with him. MICELI identified himself, explained that he was a student from Michigan Tech, showed him a map of the project and where he was headed, and explained that no research or collection was being done on his property. He said his contact with the man was very pleasant and that there was no hostility whatsoever. The man gave him directions to get out to H-58 (the nearest county road) and said goodbye. MICELI stated that at no time did he feel threatened or feel that the man was upset by his presence. MICELI left the property using the directions the man had

SUBMITTED BY (SIGNATURE AND DATE) <i>Timothy F. Calver</i>	APPROVED BY (SIGNATURE AND DATE)
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SUPPLEMENTAL CASE / INCIDENT RECORD

ORGANIZATIONAL (PARK) NAME <b>Pictured Rocks National Lakeshore</b>	CASE INCIDENT NUMBER 09-117
LOCATION OF INCIDENT <b>Inland Buffer Zone – Coggins Property near Shoe Lake</b>	DATE OF INCIDENT July 22, 2009
NATURE OF INCIDENT <b>Trespass on Private Property / Threatening email</b>	

provided him and never crossed the property again. MICELI felt that it was a good, proactive contact made to alleviate and concerns of park neighbors. At the time of my interview with MICELI he had not yet read the email or been told of its contents. He only knew that a complaint had been made and that the landowner was very upset. Initially MICELI felt that it had to have been a different researcher because his contact with COGGINS was so pleasant he couldn't imagine a complaint having come from it. Using a plat map, MICELI confirmed that it was COGGINS' property that he was on.

I contacted John Coggins via \*\*\*-\*\*\*-\*\*\*\* at 1730 hours on 07/23/09. I introduced myself as the chief ranger of Pictured Rocks National Lakeshore and stated that I was following up on a trespassing complaint. COGGINS seemed genuinely surprised to hear from me. He asked how I got involved with the situation. COGGINS stated, "Really this is none of your business, I have no complaint with the park. What I have a problem with is these college kid's supervisors sending them out to do research projects and leaving them under the impression that they can just disregard trespassing signs and wander around on private property like they have a right to be there. COGGINS reiterated several times that his only complaint was with whomever the researcher's supervisor was and he intended to pursue the situation until he found out. I explained that I could help with that because I had spent the afternoon investigating it.

I offered to meet with COGGINS in person and informed him that the researcher involved, his supervisor, and the Lakeshore's point of contact would all be happy to meet with him and discuss the incident and offer their apologies for the trespass situation. COGGINS stated that he appreciated the offer but felt that it was unnecessary because it "would just take more of his time."

I explained to COGGINS that the researcher did not feel that he had crossed a posted line and that the intent of his contact was to prevent such a complaint, not to create one. COGGINS argued that there was no way he couldn't have crossed his property line because he was right next to his garage. I acknowledged that and reiterated that the researcher's intent was to reach out and that he was shocked and upset to learn that he had created a problem.

COGGINS stated that he was sorry I had to get involved and that he felt that the incident was over. He just wanted the researchers and their supervisors to know they had to respect private property and he felt that had been accomplished. COGGINS thanked me for my time and prepared to hang up but I told him I had some concerns with the threatening email he had sent.

SUBMITTED BY (SIGNATURE AND DATE) <i>Timothy F. Calver</i>	APPROVED BY (SIGNATURE AND DATE)
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SUPPLEMENTAL CASE / INCIDENT RECORD

ORGANIZATIONAL (PARK) NAME <b>Pictured Rocks National Lakeshore</b>	CASE INCIDENT NUMBER 09-117
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COGGINS immediately defended his email stating, "We could debate all day whether that's a threat or not and could even read about it in the paper someday if it comes to that but I didn't threaten anybody." I told COGGINS that I understood his perspective because no specific threat was ever made against anybody but felt that he could not deny the letter had a very threatening tone and used very offensive language. I also explained that the professors at Michigan State University forwarded the message to our agency because they felt there was a very clear threat to the safety of their researchers or any other researchers in the area.

COGGINS stated that no one was ever in any danger because he is "not a gun nut." He stated he used the harsh language because he felt that it was the only way he could get their attention and get a response, adding, "And it worked." He explained that he never said he was going to shoot or shoot at anybody. He simply stated that he shoots on his property sometimes and if someone was walking on his property that he was unaware of, they could be hurt.

