Identification and Management of Natural Red Pine in the Central Upper Peninsula of Michigan

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We collectively acknowledge that Michigan State University occupies the ancestral, traditional, and contemporary Lands of the Anishinaabeg – Three Fires Confederacy of Ojibwe, Odawa, and Potawatomi peoples. In particular, the University resides on Land ceded in the 1819 Treaty of Saginaw. We recognize, support, and advocate for the sovereignty of Michigan's twelve federally recognized Indian nations, for historic Indigenous communities in Michigan, for Indigenous individuals and communities who live here now, and for those who were forcibly removed from their Homelands. By offering this Land Acknowledgement, we affirm Indigenous sovereignty and will work to hold Michigan State University more accountable to the needs of American Indian and Indigenous peoples.

We also acknowledge that Indigenous Peoples and their cultural practices were, and are, integral parts of Michigan's ecosystems.

Cover Photo: Dry northern forest along the south shore of Lake Superior east of Grand Marais. Photo by Jesse M. Lincoln.

ACKNOWLEDGEMENTS

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MNFI ecologist Jesse Lincoln observing a red pine

EXECUTIVE SUMMARY

Red pine is a tree of ecological, economic, and cultural importance in Michigan but has declined significantly in recent years. Naturally regenerated red pine has become particularly rare and is threatened by plantation-style management, fire suppression, and changing climate. In a 2004 report, the Michigan DNR identified holistic red pine management for ecological and economic objectives as a high priority, including use of prescribed fire to maintain and enhance red pine.

In 2023, the Michigan DNR commissioned Michigan Natural Features Inventory (MNFI) to conduct field surveys of natural red pine stands in the Newberry and Shingleton Forest Management Units in the Central Upper Peninsula. MNFI ecologists assessed the condition of natural red pine in the region by targeting late successional stands with potential for landscape-scale management.

Four areas that met criteria for new element occurrences (outstanding examples of the community type) of dry northern forest and one update of an existing occurrence of dry northern forest were added to the Michigan Natural Heritage Database. All of the natural red pine stands surveyed showed evidence of historic fire, such as scars and charred stumps, indicating fire was an ecological process that shaped their development. The highest quality natural pine stands documented during this project occurred along the south shoreline of Lake Superior and had higher plant diversity, older trees, and a less intensive management history than lower-quality pine stands. Red pine >150 years old were rare on the landscape and those that were found were not well documented in existing Michigan Forest Inventory notes. These older age classes appear to be much lower in abundance compared to pre-logging era pine forests based on General Land Office notes. Past and current management of natural red pine was prevalent and was associated with degradation of pine stands through fragmentation and loss of biodiversity, particularly loss of culturally important species such as huckleberry. Natural red pine regeneration was very rare and localized and mesophication of understories due to protracted fire suppression was common.

Conservation priority areas centered around the highest-quality red pine stands along Lake Superior are recommended to maintain and enhance red pine into the future. Maintaining old trees, protecting ground layer diversity, and maintaining large blocks of forest with no harvest in these areas is recommended. These areas also merit consideration as Ecological Reference Areas. We also recommend this management approach be used in and around other element occurrences of dry northern forest in the Newberry and Shingleton Forest Management Units that were not surveyed during this project. In addition, project areas centered around recoverable natural pine stands could be used to maintain and expand red pine cover through prescribed fire and limited timber harvest. The Muskrat Lake dry northern forest element occurrence in the Newberry Forest Management Unit, which burned in a 2012 wildfire and was subsequently thinned, is a helpful model for management of recoverable pine stands that meets both ecological and economic objectives.

We recommend systematic surveys of natural pine stands to identify the highest-quality reference areas of dry and dry-mesic northern forest in the state. High quality stands should be protected from harvest and managed in a way that replicates natural disturbance, particularly through fire, to enhance their ecological and cultural value

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INTRODUCTION

Red pine (*Pinus resinosa*) is one of the dominant trees of dry northern forest and dry-mesic northern forest in the Great Lakes Region, occupying a relatively small geographic range centered around 45 degrees N latitude (Fig. 1) (Little and Viereck 1971; Burns and Honkala 1990). The Upper Peninsula and Northern Lower Peninsula of Michigan are within the core range of red pine with red pine-dominated natural communities historically covering about 1.05 million ha (2.6 million acres) in the state (Comer et al. 1995). Red pine is a tree of cultural significance for Indigenous Peoples and remains important ecologically, culturally, and economically. Despite its value, the amount of natural red pine on the landscape throughout Michigan and the Great Lakes Region has declined by an estimated 87 percent from historic levels (Gilmore and Palik 2006). The loss of natural red pine, the prevalence of plantation management, and aging of existing stands planted in the 1930s, has spurred efforts to better understand how to manage red pine on State of Michigan lands to achieve both economic and ecological objectives and ensure the persistence of resilient and diverse red pine stands (Bielecki et al. 2004).

There are over 1,618,000 ha (four million acres) of State Forest across the Upper Peninsula and Northern Lower Peninsula of Michigan. State Forests are jointly managed by the Forest Resources Division (FRD) and Wildlife Division (WLD) of the Michigan Department of Natural Resources (DNR) for long-term forest health, sustainable forest products, wildlife habitat, recreational opportunities, and ecosystem services. The FRD and WLD are responsible for assuring that management activities do not harm threatened and endangered species. Through dual forest certification, the DNR maintains a network of Ecological Reference Areas composed of high-quality and representative natural communities. Michigan Natural Features Inventory (MNFI) maintains a geospatial database of populations of rare and declining plants and animals and benchmark natural communities. In 2023, the DNR contracted MNFI to identify areas of interest for management and conservation of natural red pine in the Newberry and Shingleton Forest Management Units (FMUs) in the Central Upper Peninsula.

Background

The Newberry and Shingleton FMUs are in the Grand Marais Sandy End Moraine and Outwash sub-subsections of the Central Upper Peninsula, extending to a lesser extent into the Seney Sand Lake Plain, and occupy 314,035 ha (776,000 acres) and 511,120 ha (1,263,000 acres), respectively (Fig. 2) (Albert 1995). The landscape of these FMUs was shaped by the most recent Wisconsinan glaciation. The Laurentide ice sheet retreated from the Central Upper Peninsula approximately 10,000 years BP and subsequent increases in Great Lakes water levels and variations in climate created a landscape characterized by lakeplain, moraines and glacial

Figure 1. The range of red pine (*Pinus resinosa*) encompasses the Upper Peninsula and Northern two-thirds of the Lower Peninsula of Michigan. Map adapted from Little and Viereck 1971.

ejection ridges, outwash plains, and sand dunes. An important natural feature of the region, sand dunes developed along Great Lakes shorelines from wind and fluctuating water levels, and also inland from wind-driven sands during historical periods of warm and dry climate (Schaetzl et al. 2021). In the present landscape, inland dunes, or transverse dune ridges, have often become forested “islands” surrounded by muskeg, bog, fen, and other peatland types that developed in the surrounding lower and poorly-drained lakeplain and outwash plain (Albert 2000). Soils covering a large area of the Central Upper Peninsula developed on lacustrine and outwash sands and are acidic and low in nutrient availability, which has influenced the development of plant communities of the region.

Pollen records from the Central Upper Peninsula suggest a pine-dominated landscape established as early as 8,500 years BP. Lake sediment cores from Tower Lake (about 15 km south of Grand Marais in Alger County) found that pine species accounted for 50 to 75% of the pollen and that red pine needles were frequent in the sediment deposited from 6,500 to 7,500 years BP (Jackson et al. 2013). Pollen records suggest subsequent shifts in vegetation in the surrounding landscape depending on variations in climate and the arrival of tree species new to the region, such as hemlock (*Tsuga canadensis*) and American beech (*Fagus grandifolia*), followed by a stabilization of tree composition similar to the present beginning about 3,000 years BP (Davis 1983).

Ecological processes, including fire, also played a major role in the development of forests in Northern Michigan. Severe or catastrophic crown fires had high enough heat to kill most trees and other vegetation in the areas they burned (Heinselman 1973; Flannigan and Bergeron 1998). These fires are estimated to have occurred with a frequency of between 100 to 320 years in pine-dominated forests in Michigan. Zhang et al. estimated a return interval of approximately 320 years for stand-replacing fires in red pine-white pine stands and 163 years for mixed pine stands in the Eastern Upper Peninsula (1999). In the Northern Lower Peninsula Cleland et al. estimated

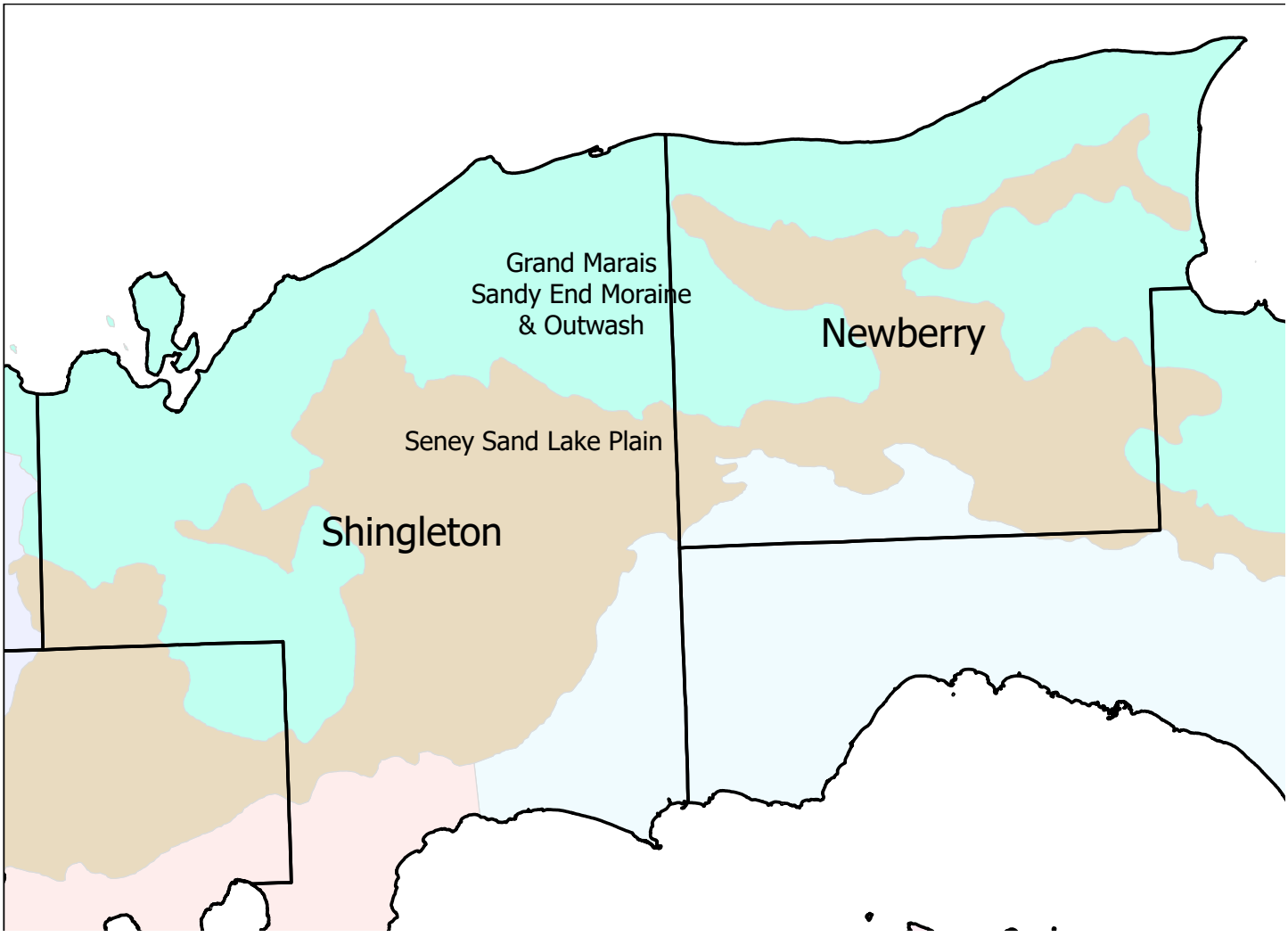

Figure 2. Michigan ecoregions and state forest management units show the location of the Newberry and Shingleton Forest Management Units in the Grand Marais Sandy End Moraine and Outwash and Seney Sand Lake Plain sub-subsections (green and brown) (Albert 1995). Sandy soils are common in the region.

a fire rotation period of 107 years for the red pine-white pine community type (2004) and Whitney estimated severe crown fires occurred every 120 years in red pine-jack pine-white pine stands (1986). Severe fires favored the initiation of pine forests in burned areas where red pine and jack pine (*Pinus banksiana*) could regenerate on exposed mineral soils in full sun and with little competition. In the Great Lakes Region lower-intensity surface fires occurred at higher frequency in pine forests around every five to 20 years. This fire regime caused high mortality of jack pine and red pine seedlings while promoting the persistence of fire-adapted understory vegetation (Heinselman 1973; Cohen 2002).

During land surveys conducted by the General Land Office (GLO) in 1840-1856, burned forests were noted in the Central Upper Peninsula. The surveys found approximately 21,259 ha of burned lands in the Luce District, which encompasses the Newberry and Shingleton FMUs. The patch size of burned areas ranged from 11.6 to 3,000 ha (Zhang et al. 1999). Reconstruction of vegetation cover around the year 1800 using GLO survey data shows pine-dominated forests were common in the Newberry and Shingleton FMUs (Fig. 3). 1800 Land Cover maps created from GLO data show that approximately 15,497 ha (38,295 acres) of the Newberry FMU was white pine-red pine forest and 31,226 ha (77,162 acres) of the Shingleton FMU was white pine-red pine forest (Comer et al. 1995). The jack pine-red pine forest cover type accounted for 23,531 ha (58,145 acres) in the Newberry FMU and 9,050 ha (22,364 acres) in the Shingleton FMU. Pine barrens covered 866 ha (2,141 acres) in the Newberry FMU and 434 ha (1,073 acres) in the Shingleton FMU (Appendix Table A1).

Natural Community Types

Red pine occurs as a dominant component of three natural community types in the Central Upper Peninsula: dry northern forest, dry mesic-northern forest, and pine barrens. These natural communities

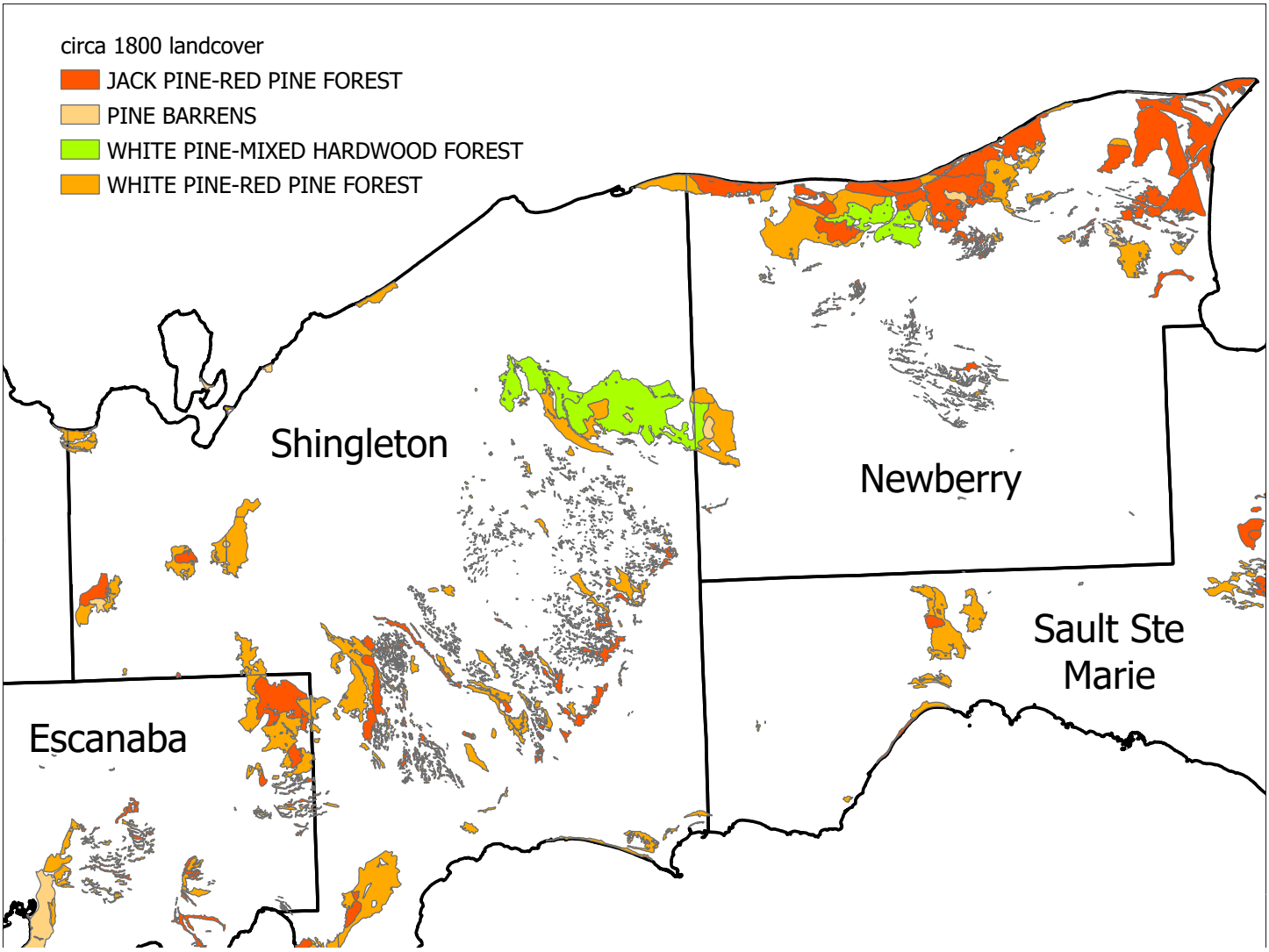

Figure 3. Circa 1800 Landcover derived from General Land Office Notes (Comer et al. 1995). The red (jack-red pine) and orange (white-red pine) indicate dry forest dominated by pine, the green is white pine-hardwoods. The small grayish patches are small patches of pine forest, ususally surrounded by peatlands.

developed as a result of frequent fires, drought-prone sandy soils, and cold temperatures that limited the development of broad-leaved deciduous trees. MNFI documents occurrences of natural communities that meet minimum thresholds of ecological integrity (referred to as element occurrences [EOs]). There were 27 element occurrences of dry northern forest (26 extant) representing 1,648 ha (4,071 acres) in the Michigan Natural Heritage Database (MNFI 2024) (Appendix Table A2). Eighteen of the 27 occurrences were considered to have good or excellent viability. Ten occurrences totaling 644 ha (1,593 acres) were in the Newberry FMU. The Shingleton FMU had three occurrences of dry northern forest totaling 202 ha (499 acres). There were 77 element occurrences of dry-mesic northern forest in Michigan totaling 4,664 ha (11,525 acres). The Newberry FMU had eleven occurrences totaling 748 ha (1,848 acres). The Shingleton FMU had three occurrences totaling 76 ha (187 acres) (Appendix Table A3). Red pine was also a component of pine barrens which occurrs locally throughout the Eastern and Central Upper Peninsula, often within a shifting mosaic of dry northern forest where disturbance was most frequent. There are element occurrences of pine barrens in the neighboring Sault Ste. Marie FMU.

The structure of dry northern forest and dry-mesic northern forest is highly dependent on local moisture and soil conditions as well as fire history. However, pines are always a dominant component of the forest canopy of these natural communities. Red pine often forms a semi-open canopy of mature trees with multiple age and size cohorts of other pine species regenerating underneath, and fire-dependent shrubs, forbs, and grasses in the ground layer (Whitney 1986). In addition to red and jack pine, eastern white pine (*Pinus strobus*) and red oak (*Quercus rubra*) are frequent canopy associates of the dry northern forest and dry-mesic northern forest community type, especially on moister sites. Red pine is typically the longest-lived of the canopy dominants in dry northern forest and dry-mesic northern forest and can regularly achieve ages of 300 to 400 years (Burns and Honkala 1990). Old red pine stands are still extant, especially adjacent to lakes and other wetlands where they are protected from severe crown fires (Bergeron and Gagnon 1987). These natural fire refugia are important seed sources for red pine regeneration. Red pine is well-adapted to survive low-intensity fires due to its thick bark and its habit of self-pruning lower branches limits its susceptibility to crown fires. However, when severe crown fires do occur, local seed sources may be destroyed and allochthonous seeds from unburned refugia can allow red pine to effectively recolonize burned areas (Larson et al. 2021). Red pines produce large seed crops every five to ten years and therefore the coincidence of suitable seedbeds in the aftermath of low-intensity

Pine-dominated forest is well-developed on old dune ridges along the shore of Lake Superior. Jack pine, red pine, and white pine are all common in these forests. Photo by J.M. Lincoln.

fire and large seed rains are important for red pine establishment (Kozlowski and Ahlgren 1974).

