Surveys and Monitoring for the Hiawatha National Forest – Vernal Pools: FY2015 Report

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Center photo - Vernal pool, Hiawatha National Forest, Alger County, MI. Photo by Yu Man Lee, MNFI.

EXECUTIVE SUMMARY

Vernal pools are important to the biodiversity and health of Michigan's forests. Vernal pools are small, temporary pools of water that form in shallow depressions primarily in forested areas throughout Michigan. Despite their small size and temporary nature, vernal pools can be incredibly diverse and productive ecosystems. Vernal pools provide important habitat for many plants and animals. Because vernal pools lack predatory fish populations, these wetlands provide critical breeding habitats for a host of forest-dwelling amphibians and invertebrates, including some species that are specialized for life in vernal pools and depend on these unique habitats for their survival. Vernal pools contribute other important ecosystem services including nutrient cycling, water storage and infiltration, groundwater recharge, and flood control.

Due to increased awareness of the ecological significance of vernal pools, there has been growing interest in identifying, mapping, monitoring, and protecting these small but valuable wetlands in Michigan. Information on the status, distribution, and ecology of vernal pools is critical for developing and implementing appropriate management of these wetlands. The Hiawatha National Forest (HNF) is interested in obtaining this information regarding vernal pools within the Forest. To address this information need, the Hiawatha National Forest contracted with the Michigan Natural Features Inventory (MNFI) in 2015 to initiate a targeted effort to identify and map vernal pools within the Forest. Information on the locations and basic ecological characteristics of vernal pools were compiled as part of this project, and were provided to the HNF and added to a statewide spatial database of vernal pools in Michigan. This project included efforts to evaluate the effectiveness of aerial photograph interpretation for identifying and mapping vernal pools remotely.

A total of 419 potential vernal pools were identified and mapped within the project's study areas using aerial photograph interpretation. The project focused on the three project areas within the Hiawatha National Forest, the Plumb-Bruno, Raco, and Eckerman project areas (hereafter referred to as the Plumb-Bruno and the Raco-Eckerman Project Areas). These project areas are located in Alger, Chippewa, Delta, and Schoolcraft counties in the eastern Upper Peninsula (U.P.) of Michigan. The Plumb-Bruno Project Area is located on the west side of the Hiawatha National Forest in the Munising Ranger District. The Raco-Eckerman Project Area is located on the east side of the Hiawatha National Forest in the St. Ignace/Sault Ste Marie Ranger District. These forest lands are under active forest management. Total acreage of national forest lands that were included in the project areas and were reviewed for potential vernal pools using aerial photo interpretation was approximately 234,110 acres (94,741 ha).

MNFI staff surveyed a total of 118 potential and new vernal pools in the field in 2015. Of these, 93 (22%) were potential vernal pools that had been identified and mapped from aerial photograph interpretation, and 25 were new or potential vernal pools identified in the field that had not been mapped during aerial photo interpretation. Of the 118 potential or new vernal pools surveyed, a total of 74 (63%) were verified as vernal pools. An additional 15 pools (13%) were identified as potential or likely vernal pools but their status is uncertain at this time, and additional data are needed for final designation of their status. Of the 29 potential pools that were verified as not being vernal pools, 16 (14%) were other types of wetlands, and 13 (11%) were areas that were dry and did not appear to hold water for extended periods of time.

The overall accuracy rate for correctly identifying vernal pools from aerial photograph interpretation was moderate. Of the 93 potential vernal pools that were identified and mapped from aerial photos and surveyed in the field in 2015, 55 (59%) were verified as vernal pools in the field, and an additional 11 (12%) were identified as potential or likely vernal pools that need additional information to confirm their status. Combining the verified and potential/likely vernal pools would result in a total of 66 vernal pools identified in the field, and an overall vernal pool mapping accuracy rate of 71% for aerial photo interpretation across both study areas. The vernal pool accuracy rate varied between the two main project areas, with the Plumb-Bruno Project Area having an accuracy rate of 47% (22 verified vernal pools of 47 potential vernal pools) and the Raco-Eckerman Project Area having an accuracy rate of 72% (33 of 46). Commission error was moderate. A total of 28 (30%) potential vernal pools identified from air photos was surveyed and verified as not being vernal pools in the field. This also varied by project area, with the Plumb-Bruno Project Area having a commission error rate of 51% (24 of 47) and the Raco-Eckerman Project Area having a commission error rate of 9%. These accuracy and commission error rates are similar to and a little higher than results from previous vernal pool mapping efforts in the western U.P.

Vernal pool indicator species were documented in 14 (37%) of 38 vernal pools that were surveyed in the Plumb-Bruno Project Area in the spring and early summer of 2015. These include observations of fairy shrimp (only in one pool), wood frog tadpoles, blue-spotted salamander egg masses and larvae, and spotted salamander egg masses and larvae. At least 18 other invertebrate taxa and five additional amphibian and reptile species associated with vernal pools also were documented in 2015. Potential exists for vernal pool indicator species and other amphibians, reptiles, and invertebrates to occur in the vernal pools in the two project areas.

While mapping potential vernal pools using aerial photo interpretation can be time consuming and was only moderately accurate across the two project areas (and across the UP in general), aerial photo interpretation is currently still the most effective method we have for identifying and mapping vernal pools remotely. The accuracy rate was a little higher and more promising for one of the project areas, suggesting that the availability and use of more recent and higher resolution leaf-off, color-infrared aerial imagery can increase vernal pool mapping accuracy rates. We were able to identify and map a fairly large number of potential vernal pools across an extensive area over a relatively short period of time (i.e., ~5-7 days). While not all of these represent actual vernal pools on the ground, having this information has allowed us to conduct targeted field surveys which have resulted in identifying a total of 74 active vernal pools on the ground. These represent the first group of vernal pools identified and mapped in the eastern U.P. that has been entered into the statewide vernal pool database.

Results from this project will inform management and protection of vernal pools, and provide the foundation for future vernal pool research and monitoring efforts in the HNF. This information will assist the HNF with forest planning and management efforts, and help facilitate sustainable forest management practices, ensuring the long-term productivity and health of Michigan's forest ecosystems. This project also complements and builds upon recent vernal pool mapping and assessment efforts in the Upper Peninsula and statewide. This additional information will help us develop an effective and efficient approach for identifying and mapping vernal pools, and enhance our understanding of their distribution and ecology in Michigan and how to effectively manage and protect them.

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INTRODUCTION

Vernal pools are important to the biodiversity and health of Michigan's forests. Vernal pools are small, temporary pools of water that form in shallow depressions primarily in forested areas throughout Michigan. These wetlands fill with water from rainfall, snowmelt, and/or groundwater between late fall and spring, and usually dry up by mid- to late summer. Vernal pools are generally isolated depressions, although they can be part of or connected to larger wetland complexes. They also lack persistent surface water connections with permanently flooded water bodies, but can be temporarily connected to permanent water (e.g., vernal pools in river floodplains). The periodic drying of vernal pools prevents fish from establishing populations in these wetlands.