I expressed my concerns that posting his property does not relieve him of responsibility of any harm that may come from the discharge of a firearm. I offered my contact information and asked that in the future he contact me directly if he has any complaints, concerns, or other questions. I also told him that I thought correspondence would be more productive without the threatening tone and vulgarity.

COGGINS again thanked me for my time and seemed to sincerely appreciate the contact. The conversation ended very cordially and I believe that the incident is resolved. I am not confident that COGGINS sees the problem with using threatening letters to get attention but I do not feel he is a threat. He seems like an otherwise nice and reasonable man with a very hot-button topic, that of privacy and private property rights.

I followed up with LOOPE and briefed her on the outcome of the call. I asked her make sure all researchers were reminded about staying clear of private property unless they had the permission of the owner. I also asked that she add that restriction to future research and collection permits issued by the Lakeshore.

The following 2 pages contain the thread of emails I received regarding the threatening message sent by COGGINS.

SUBMITTED BY (SIGNATURE AND DATE) <i>Timothy F. Calver</i>	APPROVED BY (SIGNATURE AND DATE)
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U. S. DEPARTMENT OF THE INTERIOR  
NATIONAL PARK SERVICE  
SUPPLEMENTAL CASE / INCIDENT RECORD

ORGANIZATIONAL (PARK) NAME <b>Pictured Rocks National Lakeshore</b>	CASE INCIDENT NUMBER 09-117
LOCATION OF INCIDENT <b>Inland Buffer Zone – Coggins Property near Shoe Lake</b>	DATE OF INCIDENT July 22, 2009
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**Bruce  
Leutscher/PIRO/NPS**  
07/23/2009 10:39 AM

To Tim Colyer/PIRO/NPS@NPS, Jim Northup/PIRO/NPS@NPS,  
Chris Case/PIRO/NPS@NPS  
cc Lora Loope/PIRO/NPS@NPS  
Subj Fw: trespassers 7-22-09  
ect

Please see the threatening email below. Sherry Stanley, from MI State Univ. called me today and then forwarded this email.

Our current thinking is that the researcher in this case was actually from MI Tech. Univ. as they are working on a vernal pools project. Contrary to the email below the researchers are well aware that there is private land in the IBZ and they do not have permission to work on those parcels. Lora and/or I will be contacting MTU researchers immediately to determine if they are involved and rectify the situation if they don't include avoiding private property in their daily planning.

TC, please let me know what follow up to this threat must take place.

Thank you,

Bruce Leutscher, Biologist  
Pictured Rocks National Lakeshore  
P.O. Box 40 Munising, MI 49862  
Office (906) 387-2680  
Cell (906) 202-0100  
Fax (906) 387-2029  
bruce\_leutscher@nps.gov

----- Forwarded by Bruce Leutscher/PIRO/NPS on 07/23/2009 10:31 AM -----

"Stanley, Sherry"  
<stanle80@ora.msu.edu>  
07/23/2009 10:19 AM

To <bruce\_leutscher@nps.gov>  
cc  
Subj FW: trespassers 7-22-09  
ect

Hi Bruce,

Thanks for your help.

SUBMITTED BY (SIGNATURE AND DATE) <i>Timothy F. Colyer</i>	APPROVED BY (SIGNATURE AND DATE)
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SUPPLEMENTAL CASE / INCIDENT RECORD

ORGANIZATIONAL (PARK) NAME <b>Pictured Rocks National Lakeshore</b>	CASE INCIDENT NUMBER 09-117
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Best Regards,

Sherry Stanley  
Michigan State University  
Office of Regulatory Affairs  
517-432-4501  
[Stanle80@msu.edu](mailto:Stanle80@msu.edu)

**From:** Diane [mailto:\*\*\*\*\*@jamadots.com]  
**Sent:** Thursday, July 23, 2009 8:38 AM  
**To:** ora@msu.edu  
**Subject:** trespassers 7-22-09