Although often considered to be dependent on severe fires for stand initiation, Palik and D'Amato suggest that a mixed-severity disturbance regime is a better description of the origin of many old-growth red pine in the Great Lakes Region (2019). Instead of severe fires that had very high mortality over large areas, the mixed-severity paradigm emphasizes the prevalence of historical fires with spatially variable intensity depending on local variation in topography and fuels in which trees of multiple age and size cohorts survive fires and provide a seed source to perpetuate red pine (Palik and D'Amato 2019). Mixed-severity disturbance may have been particularly frequent where topographical and moisture variation is high, in contrast to flat plains where fires burned with more uniform intensity (Muzika et al. 2015).

The understory and ground layer components of dry northern forest and dry-mesic northern forest are also variable depending on site conditions and history. Slow-growing, clonal ericaceous shrubs that are adapted to fire such as blueberries, huckleberry, bearberry, and wintergreen are important components of the ground layer of dry northern forest and dry-mesic northern forest. Many of these low shrubs form unique associations with the soil microbiome while providing a food source for many birds and mammals (Matlack et al. 1993, Cohen et al. 2015). The dry northern forest and dry-mesic northern forest natural communities are stable in time and space at a landscape scale when regular disturbance such as low-intensity surface fire exists. In the absence of fire, these forests undergo compositional and structural changes with meshophytic species becoming more prevalent and pines decreasing. In their 1850 study of the region, Foster and Whitney describe pine forests of the Eastern Upper Peninsula as follows:

> "The red pine occurs not only scattered through the mixed forests, but occupying alone tracts of considerable extent, and on low sandy plains generally forming 'pine plains,' in which the trees stand, orchard-like, singly, not far enough apart to prevent their boughs from interlacing at the top, yet leaving free communication among their trunks at the base; the ground under them being quite bare of underbrush, and at most only covered with low trailing bushes of the whortleberries. The trees on these plains are from seventy to a hundred feet high, with straight, shapely trunks, which are free of branches nearly to the summit, and of size sufficient to furnish very good timber" (Foster and Whitney 1851).

Pine-dominated forests are fire-dependent with a relatively open understory and ground layer dominated by ericaceous shrubs such as huckleberry (*Gaylussacia baccata*) (light greenish-yellow leaves covering ground layer in photo). Photo by J.M. Lincoln

Several plants and animals that are now rare in Michigan occur in Central Upper Peninsula pine forests, including plants such as Canada rice grass (*Piptatherum canadense*, State Threatened) and pine drops (*Pterospora andromedea*, State Threatened) and birds including American goshawk (*Accipiter gentilis*, State Threatened), Kirtland's warbler (*Setophaga kirtlandii*, State Endangered), black-backed woodpecker (*Picoides arcticus*, Special Concern), common nighthawk (*Chordeiles minor*, Special Concern), eastern whip-poor-will (*Antrostomus vociferus*, State Threatened), spruce grouse (*Canachites canadensis*, State Threatened), and sharp-tailed grouse (*Tympanuchus phasianellus*, Special Concern) (Derosier et al. 2015, MNFI 2024). The DNR lists 31 animals that are dependent on red pine and associated natural communities (Bielecki et al. 2004)

Role of Indigenous Peoples

Indigenous Peoples of the Central Upper Peninsula shaped the landscape in ways that favored the development of red pine-dominated ecosystems. Use of fire and intentional burning were integral practices of Anishnaabe and other Indigenous cultures and, although difficult to categorize, motivations for burning may have included efforts to improve hunting and wildlife habitat, to provide improved views and easier travel, and to encourage growth and fruiting of food and medicinal plants such as blueberry and huckleberry (Smith 1923; Cleland 1992; Anderton 1999; Davidson-Hunt 2003). Fire scars and traditional knowledge suggest that the frequency, intensity, timing, and spatial coverage of historical burns would have varied widely (Chapeskie 2001).

It was formerly suggested that pre-colonial human influence on forests of the Upper Peninsula was

A >200 year-old culturally-modified red pine in the Upper Peninsula. The bark was peeled from this tree to gather resin and the tree healed the wound, preserving the hatchet marks. Photo by Joshua G. Cohen

minimal (Zhang et al. 1999); however recent studies of fire histories in the Great Lakes region suggest a more active and pervasive role for Indigenous stewardship of the landscape of the Upper Peninsula than has previously been recognized. Red pine stands in the Boundary Waters region of Northern Minnesota show extensive evidence of cultural burning by Indigenous Peoples. The historical fire regime helped perpetuate fire-adapted species such as red pine throughout Northern Minnesota (Kipfmueller et al. 2017; Kipfmueller et al. 2021). The majority of fires since 1700 in the Seney National Wildlife Refuge occurred late in the season (53.3.%) and large fires occurred almost exclusively late in the season suggesting only a minor role of lightning strikes in igniting wildfires (Drobyshev et al. 2008). Similarly, fire histories from Betchler Lake in the Central Upper Peninsula and the Huron Mountains in the Western Upper Peninsula indicate that most fires burned in the dormant season (late fall to early spring) (Muzika et al. 2015; Sutheimer et al. 2021). Estimates of fires ignited by lightning compared to the potential for Indigenous Peoples to start fires suggest that the role of Indigenous People was much greater than lightning (Kay 2007). Present-day wildfire records also show a preponderance of human ignitions compared to lightning ignitions in the Great Lakes Region (Balch et al. 2017). Fires in coastal sites on Lake Superior in Upper Michigan occurred ten times more frequently than would be expected based on lightning-caused ignitions alone (Loope and Anderton 1998). The pervasiveness of historical fires in dry northern forests across the region is difficult to reconcile with the prevailing idea that the overall influence of humans was minimal because the Indigenous population was estimated to be small – about 1% of the present-day population in the region. Even remote stands of red pine surrounded by large wetlands show evidence of frequent historical burning in the dormant season when lightning strikes are low (Drobyshev et al. 2008; Sutheimer et al. 2021).

An Anishinaabeg camp in Northern Minnesota shows the historical structure of pine forests that were managed for cultural purposes. These forests have open understories with large, mature pine in the canopy. (Minnesota Historical Society).

Due to its longevity, red pine is uniquely valuable as evidence of Indigenous and early Euro-American cultures. Living red pines that are several hundred years old can provide evidence of historic burning regimes and even preserve evidence of cultural activities such a gathering resin in the form of peel scars and hatchet marks (culturally-modified trees) (Turner et al. 2009, Larson et al 2021). Stumps can provide valuable information about fire regimes and growth rates dating back as far as 1520 in the Eastern Upper Peninsula (Sutheimer et al. 2021) and 1439 in the Western Upper Peninsula (Muzika et al. 2015). Due to red pine's longevity and resin-preserved wood, many fire histories in the Great Lakes Region have been reconstructed from red pines.

Fire histories in Michigan suggest variation in historical fire frequencies before Euro-American settlement, with higher frequencies after 1752 through the 1890s to 1910s compared to earlier time periods, possibly reflecting changes in settlement and movement patterns of Indigenous Peoples (Loope and Anderton 1998; Muzika et al. 2015). In the Lower Peninsula, peak fire frequency was associated with a "wave" in the 1850s to 1860s coinciding with Euro-American colonization and logging followed by a rapid decline (Stambaugh et al. 2018; Stambaugh et al. 2024).

Decline of Red Pine

The DNR estimated that red pine cover had declined by 50 to 60 percent compared to estimated cover in 1800 (Bielecki et al. 2004). Old-growth red pine is among the rarest forest cover type in the Great Lakes Region (Frelich 1995). Before European colonization approximately 55% of the red-white pine forest cover type was old growth compared to approximately 2.5% on the current landscape (Frelich 1995; Kellett et al. 2023). In the Grand Marais Forest District there are fewer trees in large size classes compared to the pre-colonization forests (Zhang et al. 2000). Red pine in pre-colonization forests of the Lower Peninsula frequently achieved heights of 31 m (100 ft) and diameters of 43 to 55 cm (Collins 1958). The Newberry and Shingleton FMUs contain the largest coverage of natural red pine and natural mixed pine on the current Michigan landscape (Appendix Table A4).

Widespread logging and post-logging slash fires have influenced the current demographics and distribution of pine. In addition to preferentially cutting the largest trees, skewing natural size distributions, areas that were intensively logged often experienced intense slash fires that destroyed the seed bank and local seed sources. With limited seed sources these burned areas often became open grasslands or "stump fields" with low diversity and limited capacity for reforestation (Barrett 1995).

After widespread logging ceased, plantation forests and management styles became the dominant paradigm or pine management. Widespread planting by the Civilian Conservation Core occurred in the 1930s and continued into the early 1960s (Bielecki et al. 2004). Past planting efforts and associated management have resulted in many red pine stands in Michigan that are in the 60 to 100 year age range but very few that are of greater age. Natural red pine stands show a similar trend with a low proportion of stands greater than 100 years old (Fig. 4). Regeneration of red pine is accomplished primarily by scarifying the soil or by planting with accompanying trenching and herbiciding. Natural regeneration is largely limited to burned areas. To accommodate economic goals, harvest intervals in the 60–100-year range are often used, which continue to skew red pine demographics in Michigan in favor of younger age

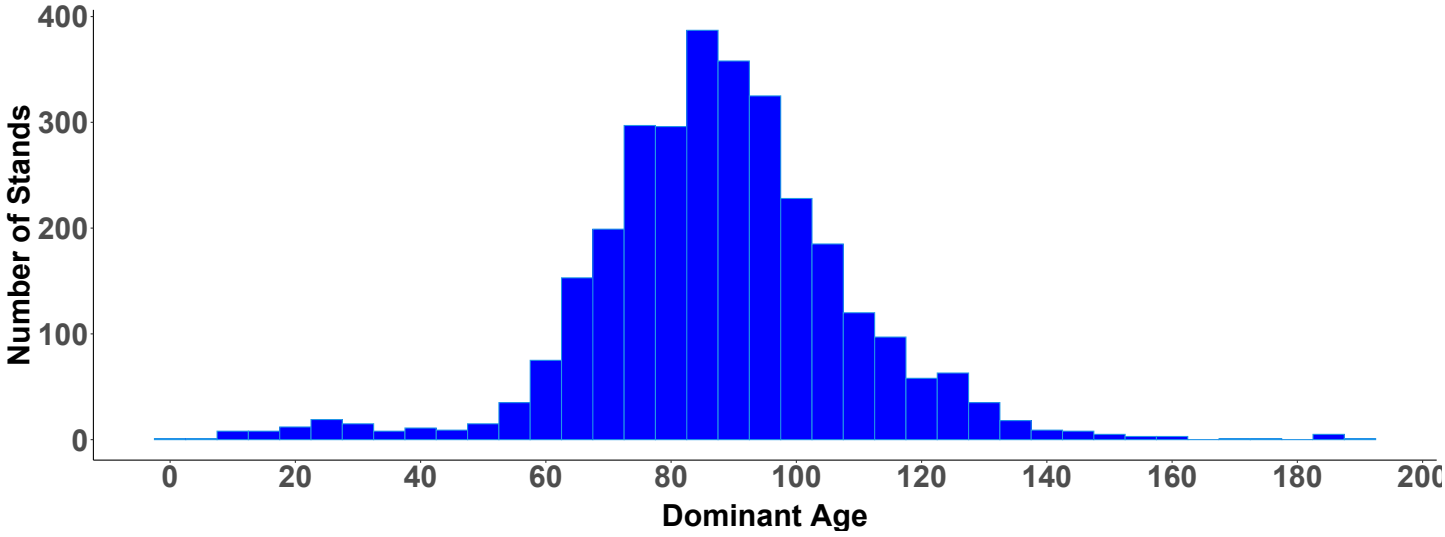

Figure 4: Natural red pine stands on state of Michigan lands (Forest, Park, and Wildlife Divisions) by dominant age from 2023 Michigan Forest Inventory records (Michigan DNR). There are relatively few old stands on the current landscape despite the longevity of red pine.

classes (D'Amato et al. 2010). Plantations lack the structural complexity and biodiversity of unmanaged natural pine stands (Fraver and Palik 2012; Silver et al. 2013).

Climate change poses a new threat to the persistence of red pine in the Great Lakes Region. With the southern edge of its range located in Lower Michigan, the distribution of red pine is forecast to shift north as the climate continues to warm (Flannigan and Woodward 1992; Peters et al. 2020). Red pine has low genetic variability and red pine ecosystems are considered to have moderate to low adaptive capacity to climate change in Michigan (Handler et al. 2014). A warmer and drier climate could favor more frequent wildfires that may facilitate the survival and spread of red pine (but see Flannigan et al. 1998). Increasing drought frequency may increase susceptibility to pathogens and increase mortality, especially in overstocked stands such as plantations (Magruder et. al 2013; Larson et al. 2021). Fire suppression is a major stressor of red pine ecosystems and regular burning is predicted to increase the resilience of these ecosystems (Handler et al. 2014)

Alternative Management Approaches

The loss of red pine from the landscape in the Great Lakes region has long been recognized as a conservation and management challenge (Fowler 1970; Van Wagner 1970). Beyond planting red pine, efforts to preserve and regenerate red pine have centered around prescribed fire (Buckman 1964). Long-term implementation of prescribed burning in Minnesota has demonstrated an ability to restore and maintain fire-adapted species with little to no effect on mortality or growth of canopy red pine trees, even with high fuel loads (Scherer et al. 2016; Bottero et al. 2017). Other management approaches such as extended rotations and variable retention harvest can improve the conservation value of existing red pine stands but have shown limited ability to facilitate subsequent natural regeneration of red pine (Roberts et al. 2017). Although the ability of prescribed fire to accomplish multiple management goals is widely appreciated, the ability to implement prescribed burning due to limitations in personnel and financial resources is an obstacle to implementation. The State Forestland Red Pine Type Management Project addressed concerns about loss of red pine and conflicting management objectives for economic and ecological objectives in their 2004 report. The challenges for red pine management are summarized in the 2004 DNR report as follows:

> "Another major issue with the red pine resource on State Forestlands is the overall lack of naturally regenerated stands on ecologically suitable sites. This is contributing to a decline in several wildlife species and the loss of dry-mesic, dry northern forest, and barrens communities. Although fire can significantly help with the natural regeneration of red pine and is a critical part of natural processes, reestablishing red pine stands is still difficult due to inconsistent seed production. Social constraints, such as those that limit the use of prescribed fire, also make it difficult to manage red pine naturally. As a result, this report explores opportunities to establish red pine in a quasi-natural setting through modified planting techniques including the use of fire on a limited basis. The effects of the reduction of natural red pine communities are also explored." (Bielecki et al. 2004)

Ground layers and understories of red pine stands often contained few or no red pine seedlings or saplings. Photo by J.M. Lincoln.

Project Goals

The priary goal of our work was to identify high quality natural red pine stands in the Newberry and Shingleton FMUs and to develop management strategies based on data from site visits to protect and perpetuate diverse natural red pine in the Central Upper Peninsula of Michigan. The specific goals of our surveys were to: 1) Identify high-quality natural red pine stands in the Newberry and Shingleton FMUs and document any potential dry northern forest, dry-mesic northern forest, or pine barrens natural community element occurrences; 2) Document plant diversity in high-quality stands, including any endangered, threatened, or special concern species and conduct Floristic Quality Assessments (FQAs) to determine the stands with highest floristic diversity; 3) Document any cultural value and provide recommendations to increase cultural value, such as heavy fruiting of blueberry, chokecherry (*Prunus virginiana*), hazels (*Corylus cornuta*), or other fruits in response to fire; 4) Document any presence of burn or peel scars; 5) Identify potential project areas for natural red pine management that preserve natural stand characteristics in high-quality stands, including multiple age classes, large canopy trees, and a diverse ground layer that can support frequent, low-intensity, fires. These areas would incorporate fire and timber harvest to achieve management goals, and promote a climate-resilient community.

Specific stewardship recommendations were developed to help managers protect and sustain these important fire-dependent forests. Protecting and managing representative natural communities is critical to biodiversity conservation because native organisms are best adapted to environmental and biotic forces with which they have survived and evolved over millennia (Cohen et al. 2015). Biodiversity is most easily and effectively protected by preventing high-quality sites from degrading. We believe this approach is the best chance to ensure the persistence of natural red pine on the landscape and protect the best examples of dry and dry-mesic northern forest. This ecological evaluation is aimed at creating a more diverse and resilient landscape that prevents continuing degradation of the few remaining natural red pine forests.

A large fire scar on a pine in the Lake Superior Campground dry northern forest.Photo by J.M. Lincoln

METHODS

Selection of Stands and Priority Areas

To identify potential survey sites we used MiFI stand data and selected stands that were classified as red pine or mixed pine where at least 50 percent of the canopy cover is composed of pine. We also selected stands that were classified as being of natural origin as opposed to stands that were classified as planted. There were a total of 2,318 stands in the Newberry and Shingleton FMUs that met these criteria. We selected natural pine because we expected that these stands were more likely to have exceptional characteristics in terms of vegetation structure, diversity, intact ecological processes, and higher ecosystem integrity. We further narrowed our survey targets to those with a dominant age of 100 years or greater. We expected that stands of this age would be more likely to have higher diversity, more natural structure such as old-growth characteristics, higher conservation value, and more potential to manage for old-growth structure. There were 571 stands of natural red pine or natural mixed pine with a dominant age of 100 years or greater in the Newberry and Shingleton FMUs. Of the 571 pine stands 312 were classified as red pine with a dominant age of 100 years or greater (Fig. 5).

After locating natural pine stands that had a dominant age of 100 years old or greater, we evaluated the landscape context of the stands. We prioritized larger stands that were near water bodies or wetlands as we anticipated these stands would have greater diversity and would be more conducive to fire management due to the natural breaks present. We also considered pine cover in the surrounding landscape and whether landscape-scale management with fire would be practical to implement. We avoided small, isolated stands on dune ridges surrounded

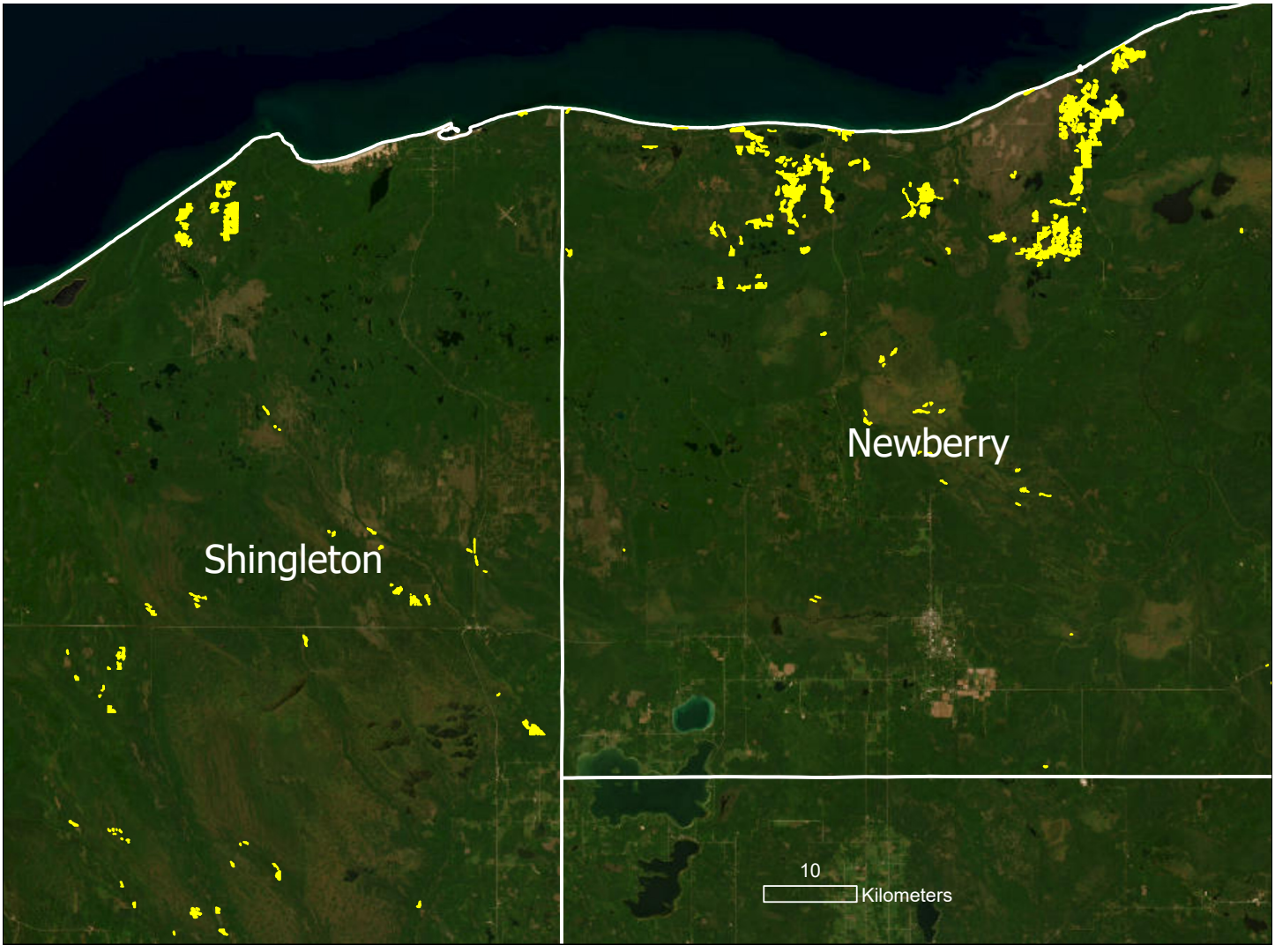

Figure 5. Natural red pine stands (yellow) with dominant age of 100 years or greater on State Lands in the Newberry and Shingleton Forest Management Units from Michigan Forest Inventory records (DNR 2024).

by peatlands. We also avoided selecting stands that had treatments scheduled in the next year as well as areas that had recent harvest. We also consulted with DNR foresters and wildlife biologists to fine-tune our survey areas.