Despite their small size and temporary nature, vernal pools can be incredibly diverse and productive ecosystems. Vernal pools provide important habitat for many plants and animals. Over 550 to 700 animal species have been documented in vernal pools in northeastern U.S. (Colburn 2004). Because vernal pools dry up and lack predatory fish populations, these wetlands provide critical breeding habitats for a host of forest-dwelling amphibians and invertebrates, including some species that are specialized for life in vernal pools and depend on these unique habitats for their survival. These include the Blue-spotted Salamander (*Ambystoma laterale*), Spotted Salamander (*Ambystoma maculatum*), Wood Frog (*Rana sylvatica*), and fairy shrimp (*Eubranchipus* spp.) (Calhoun et al. 2003, Calhoun and deMaynadier 2008). Vernal pools also provide habitat for several endangered, threatened, or rare species in Michigan, such as the state special concern Blanding's Turtle (*Emydoidea blandingii*), as well as U.S. Forest Service Regional Forest Sensitive Species for Region 9 and the Hiawatha National Forest. As wetlands, vernal pools contribute other important ecosystem services including nutrient cycling, water storage and infiltration, groundwater recharge, and flood control.

Due to increased awareness of the ecological significance of vernal pools, there has been growing interest in mapping, monitoring, and protecting these small but valuable wetlands in Michigan and other states. However, little information is currently available on the status, distribution, and ecology of vernal pools in Michigan. Because vernal pools are small, isolated, and dry for part of the year, they can be difficult to identify in the field, and can be easily overlooked, and unintentionally damaged or destroyed. Additionally, because of their small and isolated nature, vernal pools are not well-protected under current wetland regulations, and many have been destroyed or degraded due to development and other land uses. Vernal pools can be impacted during forest management activities, and as a result, they have been afforded some protection under the State of Michigan's recommended sustainable soil and water quality practices on forest land and the Sustainable Forestry Initiative® (SFI®) and Forest Stewardship Council's forest certification standards (Michigan Department of Natural Resources and Michigan Department of Environmental Quality 2009, Sustainable Forestry Initiative 2010, Forest Stewardship Council 2010). Tree harvesting equipment also can get damaged if they are inadvertently used in vernal pool depressions when they are dry and difficult to identify on the landscape. Vernal pools also may be vulnerable to impacts of climate change since their hydrology is closely tied to precipitation and air and water temperatures, and some of the animals associated with vernal pools are very sensitive to changes in pool hydrology and temperatures.

Information on the status, distribution, and ecology of vernal pools is critical for developing and implementing appropriate management of these wetlands. The Hiawatha National Forest (HNF) is interested in obtaining this information regarding vernal pools within the Forest. To address this information need, the Hiawatha National Forest contracted with the Michigan Natural Features Inventory (MNFI), a program of Michigan State University Extension, in 2015 to initiate a targeted effort to identify and map vernal pools within the Forest. Information on the locations and basic ecological characteristics of vernal pools were compiled as part of this project, and were provided to the HNF. Results from this project provide the foundation for future vernal pool research and monitoring efforts in the HNF, and help inform management and protection of vernal pools in the Forest. This information will assist the Hiawatha National Forest with forest management and planning efforts, and help facilitate sustainable forest management practices, ensuring the long-term productivity and the overall health of Michigan's forest ecosystems.

This project also complements and builds upon recent efforts to identify, map, and assess vernal pools in the Upper Peninsula and statewide. Recent efforts to assess and map vernal pools have been conducted mainly in the western Upper Peninsula, so this project provides new information regarding vernal pools in the Upper Peninsula. Vernal pool locations and information compiled through this project were added to a statewide spatial database of vernal pools in Michigan. Additional data on the distribution and ecological characteristics of vernal pools in the Upper Peninsula generated from this project will enhance our knowledge and understanding of vernal pool status, distribution, and ecology in the state, and how to effectively manage and conserve these unique and important wetlands. Results from this project also will contribute to continued efforts to develop an effective and efficient approach for identifying and mapping vernal pools remotely and in the field across the state, particularly in the Upper Peninsula.

PROJECT GOAL

The goal of the overall vernal pool project is to gain baseline information and a better understanding of the status, distribution, and ecology of vernal pools on the Hiawatha National Forest, including threats and management impacts, to inform management of these wetlands. This will be achieved by conducting vernal pool mapping, research, and monitoring on the Forest. The goal of the first year of this project (i.e., 2015) is to obtain baseline data on the status, distribution, and ecology of vernal pools in the Forest by initiating identification and mapping of vernal pools within the Forest and collecting basic information about their ecological characteristics.

PROJECT OBJECTIVES

This project addressed the following objectives:

1) Identify and map potential vernal pools across selected project areas within the Hiawatha National Forest (HNF) based on aerial photograph interpretation. Conduct aerial photo interpretation of at least 100,000 acres within targeted project areas. Project areas and

aerial photo interpretation during this first year will focus on the 40/50/90 and 60 Ecological Land Type (ELT) groups (i.e., primarily northern hardwoods and transitional forests between uplands and wetlands) within 2-3 project areas in the HNF (i.e., 2 project areas in the Western Zone and/or 1 project area in the Eastern Zone). Potential vernal pools in other ELTs within targeted project areas also will be mapped as time and resources allow. Project areas will focus on lands under active forest management.

2) Verify and map vernal pools in the field across a portion of the targeted project areas. This will include verifying potential vernal pools mapped using aerial photo interpretation and mapping additional vernal pools encountered during field sampling. Effort will be made to survey for vernal pools in the field in areas with different geology and landforms if possible.

3) Collect initial information on the physical and biological characteristics of vernal pools identified in the field during surveys to verify and map vernal pools. These characteristics will include pool type, size (area), isolation, presence and type of inlet/outlet, surrounding forest or habitat type, water level, approximate water depth, general vegetation structure, natural and anthropogenic disturbances in and around the pool, presence of vernal pool obligate/indicator species, and presence of fish.

4) Evaluate the effectiveness of identifying and mapping vernal pools remotely using aerial photo interpretation. If possible, examine if and how forest type, vernal pool type, and/or other factors impact the effectiveness of identifying vernal pools remotely using aerial photo interpretation.

5) Compile and enter information on the locations and physical/biological characteristics of vernal pools identified and mapped for this project in the statewide vernal pool spatial database.

6) Conduct training for HNF staff on vernal pools focusing on how to identify them in the field, their ecological values, and management considerations.

7) Work with HNF to develop vernal pool research and monitoring strategy.

8) Prepare and provide a final report summarizing project activities and results.