On 7-22-09 I was standing in my garage in the middle of my private 30, posted acres when one of your researchers suddenly appeared. He had come out of the woods walking right by my house where my wife was laying in bed reading. He said he was a researcher from MSU looking for wet spots in the Pictured Rocks area. He stated he had just walked from my neighbor's camp where several burglaries have occurred and didn't know it was private. My property is heavily posted. I want to know who his supervisor is and I will go to great lengths to find out. First of all he was trespassing. He could have been injured as I do shoot my guns on occasion on my own private property. Thirdly his bosses did not tell him there is an abundance of private land in the area of Shoe Lake nor provide him with a plat map. When someone shows up like he did they could be hurt real easily. Next time I will deal with it differently and you will be responsible. I don't expect to hear from anyone as I know how you assholes work. Head in the sand, it's only a researcher. Don't blame me if something else happens when I protect my property from assholes like you. Call me and we will discuss this or else. If I am at the wrong place please pass this on to whoever is in charge of the research program in Pictured Rocks. It may save a life. John Coggins 906 452 6352

SUBMITTED BY (SIGNATURE AND DATE) <i>Timothy F. Coggins</i>	APPROVED BY (SIGNATURE AND DATE)
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## Appendix D: Figure 4-1 permission from copyright holder Dr. Michael W. Klemens and Metropolitan Conservation Alliance (2014).



Wilfred Previant <wjprevia@mtu.edu>

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### Permission to use figure

4 messages

Wilfred Previant <wjprevia@mtu.edu>  
To: fenbois@aol.com

Wed, Feb 5, 2014 at 4:03 PM

Dear Michael Klemens,

My name is Wilfred Previant, a PhD candidate at Michigan Tech University. I am preparing a manuscript for publication in the journal *Wetlands* investigating the association between vernal pools and forest structure and diversity. As part of my field sampling techniques, I used the recommended guidelines regarding forest management activity around a vernal pool. This figure was used by Calhoun and deMaynadier (2004; 2008; citations below) and was illustrated by M. McCollough. I have also attached the figure.

I have exchanged emails with Dr. Calhoun and Dr. deMaynadier regarding permission, and they indicated the copyright owner is MCA (Metropolitan Conservation Alliance). If this is correct, please indicate what information I need to provide to formally request permission.

Thank you for your time and assistance in this matter.

Sincerely,

Wilfred

#### Citations:

*Figure 3 on page 15*

Calhoun AJK, deMaynadier PG (2004) Forestry habitat management guidelines for vernal pool wildlife. MCA Technical Paper No. 6, Metropolitan Conservation Alliance, Wildlife Conservation Society, Bronx, New York.

*Referenced in Chapter 13*

Calhoun AJK, deMaynadier PG (2008). Science and conservation of vernal pools in northeastern North America. CRC Press, Boca Raton, FL.

-----  
Wilfred Previant  
Ph.D. Candidate in Forest Science

Forest Resources and Environmental Science  
Michigan Technological University

1400 Townsend Drive  
Houghton, MI 49931

(906) 869-7021  
[wjprevia@mtu.edu](mailto:wjprevia@mtu.edu)

---

**fenbois@aol.com** <fenbois@aol.com>

Wed, Feb 5, 2014 at 4:40  
PM

To: [wjprevia@mtu.edu](mailto:wjprevia@mtu.edu)  
Cc: [Calhoun@maine.edu](mailto:Calhoun@maine.edu)

Dear Wilfred Previant:

the acknowledgement should read as follows please...

"reprinted by permission of the copyright holder: Dr. Michael W.  
Klemens, Metropolitan Conservation Alliance, POB 506, Salisbury CT  
06068"

the Journal may require some additional forms which I would be willing  
to sign as required..please advise me if that is necessary.

*thank you for your courtesy in requesting permission , I would  
appreciate a copy of the Journal article for MCA's files.*

**Wilfred Previant** <[wjprevia@mtu.edu](mailto:wjprevia@mtu.edu)>  
To: [fenbois@aol.com](mailto:fenbois@aol.com)

Thu, Feb 6, 2014 at 9:37 AM

Dear Dr. Klemens,

Thank you for approving this request. The figure will be attributed as indicated.  
Wetlands does not require any forms, just "evidence that such permission has  
been granted". Unless you have an objection, I will use this email exchange as a  
supporting document.

Upon publication, I will provide a copy for MCA.

Again, thank you for your help!

Sincerely,  
Wilfred