Field Surveys
Using the above criteria, we selected twelve survey areas in the Newberry FMU and six in the Shingleton FMU. The priority areas were demarcated by features such as roads or wetlands and varied from 80 to 2,000 ha (197 to 4942 acres) . Priority blocks contained at least one stand with natural pine >100 years old in a pine-dominated landscape that could be included in potential holistic management.

We conducted field surveys from June 5th to June 9th, 2023. Field surveys involved walking through priority blocks and gathering stand-level data on floristic composition and vegetation structure. We noted any outstanding natural or culture features in stands such as evidence of fire or pest outbreaks or presence of fruiting shrubs. We measured the diameter at breast height (dbh) of representative canopy trees in each stand and estimated their age using an increment borer. We selected trees that appeared to be the oldest based on size and bark characteristics for ageing. We made note of wildlife and wildlife habitat in stands including the presence of any priority species and species of greatest conservation need in Michigan.

Natural Communities
A natural community is defined as an assemblage of interacting plants, animals, and other organisms that repeatedly occurs under similar environmental conditions across the landscape. Natural communities are predominantly structured by natural processes rather than modern anthropogenic disturbances such as timber harvest, alterations to hydrology, and fire suppression (Kost et al. 2007; Cohen et al. 2015). Historically, Indigenous Peoples were an integral part of natural communities across the Great Lakes region with many natural community types being maintained by native cultural practices such as prescribed fire, wildlife management, and plant harvesting, seeding, and planting (Kimmerer and Lake 2001). Their interactions were widespread, sophisticated, and central to maintaining historic biodiversity and ecosystem functions.

We used MNFI methodology to document element occurrences of natural communities. Natural Heritage methodology uses three criteria to rank the quality of a natural community: condition, size, and landscape context (Faber-Langendoen et al. 2008, 2015). If the site meets minimum criteria in each category it is classified as an element occurrence, given a unique identifier (EO ID), and entered into MNFI's statewide natural heritage database (MNFI 2024). Each category ranges from an A rank (excellent ecological integrity) to a D rank (poor ecological integrity). Determination of condition involves evaluating species richness, tree composition and age, and threats to ecological integrity such as fire suppression, invasive species, changes in soils or hydrology, and historical changes to the biotic or abiotic components of the community such as past logging or agriculture.

An important component of assessing condition is conducting a floristic quality assessment (FQA). The FQA is a standardized method to assess the quality of a natural community using coefficients of conservatism (C-value) assigned to each plant species ranging from 0 to 10 (Freyman et al. 2016). The values are assigned using the consensus of local expert botanists (Reznicek et al. 2014). Plants with higher C-values have higher fidelity to natural communities with high ecological integrity and low anthropogenic disturbance and non-native species are assigned a value of 0. The standard metric obtained from an FQA is the floristic quality index (FQI).

We calculated the FQI of natural communities as:

$$FQI = \bar{C} \times \sqrt{n}$$

where $\bar{C}$ = mean C-value of all the observed plant species and n = plant species richness. Natural communities with an FQI of 35 or greater are considered floristically important from a statewide perspective. FQI scores greater than 50 indicate exceptional sites with extremely high conservation value (Herman et al. 2001). Mean C-values may represent a less biased indicator of relative conservation value and are also provided with the FQIs (Matthews et al. 2005, Slaughter et al. 2015).

Cores were taken to estimate the ages of the oldest trees. This core from a 16.1" dbh jack pine in the Grand Marais dry northern forest had 129 rings. Photo by J.M. Lincoln

RESULTS

We surveyed 55 pine stands within eleven priority survey areas. Thirty-three stands were in the Newberry Unit and 22 in the Shingleton Unit (Appendix Table A5). We located 14 stands that met criteria for natural community EOs within five unique polygons representing four new EOs (Fig. 6). The four natural communities were classified as dry northern forest EOs. Three occurrences of dry northern forest totaling 110.1 ha were on state lands, with two in the Newberry FMU and one in the Shingleton FMU. An additional dry northern forest element occurrence of 25.4 ha was located on land owned by Pictured Rocks National Lakeshore while traveling between state lands. Our surveys increased the area of the dry northern forest community type in the Michigan Natural Heritage Database by eight percent (MNFI 2024). We also updated one existing 68.6 ha dry northern forest EO in the Shingleton FMU (Table 1).

The dry northern forest EOs ranged from good (B-rank) to poor (D-rank) estimated viability. The highest-ranked was the existing Lake Superior Campground dry northern forest in the Newberry FMU (B-rank). Overall, EOs had greater floristic diversity, older trees, and lower evidence of anthropogenic disturbance than other stands.

In the following section we provided a detailed description of the vegetation, structure, and management considerations of each EO.

Table 1: Natural community Element Occurrences identified or updated during surveys. EO rank abbreviations are as follows: B, good estimated viability; C, fair estimated viability; D, poor estimated viability. The total FQI is the Floristic Quality Index and the Total Mean C is the average coefficient of conservatism of the plant species identified in the stand.

EO ID	FMU	Site Name	Community Type	Compt.	Stand(s)	Survey Date	Size ha (acres)	EO Rank	Total FQI	Mean C-value
27080	Newberry	Crisp Point Forest	Dry northern forest	42043	10, 71	06/08/2023	15.4 (38)	C	25.3	4.7
18810	Newberry	Lake Superior Campground	Dry northern forest	42004	1, 23, 26, 27,	06/05/2023	68.6 (169.6)	B	32.4	5.4
27081	Newberry	Muskrat Lake Forest	Dry northern forest	42040	19, 29	06/08/2023	56.7 (140)	D	21.2	3.9
27075	NA (Pictured Rocks National Lakeshore)	Pictured Rocks Forest	Dry northern forest	NA	NA	06/06/2023	25.4 (62.8)	B	25.5	4.9
27105	Shingleton	Grand Marais Forest	Dry northern forest	41101	8, 9, 10, 16, 52	06/06/2023	38 (93.9)	C	24.6	4.5

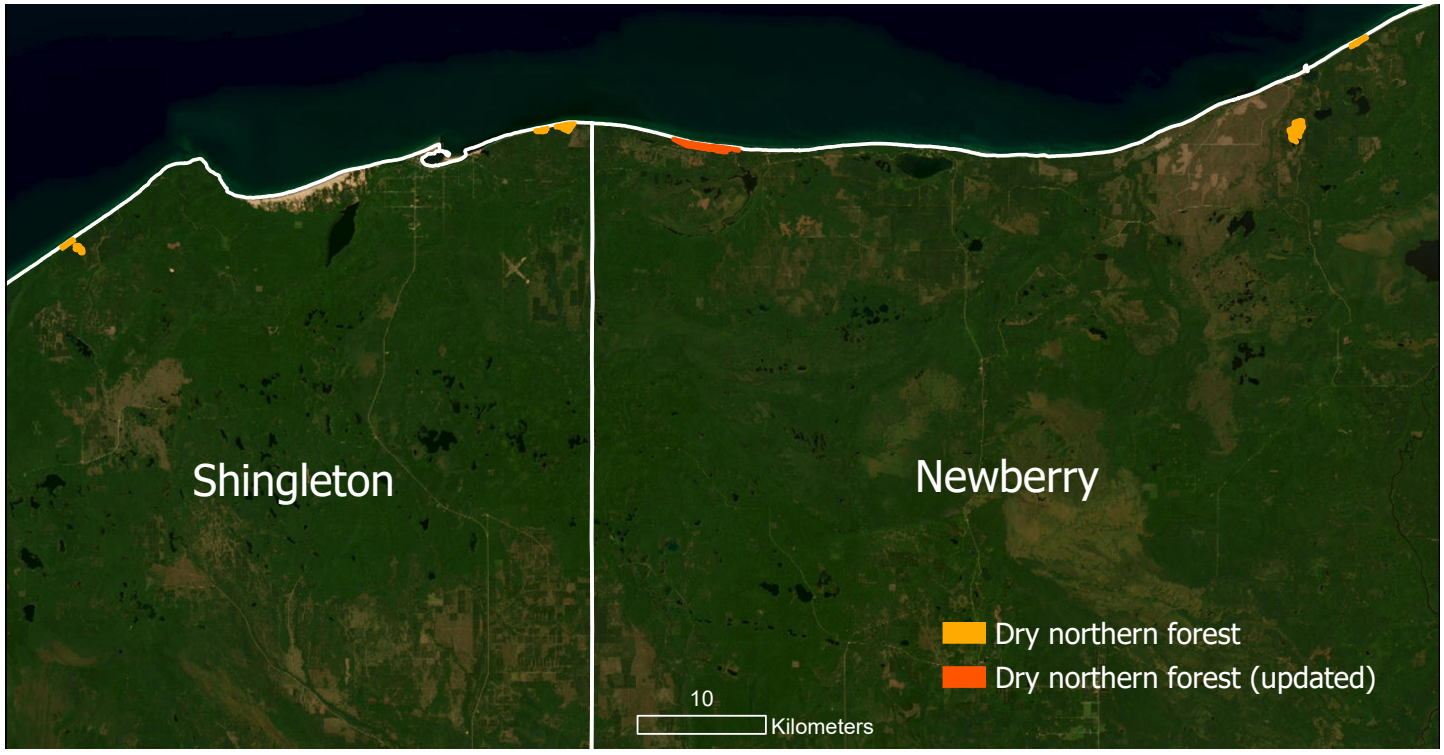

Figure 6: Location of natural community element occurrences identified or updated during 2023 field surveys.

Natural Community Element Occurrences

Crisp Point
Location: Newberry Forest Management Unit; Compartment 42043, Stands 10 and 71.
Natural Community Type: Dry Northern Forest
Rank: G3? S3; vulnerable throughout range
Element Occurrence Rank: C, fair occurrence
Size: 15.3 ha (38 acres)
Element Occurrence Identification Number: 27080 (new)

Site Description: This is a pine-dominated forest on bands of dune ridges along a steep slope above the Lake Superior shoreline (Fig. 7). Locally, the landscape features vast expanses of excessively drained sands with features such as beach ridges, dunes, and terraces associated with historic lake level fluctuations. The structure and composition of the forest is influenced strongly by historic clearing, fire suppression, and proximity to the lake. This area was potentially historically influenced by Indigenous Peoples. Protracted fire suppression has led to an accumulation of white spruce (*Picea glauca*) in the subcanopy, which may increase the risk of canopy tree mortality during a fire by functioning as ladder fuels.

Supercanopy white pine (*Pinus strobus*) and red pine (*Pinus resinosa*) occur over red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), and jack pine (Pinus banksiana). The canopy ranges from 60 to 80 % canopy coverage, often around 70%, and dominated by red pine and white pine with red oak, paper birch, and jack pine throughout. The system locally trends towards dry-mesic northern forest with an abundance of red oak and paper birch in gaps where windthrow has reduced pine. Red pine are dominant (~65% of the canopy) and typically 30 to 55 cm dbh and range between 100 to 190 years old. Red pines were aged at 186 rings (46.8 cm dbh), 151 rings (56.6 cm dbh) and 100 rings (44.2 cm dbh). White pine typically range from 50 to 70 cm dbh. Jack pine are typically 20 to 30 cm dbh.

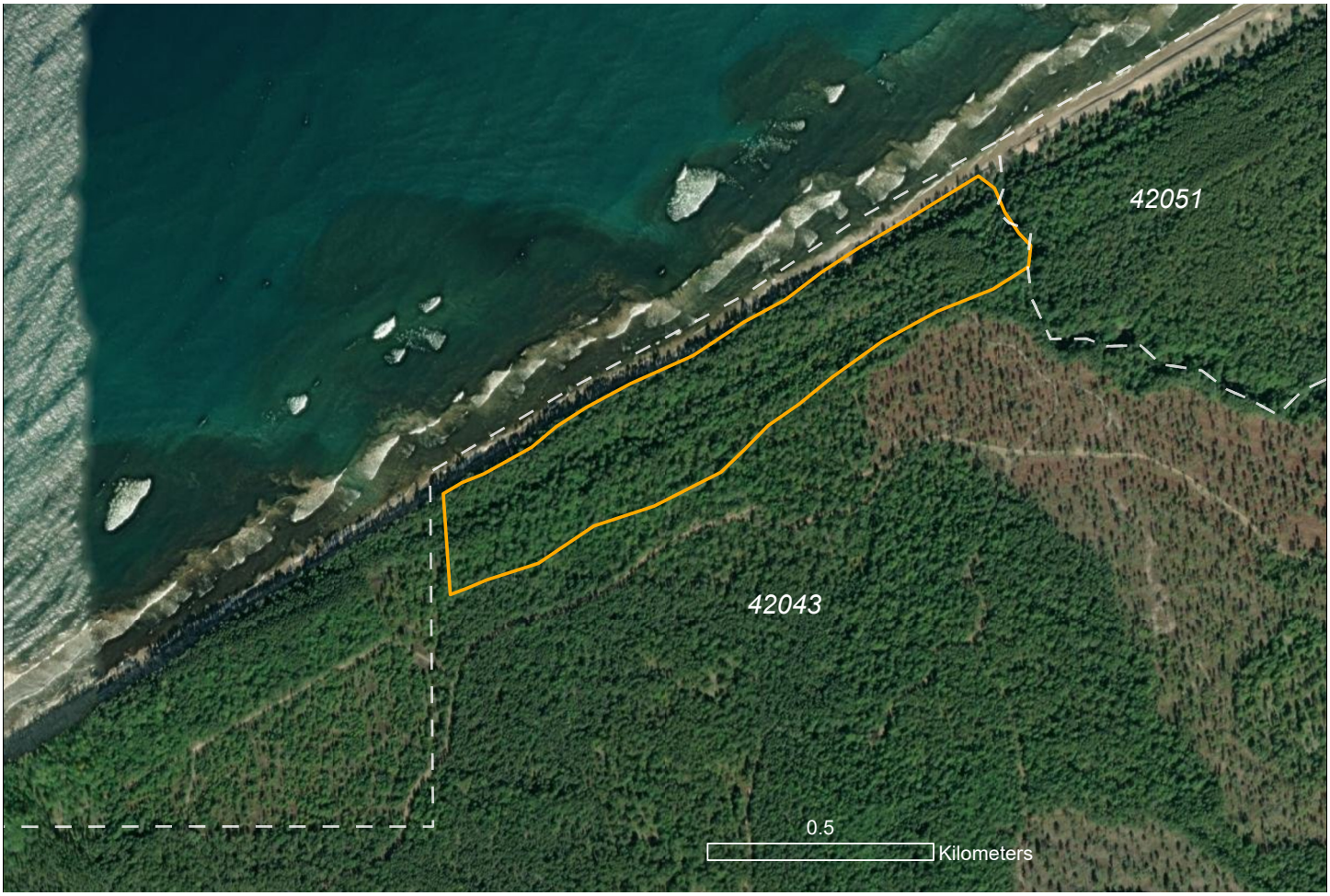

Figure 7: Crisp Point dry northern forest (EO ID 27080) is part of a large zone of pine-dominated forest on old dune ridge along Lake Superior.

The subcanopy and understory is patchy (50 to 80% cover) and characterized by white spruce, red maple, white pine, red oak, balsam fir, and paper birch, and rare American beech and serviceberry (*Amelanchier* sp.). The dominance of white spruce appears to be a feature of fire suppression and there is no red pine regeneration. Lack of fire and proximity to the lake is causing some areas to trend toward more dry-mesic northern forest species.

The low shrub layer is patchy (50-80% cover) and features several berry-producing species but especially blueberries (*Vaccinium angustifolium, V. myrtilloides*), huckleberry, and Labrador tea (*Rhododendron groenlandicum*) on rotting wood along the shoreline. Overall low sweet blueberry is the most abundant shrub.

The ground layer is patchy to dense (30-70%) with diversity increasing towards the shoreline. Bracken fern (*Pteridium aquilinum*) is abundant throughout. Other characteristic species include bearberry (*Arctostaphylos uva-ursi*), bunchberry (*Cornus canadensis*), Pennsylvania sedge (*Carex pensylvanica*), stiff clubmoss (*Spinulum annotinum*), twinflower (*Linnea borealis*), wintergreen (*Gaultheria procumbens*), Canada mayflower (*Maianthemum canadense*), goldthread (*Coptis trifolia*), cow-wheat (*Melampyrum lineare*), star-flower (*Trientalis borealis*), wavy hair-grass (*Avenella flexuosa*), and pink lady-slipper (*Cypripedium acaule*).

In the absence of fire, red pine is not regenerating and gaps caused by windthrow often are dominated by red oak and paper birch. The subcanopy is locally dominated by white spruce and white pine. The influence of the lake and lack of fire is causing the system to trend towards dry-mesic northern forest. Subtle troughs between dune ridges feature microclimates with increased striped maple in the subcanopy and bluebead lily (*Clintonia borealis*), bunchberry, and goldthread in the ground layer. Fluctuating lake levels are an important ecological process influencing vegetation structure. High lake levels and storms erode the steep slope along the shoreline and dramatically increase the accumulation of coarse woody debris. Windthrow from severe storms from Lake Superior also increases coarse woody debris and structural complexity of the forest. Because of these disturbances, the system is uneven-aged and has an abundance of red pine coarse

Crisp Point dry northern forest had a canopy dominated by red and white pine. The forest is subject to erosion from storms and high lake levels. Photo by J.M. Lincoln

woody debris at several stages of rot. Labrador tea and creeping-snowberry (*Gaultheria hispidula*) are locally abundant on decaying logs. There were some fire scars on older red pine trees. Some standing snags had scars from lightning strike.

A soil sample taken from eastern end, midslope of old beach ridge had an O layer that was 7 cm of needle duff with wood chunks and a pH of 4.0.The A layer was approximately 6 cm of light gray fine sands with organics and a ph of 4.5 to 5.0. Continual sand deposition from eroding beach and windblown sands makes boundary between other layers difficult to discern. The B layer was fine, tan sands, about 13 cm down with a pH of 6.0 to 6.5.

A total of 29 plant species were observed in the dry northern forest with no observed non-native species. The total FQI was 25.3. The total mean C-value was 4.7.

Management considerations:
Prescribed fire should be introduced at intervals of 5 to 20 years to promote fire-adapted species and increase establishment and recruitment of pines. Initial fires should be low intensity and may require removal of ladder fuels, such as white spruce, to avoid the risk of mortality of canopy trees. Natural disturbance such as erosion and storms from Lake Superior will create canopy gaps making thinning and harvest unnecessary to achieve canopy cover within a natural range of variation. Partnerships with local tribes should be explored to better understand fire regimes and cultural uses of these lakeshore pine forests.