METHODS

Project Areas

Based on input from HNF staff, the vernal pool mapping project focused on two main project areas within the Hiawatha National Forest, the Plumb-Bruno and Raco-Eckerman project areas (Figure 1). These project areas are located in Alger, Chippewa, Delta, and Schoolcraft counties in the eastern Upper Peninsula of Michigan (Figure 1). The Plumb-Bruno Project Area is located on the west side of the Hiawatha National Forest in the Munising Ranger District. The Raco-

Eckerman Project Area is located on the east side of the Hiawatha National Forest in the St. Ignace/Sault Ste. Marie Ranger District. These forest lands are under active forest management. Total acreage of national forest lands that were included in the project study areas was approximately 234,110 acres (94,741 ha).

The vernal pool project areas encompass a number of Land Type Associations (LTAs). The Plumb-Bruno Project Area includes four LTAs: the Lake Stella Complex, Steuben Segment, Steuben Outwash, and Ridge-swale Complex (Figure 2). The Raco-Eckerman Project Area is primarily comprised of eight LTAs: East Tahquamenon Drainage, Lake Superior Highlands, Tahquamenon River Drainage, Wilwin Wetlands, Raco Plains South, Raco Plains North, Betchler Marsh, and Strongs Road Outwash Hills (Figure 2). The Raco-Eckermen project also includes small amounts of five additional LTAs (Figure 2). Brief descriptions of these LTAs are summarized in Appendix 1, and more detailed descriptions are provided in a report on LTAs of the HNF (U.S. Forest Service and The Nature Conservancy of Michigan 2011).

The Plumb-Bruno and Raco-Eckerman project areas also are associated with several physiographic regions inthe Eastern Upper Peninsula Lowlands major physiographic region (Figure 3) (Schaetzl et. al 2013, Michigan Geological Survey 2016). Additionally, the project areas are located in two regional landscape ecosystems or ecoregions, the Seney Sand Lake Plain (Sub-subsection VIII.2.1) and the Grand Marais Sandy End Moraine and Outwash (Sub-subsection VIII.2.2) ecoregional sub-subsections (Albert 1995) (Figure 4). Brief descriptions of these physiographic regions and ecoregions are summarized in Appendix 2, and more detailed descriptions are provided in Albert (1995), Schaetzl et al. (2013), and Michigan Geological Survey (2016).

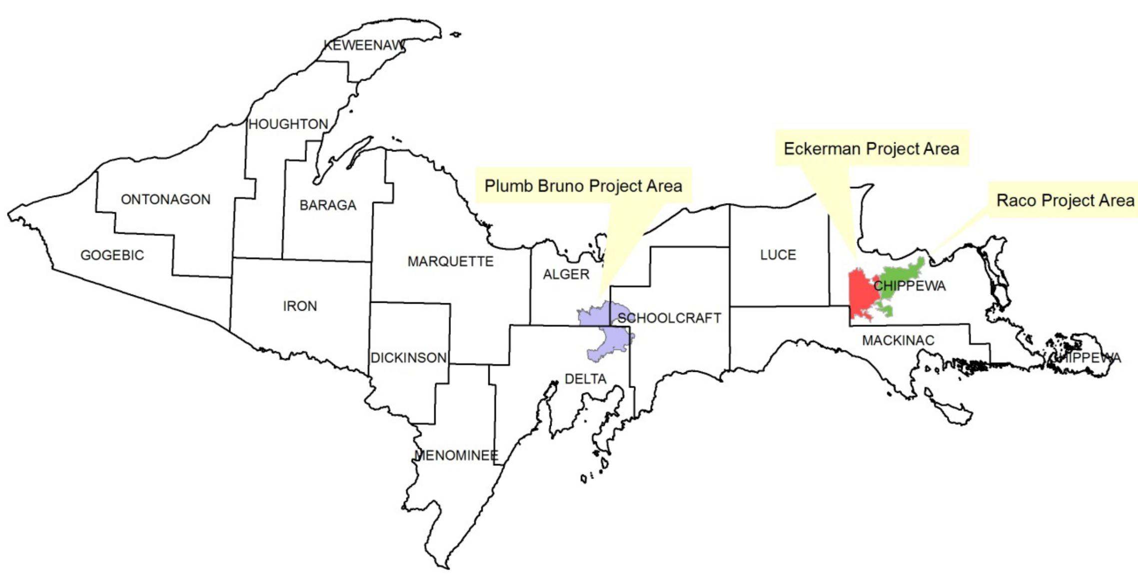


Figure 1. Map showing the general locations of the two project areas within the Hiawatha National Forest in which vernal pool identification and mapping were conducted in 2015.