The understory of the Crisp Point dry northern forest showed evidence of historical fire (charred snag) but is experiencing mesophication of the understory with spruce and balsam fir replacing pine. Photo by J.M. Lincoln

Grand Marais Forest
Location: Shingleton Forest Management Unit; Compartment 41101, Stands 9, 10, 16, and 52.
Natural Community Type: Dry Northern Forest
Rank: G3? S3; vulnerable throughout range
Element Occurrence Rank: C, fair occurrence
Size: 38 ha (93.9 acres)
Element Occurrence Identification Number: 27105 (new)

Site Description: Grand Marais dry northern forest is on relatively broad, shallow to moderately steep dune ridges (Fig. 8). The dunes are widely spaced with an axis from northeast to southwest and an arc protruding southeast. The dunes formed in lakeplain but may be of primarily aeolian origin due to their parabolic shape.

Dry northern forest of primarily red pine and jack pine has developed on the excessively drained, acidic beach sands with areas in troughs having greater moisture levels near the lake trending toward dry-mesic northern forest.

The forest is characterized by red pine (75% cover), jack pine (10% cover), and white pine (10% cover) in the canopy with the remaining 5% composed of red oak and red maple. Canopy coverage varies from 50 to 90% but averages around 75%. White pine supercanopy trees occur locally. Canopy coverage is higher closer to the lakeshore, except immediately adjacent to the beach where wind and loose sands have resulted in many uprooted large pines. Red pines were aged at 182 years (48.7 cm dbh), 190 years (42.2 cm dbh), 199 years (43.5 cm dbh), 223 years (59.1 cm dbh), and 236 years and jack pine aged at 129 years (42.7 cm dbh). A white pine was 64 cm dbh.

The subcanopy is patchy and composed of jack pine (50% cover), white pine (30% cover) and red pine (20% cover). The remainder is paper birch, red maple, red oak, and balsam fir. The shrub layer varies from dense near the lake to patchy further inland. Huckleberry is locally common in the understory along with blueberries (*Vaccinium angustifolium*, *V. myrtilloides*). Bearberry is locally common in canopy openings on ridges. Other ground layer species include red oak, wintergreen, striped maple (*Acer pensylvanicum*), red maple, star-flower, pink lady-slipper (*Cypripedium acaule*), cow-wheat, bracken, wavy hair-grass, Canada mayflower, and Pennsylvania sedge and reindeer lichens *(*Cladonia spp.) in more open and disturbed areas, while moss is more common closer to the lakeshore. The dry northern forest has small dry-mesic inclusions with denser subcanopy cover in troughs between dunes and close to the lake. These contain red oak, balsam fir, paper birch, and red maple in the canopy and a ground layer with bunchberry (*Cornus canadensis*),

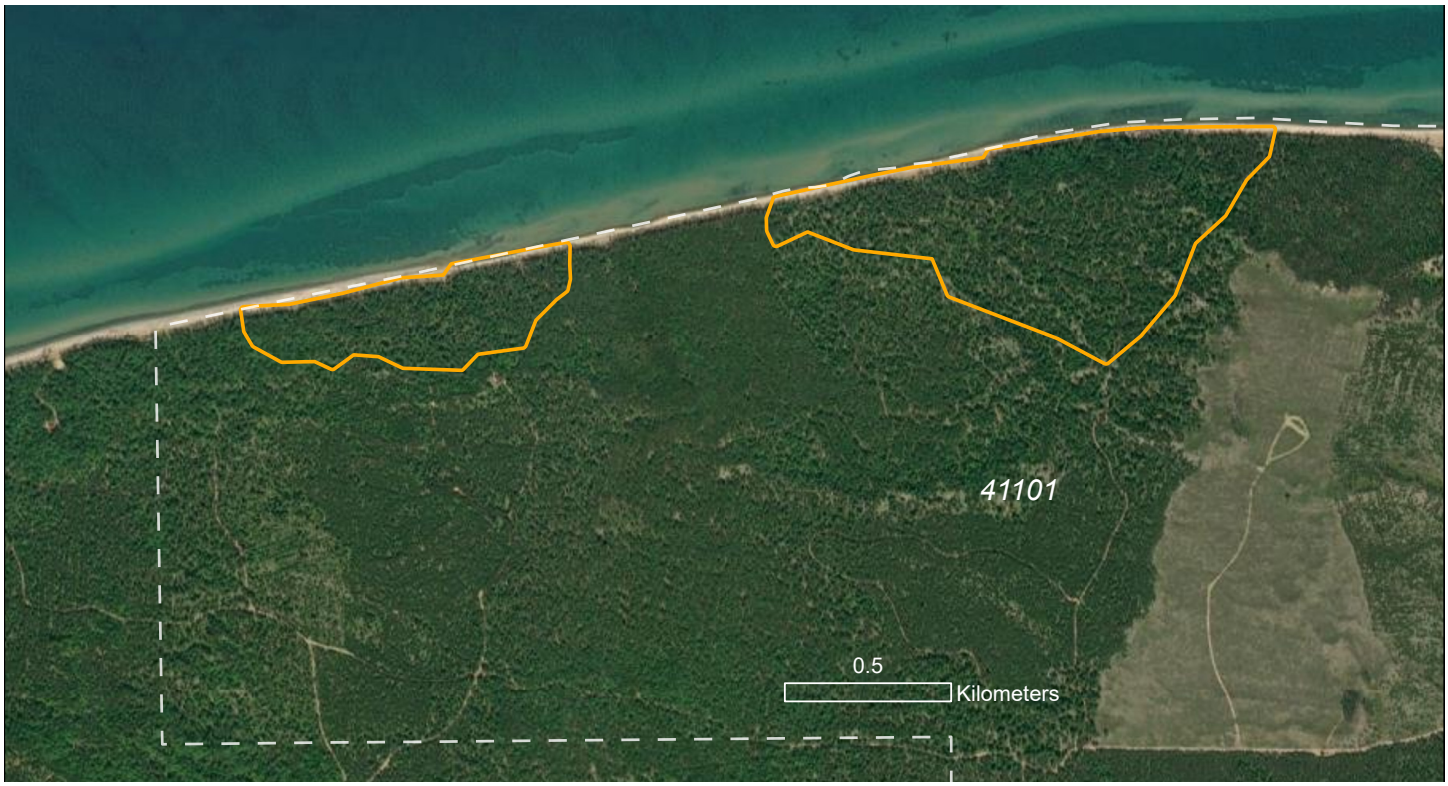

Figure 8. Grand Marais dry northern forest (EO ID 27105) is located on an extensive old dune field east of Grand Marais.

creeping-snowberry (*Gaultheria hispidula*), gay-wings (*Polygala paucifolia*) and abundant moss. A total of 30 plant species were observed in the dry northern forest of which one, bluegrass (*Poa nemoralis*), was non-native. The total FQI was 18.2. The total mean C-value was 4.5 and the native mean C-value was 4.7.

There are numerous burned snags and stumps throughout the stands and many older trees contain one or more fire scars. The canopy red pine and white pine likely originated after a crown fire and the stand has experienced subsequent surface fires as evidenced by multiple fire scars on the oldest trees. Fire suppression is a major threat to the continuance of the dry northern forest with red pine regeneration currently uncommon and localized. Portions of the forest have undergone thinning as recently as 1995 with subsequent planting of oaks in some areas (DNR 2024). This thinning likely accounts for lower canopy closure further inland from the lake in Stand 9.

Management Considerations:
The primary threat to this forest is the lack of pine regeneration due to fire suppression. Reintroducing prescribed fire could help maintain red pine as a dominant component of the forest and limit the presence of more mesic species such as spruces, fir, and red maple. Portions of this forest have already been thinned and the canopy gaps created by wind, ice, snow, and unstable sands are adequate to create openings without additional thinning. The ground layer cover and diversity in portions of the stand have been decreased by scarification. Low-intensity surface fires at intervals between 5 and 20 years should be used instead of scarification to protect the ground layer and create conditions that favor pine establishment. The forest has decreased in size due to erosion of the dunes from high Great Lakes water levels and storms. The potential for additional erosional loss of forest area should be considered when developing management goals.

The Grand Marais forest contains numerous old-growth red pine in the overstory cohort. These trees were over 150 years old and exhibited characteristics of old-growth red pine including concave bark plates and multiple fire scars. Photo by J.M. Lincoln

Lake Superior Campground
Location: Newberry Forest Management Unit; Compartment 42004, Stands 1, 23, 26, 27, 36.
Natural Community Type: Dry Northern Forest
Rank: G3? S3; vulnerable throughout range
Element Occurrence Rank: B, good occurrence
Size: 68.6 ha (169.6 acres)
Element Occurrence Identification Number: 18810 (update)

Site Description: This is a pine dominated forest that occurs on bands of dune ridges along the Lake Superior shoreline (Fig. 9). Locally, the landscape features vast expanses of excessively drained sands with features such as beach ridges, dunes, and terraces associated with historic lake levels. The structure and composition of the forest is influenced strongly by historic timber harvest and proximity to lake. Fluctuating lake levels play an important role as an agent of natural disturbance causing tree falls and generating coarse woody debris.

The system is influenced by drought, windthrow, intense snow fall, and, historically, low intensity fires. There were fire scars and charred stumps throughout the forest. This area was potentially historically influenced by Indigenous Peoples that would have burned to improve berry crops. Protracted fire suppression has led to an accumulation of white spruce in the subcanopy, which may increase the risk of canopy tree mortality during a fire by functioning as ladder fuels.

The canopy is sparse to dense, with 40 to 80 % canopy coverage, often around 70%, and dominated by red pine and white pine with jack pine and red oak throughout and occasional super canopy white pine. Red pine are typically 30 to 55 cm dbh and around 150 to 170 years old. A 53.3 cm dbh red pine had 170 rings. White pine typically range from 40 to 70 cm dbh. Jack pine are typically 30 to 40 cm dbh and around 100 years old. One 35.8 cm dbh jack pine had 132 rings. Close to the lake, canopy coverage increases to 80%, with more white pine and some canopy red oak and paper birch.

The subcanopy and understory is patchy (50 to 80% cover) and characterized by white spruce, red maple,

Figure 9. Lake Superior Campground dry northern forest (EO ID 18810) occupies a narrow strip of old dune north of the Grand Marais Truck Trail.

white pine, red pine, paper birch, and locally jack pine. The dominance of white spruce in the subcanopy appears to be associated with a long period of fire suppression.

The low shrub layer is patchy to locally dense (50-80% cover) and features several berry-producing species but especially low sweet blueberry, huckleberry, and Labrador tea along the shoreline. Overall low sweet blueberry is the most abundant shrub.

The ground layer is patchy to dense (30-70% cover) with diversity increasing towards the shoreline. Bracken is abundant throughout. Other characteristic species include bearberry, bunchberry, stiff clubmoss, trailing arbutus (*Epigaea repens*), wintergreen, Canada mayflower, goldthread, pipsissewa (*Chimaphila umbellata*), cow-wheat, gay-wings, star-flower, wavy hair-grass, Pennsylvania sedge, Menzies's rattlesnake plantain (*Goodyear oblongifolia*), and pink lady-slipper.

Towards the lakeshore, understory hemlock, balsam fir, Labrador tea, bunchberry, twinflower, rough-leaved rice-grass (*Oryzopsis asperifolia*), and bluebead lily increase in abundance. Hooker's orchid (*Platanthera hookeri*) was observed only along the lakeside edge.

Some areas in Stand 26 appear to have been impacted by selective logging and have a simplified canopy structure with a much greater component of jack pine and old red pine throughout. The ground layer of this area had abundant low sweet blueberry, star-flower and increased abundance of trailing arbutus and bracken fern.

The shallow acidic (pH 4.3-4.5) soils consisted of an organics layer (5-10cm) over acidic fine-textured dune sands (pH 4.5-5.0).

A total of 36 plant species were observed in the dry northern forest with no observed non-native species. The total FQI was 32.4. The total mean C was 5.4.

Management considerations:
Introducing prescribed fire would help promote and maintain fire-adapted species and increase the regeneration of red pine. Fires should be low intensity and low severity at intervals of every 5 to 20 years and cover as large of an area as possible. Due to the presence of subcanopy spruce, mechanical thinning may be needed before fire is introduced to protect canopy pine trees from mortality. Working with area tribes to understand the historical fire regime and cultural resources at this site would be valuable.

MNFI ecologlist Jesse M. Lincoln stands next to a charred pine snag at the Lake Superior Camground dry northern forest. Such evidence of fire was common at the site. Photo by P.R. Schilke

Muskrat Lake
Location: Newberry Forest Management Unit; Compartment 42040, Stands 19 and 29.
Natural Community Type: Dry Northern Forest
Rank: G3? S3; vulnerable throughout range
Element Occurrence Rank: CD, fair to poor occurrence
Size: 57 ha (140 acres)
Element Occurrence Identification Number: 27081 (new)

Site description: This is a red pine--dominated forest on subtle dune ridges surrounding two small kettle lakes within an expanse of excessively drained sands close to the Lake Superior shoreline (Fig. 10). A soil sample was taken from the southern part of the EO, at mid-slope on a dune ridge above a bog. The O horizon was ~ 2.5 cm thick with dark chunky wood and needle fragments and acidic (pH 4.0). The A horizon was ~ 6 cm thick with dark organics and charcoal from the fire and acidic (pH 4.0 to 4.5). The B horizon consisted of fine gray sand with a pH of 5.5.

The dry northern forest is maturing second growth with no old growth individuals and low diversity characteristic of dry northern forest. The canopy is sparse (40-70% canopy coverage) and dominated by red pine with white pine throughout and infrequent canopy jack pine. Red pine typically range from 25 to 55 cm dbh and are 100 to 110 years old. White pine are less frequent and typically range from 45 to 75 cm dbh. Jack pine are relatively rare in the canopy and the few observed were around 20 cm dbh. Red oak occasionally occur in the canopy and are typically around 30 cm dbh with a few older individuals 70 to 80 cm dbh.

The Duck Lake Fire burned through this forest in late May of 2012. The forest was then thinned in 2013, which reduced canopy cover by about 25% and has reduced structural complexity. The fire appears to have been severe in areas with some mortality of canopy trees occurring. In addition, about 50% of the living canopy trees were impacted by “duff scald” where the accumulation of organic materials at the base of the tree burned with enough intensity and/or duration to destroy a portion of the outer bark layer. The accumulated pre-fire organic layer may have been greater than the historical range of variability due to protracted fire suppression.

The subcanopy and understory is patchy (20-50% cover) and characterized by white and red pine with red oak, paper birch, and red maple throughout. Red oak is locally dominant in the understory and is locally

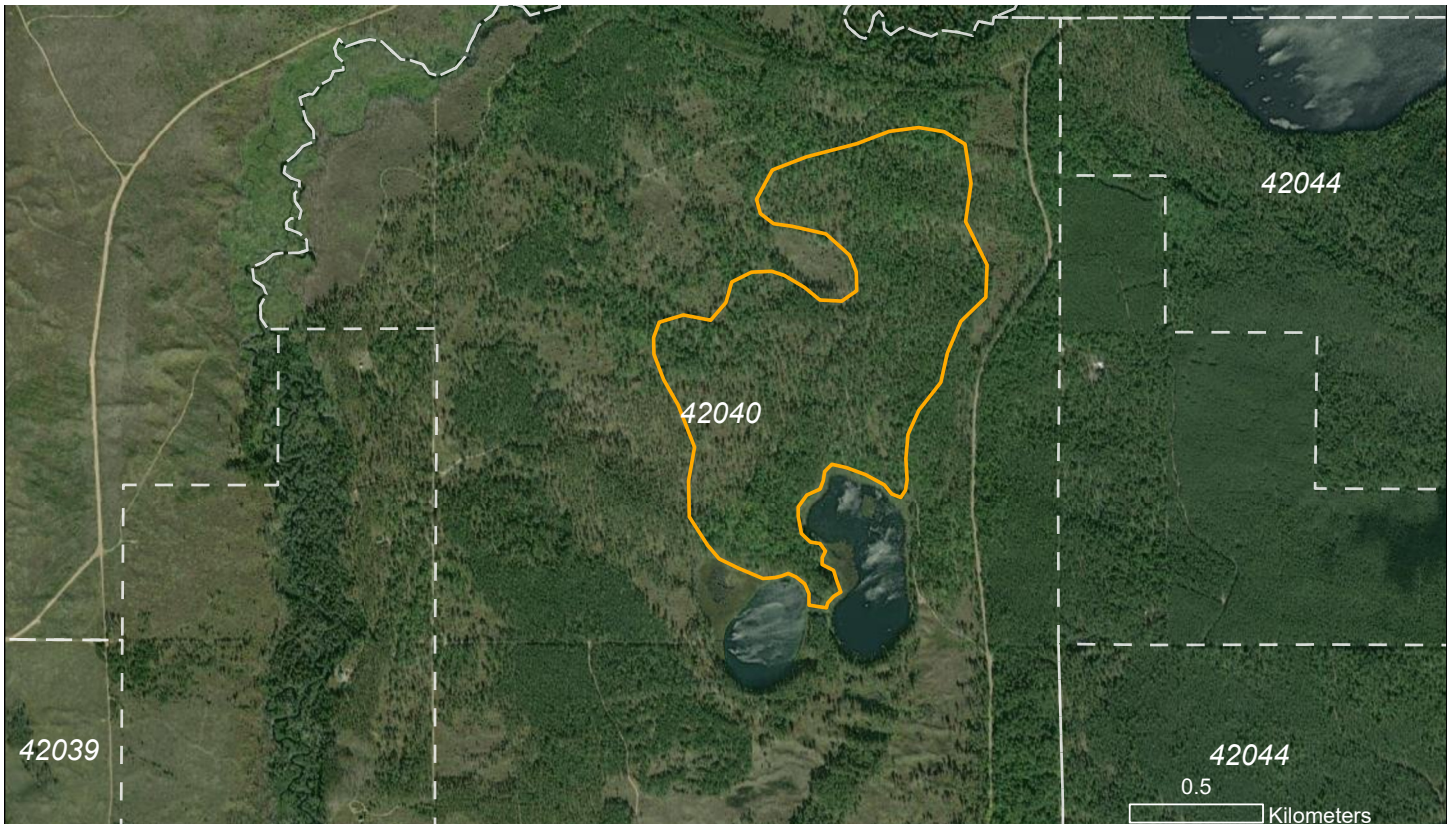

Figure 10. The Muskrat Lake dry northern forest (EO ID 27081) occurs in a pine-dominated landscape on outwash with several kettle lakes.

outcompeting pine. Many subcanopy red oaks and red maples were severely injured during the fire and are stump sprouting. Fire killed pole-sized oaks and maples occur in the subcanopy, spruce occurs in the understory, and pine seedlings in the ground layer. Understory pines larger than 5 to 7 cm dbh seemed to survive the fire with minimal effects.

The low shrub layer is sparse to locally dense (20-60% cover) and features thickets of low sweet blueberry (*Vaccinium angustifolium*) and huckleberry. Pine seedlings occur throughout the area with jack pine more abundant along Muskrat Lake where the fire appeared to be more intense. The ground layer is patchy (10-40% cover) with low diversity. Bracken is locally dense though the fire appeared to lower bracken densities compared to nearby forests that were not burned. Other characteristic species include wintergreen (*Gaultheria procumbens*), Canada mayflower (*Maianthemum canadense*), cow-wheat (*Melampyrum lineare*), star-flower (*Trientalis borealis*), Pennsylvania sedge, rice-grass (*Piptatherum pungens*), and hair grass (*Avenella flexuosa*). Diversity is highest in the ecotone along Muskrat Lake. A total of 31 plant species were observed in the dry northern forest, of which 27 were native species. The total FQI was 21.2 and the total mean C-value was 3.9.

Structure and composition of this forest are strongly influenced by historic clearing in the 1800s and there were several stumps remaining. One ancient red pine stump was 91.4 cm (36”) dbh. Most of these old stumps were much larger than the trees of today. The structure observed after fire and thinning is likely close to a dry northern forest that has had fire regularly applied, though older stands would have an uneven age distribution with several trees over 200 to 300 years old. There appears to be continuing mortality of trees impacted by the fire and coarse woody debris is beginning to accumulate, a characteristic feature of mature forests.

Following the fire, pine seedlings established throughout the forest, a feature lacking in many natural red pine stands in the Newberry and Shingleton Units. Though impacted by selective logging and invasive species along the logging roads, the Duck Lake site has the structure and composition of an exemplary dry northern forest and its rank could improve with time, continual application of low-intensity/low-severity fire, and closure of roads within the mapped high-quality area. Over time, trees may continue to die from the impacts of the fire (especially via duff scald cambial injuries). Additionally, windthrow from severe storms from Lake Superior will also increase coarse woody debris as the ecosystem matures and the structural complexity will improve,

The Muskrat Lake dry northern forest (EO ID 27081) consisted of pine-dominated forest with two kettle lakes and small bog.The area burned in a wildifre in 2012. Photo by J.M. Lincoln

especially if fire can be regularly applied. An active badger den was observed in 2023.

Management Considerations:
The Duck Lake fire has damaged the basal bark layer of several trees. A fire regime in the historical range of variability would likely have prevented much of the mortality that is occurring due to effects of anomalously high fuel accumulations. Prescribed fire should be introduced to replicate the historical fire regime. Fires should be low-intensity/low-severity and efforts should be made to protect older trees with duff scald injuries from mortality to promote an uneven age structure. Prescribed burns at intervals of every 5 to 20 years will encourage continued recruitment and establishment of pine and reduce oak and maple. Include lakes and wetlands in prescribed burns and burn as large an area as possible. Close as many roads within the burn unit as possible to reduce invasive species encroachment.

Red pine that burned in the 2012 Duck Lake fire showing bark injury (duff scald) (above). Open structure with relatively low tree density in the Muskrat Lake dry northern forest after burning and thinning. Photos by J.M. Lincoln

Pictured Rocks
Location: Pictured Rocks National Park
Natural Community Type: Dry Northern Forest
Rank: G3? S3; vulnerable (inexact) globally and vulnerable in Michigan
Element Occurrence Rank: B, good occurrence
Size: 25.4 ha (62.8 acres)
Element Occurrence Identification Number: 27075 (new)

Site Description: This is a pine-dominated forest occurring as two distinct polygons on a lower and upper terrace of Lake Superior (Fig. 11). Locally, the landscape features vast expanses of excessively drained sands with extensive outwash features such as beach ridges, dunes, and terraces associated with historic fluctuations in lake levels. The lower terrace is adjacent to the Lake Superior shoreline and features older, more stunted trees, and more white pine. The polygon on the upper terrace features a sparser canopy, less white pine, lower diversity, and more jack pine. It is likely that additional areas of dry northern forest occur on both terraces. The beach ridge between the polygons trends towards mesic northern forest with red maple, sugar maple (*Acer saccharum*), hemlock (*Tsuga canadensis*), and yellow birch (*Betula alleghaniensis*). A soil sample from the upper terrace showed an O horizon with 4cm of compressed duff of mostly needles that was acidic (ph 4.0), and A horizon of sand with organics (ph 5.0) and a B horizon of fin, light gray sands (pH 5.5).

The system is influenced by drought, wind throw, intense snow fall, and, historically, low intensity fires. There were more fire scars and charred stumps within the shoreline portion. This area was potentially historically influenced to a greater extent by Indigenous Peoples.

The canopy is sparse (50-70 % cover), average around 70%, and dominated by red and jack pine. Jack pine are typically 30 to 45 cm dbh and around 100 years old. One 34.9 cm dbh jack pine had 103 rings. Red pine are typically 30 to 60 cm dbh and 80 to 120 years old. A 57.5 cm dbh red pine was 129 years old. White pine are less frequent and typically

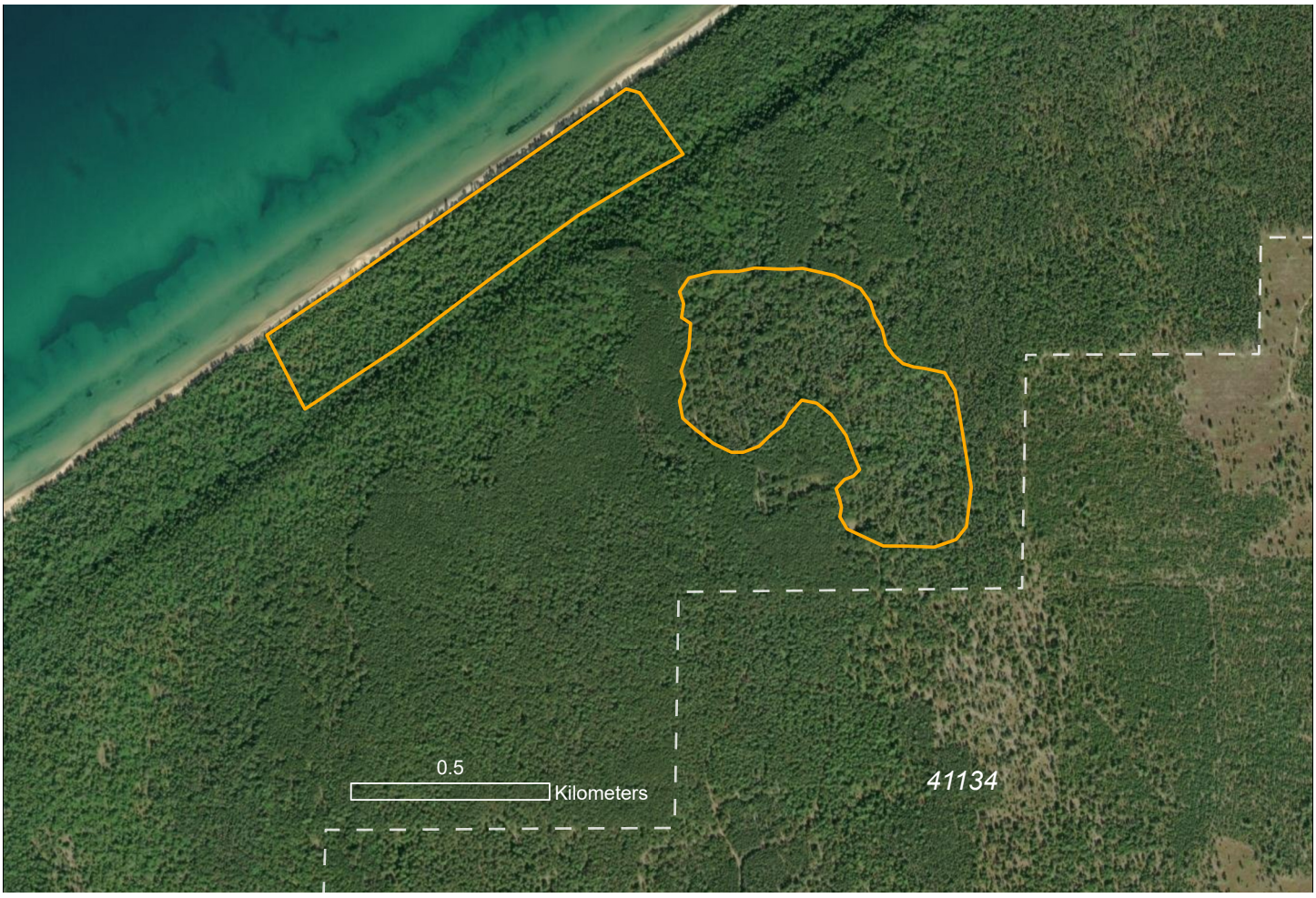

Figure 11. The Pictured Rocks dry northern forest (EO ID 27075) included a shoreline section on old dunes and an upland section occupying the ridge above Lake Superior.

range from 50 to 80 cm dbh. Towards the lake canopy coverage increases to 80%, with more white pine and some canopy red oak and paper birch. Along the lakeshore, trees are smaller but older and there is more white pine and less jack pine. One red pine along the shoreline with a fire scar and a dbh of 39.8 cm and had a ring count of 195 and the first 2.5 cm of the core had 52 rings. A 59.8 cm dbh white pine on the lakeshore terrace had 158 rings.

The subcanopy and understory is patchy (45-60% cover) and characterized by white, red, and jack pine with paper birch and red maple. Towards the shoreline there is increased fir and striped maple. A 2 m twisted subcanopy white pine growing along the shoreline had a 4 cm dbh and 62 rings.

The low shrub layer is sparse to locally dense (10-60% cover) and includes several berry-producing species but especially blueberries (*Vaccinium angustifolium*, *V. myrtilloides*, and *V. membranaceum*), Huckleberry, and serviceberry (*Amelanchier spicata*). Overall low sweet blueberry is the most abundant shrub.

The ground layer is patchy (10-40% cover) with low diversity. There is locally dense bracken that may be due to fire suppression. Other characteristic species include trailing arbutus (*Epigaea repens*), wintergreen, Canada mayflower, cow-wheat, star-flower, wavy hair-grass, and Pennsylvania sedge. Cladonia lichens coverage is 10-25% and typically less than in nearby younger, managed forests. Moss is also an important ground cover at around 10-25%.

A total of 27 plant species were observed in the dry northern forest with no observed non-native species. The total FQI was 25.5. The total mean C-value was 4.9.

Management considerations:
Include the forest and surrounding area in low-intensity, low-severity prescribed burns at intervals of every 5 to 20 years to promote regeneration of pines and maintain fire-adapted species. Lake Superior coastal areas may have been used by Indigenous People for cultural purposes. Work with local tribes when developing management goals.
Prevent new roads and trails from impacting this forest and close nearby trails and roads to reduce the harmful effects of fragmentation and other anthropogenic disturbance.

The lakeshore section of the forest included multiple age classes of pines in the canopy and understory. Many of the smaller diamter pines were well over 50 years old. Photo by J.M. Lincoln

Additional Stands Surveyed
In addition to the dry northern forests that met EO criteria, we summarize the condition of all the natural red pine stands we surveyed below.

Stand Structure and Composition
We targeted stands with natural red pine and a dominant stand age of 100 years or greater but also surveyed adjacent stands of natural pine, including jack pine and mixed pine. The oldest tree we aged was a red pine that was 223 years old in the Grand Marais Forest EO. Several stands contained trees that were much older than the dominant age recorded in MiFI but trees older than 150 years were rare throughout all stands (Appendix Table A5). Older trees were less common in stands that had been thinned. The plant species richness ranged from 10 species to over 30 species (36 species were recorded in the Lake Superior Campground EO). Mesophication was prevalent in the understories throughout the survey area, particularly on more mesic sites and tree densities were high in stands that hadn't been thinned. Standing dead wood was present throughout, particularly old charred snags.

Ecological processes
We observed evidence of historical fire in every natural red pine stand we surveyed. Despite decades of fire suppression all natural red pine stands surveyed contained charred stumps or snags demonstrating the ubiquity of fire as a process shaping natural red pine stands in the region. In addition to charred stumps and snags, fire scars were commonly observed on the oldest red pines but were rare on younger age cohorts, except in stands that burned in the Duck Lake fire.

Erosion is having a significant effect on natural red pine stands adjacent to the shoreline of Lake Superior. These stands included dry northern forest EOs at Grand Marais, Lake Superior Campground, and Crisp Point. Within these stand the erosion of the forested dunes due to high water levels and possibly the secondary effects of wind on unstable, eroded dunes is resulting in toppled pines along the lakeward margins of these forests.

Anthropogenic disturbance
All of the natural red pine stands we surveyed showed evidence of anthropogenic disturbance. The primary disturbances were thinning/logging, roads and trails, and a denuded ground layer due to past soil scarification or soil disturbance from logging. The intensity of disturbance ranged from low in the stands adjacent to Lake Superior to severe in natural red pine stands with a dominant age of over 100 years that were clearcut or had seed-tree cuts in the last decade.

Cultural elements
We observed stands with high cover of ground layer species that were valued by Indigenous People, such as huckleberry and blueberries. These stands were primarily located adjacent to Lake Superior in stands with low levels of anthropogenic disturbance. We did not observe any culturally-modified trees with peel scars but we did observe numerous red pines with fire scars that are likely evidence of cultural burning by Indigenous Peoples.

Stands for Management
One of the goals of this project was to identify stands that could be managed in a more holistic approach using principles of ecosystem management that also incorporate timber harvest. There were several stands identified during this process that did not meet the criteria for element occurrence that still retain important conservation potential. These areas of interest, or project areas, are characterized by mature trees, a semi-intact ground layer, large size, and are located in pine-dominated landscapes. Brief descriptions of potential suitable stands are provided in Appendix Table A5 and shown in Appendix Figure A1, and comprehensive management recommendations are detailed in the Discussion of this report.

Priority Species
We documented the presence of red crossbill (*Loxia curvirostra*) in several stands in two focal areas. This is a featured species in the State Forest management system (MacKinnon 2016 Featured Species Habitat Management Guidance). The stands where we detected red crossbills contained mature, natural red pine and had been thinned in the past five to 20 years. Our observations seem to have represented the vanguard of a larger movement of this peripatetic species so it is not clear whether the birds we observed were currently breeding or had previously bred in the area or had moved in more recently to feed on red pine seeds. We observed males and females but did not document breeding.

DISCUSSION

The Condition of Natural Red Pine Forests

Natural red pine stands in the Newberry and Shingleton FMUs are younger, have higher tree densities, and have understories with more mesophytic trees compared to pre-logging era stands. These stands contained numerous charred snags and stumps from historical fires. Recent wildfires have occurred locally within the area and include the 2007 Sleeper Lakes Fire and the 2012 Duck Lake Fire. Within the stands we surveyed, natural red pine regeneration was rare and highly localized. This shift toward mesophytic species has been observed throughout the Great Lakes Region and is fundamentally destabilizing the landscape because these sites are less resilient to drought and more susceptible to severe wildfires with their dense understories (Magruder 2013; Kipfmueller et al. 2021). In addition, the lack of pine regeneration will result in continued loss of red pine from the region. With appropriate management, particularly the renewal of low-intensity surface fire as a predominant ecological process.

Historically, pine-dominated forests had multiple age and size cohorts of pine, often with a substantial proportion of the canopy trees over 250 years old in the oldest stands. Although difficult to determine the precise age demographics of historical pine forests, we consistently located pine stumps substantially larger than any living trees on the landscape. One stump was 91.4 cm (36 in) with an estimated age of approximately 500 years based on the 90 rings counted in a 16.5 cm (6.5 in) section of the remaining stump. This age approximates the oldest documented red pines (Rudolf 1957).

Michigan Forest Inventory records were not always a reliable indicator of the presence of old red pine in a stand. Although most stands surveyed were even-aged with canopy red pine in the 90 to 110-year-old range, we located a few much older individual red pines. Multiple stands contained a small percentage

Mesophication was common in natural red pine stands in the Upper Peninsula. This photo shows mature red pine with an understory dominated by red maple and white pine and no red pine regeneration

Mesophication in a red pine stand that was managed by Indigenous Peoples in Upper Michigan (above). Photo by J.M. Lincoln. Open understory in a historical photo of a pine stand in Minnesota (Minnesota Historical Society).

(<5%) of red pine trees that were 150 to 230 years old. One of the oldest trees that we aged (223 years) was in a stand that had been thinned, had a dominant age of 70 years recorded in MiFI, and had no mention of older trees in the stand notes (Shingleton FMU; Stand 9, Compartment 41101). Red pine that are 150 years and older had a unique visual appearance including concave bark plates separated by relatively wide and deep fissures, large diameter lateral branches, asymmetrical crowns from wind damage, and frequently large cavities. The greater topological complexity of old red pines likely provides significantly more value to wildlife than the comparatively simple structure of younger pines that account for the majority of pines on the landscape.

Due to the potential undocumented presence of old pines, we recommend managers and planners conduct a thorough field survey before developing stand management goals and particularly before scheduling treatments in natural pine stands. We also encourage resource managers to look for culturally-modified trees, both canopy trees with fire scars or peel scars. Evidence of these cultural artifacts in natural red pine stands provides evidence of cultural burning within these forests. These living cultural artifacts as well as pine stumps with fire scars should be protected because they provide a connection to the past and information for researchers to reconstruct fire histories to better inform management of these ecosystems. The absence of older red pines on the landscape and the dearth of natural red pine regeneration necessitates protecting any remaining older trees from harvest to restore demographics that are closer to the range of natural variability.

All natural red pine stands surveyed contained either old charred snags and stumps or living trees with burn scars. Large, charred stumps greater than 60 cm (2 ft) in diameter are consistent with widespread fires that occurred in the region during the wave of Euro-American colonization (Loope and Anderton 1998; Stambaugh et al. 2021). The oldest living red pines also frequently had multiple basal fire scars. The ubiquity of fire evidence is consistent with fire histories from red pine stands in the Great Lakes Region documenting frequent, low-intensity fires at 5-to-20-year intervals in dry and dry-mesic northern forests, often ignited by Indigenous Peoples (Loope and Anderton 1999; Drobyshev et al. 2008; Kipfmueller et al. 2017; Sutheimer et al. 2021; Meunier 2022). The lack of recent fires and the associated loss of pine and other fire-adapted species creates a feedback loop that makes these forests increasingly resistant

The old red pine phenotype includes large concave bark plates, large-diameter, often gnarled lateral branches, and an asymmetrical crown. Photo by J.M. Lincoln.

to low-intensity surface fires, thereby perpetuating mesophytic species and accelerating the loss of pine and other fire-adapted species (Nowacki and Abrams 2008).

Natural red pine stands in the Newberry and Shingleton FMUs had very low levels of red pine regeneration and often high density of mesophytic tree species in the understory. For hundreds of years, red pine forests in the region were maintained and perpetuated by frequent, low-intensity surface fires, primarily ignited by Indigenous Peoples. Topographical and moisture gradients created uneven fire intensity, causing highly variable mortality of trees and shrubs, with multiple age and size cohorts of pines surviving fires and serving as seed sources for stand replacement (Meunier et al. 2019; Palik and D'Amato 2019; Kipfmueller et al. 2021). Frequent low-intensity surface fires promoted pine recruitment and maintained open conditions in the understory. With the loss of fire as an ecological process, the stands we surveyed often had a dense understory with red maple, birch, spruce, and balsam fir, particularly in moister microsites. Observations of the modern landscape are a stark contrast to historical descriptions of red pine stands along Lake Superior that noted a complete lack of understory vegetation between the red pine canopy and the ground layer as recorded by Chandler Gilman describing a forest near Pendills Bay west of Sault Ste. Marie in 1836:

> ...exclusively of pine trees of largest size; for miles there is not a maple or birch tree, though both have hitherto been common, nor a single particle of brush or underwood of any kind. (Gilman 1836)

A natural pine stand that has been thinned and scarified had pine regeneration but low ground layer diversity. Photo by J.M. Lincoln

Current Approaches to Management

Management practices that prioritize even-aged management are causing reduced diversity and diminished structural complexity within pine stands while also failing to naturally regenerate red pine. Managed stands observed during these surveys tended to have reduced cover and richness of ground layer plant species. The lack of natural red pine, understories dominated by mesophytic species, and increasingly variable climate conditions reduces the resilience of natural red pine forests to wildfire and disease and reduces their cultural value and value to wildlife.

Thinning and clearcutting is the most prevalent forest management in the region with many of the oldest natural red pine stands having undergone multiple thinnings. Current management is degrading recoverable, EO-quality dry northern forest and dry-mesic northern forest, particularly on dune ridges along Lake Superior. We documented a dry northern forest EO (EO ID 27015) in a forest that was thinned in 1995. This stand featured 200+ year old red pine and supported high ground layer diversity. Areas of the stand that were thinned and scarified had decreased ground layer diversity dominated by Cladonia lichens, lacked characteristic long-lived shrubs, and lacked significant red pine regeneration. A stand of natural jack pine adjacent to the EO was clearcut in 2016 (Stand 5; Compartment 41101) despite containing 150+ year old red pine. These intensive management interventions may achieve some forestry goals but degrade ecosystem integrity and jeopardize the sustainable management of natural red pine forests. Thinning can create a canopy structure and tree density that resembles natural conditions, but scarification of the soil needed to regenerate pine in the gaps denudes the ground layer. Likewise, converting natural pine stands to plantations by clearcutting, trenching, and planting results in the accelerated loss of old trees and a simplified vegetation composition with decreased value to wildlife and to Indigenous Peoples that use these forests to gather food and medicines. Even-aged management does not replicate mixed-severity disturbance that shaped dry northern forest ecosystems historically, particularly in areas with high

A natural jack pine stand **(**Stand 5 in compartment 41101 in the Shingleton FMU) was clearcut in 2016. This stand contained 150+ year old red pines and is adjacent to a new dry northern forest EO. Photo by P.R. Schilke

topographical complexity, such as those near Lake Superior, and it often eliminates seed sources needed for natural pine regeneration (Nyamai et al. 2014; Palik and D'Amato 2019).

Ground cover in pine stands varied from near continuous to patchy to unvegetated sands with few plant species. Unvegetated areas appear to be associated with scarification, trenching, and herbiciding that destroyed the upper soil layer. The combination of logging, scarification, and herbiciding is detrimentally impacting culturally significant, slow growing perennials and shrubs such as huckleberry, low sweet blueberry, and bearberry. These species are adapted to frequent, low-intensity fires and even when top-killed by fire can resprout from underground buds that survive surface fires. Fire also stimulates fruiting in many fire-adapted species such as huckleberry and blueberries (Duchesne and Wetzel 2004). While fires slow the growth of the ground layer they do not seem to cause the significant long-term decrease in cover and decreased biodiversity as do scarification and trenching (D'Amato et al. 2012).