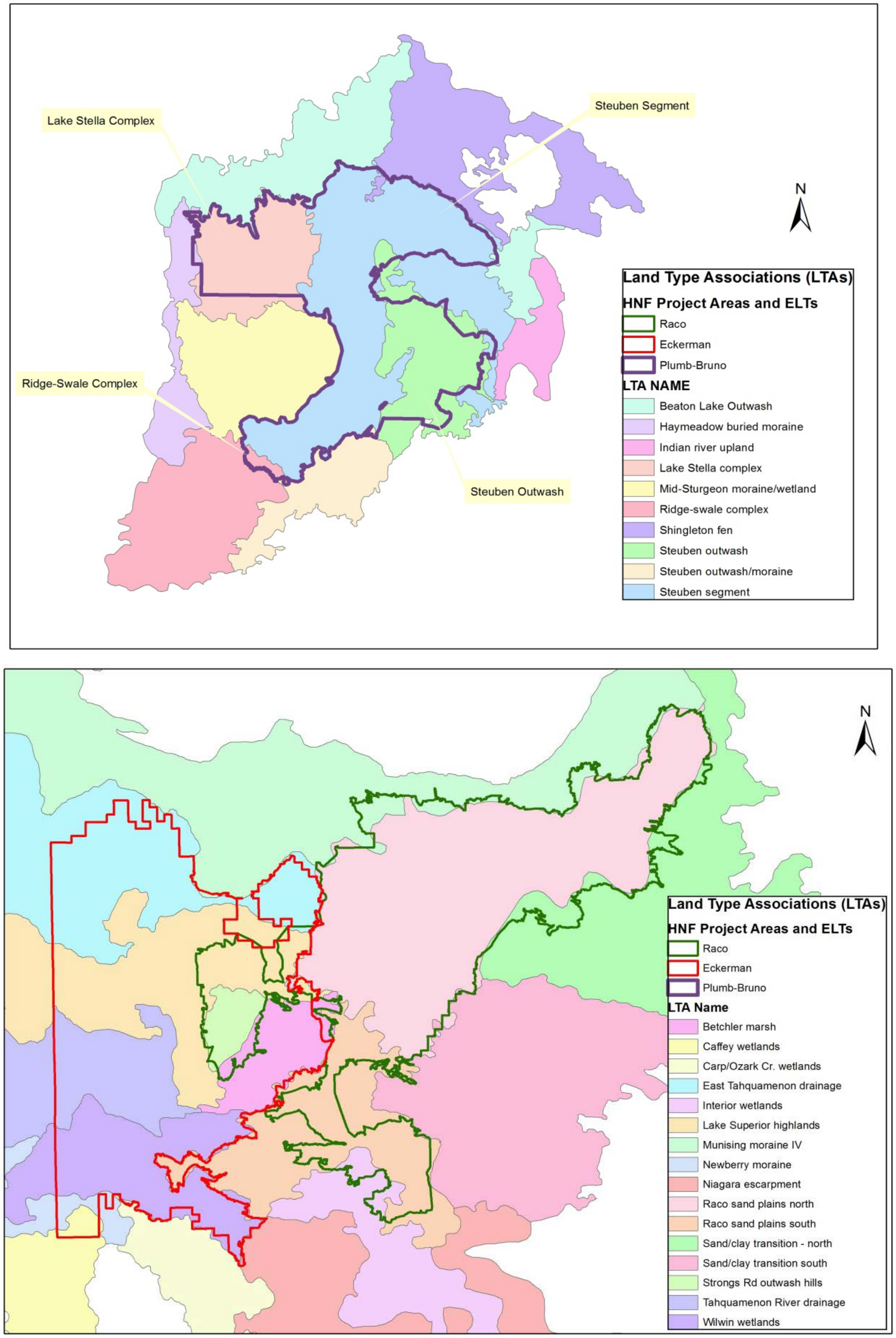


Figure 2. Maps showing the Land-type Associations (LTAs) included within the Plumb-Bruno (top) and Raco-Eckerman (bottom) project areas in the Hiawatha National Forest.

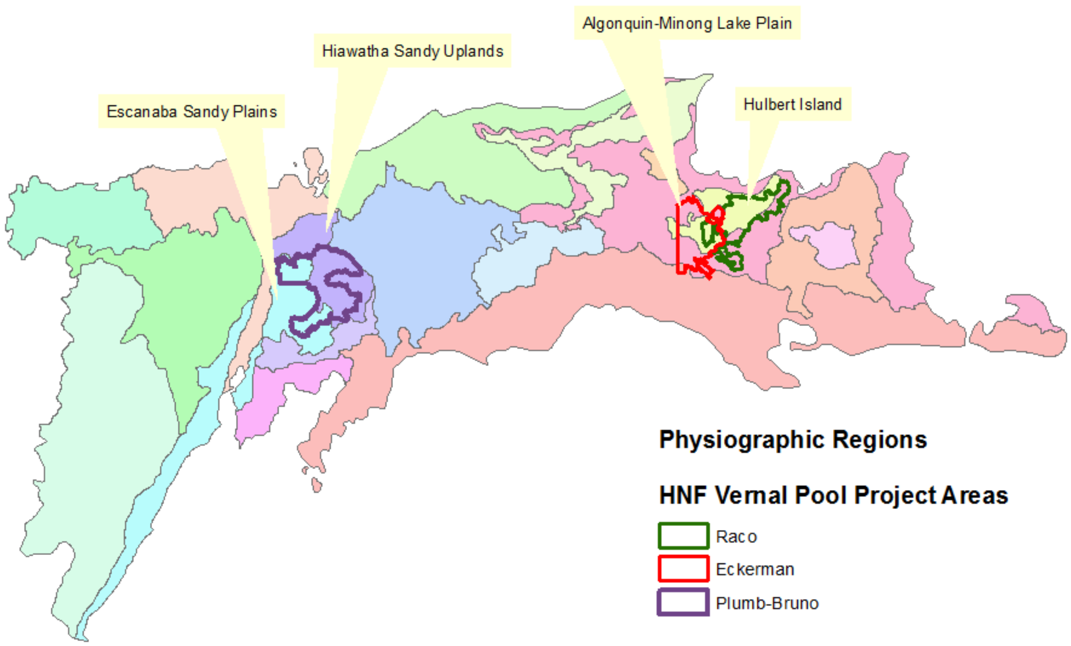


Figure 3. Map showing the physiographic regions in which the vernal pool project areas are located within the Hiawatha National Forest in Michigan's eastern Upper Peninsula.

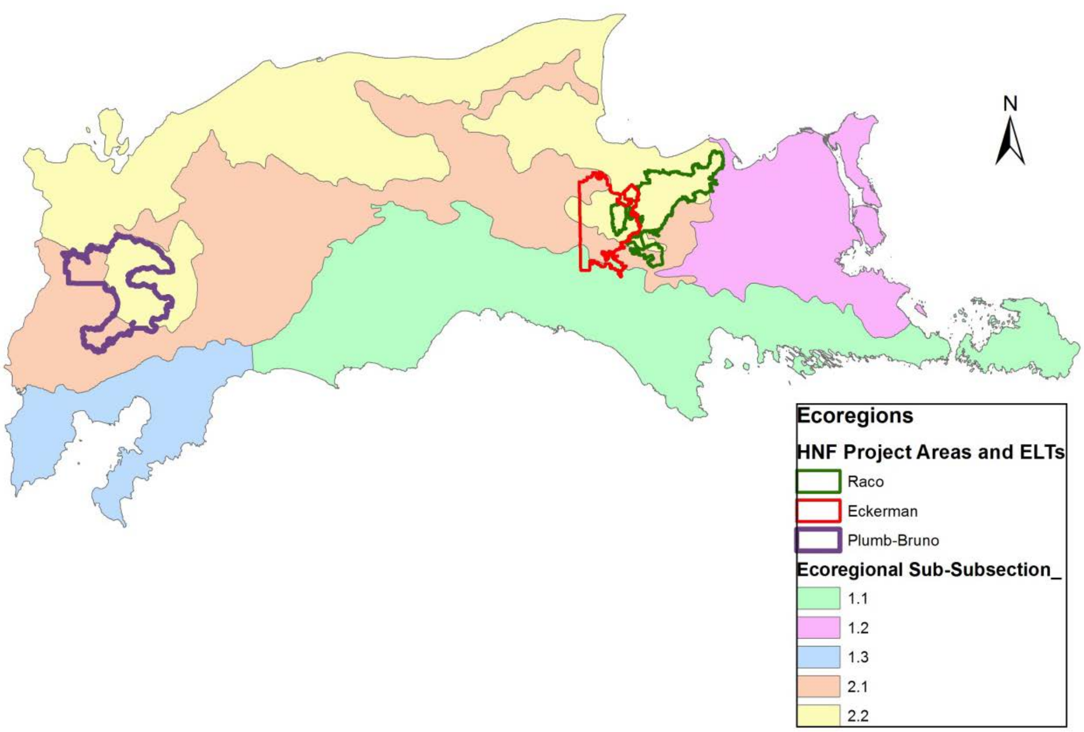


Figure 4. Map showing the regional landscape ecosystems in which the vernal pool project areas are located within the Hiawatha National Forest in Michigan's eastern Upper Peninsula.

Vernal Pool Identification and Mapping

Vernal Pool Definition and Types

Vernal pools have been defined differently among states, programs, projects, and individuals, although certain core elements have been consistent across definitions. Some states have defined vernal pools based solely on physical attributes while other states require certain biological attributes as well, such as the presence of vernal pool indicator species. For example, in Maine, vernal pools are defined as naturally occurring, seasonal bodies of water that are free of predatory fish populations and provide breeding habitat for one or more of Maine's four vernal pool indicator species (Morgan and Calhoun 2012). In Ohio, a vernal pool is any wetland that fills annually from precipitation, runoff, and rising groundwater, and does not have a permanent outlet stream, does not harbor fish, and dries out during some part of the year in most years (Ohio Vernal Pool Partnership 2014).

The following definition and required attributes of vernal pools (Table 1) was developed by MNFI in collaboration with representatives from the MDNR, MDEQ, and other partners to provide a common definition for vernal pool mapping and monitoring in Michigan as part of MNFI's earlier vernal pools project, and was utilized for this project:

"Vernal pools are naturally occurring, small (typically less than 1 ha/2.5 acres), temporarily-flooded wetlands found in depressions primarily in forested settings throughout Michigan. As confined-basin depressions, they lack continuously flowing inlets or outlets, and they have no continuous surface-water connection with permanently flooded water bodies. Vernal pools may be connected to other wetlands or part of larger wetland complexes as long as those wetlands are also confined and not continuously connected to permanent water bodies. In most years, vernal pools are filled with water in the spring, and dry down or significantly draw down in summer, exposing all or most (i.e., >50%) of the pool bottom and retaining only a fraction of the peak volume. Vernal pools generally contain water for a minimum of two months in most years. Because of their temporary and variable hydroperiod, vernal pools lack permanent fish populations. Vegetation may consist of trees, shrubs, submergent and floating-leaved plants (e.g., duckweed), and generally sparse cover of persistent emergent plants. Substrates are comprised of hydric soils and often covered by leaf litter." (Lee et al. 2014)

It is important to note several additional considerations regarding how vernal pools were defined for this project and MNFI's earlier vernal pools project. Because vernal pools are often so small and are generally characterized by the surrounding natural community, vernal pools are often natural features within natural communities and not necessarily distinct natural communities themselves, although some natural communities (e.g., inundated shrub swamp, intermittent wetland, northern hardwood swamp) can be considered vernal pools in terms of how they function. Although vernal pools often occur as isolated depressions in upland forest stands, they also can occur in and/or be connected to lowland forests and other wetland types. This may be different from how others have defined vernal pools in the state.

Table 1. Summary of required attributes for vernal pools developed by MNFI and a Vernal Pools Work Group for vernal pool mapping and monitoring in Michigan (Lee et al. 2014).

Origin	Naturally occurring
Size	Small (typically less than 2.5 ac/1 ha)
Geomorphology	Confined basin/depression with no continuously flowing surface water inlet or outlet; no continuous surface water connection with permanently flooded water bodies. Vernal pools can be connected to other wetlands or part of larger wetland complexes as long as those wetlands are also confined and not continuously connected to permanent water bodies.
Hydrology	Temporarily flooded; fluctuating water regime with alternating periods of flooding and drying; typically filling with water in spring and drying down or significantly drawn down in summer in most years; also can fill in the fall or winter but must have water in the spring; typically hold water for minimum of two months in most years. Some vernal pools are semi-permanent, and may only dry in some years (e.g., 3 out of every 5 years).
Substrate	Hydric soil
Biological Community	Fishless or free of a permanent fish population. Evidence of breeding (i.e., egg masses, larvae, breeding/mating adults) by vernal pool indicator species is not required for a vernal pool, but indicates a vernal pool if present. Vernal pool indicator species in Michigan include the Wood Frog, Spotted Salamander, Blue-spotted Salamander, and fairy shrimp.

Vernal pools can be highly variable in terms of their physical attributes (e.g., hydroperiod or how long they hold water, water depth, water chemistry), which in turn can significantly impact their biological attributes and ecological values (e.g., vegetative composition and structure, animal species richness and diversity, presence and success of vernal pool obligate species). As a result, in addition to verifying and mapping vernal pools in the field, we categorized vernal pools into the following general types: (1) open pool; (2) sparsely vegetated pool; (3) shrubby pool; (4) forested pool; and (5) marsh pool (Table 2 and Appendix 3). These pool types were based on vernal pool classification schemes proposed by Brown and Jung (2005) and Colburn (2004), and were developed and used as part of MNFI's previous vernal pool project (Lee et al. 2014). This information can be used to help classify and assess the ecological characteristics of vernal pools across the state, and help inform management and conservation of vernal pools in the future. It is important to note though that these classifications should be considered preliminary. More research is needed to determine the most ecologically appropriate or meaningful way to classify vernal pools in Michigan.

Table 2. Vernal pool types and definitions used to categorize vernal pools identified and mapped in the Hiawatha National Forest in the eastern Upper Peninsula for this project.

Vernal Pool Type	Definition
Open Pool	Few to no rooted, live trees growing directly within the pool and <10% cover of shrubs, herbaceous plants, and persistent emergent plants within the pool basin.
Sparsely Vegetated Pool	Several to no rooted, live trees growing directly within the pool and 10% to <30% cover of shrubs, herbaceous plants, and persistent emergent plants within the pool basin.
Shrubby Pool	Tall shrubs (>1 m tall, >1 cm in diameter) dominate at least 50% of the perimeter of the pool, or ≥30% of the uppermost vegetation layer in the pool basin; trees and herbaceous/emergent plants may be present but comprise <30% of the cover within the pool basin. Pools dominated by shrubs growing within the pool basin, pools occurring within larger shrub-dominated wetlands, or small, isolated shrub swamps.
Forested Pool	Rooted, live trees dominated by flood-tolerant trees (> 6 m (20 ft) tall) commonly growing within the pool basin, and generally comprising ≥30% of the uppermost vegetation layer within the pool basin. Examples include isolated depressions dominated by red maple *(Acer rubrum)* around or in the pool basin but surrounded by upland forest, flooded depressions that occur within a larger wetland complex (e.g., larger red maple swamp areas or coniferous swamps), or in river floodplains or oxbows.
Marsh Pool	Pool dominated by non-woody herbaceous plants, usually graminoids, comprising the uppermost vegetation layer within the pool basin with ≥30% cover. Trees and shrubs may be present but comprise <30% of the cover within the pool basin. Colburn (2004) – Marsh pools may be extensively vegetated with non-woody submergent, floating, and/or emergent plant species (mostly annual/non-persistent but also some perennial plants potentially as well) commonly found in marshes and along the shorelines of lakes and ponds, and generally have long hydroperiods and open canopies.