Herbicide application is used to reduce competition with planted pines; however, the long-term effects of herbicide use on biodiversity and ecosystem function in pine stands have not been studied. Herbicide use may disturb or deplete soil fungal communities. Tests of herbicides on mycorrhizal colonization of conifers have been mixed with some studies finding reduced mycorrhizal colonization and others no difference in soils treated with herbicide compared to those without (Chakravarty and Chatarpaul 1990; Sidhu and Chakravarty 1990). Ericaceous species are dominant in the ground layer of dry and dry-mesic northern forests in Michigan and depend on ericoid mycorrhizal fungi to obtain nutrients in low-nitrogen soils, possibly by allowing plants to access nitrogen in decomposing organic matter. Red pine also forms mycorrhizal associations that increase its growth rate (Burns and Honakala 1990).

Fire suppression that has been a tenet of forest management for the past century may also contribute to depauperate, low diversity ground layers in dry northern forest and dry-mesic northern forest. As fire-adapted species decrease in the absence of fire their seedbanks become depleted and the distance to other seed sources and subsequent time needed to colonize newly burned areas increases. In addition, many of these species benefit from reduced competition and nutrient inputs that occur after burning. At the same time, fire suppression is associated with increased understory density of mesophytic species that reduce ground layer cover and increase the risk of severe wildfires and may increase the prevalence of pathogens (Ostry et al. 2012).

Non-native species are present on the landscape throughout the Newberry and Shingleton FMUs but are mainly limited to roads, trails, and other areas with frequent disturbance. Spotted knapweed (*Centaurea stoebe*), hawkweeds (*Hieracium piloselloides/ aurantiacum/caespitsoum*), and St. John's wort (*Hypericum perforatum*) are the species that pose the most significant threat with their ability to colonize recently disturbed areas such as logged stands. We did not see evidence of non-native species significantly altering ecosystem integrity in the stands we surveyed, regardless of management history.

Even-aged management with clearcuts, trenching, and planting is commonly used to reestablish red pine. Photo by J.M. Lincoln

We observed a frequent successional sequence in the ground layer of managed pine stands from unvegetated sand to increasing coverage by Cladonia lichens that appears to be a legacy of past anthropogenic disturbance. In sites that had well established Cladonia cover, Pennsylvania sedge occurred as a sparse cover within a matrix dominated by Cladonia. Cladonia may be capable of fixing atmospheric nitrogen and can tolerate prolonged drought and thus may have a competitive advantage on recently disturbed soils with very low nutrient and moisture availability. Thinning red pine on sandy soils can result in reduced soil moisture (Tarpey et al. 2008). After Cladonia becomes established and organic materials build up, nutrient and moisture levels increase and additional plant species are able to colonize these areas. Lichens and plant growth is typically very slow (3-5 mm per year for Cladonia) in these low nutrient soils and the effects of anthropogenic disturbance on the soils and ground layer remain visually evident for decades and possibly even longer. Lichens may have additional effects on plant succession by directly inhibiting the growth of some vascular plants through production of allelochemicals and shading of the soil surface. Some conifer species exposed to usnic acid, a secondary metabolite produced by Cladina lichens, showed reduced growth (Pizňak et al. 2019). However, the effects of lichens on dry northern forests and dry-mesic northern forests at landscape scales have not been well quantified (Crittenden 2000). Potential effects of lichens on dry northern forest and dry-mesic northern forest succession may be compounded by the extirpation of caribou (*Rangifer tarandus*), which are thought to have been common in the late Pleistocene to early Holocene, from the Upper Peninsula (Lemke 2015). Cladonia spp. are the primary winter food source for caribou but are unpalatable to other ungulates such as white-tailed deer (*Odocoileus virginianus*) and moose (*Alces alces*). Lichens may have also been harvested by Indigenous Peoples although we are not aware of any studies on possible landscape-scale effects of this practice on lichens abundance.

An opening with Cladonia lichens dominating the ground layer suggests a history of anthropogenic disturbance to the upper soil layer. Photo by P.R. Schilke

Alternative Management Considerations

Our management recommendations are centered on maintaining natural red pine on the landscape by renewing fire as a predominant ecological process and eliminating fragmentation around the highest quality forests that persist. We outline three actions to protect red pine and associated dry and dry-mesic forests. 1) Establish dry northern forest and dry-mesic northern forest conservation priority zones along Lake Superior and around other high-quality occurrences of the community type 2) establish project management areas in pine-dominated landscapes 3) introduce fire to replicate historical disturbance regimes.

Conservation Priority Zones

Dry northern forests along Lake Superior in the Newberry and Shingleton FMUs contain significant concentrations of old, natural red pines. In addition to old pines, these stands have relatively high plant diversity, low anthropogenic degradation, and high cultural value with a well-documented history of Indigenous management stretching back centuries (Loope and Anderton 1998). These areas represent a unique conservation opportunity and we recommend establishing conservation priority areas to protect and maintain them. In addition, there are existing dry northern forest EOs in the interior of the Newberry and Shingleton FMUs that merit consideration as Conservation Priority Zones. Some of these are already Ecological Reference Areas.

To preserve the ecological integrity of these forests we recommend replicating natural disturbance regimes and avoiding intensive management such as thinning, clearcutting, scarification, herbiciding, and trenching within natural pine and surrounding stands that are within one kilometer of Lake Superior. EOs 18810, 27080, and 27105 are high-quality examples of this forest type but are threatened by fragmentation, degradation, and erosion (Fig. 12). To protect these stands and other natural pine stands they should be buffered at least 500 m from logging and intensive management. Over the past two decades, high water levels and storms have eroded high-quality forest area, so to maintain current coverage and anticipate future losses to erosion, conservation priority areas should extend at least one kilometer inland.

Fire is a critical disturbance for maintaining the composition of high-quality dry northern forests and dry-mesic northern forests. Dry northern forests along

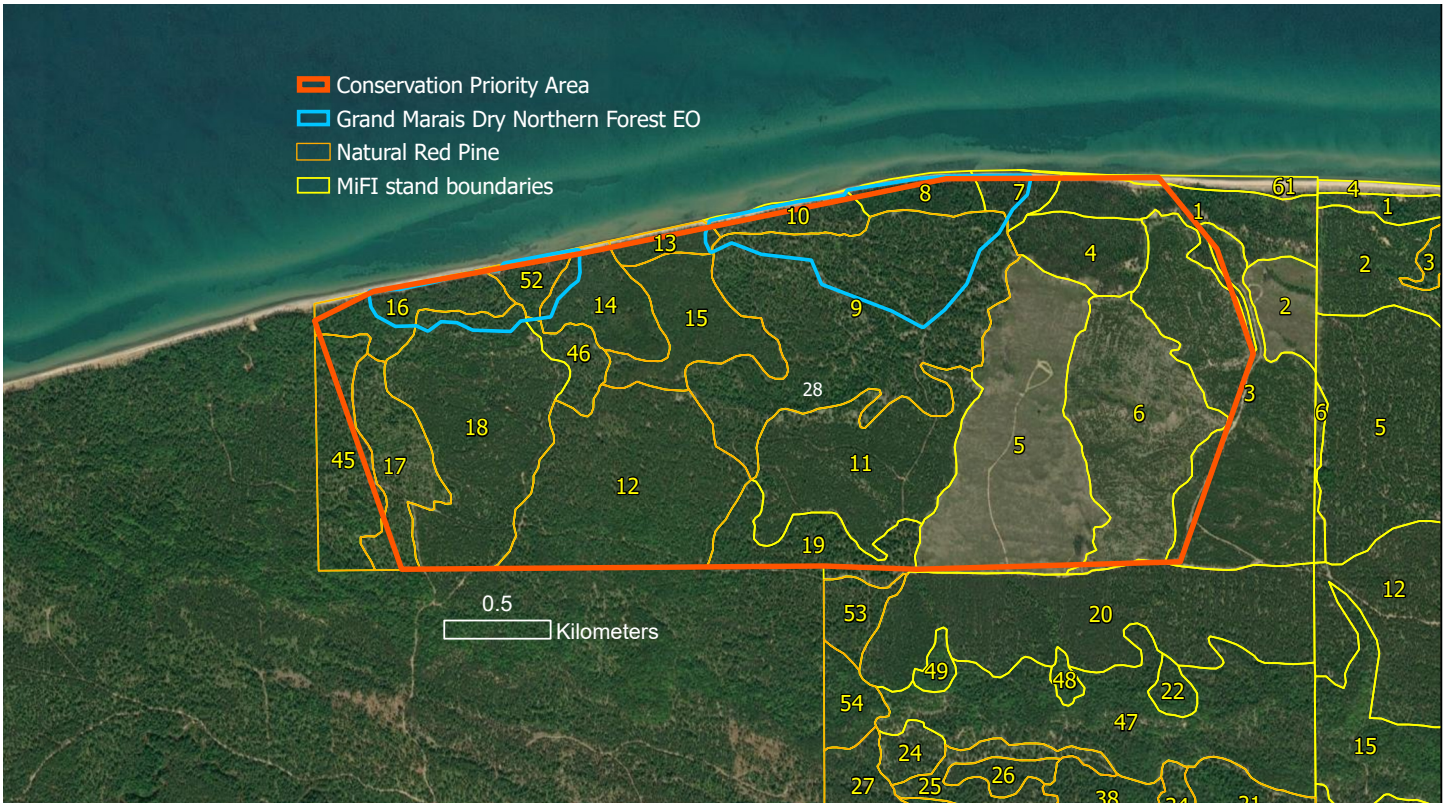

Figure 12. Potential Conservation Priority Zone in the Shingleton FMU east of Grand Marais. These areas have the highest conservation value and ecosystem integrity with core areas of high-quality dry northern forest such as in the Grand Marais EO (EO ID 27105) and areas of recoverable EO-quality dry northern forest in the surrounding stands. Prioritizing management with fire and avoiding timber harvest is suggested to preserve and enhance these areas.

Lake Superior developed in the presence of frequent fires, including low-intensity surface fires that occurred every 5 to 20 years since at least 1750 (Loope and Anderton 1998). With continued fire suppression, red pine will not regenerate and will continue to decrease in abundance. Additionally, the lack of recent fire has resulted in understory dominance by mesophytic species, leading to lower forest resilience to drought and greater susceptibility to wildfire. Use of scarification as a management tool to increase pine regeneration is not compatible with the conservation and maintenance of these forests due to the degradation of the ground layer and the associated loss of ecological and cultural value that results.

The ground layer of Lake Superior dry northern forests is of uniquely high ecological and cultural value. We observed several conservative plant species in lakeshore stands that we did not observe inland such as Hooker's orchid (*Platanthera hookeri*) and Menzies' Rattlesnake-plantain (*Goodyera oblongifolia*). We also observed large clones of huckleberry, blueberry, and bearberry in these forests. These plant species are well adapted to fire and are important features of cultural interest that were managed by Indigenous Peoples, who used them for food and medicine (Smith 1923; Loope and Anderton 1998; Anderton 1999). We estimate that some huckleberry stands in the Lake Superior Campground and Grand Marais dry northern forest EOs (EO IDs 18810 and 27105) are over 100 years old, assuming uniform radial spread from the center of clones (Pooler et al. 2008). Our observations are consistent with historical observations that noted the abundance of berries along Lake Superior in the Eastern Upper Peninsula in 1850:

> The huckleberries and blueberries especially abound along the south shore of the lake, on the sandy soil, under the shade of the red pines. Their fruit is much larger and sweeter, and borne in profusion than we had ever seen it elsewhere. (Foster and Whitney, 1851)

Anderton provides a comprehensive summary of the evidence for Indigenous management of shoreline areas with fire for berry production (1999). Indigenous management practices included lakeside territories that extended 80 to 160 km (50 to 100 miles) inland from the shoreline of Lake Superior (Cleland 1992). Such a pattern of Indigenous fire use would suggest that the vegetation of most of the Eastern and Central Upper Peninsula, and not only lakeshore areas, developed in the presence of Indigenous-ignited fire.

Along with use of fire to maintain these stands, we recommend exploring collaborations with local Tribal Nations, particularly to protect and maintain stands with unique characteristics and extensive histories of Indigenous management, such as those along the south shore of Lake Superior. We include more specific recommendations for implementing fire in the Returning Fire to the Landscape section below.

Excllent tree density, canopy struture, and groundcover of culturally valuable shrubs such as huckleberry has developed after this stand was burned in the 2012 Duck Lake fire and subsequently thinned. Photo by J.M. Lincoln

Potential Project Areas

We propose creating project areas around high-quality, recoverable natural red pine stands where an alternative management approach that combines periodic low-intensity surface fire and selective timber harvest can be used to promote red pine and biodiversity of fire-adapted species.

The Muskrat Lake Dry Northern Forest (EO ID 27081) in the Newberry FMU is a useful site to evaluate an approach to management that includes fire and timber harvest (Fig. 13). The site was burned in the Duck Lake Wildfire in May of 2012. Shortly after, the burned area was selectively logged. In 2023 the burned and thinned stands had excellent structure and composition and despite impacts of logging, qualified as an EO. One of the important features of the site was the adjacent wetlands that also burned in the fire. The ecotone, or transition between wetland and upland, was especially floristically diverse. The burned area also contained high coverage of slow-growing shrubs and sub-shrubs such as huckleberry only 12 years after it burned and areas with significant pine regeneration.

Late-successional natural red pine stands, especially those 90 years and older, typically have the greatest recovery potential. Combining selective timber harvest with low-intensity surface fire can help maintain and enhance the ecological integrity of dry northern forest and dry-mesic northern forest that don't qualify as EOs. Selective, periodic timber harvest creates canopy gaps that replicate natural disturbance to encourage pine regeneration while also providing economic returns. Burning encourages red pine regeneration while maintaining other important fire-adapted species. Adjacent cover types, particularly lakes, rivers, and other wetlands, should be prioritized when choosing project areas. The ecotones between wetlands and uplands are frequently areas of high biodiversity and can also buffer pine stands from severe droughts and fires. These ecotones are often less disturbed by human activity compared to uplands and thus have higher recovery potential.

We identified several stands of natural red pine that did not qualify as EOs but would be well-suited for management that combines low-intensity surface fire and selective timber harvest. We developed a map of potential project areas around these stands in the Newberry and Shingleton FMUs (Appendix Figure A1). Each project area includes at least one natural red pine or mixed pine stand with a dominant

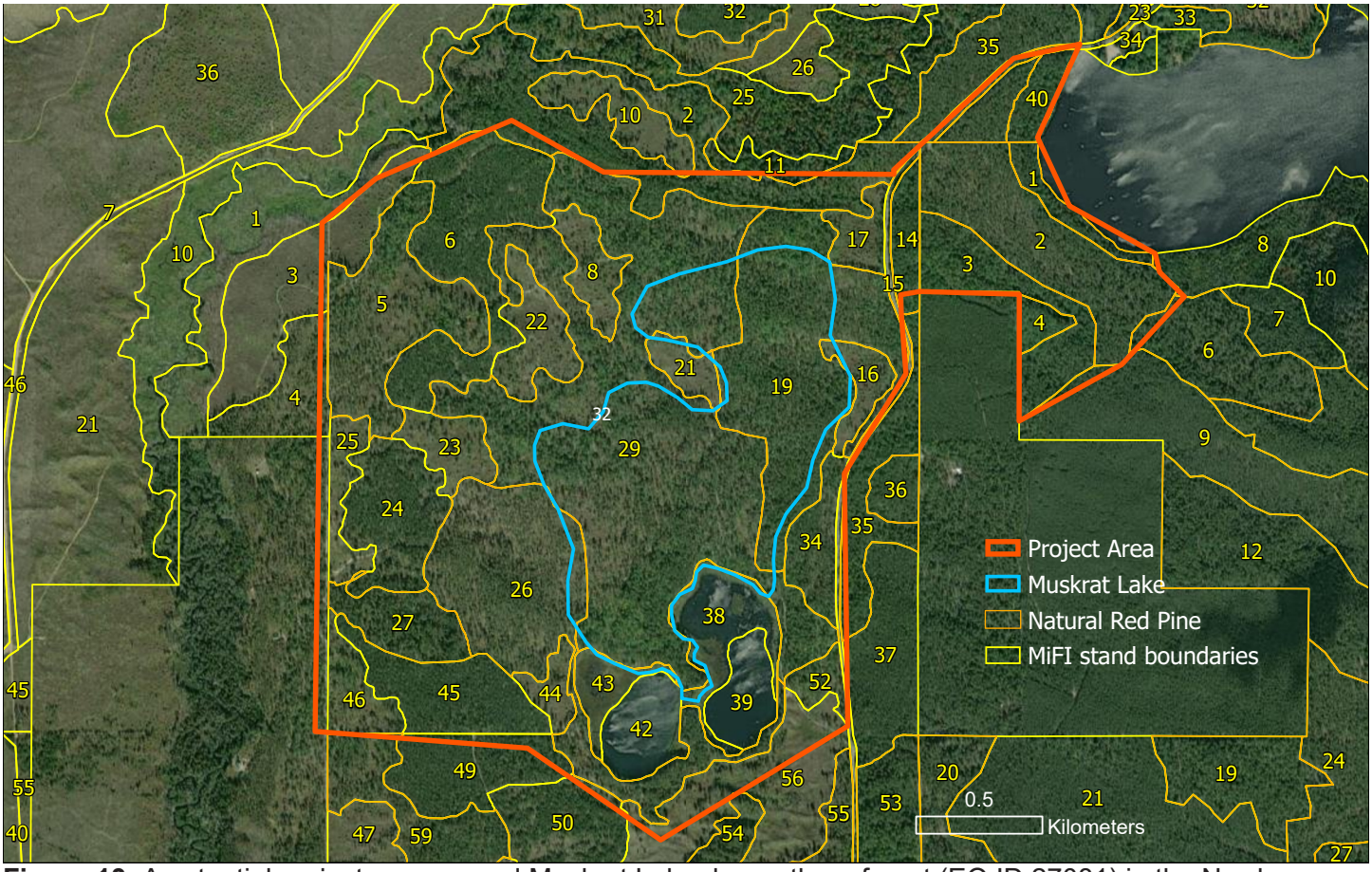

Figure 13. A potential project area around Muskrat Lake dry northern forest (EO ID 27081) in the Newberry FMU that can be maintained and expanded by combining low-intensity surface fire with selective timber harvest. Project areas are recommended around natural pine stands with high recovery potential and high diversity, such as those near lakes or wetlands, that don't qualify as EOs.

age greater than 90 years. The project areas are located within fire-adapted landscapes, often with lakes and other wetlands, that could be amenable to prescribed fire as a management tool. These project areas present opportunities for management with low-intensity prescribed burns that encompass multiple natural communities, including wetlands. Burning through upland/wetland ecotones can increase landscape-scale diversity and facilitate the spread of fire-dependent species among stands by creating natural gradients in fire intensity and severity based on species composition, soil moisture, and fuel accumulations. Project areas align with historical pine-dominated forests and areas with high fire need (Cohen et al. 2021) (Appendix Figure A2).

The main priority in managed stands is to retain the oldest red pines and to maintain a diverse ground layer that provides value to wildlife and cultural value to Indigenous Peoples. Where harvest is implemented, using light equipment and entering stands when the ground is frozen can reduce damage to the ground layer. Equipment should also be cleaned before entering a site to avoid the spread of non-native species.

We believe our approach maximizes the protection of biodiversity, maximizes resiliency to climate change, decreases costs associated with intensive management, protects water quality of the Great Lakes, and provides economic returns. In addition, establishing project ares for natural management can help align the use of prescribed fires to the natural communities that are most dependant on it.

Returning Fire to the Landscape

Fire has several benefits that cannot be replicated by other management techniques. In addition to replicating historical disturbance, fire creates complex vegetation structure such as standing dead wood and patchy tree and shrub cover. It encourages fire-adapted plants and enhances fruiting of species of cultural value and wildlife value. Fire remains an important part of the culture of the Indigenous Peoples of the region. Although questions remain, recent studies provide additional insights into the historical fire regimes in which dry northern forest and dry-mesic northern forest in the Upper Peninsula developed.

Recent evidence from tree and stump cores in the Upper Great Lakes suggests a higher frequency of historical surface fires than was previously understood. Low-intensity surface fires occurred every 5-20 years, on average, in dry northern forest across Upper Michigan. Frequency is particularly important for red pine regeneration where frequencies must be high enough to create suitable conditions for establishment that coincide with large red pine seed crops that occur only every five to ten years (Horton and Bedell 1960; Kozlowski and Ahlgren 1974). Higher fire frequencies also prevent mesophytic species from spreading and keep fuel levels low, reducing the risk of more severe fires. Some mesophytic species respond positively to fire initially but are limited by fire over long time scales (Nowacki and Abrams 2008). We recommend using the historical frequency of a fire every 5 to 20 years as a baseline for long-term maintenance of dry

A dry northern forest/wetland ecotone that burned in the 2012 Duck Lake fire. Note the standing dead wood on the distant shore. Allowing prescribed fires to burn into wetlands can increase diversity and structural complexity. Photo by J.M. Lincoln

northern forest and dry-mesic northern forest stands. More frequent burns, two to three per decade, may be necessary initially, depending on the history of the stand and available fuel, to provide a competitive advantage to fire-adapted plants and regenerate red pine.