Identifying Potential Vernal Pools Using Aerial Photograph Interpretation

Aerial photograph interpretation was conducted in the spring and summer of 2015 to identify and map potential vernal pools (PVPs) within the study areas. We reviewed aerial photo imagery and mapped potential vernal pools across all the lands included in the Plumb-Bruno and Raco-Eckerman project areas. Although we had initially proposed focusing vernal pool mapping on the 40/50/90 and 60 Ecological Land Type (ELT) groups (i.e., primarily northern hardwoods and transitional forests between uplands and wetlands) within the project areas, we decided it was easier to review, identify, and map potential vernal pools across the entire project areas.

Aerial photograph interpretation consisted of using ESRI ArcGIS software to visually examine available aerial imagery and other imagery and maps of the study areas on a computer screen. Aerial imagery that were available and reviewed for this project included color infrared aerial imagery from the spring of 2007 of the Hiawatha National Forest (2007 CIR QQ) as well as statewide color infrared aerial imagery from the spring of 1998 (NAPP 1998 CIR) and natural color aerial imagery from the summer of 2005, 2010, and 2012 (NAIP 2005, NAIP 2010, and NAIP 2012 True Color). Topographic maps and a stream data layer (NHD100) also were examined to help identify potential vernal pools from aerial photos. The aerial imagery and other data layers were available through the Hiawatha National Forest and Michigan State University's Remote Sensing & GIS (RSGIS) Center and the State of Michigan. We used a map scale of 1:5000 as a compromise between a high level of visible detail and spatial extent of the imagery displayed on computer screen to detect potential vernal pools.

Potential vernal pools were digitized and mapped as polygons using ESRI ArcGIS software. A single interpreter identified and mapped all the potential vernal pools in the study areas to provide consistency in interpretation across the study areas. Potential vernal pools were identified based on the presence of standing water in an area indicated by aerial imagery taken in the spring (e.g., 2007 CIR QQ and NAPP 1998 CIR) and the lack of standing water in the same area indicated by aerial imagery taken in the summer (e.g., NAIP 2012 True Color). Potential vernal pools were digitized, mapped, and added to the statewide vernal pool geodatabase developed by MNFI using ESRI ArcGIS software to record and organize data on potential vernal pools and verified vernal pools in the state. Each potential vernal pool polygon mapped and added to the geodatabase was assigned a unique pool identification number for reference, and some preliminary information about these polygons were included in the geodatabase.

Field Sampling to Identify and Map Vernal Pools

MNFI staff conducted field sampling in the HNF project areas in the spring, summer, and/or fall of 2015 to identify, map, and assess vernal pools on the ground. Field sampling consisted of surveyors locating potential vernal pools in the field using Ashtech GPS units and aerial photographs. Surveyors verified if potential vernal pools represented actual vernal pools in the field, or if the potential vernal pools were other types of wetlands or other habitats. Field sampling included mapping vernal pools and other wetlands verified in the field using GPS, and collecting some basic information about the general condition and plants and animals within the pools, particularly the presence of vernal pool indicator species (e.g., fairy shrimp, wood frog egg masses and tadpoles, and/or blue-spotted and spotted salamander egg masses and larvae) (Appendix 4). Field sampling results were used to evaluate the effectiveness and efficiency of these different methods for identifying and mapping vernal pools.

Field sampling was conducted during three different time periods in 2015. We conducted field sampling in the spring and early summer of 2015 (i.e., early season sampling) to identify vernal pools when they are typically filled with water. Early season sampling was conducted in early and late May and mid-July of 2015. We conducted field sampling in early fall of 2015 in early to mid-October to revisit vernal pools identified during the early season sampling to verify drying, and to identify additional vernal pools in the field.

The status of potential vernal pools visited in the field was documented using four different classifications or designations (Table 3). Potential vernal pools were designated either as a verified and active vernal pool in the field (H2O-VP), a potential vernal pool verified in the field but status uncertain/need additional information (H2O-VP?), not a vernal pool but some other type of wetland (H2O-NVP), or not a vernal pool and dry/no water present. Vernal pools verified in the field were mapped in the field using GPS, when possible, either as a polygon or a point. Vernal pools were mapped as a polygon by walking along the edge of the wetland basin or water's edge during the early season survey, and along the edge of the wetland basin and/or along the edge of wet or water-stained (i.e., dark brown/black) soil and/or leaves observed within the basin during the late season survey. Additional vernal pools or potential vernal pools that were encountered during field sampling outside of mapped potential vernal pools also were recorded and mapped, when possible. Field data were recorded in the field on a handheld GPS unit (i.e., Ashtech GPS unit) and on paper field survey forms (Appendix 4). Vernal pools and other wetlands and habitats identified in the field were photographed for documentation and verification. Field data and results were entered and compiled in the statewide vernal pool geodatabase in fall 2015 and winter 2016.

Table 3. Categories used to designate potential vernal pools sampled in the field in the Hiawatha National Forest in the eastern Upper Peninsula for this project.

Vernal Pool Category	Category Definition/Description
H2O-VP	Water/wetland was present in the test cell, and the wetland was a vernal pool.
H2O-VP?	Water/wetland was present in the test cell, and the wetland may be a vernal pool, but not certain or lack sufficient information to make determination. These wetlands need to be revisited, need additional data, and/or further consideration for final designation.
H2O-NVP	Water/wetland was present in the test cell, but the wetland was NOT a vernal pool (i.e., some other kind of wetland, permanent pool/pond).
H2O-None	No water/wetland or sign of water or wetland was present in the test cell.

Accuracy Assessment

To evaluate the effectiveness of aerial photograph interpretation for identifying and mapping vernal pools in the project areas, we conducted an accuracy assessment by comparing vernal pool mapping results from the aerial photograph interpretation to field sampling results from 2015. Understanding the accuracy of the vernal pool mapping effort also helps us evaluate the results in terms of the potential pools that were not field verified in 2015 (i.e., how many of the potential vernal pools may be actual vernal pools on the ground). For the accuracy assessment, we quantified the rate for accurately mapping vernal pools (i.e., true positives) as well as commission error (i.e., potential pools mapped from aerial photographs that were not vernal pools in the field, also known as false positives) (Table 4). Commission error could come in two forms: (1) features that were water bodies or other wetland types that did not meet the definition of a vernal pool; and (2) features that were not waterbodies or wetlands (i.e., dry land). We generated accuracy rates and commission error for the two project areas combined and separately for comparison. We were not able to generate a true estimate of omission error (also known as false negatives) (Table 4) since we did not systematically or randomly survey areas that did not contain potential vernal pools that were mapped from aerial photos to determine if vernal pools did not occur in the area. However, we were able to generate a quasi- or proxy estimate of omission error based on the number of vernal pools found in the field that were not initially mapped from aerial photographs. This likely does not represent a true estimate of omission error since we only targeted potential vernal pools for sampling and did not really survey other areas for vernal pools except on the way to or from potential vernal pools sampled in the field. We also were not able to generate an accuracy rate for true negatives since we did not systematically or deliberately survey areas that did not have potential vernal pools mapped from aerial photos.

Table 4. Summary of comparisons for accuracy assessment for vernal pool mapping using aerial photo interpretation. Accuracy rate in terms of true positives and commission error, as described below, were generated for the vernal pool mapping effort in the Hiawatha National Forest in the eastern Upper Peninsula for this project.

Accuracy Rate – True Positives = Total Number of Potential Vernal Pools Surveyed and Verified as Vernal Pools in the Field (i.e., H2O-VP, H2O-VP?) / Total Number of Potential Vernal Pools Surveyed	**Commission Error – False Positives =** Total Number of Potential Vernal Pools Surveyed and Verified as Not Vernal Pools in the Field (i.e., H2O-NVP, H2O-None) / Total Number of Potential Vernal Pools Surveyed
Omission Error / False Negatives = Total Number of New/Previously Unmapped Vernal Pools Found in the Field / Total Number of Locations Surveyed with No Potential Vernal Pools Mapped	**Accuracy Rate / True Negatives** = Total Number of Locations Surveyed and Verified as Not Having Vernal Pools in the Field / Total Number of Locations Surveyed with No Potential Vernal Pools Mapped

Although this was not part of the original objectives of the project, we also examined whether Land Type Associations (LTAs) and Ecological Land Types (ELTs) potentially impact the distribution of vernal pools and the effectiveness of identifying vernal pools remotely using aerial photo interpretation. We compared the accuracy rates and commission error rates based on the number and percentage of potential vernal pools verified as vernal pools in the field among the different LTA and ELTs included in the project. Because this project focused on the ELT 40-50-90 and ELT 60, this analysis only included accuracy rates and comparisons between these two ELT groups.

RESULTS

Aerial Photograph Interpretation

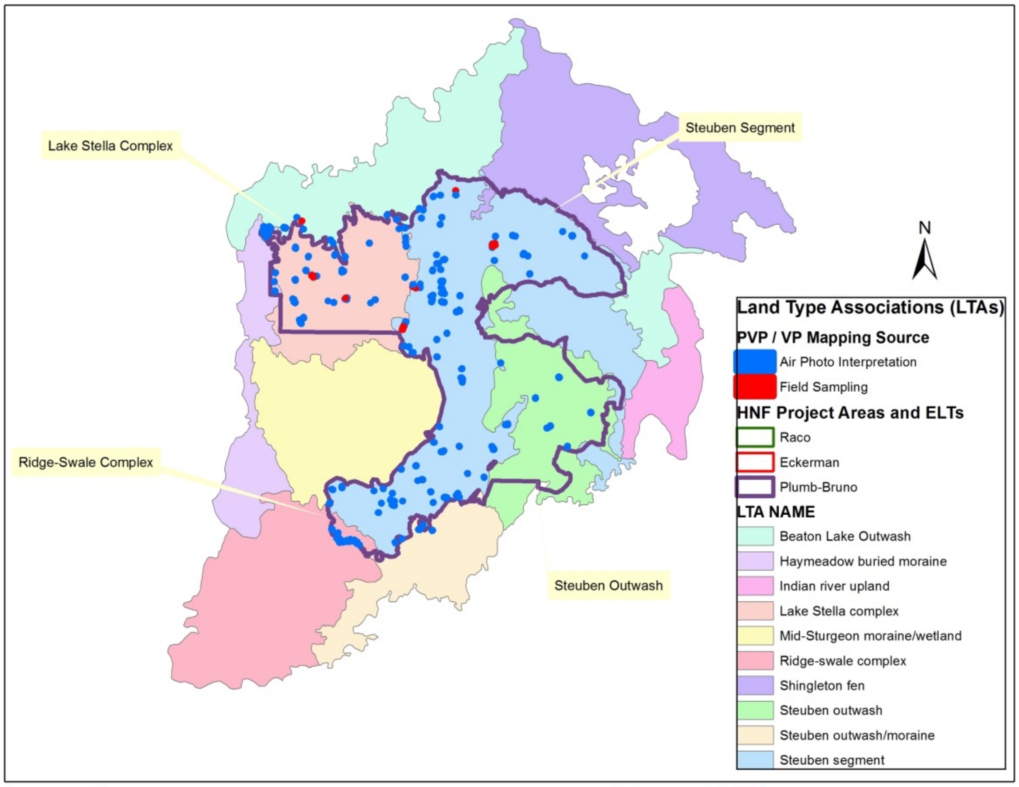
A total of 419 potential vernal pools (PVPs) was identified and mapped within the project areas in the Hiawatha National Forest using aerial photograph interpretation in 2015. Of these, 201 were mapped within and immediately adjacent to the Plumb-Bruno Project Area, and 218 were mapped within and adjacent to the Raco-Eckerman Project Area (Table 5, Figures 5 and 6).

Based on all the potential vernal pool polygons mapped within and adjacent to both project areas, PVP polygons ranged in area from less than 0.01 acre (i.e., 0.0025 acre) to 4 acres (0.001 ha to 1.6 ha), with the mean area of the PVP polygons about 0.25 acre (0.10 ha). The total acreage for all the potential vernal pool polygons across both project areas was about 107 acres (~43 ha). This acreage represents approximately 0.05% of the study area (based on an estimate of about 234,110 acres reviewed for potential vernal pools across both project areas).

The potential vernal pools that were mapped from aerial photos were distributed throughout the project areas within the HNF, but were not evenly distributed throughout the project areas and appeared to be clustered or more prevalent in certain areas (Figures 5 and 6). Potential vernal pools were mapped in all five of the Land Type Associations (LTAs) within the Plumb-Bruno Project Area, but over half (n=112) of the potential vernal pools were located in the Steuben Segment LTA, followed by the Lake Stella Complex LTA (n=43) and the Ridge-Swale Complex LTA (n=26) (Figure 5). Potential vernal pools mapped in the Raco-Eckerman Project Area were located in 8 of the 11 LTA's that occur in the project area, with the highest numbers of PVPs located in the Wilwin Wetlands LTA (n=65) and Raco Sand Plains South LTA (n=66), followed by the Lake Superior Highlands (n=21), Raco Sand Plains North (n=17), Sand Day Transition North (n=15), and East Tahquamenon Drainage LTAs (n=13) (Figure 5). In terms of ELTs, 43% of the potential vernal pools (i.e., 87 of 201 PVPs) in the Plumb-Bruno Project Area were mapped within the ELT 40-50-90, and 12% (i.e., 25 of 201) of the PVPs were mapped within the ELT 60 (Figure 6). However, in the Raco-Eckerman Project Area, potential vernal pools were mapped primarily outside of the ELT 40-50-90 and ELT 60 (Figure 6). Only one of the 218 potential vernal pools mapped in the project area was located in the ELT 40-50-90, and only 14 (6%) were located in the ELT 60.