Evidence from the Upper Peninsula shows that fires occurred disproportionately during the dormant season (late fall to early spring) based on fire scar positions relative to growth rings (Muzika et al. 2015; Sutheimer et al. 2021). Dormant season burns may increase the number of pine seeds reaching mineral soil depending on the timing of seed rain, which usually peaks in early fall. Spring and early summer burns create more competition from early plant colonizers that can become established before the peak of red pine seed rain and may cause higher tree mortality (Kozlowski and Ahlgren 1974; Meunier 2022). Late autumn fires (late September to November) may also lower the risk of severe crown fires in jack pine and red pine forests (Jolly et al. 2016).

In addition to seasonal timing of burns, we recommend considering current weather and climate to maximize the ecological returns of burning and minimize negative impacts to the pine canopy cohort. Fire scar analyses suggest that historical fires, particularly large and severe fires, often occurred during droughts (Stambaugh et al. 2024). Timing burns during droughts may increase burn intensity and tree mortality and susceptibility to disease. Burning during droughts may also maintain open wetlands as was the case during the Duck Lake fire which burned around Muskrat Lake. Water levels of many inland lakes and wetlands fluctuate with a periodicity of about 13 years (Watras et al. 2014). This frequency falls within the mean fire return interval for dry forests of the region and low water periods may be an ideal time for prescribed fires in dry northern forest and dry-mesic northern forest stands.

The reintroduction of fire to areas where it has been absent for nearly a century poses several challenges. In addition to societal concerns about burning, anomalously high fuel loads need to be considered. Large red pine boles are strongly resistant to mortality from low-intensity surface fires, even with high fuel loads (Scherer et al. 2016); however, raking away fine fuels from ecologically and culturally valuable old trees may be necessary to reduce the risk of mortality and injury such as the duff scald we observed at the base of pine trees that burned in the Duck Lake fire. High density of understory trees such as spruce and fir increases the risk of crown fires and it may be necessary to mechanically clear understory trees before introducing fire to stands with dense understories.

Benefits to Wildlife

We observed benefits to game species in Muskrat Lake Forest as a result of the fire. This area had local flushes of aspen following the fire and it is the only place we observed grouse during our surveys. Browse from white-tailed deer was also most prevalent in the areas of natural forest that had been burned. Black bears feed heavily on blueberries and huckleberries and fire will likely increase food availability for bears.

Burned (left) and unburned (right) red pine stand in the Muskrat Lake dry northern forest. The burned area has a much more open understory. Photo by J.M. Lincoln

Beyond the benefits to game species, a return of widespread fire on the landscape would benefit several rare species. Kirtland's warbler (*Setophaga kirtlandii;* State Endangered) is one of the rarest, most geographically restricted birds of North America. A portion of its breeding area occurs in the Newberry and Shingleton FMUs. Historically, this species was completely dependent on jack pine forests that regenerated after fire. The warblers occupy stands with 5- to 23-year-old jack pine (Probst 1987). This range of jack pine ages almost perfectly matches the documented return interval of cultural fire within the natural pine stands of this region. Additionally, birds in forests that have been burned have higher pairing success than in unburned forests (Probst and Hayes 1987). This once federally endangered species has been delisted in large part due to establishment of plantations. It seems its decline, like the decline of natural red pine, can be closely attributed to the cessation of Indigenous cultural fires. Our management recommendations for the non-EO project areas align with the creation and maintenance of Kirtland's warbler breeding habitat.

Additional rare species would also benefit from our recommended management approach. We provide life history of each species and potential benefits of management of dry and dry-mesic northern forest in Appendix Table A6. Rare species that may benefit from prescribed fire include eastern whip-poor-will (*Antrostomus vociferus,* State Threatened), upland sandpiper (*Bartramia longicauda;* State Threatened), spruce grouse (*Canachites canadensis,* State Threatened), common nighthawk (*Chordeiles minor;* Special Concern), evening grosbeak (*Coccothraustes vespertinus,* State Threatened), northern flying squirrel (*Glaucomys sabrinus,* Special Concern), Connecticut warbler (*Oporornis agilis,* Special Concern), smooth green snake (*Opheodrys vernalis,* Special Concern), black-backed woodpecker (*Picoides arcticus,* Special concern), northern blue (*Plebejus idas nabokovi;* State Threatened), and sharp-tailed grouse (*Tympanuchus phasianellus,* Special Concern) (Derosier et al. 2019). Supercanopy pines are also important as nesting trees for bald eagle (*Haliaeetus leucocephalus,* Special Concern), osprey (*Pandion haliaetus*, Special Concern), and merlin (*Falco columbarius*, Special Concern) (Rogers and Lindquist 1992).

Future Work

Natural red pine forests were once widespread in Michigan but old-growth red pine is now one of the rarest forest community types in the Great Lakes region. Due to the increasing rarity of natural red pine in Michigan, surveys to identify remaining stands with high ecological integrity should be a regional conservation priority. Identifying stands that have exceptional conservation value is important to protect the dry northern forest natural community type. We surveyed an estimated 10% of the existing natural red pine stands in the Newberry and Shingleton FMUs during the 2023 field season. Continuing surveys in these FMUs are critical for refining priority areas for protection and management.

While this area of the Upper Peninsula features a prevalence of natural red pine, there are several other areas around the state with natural red pine stands that warrant targeted surveys, particularly in the Atlanta, Grayling, Roscommon, and Traverse Bay FMUs in the Lower Peninsula and the Escanaba FMU in the Upper Peninsula.

Because prescribed fire is not a widely used management tool in dry forests in Michigan, monitoring the impacts of prescribed fire is essential for developing the most effective management approach. Monitoring the effects of prescribed burning will be important to maximize the ecological benefits and efficiency of fire management. Pre- and post-burn monitoring of plants and animals, particularly red pine in different vegetative strata and rare species, will be valuable to determine ideal burn size, intensity, timing, and frequency in a given stand.

Michigan Forest Inventory records may not capture the presence of rare, old red pine trees. Future inventory would benefit from prioritizing the inclusion of old red pine, either in the notes or as a separate age category. Because inventory is often used to develop stand treatments this is a critical gap. We also recommend including information on fire scars, stumps, and other culturally-modified trees in MiFI to inform management.

Implementing fire can pose unique logistical challenges, including financial constraints. Management decisions would be aided by more information on the cost of prescribed burning, particularly compared to the cost of current management such as scarification, herbicide application, and trenching and planting.

CONCLUSIONS

Red pine is an iconic species in Michigan and it extremely important culturally, economically, and ecologically. There are growing challenges to naturally regenerate red pine and current management approaches on public lands favor intensive forestry techniques that do not factor in the protection of native biodiversity. The goal of this project was to identify natural red pine stands in the Newberry and Shingleton FMUs and to develop strategies to manage these forests in a way that promotes biodiversity and allows sustainable harvest in an ecologically-informed manner.

Our process for identifying stands of natural red pine allowed us to locate four previously undocumented element occurrences of dry northern forest. These forests were of natural origin, support a high degree of ground layer diversity, and relatively old red pine in the canopy. These are frequently between 150 to 230 years old and show evidence of having survived multiple surface fires. Red pine regeneration is uncommon and localized in these stands, suggesting that natural red pine will likely continue to decrease in this region, particularly where fire is absent. We urge protection of these areas by establishing no-cut buffers around natural communities and applying regular low intensity, low severity late-season prescribed fire in a way that mimics historic cultural fires of Indigenous Peoples. We also recommend engaging with Tribal communities to learn about cultural burning and discuss opportunities for co-management of these lands

We also identified several stands of natural red pine that did not qualify as high-quality natural communities, but that would benefit from an alternative management approach that incorporates fire and timber harvest to promote a climate resilient landscape that supports both economic and ecological goals. Current red pine management guidelines and decision-making also fail to incorporate all vegetative strata, including the ground layer of low-shrubs, flowering plants, and grasses. The ground layer typically accounts for the vast majority of plant diversity in dry northern forests and is thus of critical importance when managing stands for ecological, cultural, and wildlife value. Common practices of scarification, furrowing, and herbiciding irreparably degrade the landscape through elimination of principle components of the ecosystems.

Plantations were initially developed as a tool to stabilize a landscape catastrophically altered by European colonization. The ongoing conversion of natural forest to plantations, often with the broadcast application of herbicide, is degrading state-owned natural areas at an increasing rate. Plantations are especially vulnerable to the increasing volatility of climate change. The practice of converting natural forest to plantation with the use of broadcast herbicide reduces biodiversity.

The accelerating simplification of remaining natural red pine stands in the Central Upper Peninsula is profoundly transforming the landscape. The natural red pine forests in the Newberry and Shingleton FMUs were historically maintained by cultural fire for at least hundreds of years as evidenced by the ubiquity of charred snags and stumps and fire-scarred trees. Following European settlement, removal of Indigenous Peoples from their ancestral lands, implementation of fire suppression, and the application of industry forestry policies over ecological management principles caused fundamental components of the natural red pine forests to be eliminated. We propose that these natural red pine forests could be managed with periodic fire and timber harvest to perpetuate natural red pine while avoiding the most damaging land management practices that are presently widespread.

We especially urge managers and conservation planners to conserve natural red pine stands associated with EOs of dry northern forest in the Newberry and Shingleton FMUs. We added several new EOs along the south shore of Lake Superior. These stands were shaped by a well-documented history of Indigenous stewardship and support markedly higher plant diversity than non-EO stands. These areas also generally have had less intensive forestry intervention in recent decades. We recommend enhanced protection from harvest or scarification of stands within at least one kilometer of the Lake Superior shoreline and adjacent to existing EOs and greater consideration of the ground layer in management of natural red pine throughout the region. Partnering with local Tribal Nations to protect and enhance the cultural value of these areas is also recommended.

There are likely several areas of high-quality natural red pine forest remaining on the landscape, particularly along Lake Superior and inland areas adjacent to lakes and other wetlands. With adjustments to management approaches, these areas could serve as reservoirs of native biodiversity, help make the landscape more resilient to an uncertain future, and serve as templates for reconnecting displaced peoples to their ancestral homelands and the natural areas to which they were so connected. While there are obstacles to the approach that we outline, we feel the benefits are worth the challenges.

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Moccasin Flower (*Cypripedium acaule*) was common in the Lake Superior Campground EO. Photo by J.M. Lincoln

APPENDIX

Table A1. circa 1800 Land Cover with pine-dominated land cover types by forest management units

FMU	Size (acres)	White-red pine forest	Jack-red pine forest	Pine barrens
Atlanta	1,232,414.7	147,945.6 (12%)	148,141.3 (12%)	4,070.9 (0.3%)
Baraga	3,829,238.5	63,522.5 (1.7%)	108,58.1 (0.3%)	8,762.9 (0.2%)
Cadillac	1,788,210.1	126,526.4 (7.1%)	98,759.8 (5.5%)	24,320.6 (1.4%)
Escanaba	1,859,961.5	75,579.3 (4.1%)	16,362.1 (0.9%)	19,439.1 (1%)
Gaylord	1,620,579.3	48,083.7 (3%)	38,723.0 (2.4%)	1,678.5 (0.1%)
Gladwin	2,079,318.4	97,153.8 (4.7%)	34,053.6 (1.6%)	17,853.7 (0.9%)
Grayling	1,384,529.8	156,822.0 (11.3%)	462,092.4 (33.4%)	123,435.4 (8.9%)
Gwinn	1,377,133.1	65,938.0 (4.8%)	70,710.2 (5.1%)	417.3 (<0.1%)
Newberry	776,295.0	32,973.4 (4.2%)	57,640.7 (7.4%)	2,140.9 (0.3%)
Pigeon River Country	131,879.6	23,874.9 (18.1%)	5,240.5 (4%)	0.0 (0%)
Roscommon	739,354.7	177,429.2 (24%)	82,421.5 (11.1%)	18,010.5 (2.4%)
Sault Ste Marie	1,485,466.3	22,263.8 (1.5%)	23,261.4 (1.6%)	31,333.2 (2.1%)
Shingleton	1,263,672.2	59,392.9 (4.7%)	21,329.9 (1.7%)	1,071.8 (0.1%)
Southern	15,977,626.4	36,606.6 (0.2%)	9,603.4 (0.1%)	2,949.8 (<0.1%)
Traverse City	1,498,155.9	143,361.9 (9.6%)	33,329.3 (2.2%)	14,971.0 (1%)

Table A2. Existing dry northern forest element occurences in Michigan Heritage Database (2023). EO Ranks: A = excellent integrity, AB = excellent or good integrity, B = good integrity, BC = good or fair integrity, C = fair integrity, CD = fair or poor integrity, D = poor integrity

EO ID	FMU	Survey Site	EO Rank	Last Obs Date	Acres
14557	Atlanta	Bell's Landing	Extirpated	07/20/2016	30.5
23408	Atlanta	Thunder Bay Pines	D	07/16/2019	22.2
6355	Baraga	Eagle Harbor	C	09/04/1986	242.9
16747	Escanaba	Ogontz Lakeplain	AB	08/21/2009	312.3
5689	Grayling	Little Trout Lake	BC	10/09/1991	186.3
5690	Grayling	O'Brien Lake	BC	09/02/1991	48.7
7090	Grayling	North Hoppy Lake	BC	08/05/1986	513.8
10262	Grayling	Crawford Red Pines	C	05/25/2021	18.8
11225	Grayling	Hartwick Pines	BC	07/14/2009	34.2
14556	Gwinn	Huron Mountain Jack Pines	B	07/30/1985	334.6
23799	Gwinn	Bonsai Burma Pines	B	07/23/2020	11.1
708	Newberry	Fisher Bridge Red Pines	D	07/07/2020	246.4
4328	Newberry	Barfield Lakes	C	08/11/2016	37.6
5133	Newberry	Clark Lake Pine Ridges	AB	07/13/2010	45.5
12024	Newberry	Barclay Lake Jack Pines	B	07/07/2020	175.1
14558	Newberry	Blind Sucker Creek	B	05/28/2021	136.9
17342	Newberry	Two-Hearted	AB	07/18/2018	491.5
17869	Newberry	Tahquamenon River Mouth	AB	08/06/2010	164.2
17913	Newberry	Prison Camp Dry Northern Forest	A	07/30/2015	123.6
18810	Newberry	Lake Superior Campground	B	05/28/2021	169.7
24338	Newberry	Wolf Scat Pines	C	05/29/2021	2.5
3510	Roscommon	Houghton Lake Red Pines	D	07/18/2016	10.6
11065	Roscommon	Roscommon Red Pines	BC	06/05/2018	43.2
991	Sault Ste Marie	Pointe Aux Chenes	C	08/18/1986	170.5
1762	Shingleton	Sunken Lakes Red Pines	B	07/12/2007	109.4
2709	Shingleton	Southside Bridge Red Pines	BC	07/09/2006	94.6
20695	Shingleton	Hay Meadow Pines	A	08/13/2016	294.9

Table A3. Existing dry-mesic northern forest (DMNF) element occurences in Michigan Heritage Database (2023). EO Ranks: A = excellent integrity, AB = excellent or good integrity, B = good integrity, BC = good or fair integrity, C = fair integrity, CD = fair or poor integrity, D = poor integrity

EO ID	FMU	Survey Site	EO Rank	Last Obs Date	Acres
14561	Atlanta	Chadwick Creek	D	07/21/2016	14.4
18765	Atlanta	Norway Pines	BC	07/16/2019	186.3
18843	Atlanta	Tomahawk Pines	BC	06/09/2021	9.8
26200	Atlanta	Little Ocqueoc River Pines	C	06/27/2022	34.6
26201	Atlanta	Rush Lake Pines	C	05/26/2022	72.8
3641	Baraga	Estivant Pines	B	08/12/1981	232.1
12155	Baraga	Marsh Lake Red Pines	AB	08/27/2009	16.0
17853	Baraga	Lost Lake DMNF	B	08/19/2010	57.9
18056	Baraga	Porcupine Oaks	AB	08/12/2010	94.2
18751	Baraga	Fence River Pines	C	08/20/2011	33.4
18890	Baraga	Covington-Nestoria DMNF	C	07/11/2012	134.9
4736	Cadillac	Railroad Lake	C	09/28/1989	191.4
19149	Cadillac	Pine Ridge	BC	09/02/2015	138.5
17309	Escanaba	Lost Lake	B	07/26/2020	264.4
17313	Escanaba	Groveland	B	07/22/2019	564.4
17374	Escanaba	Bill's Creek	AB	07/29/2009	98.9
19741	Escanaba	Piers Gorge Forest	C	08/29/2013	101.4
9259	Gaylord	Pointe La Bar	AB	08/24/2016	387.6
13195	Gaylord	Nebo Trail	B	08/09/2010	681.0
18860	Gaylord	Spirit Lake Pines	BC	07/05/2020	263.4
20453	Gaylord	High Island	B	08/14/2015	114.9
4499	Gaylord/Pigeon River	Pigeon River Pines	BC	06/15/2020	81.8
11917	Gladwin	Veterans Memorial Park	C	05/31/1981	11.6
24378	Gladwin	Big Charity Island	C	08/25/2021	30.8
918	Grayling	Hartwick Pines	BC	07/14/2009	54.4
7930	Grayling	Honawan Lake	BC	10/09/1991	421.5
8810	Grayling	Blockhouse Creek	C	09/17/1992	32.2
9699	Grayling	McDonald Creek	BC	10/10/1991	43.9
11519	Grayling	Byron Lake Area	BC	10/09/1991	1,219.6
11915	Grayling	Loud Dam Pond	BC	09/01/1994	64.2
17325	Grayling	Dalibarda Pines	BC	09/03/2009	77.4
18778	Grayling	Au Sable Pines	BC	07/10/2020	71.7
19489	Grayling	Mason Tract	C	05/24/2021	32.4
19490	Grayling	Chase Bridge Pines	C	05/24/2021	18.4
22093	Grayling	Trout Unlimited	C	06/05/2018	11.0
993	Gwinn	Bryan Creek	BC	07/20/2020	58.5
2929	Gwinn	Silverlead Creek	BC	09/23/1994	130.5
4432	Gwinn	Huron Mountains	AB	08/06/1981	546.1
15922	Gwinn	Landon Lake Pines	B	09/09/2010	49.8
17348	Gwinn	Pesheke Highlands	B	05/30/2021	794.4
17365	Gwinn	Rocking Chair Lakes	AB	08/22/2009	70.9
17835	Gwinn	Pesheke Pines	B	08/10/2010	13.2
18813	Gwinn	Little Presque Isle	B	08/18/2011	5.6
21316	Gwinn	Caron Pines	BC	08/23/2017	14.1
2295	Newberry	Beavertown Lakes North	AB	09/21/1986	24.6
7990	Newberry	North Branch Lakes White Pines	BC	07/27/2007	91.7

9666	Newberry	Beavertown Lakes	AB	08/20/2018	327.5
12496	Newberry	Swamp Lakes	AB	07/26/2019	109.0
15950	Newberry	Pretty Lake Pinery	AB	08/02/2007	578.6
16920	Newberry	Dawson Creek DMNF	AB	08/23/2018	77.8
16924	Newberry	Two-Hearted Lakes DMNF	B	07/16/2018	146.3
17914	Newberry	Little Two-Heated Lakes Pines	AB	07/27/2019	123.4
17923	Newberry	Prison Camp Pine Ridges	AB	07/30/2015	321.3
20625	Newberry	Lynch Creek Forest	B	07/31/2015	19.4
26197	Newberry	Pickleman's Pines	B	07/28/2022	28.4
23791	Pigeon River	Walled Lake Pines	C	06/17/2020	8.6
18783	Roscommon	Nine Mile Pines	BC	06/08/2022	6.1
18789	Roscommon	Hudson Creek	BC	06/04/2018	35.0
12200	Sault Ste Marie	Hiawatha National Forest Dunes	B	09/04/1986	502.2
19928	Sault Ste Marie	Kincheloe Pines	CD	09/15/2014	5.2
26260	Sault Ste Marie	Harbor Island	BC	07/27/2022	16.5
10665	Shingleton	Indian River Pines	BC	08/06/1983	73.6
10971	Shingleton	Negro Creek	D	06/25/2006	89.3
14560	Shingleton	Hartman White Pine	BC	07/12/2007	24.2
238	Southern	Big Goose Woods #1	C	07/29/1989	15.9
3129	Southern	Muskegon State Park	BC	07/21/2010	214.8
11914	Southern	West Tract Forest	BC	06/23/2006	62.4
18589	Southern	Port Huron DMNF	BC	08/03/2011	330.0
18974	Southern	Gulch Road Forest	C	09/20/2012	14.0
18975	Southern	Turner Creek Forest	C	08/23/2012	11.2
20103	Southern	Wabasis Forest	C	05/12/2015	20.6
20782	Southern	Heiss Forest	CD	07/08/2015	71.8
3082	Traverse City	Leffingwell Point	C	07/25/2012	11.8
3934	Traverse City	Sand Lakes	BC	07/06/2006	474.8
4712	Traverse City	Deer Lake Bayou	C	08/12/1987	16.3
19139	Traverse City	Kehl Lake	C	07/26/2012	44.4

Table A4. Current natural pine cover on state of Michigan forest lands from Michigan Forest Inventory records (Michigan DNR)

FMU	Size (acres)	Nat. white pine	Nat. red pine	Nat. jack pine	Nat. red pine >100
Atlanta	1232414.7	1,288.8 (0.1%)	5,960.7 (0.5%)	6,893.9 (0.6%)	819.2 (0.1%)
Baraga	3829238.5	1,012.2 (<0.1%)	1,223.7 (<0.1%)	5,028.5 (0.1%)	275.3 (<0.1%)
Cadillac	1788210.1	2,734.1 (0.2%)	1,609.9 (0.1%)	2,734.1 (0.2%)	141.4 (<0.1%)
Escanaba	1859961.5	3,018.4 (0.2%)	3,930.4 (0.2%)	691.5 (<0.1%)	1,471.3 (0.1%)
Gaylord	1620579.3	1,382.9 (0.1%)	1,651.8 (0.1%)	2,111.0 (0.1%)	389.0 (<0.1%)
Gladwin	2079318.4	2,435.2 (0.1%)	1,726.5 (0.1%)	2,993.0 (0.1%)	132.8 (<0.1%)
Grayling	1384529.8	1,787.5 (0.1%)	3,551.1 (0.3%)	19,173.0 (1.4%)	803.1 (0.1%)
Gwinn	1377133.1	2,143.2 (0.2%)	2,063.4 (0.1%)	5,431.7 (0.4%)	1,217.6 (0.1%)
Newberry	776295	8,511.4 (1.1%)	12,183.3 (1.6%)	29,142.7 (3.8%)	6,696.4 (0.9%)
Pigeon River	131879.6	2,760.6 (2.1%)	2,555.3 (1.9%)	1,948.2 (1.5%)	536.6 (0.4%)
Roscommon	739354.7	3,375.9 (0.5%)	3,468.3 (0.5%)	12,373 (1.7%)	945.0 (0.1%)
Sault Ste Marie	1485466.3	1,204.7 (0.1%)	622.7 (<0.1%)	690.0 (<0.1%)	20.8 (<0.1%)
Shingleton	1263672.2	9,423.2 (0.7%)	12,116.5 (1%)	20,032.5 (1.6%)	2,136.1 (0.2%)
Southern	15977626.4	556.4 (<0.1%)	432.2 (<0.1%)	513.2 (<0.1%)	0.0 (0%)
Traverse City	1498155.9	3,401.0 (0.2%)	4,133.2 (0.3%)	9,490.4 (0.6%)	241.6 (<0.1%)

Table A5. Pine stands surveyed in June 2023. We categorized stands as recoverable based on current structure, composition, and feasibility of management with prescribed fire. Survey areas correspond to the mapped areas in Figure A1. MiFI cover: NRP = natural red pine, NJP = natural jack pine, NMP = natural mixed pine, NRO = natural red oak

FMU	Survey area	Cmpt.	Stand	MIFI cover	Age	Oldest tree age (dbh cm)	Plant rich.	Recoverable
Newberry	1	42030	55	NRP	109	red pine 101 (49)	12	yes
Newberry	1	42031	3	NRP	103	NA	20	no
Newberry	1	42031	102	NJP	22	NA	13	yes
Newberry	1	42031	41	NRP	103	red pine 106 (36.9)	15	yes
Newberry	1	42030	53	NRP	84	red pine 122 (50.1)	15	maybe-dense understory
Newberry	1	42031	10	NWP	108	white pine 109 (50.8)	14	maybe-dense understory
Newberry	1	42030	54	NRP	93	red pine 103 (61.2)	12	yes
Newberry	1	42030	57	NJP	21	red pine 67 (38)	12	yes
Newberry	2	42019	64	PRP	88	red pine 98 (47.3)	15	yes
Newberry	2	42019	60	NRP	92	red pine 88 (47)	13	yes
Newberry	2	42019	52	NMP	113	red pine 177 (56.3)	16	maybe-dense understory
Newberry	2	42019	44	NJP	32	red pine 93 (53.9)	10	yes
Newberry	2	42019	53	NRP	101	red pine 110 (41.8)	15	yes
Newberry	2	42019	41	NRP	102	red pine 115 (58.9)	21	yes
Newberry	2	42019	61	NMP	92	red pine 40 (34.4)	10	yes
Newberry	2	42019	59	NWP	107	red pine 98 (44)	16	yes
Newberry	2	42019	58	NMP	106	white pine 115 (51)	16	yes
Newberry	3	42019	2	NRP	105	red pine 100 (52.5)	17	yes
Newberry	4	42040	19	NRP	103	red pine 108 (33)	14	yes
Newberry	4	42040	29	NRP	104	red pine 97 (38.1)	18	yes
Newberry	4	42040	26	NRP	103	red pine 110 (43.2)	22	maybe
Newberry	4	42040	17	NRO	11	NA	11	no
Newberry	5	42044	2	NRP	117	red pine 112 (40.6)	15	yes
Shingleton	12	41133	59	NRP	102	red pine 106 (52.4)	12	maybe-dense understory
Shingleton	12	41133	40	NRP	102	red pine 110 (53.8)	13	yes
Shingleton	12	41133	41	NMP	107	red pine 106 (49.9)	13	yes
Shingleton	12	41133	54	NRP	104	red pine 110 (38.7)	14	no
Shingleton	12	41133	63	NRP	111	red pine 118 (40.3)	16	maybe-dense understory
Shingleton	15	41128	37	PRP	62	red pine 70 (27.9	14	yes
Shingleton	15	41128	48	PRP	69	red pine 45 (25.4)	16	maybe
Shingleton	15	41128	29	NRP	84	red pine 83 43.2)	15	yes
Shingleton	15	41128	24	NWP	93	red pine 81 (38.1)	19	maybe
Shingleton	16	41134	4	NJP	27	jack pine 20 (10.7)	13	yes
Shingleton	16	41134	5	NJP	21/87	red pine 70 (38.6)	14	yes
Shingleton	16	41134	6	NRP	63	red pine 140 (46.7)	15	yes
Shingleton	16	41134	8	NRP	106	red pine 101 (33)	13	yes
Shingleton	16	41134	11	NRP	108	red pine 103 (38.1)	19	yes
Shingleton	16	41134	15	PJP	42	jack pine 31	10	no
Shingleton	17	41134	38	NRP	107	red pine 113 (56.1)	23	yes

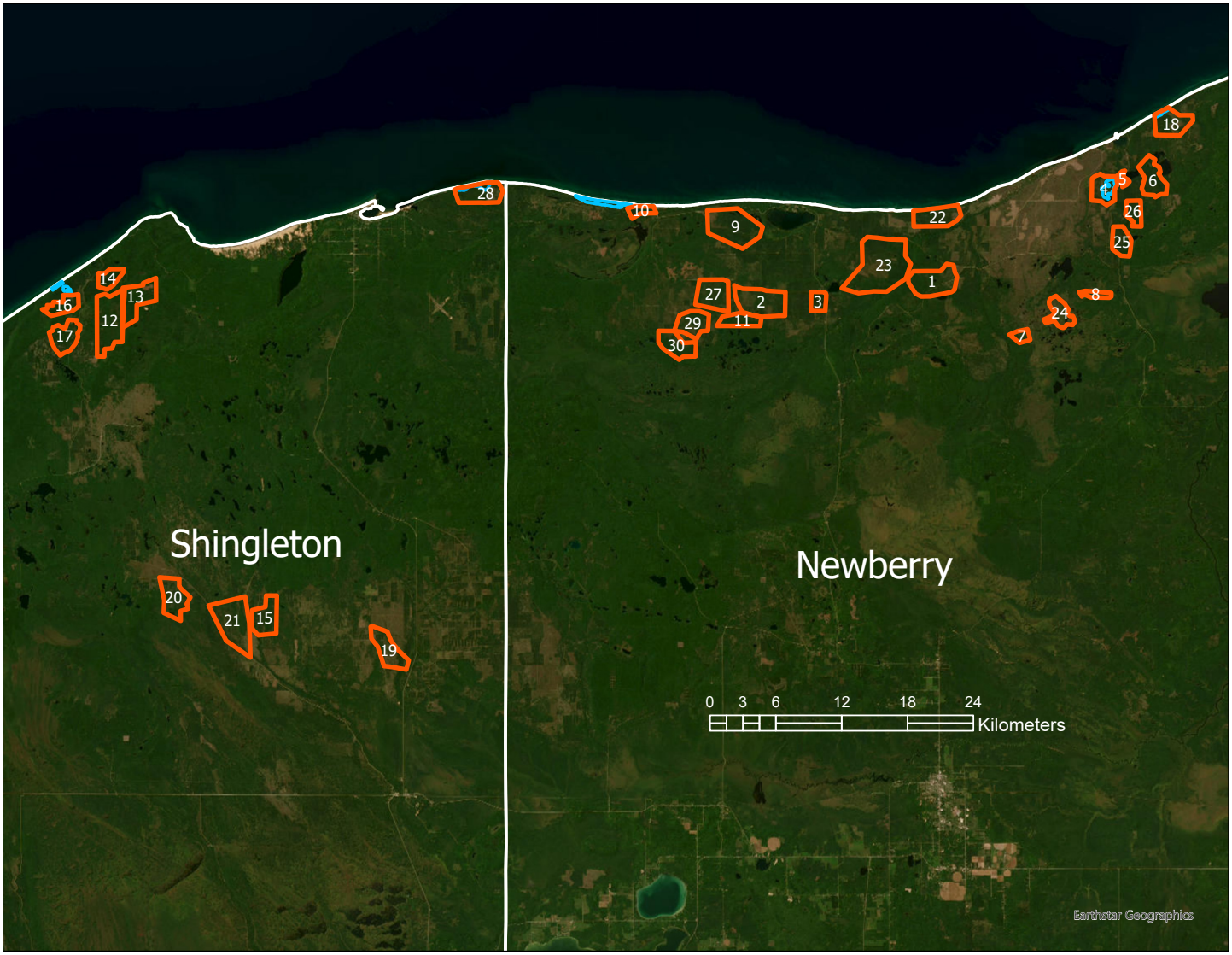

Figure A1. Conservation/Project areas in the Newberry and Shingleton FMUs. Conservation areas include or are adjacent to EOs (mapped in blue) and have high quality red pine stands. The areas we surveyed are mostly located along Lake Superior and existing EOs occur inland. We recommend avoiding intensive management in these areas. Priority areas have recoverable dry northern forest and dry-mesic northern forest ecosystems with appropriate management with fire and selective harvest.

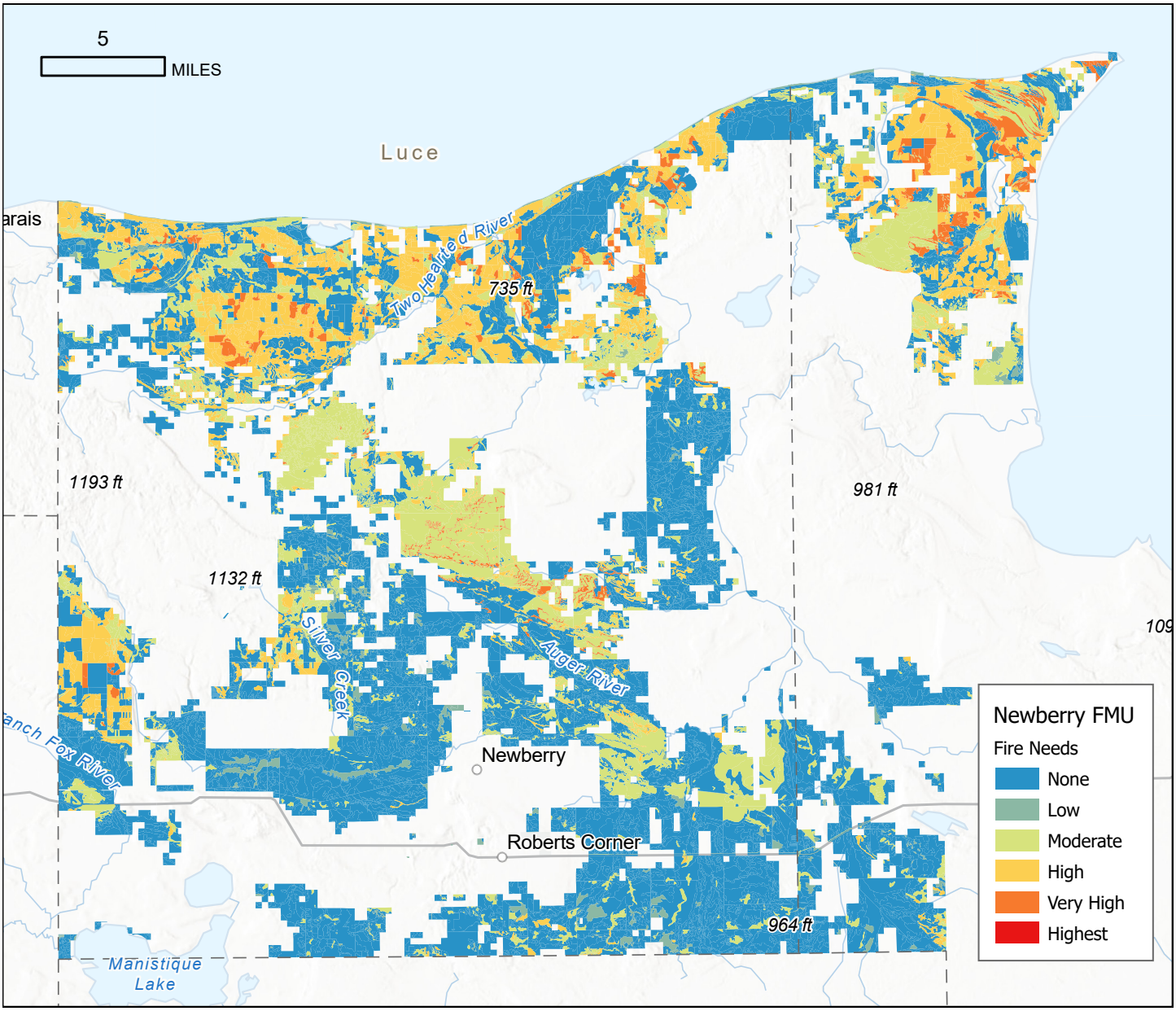

Figure A2. Fire needs model of the Newberry Forest Management Unit from Cohen et al. 2021. Areas of highest fire need typically align with pine-dominated natural communities.

Table A6. Fire-dependent species listed as Special Concern, State Threatened, or State Endangered in Michigan that are known to occur in the Newberry and Shingleton Forest Management Units.

Species	Status	Potential benefits of fire management
Black-backed woodpecker (*Picoides arcticus*)	Special Concern	Favors burned over coniferous forest as breeding habitat. In Minnesota they were more common in fire-killed trees (1-2 yrs after fire) compared to mature forest (Heinselman 1973). Woodpeckers were not present before fires but established territories within one year post-fire (Apfelbaum and Haney 1981). Habitat is reduced by post-fire salvage logging due to their requirement for deadwood (Martin et al. 2021). The loss of mature and old forest is considered detrimental for this species.
Canada rice grass (*Piptatherum canadense*)	State Threatened	Known from dry northern forest and dry-mesic northern forest in the Central and Upper Peninsula, this species is often found in ecotones between upland and lowland or along roadsides with light disturbance (Penskar and Crispin 2009). The natural communities where it occurs are fire-dependent so this species may benefit from fires that expose mineral soil and reduce competition.
Common nighthawk (*Chordeiles minor*)	Special Concern	May benefit from disturbances that create open ground used for nesting. They also appear to benefit from thinning of trees and reduction of shrubs in western US (Hagar 2004). Significantly more abundant in areas that had been burned within the past five years compared to unburned areas in Ontario (Foley 2018).
Connecticut warbler (*Oporornis agilis*)	Special Concern	Breed in dry jack pine forest as well as bogs (Robbins 1991). In Quebec they breed in jack pine forest around blueberry fields, but not in the fields themselves due to lack of cover (Blais 2014). They benefit from upland and lowland conifer forest with lower tree density and higher shrub and understory density (Lapin et al. 2013). Appear to benefit from post-wildfire habitats (Hobson and Scheck 1999).
Eastern whip-poor-will (*Antrostomus vociferus*)	State Threatened	Now most common in dry to dry-mesic forest habitats with open understories and semi-open canopies (Sauer et al. 2012). Seed tree cuts in red pine forest had higher occupancy than non-cut stands (Tozer et al. 2014). Benefit from high densities of large flying insects such as moths, open areas for hunting, and a duff layer for nesting. Open understories seem to be especially important (Wilson 1985). Few studies have evaluated the effects of fire but the species may benefit from the open understories created by surface fires.
Evening grosbeak (*Coccothraustes vespertinus*)	State Threatened	In the Upper Peninsula evening grosbeaks inhabit hardwood forests but move to jack pine during spruce budworm outbreaks (Payne 1983). May benefit from openings with *Corylus* buds that it can use for food (Hagar et al. 1996).

Kirtland's warbler (*Setophaga kirtlandii*)	State Endangered	Historically, this species was completely dependent on jack pine forests that regenerated after wildfires. The warblers occupy stands with 5- to 23-year-old jack pine (Probst 1988). Postburn forests are occupied by Kirtland's warbler at higher rates than unburned forests.
Northern blue (*Plebejus idas nabokovi*)	State Threatened	This species increased in number after a large fire in northern Europe (Gustafsson et al. 2019). This was presumed to be due to an increase in the abundance of its host plant, *Vaccinium cespitosum.*
Northern flying squirrel (*Glaucomys sabrinus*)	Special Concern	Prefers conifers and seems to be more successful in forests with old-growth characteristics, including both standing and downed dead wood (Weigl 2012). Oaks and hickories favor its competitor – the southern flying squirrel. In the Pacific Northwest it is considered to play an essential role in consuming the fruiting bodies of mycorrhizal fungi and nitrogen-fixing bacteria and dispersing them in its droppings (Smith 2007). Northern flying squirrels also consume lichens, especially in winter.
Pine-drops (*Pterospera andromedea*)	State Threatened	Known from dry northern forest and dry-mesic northern forest, particularly on old sand dunes near Great Lakes shores. This species forms an association with mycorrhizal fungi that is poorly understood but may also involve a conifer species. It's response to forest management and fire is not understood (Higman and Penskar 1999).
Sharp-tailed grouse (*Tympanuchus phasianellus*)	Special Concern	Prefers structural diversity of shrubs and grasses that provide high-quality nesting habitat. Broods depend on areas with abundant forbs and insects. Uses open coniferous woods and respond positively to fire (Kirsch et al. 1973).
Smooth green snake (*Opheodrys vernalis*)	Special Concern	Although relationships with fire have not been studied, this species uses habitats that are fire-dependent in Michigan such as grassy openings and ecotones between dry northern forest and wetlands.

Spruce grouse (*Canachites canadensis*)	State Threatened	Depends on both upland and lowland conifers for survival. It feeds on the needles of spruce and pine and habitat use studies suggest that dry northern forest dominated by pines are important habitat. In Michigan it occurs in areas of mixed conifers with jack pine where blueberry was common in understory (Robinson 1969) and appears to be dependent on habitat created by natural disturbances such as fire and insect outbreaks (Schroeder et al. 2021).
Upland sandpiper (*Bartramia longicauda*)	State Threatened	Known to breed in young jack pine stands with high graminoid cover. Birds prefer areas with varying vegetation heights. Burning is thought to benefit the species through increased invertebrate abundance. Not frequently documented in the Newberry and Shingleton FMUs but could inhabit early-successional stages of dry northern forest, particularly in the first 5 year following fire or other disturbance that reduce tree and shrub cover (Buhnerkempe and Westemeier 1988).