Field Sampling

MNFI staff surveyed a total of 118 potential and new vernal pools in the field within the Plumb-Bruno and Raco-Eckerman project areas in 2015. Of the 118 pools surveyed, 93 were potential vernal pools that had been identified and mapped from aerial photograph interpretation (API), and 25 were new or potential vernal pools identified in the field that had not been mapped during aerial photo interpretation. The 93 potential vernal pools surveyed in the field represents about 22% of the 419 total potential vernal pools identified and mapped for the study. Of the 118 potential vernal pools surveyed in the field, 60 were located in the Plumb-Bruno Project Area, and 58 were located in the Raco-Eckerman Project Area (Table 5). Of the 25 new potential pools that were identified and surveyed in the field in 2015, 13 were located in the Plumb-Bruno Project Area, and 12 were located in the Raco-Eckerman Project Area (Table 5).



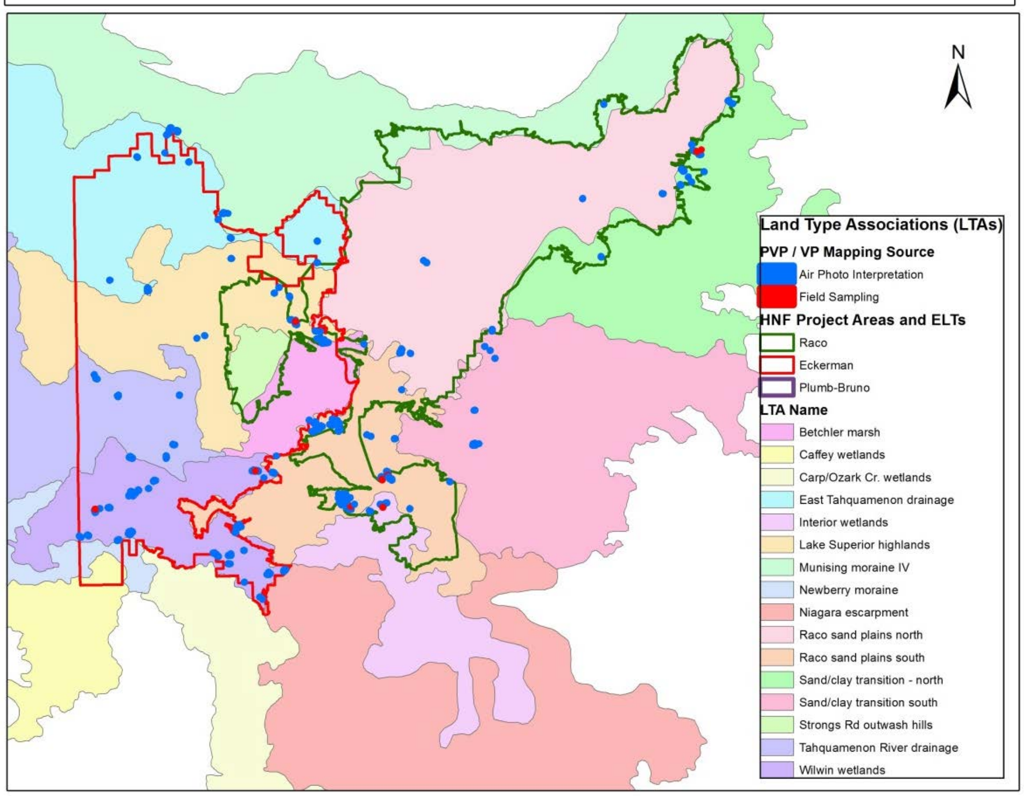
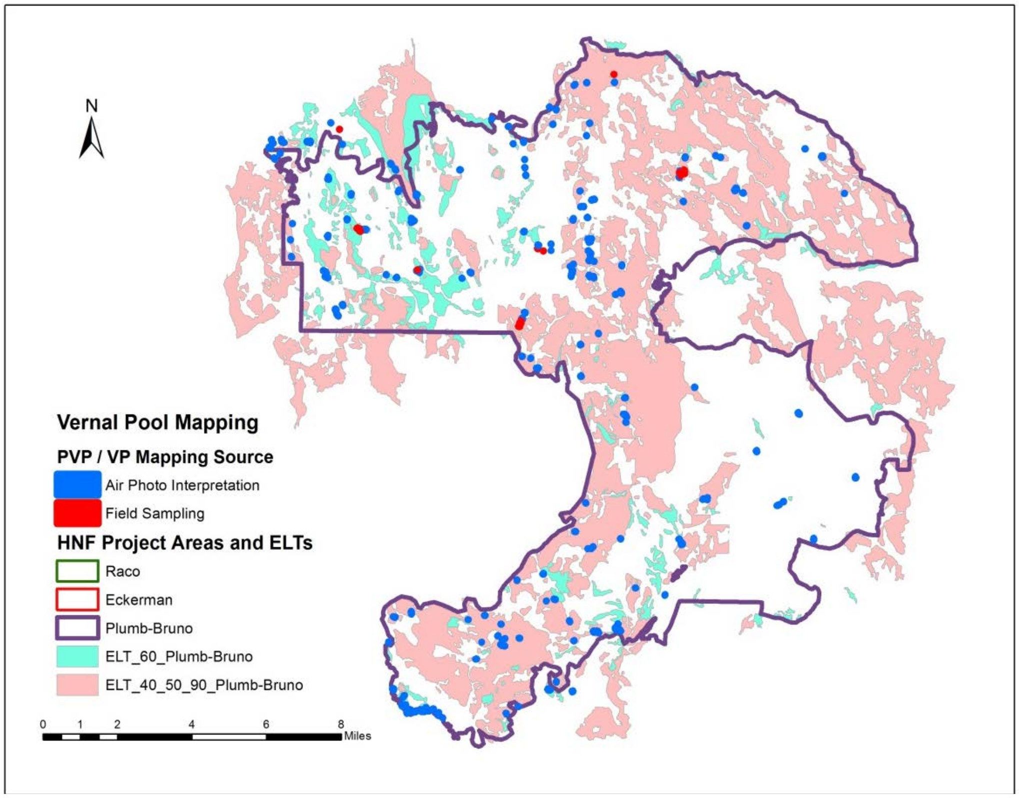


Figure 5. Maps showing the distribution of potential vernal pools (blue polygons) mapped from aerial photo interpretation and LTAs within the Plumb-Bruno Project Area (top) and the Raco-Eckerman Project Area (bottom) in the Hiawatha National Forest in the eastern Upper Peninsula.



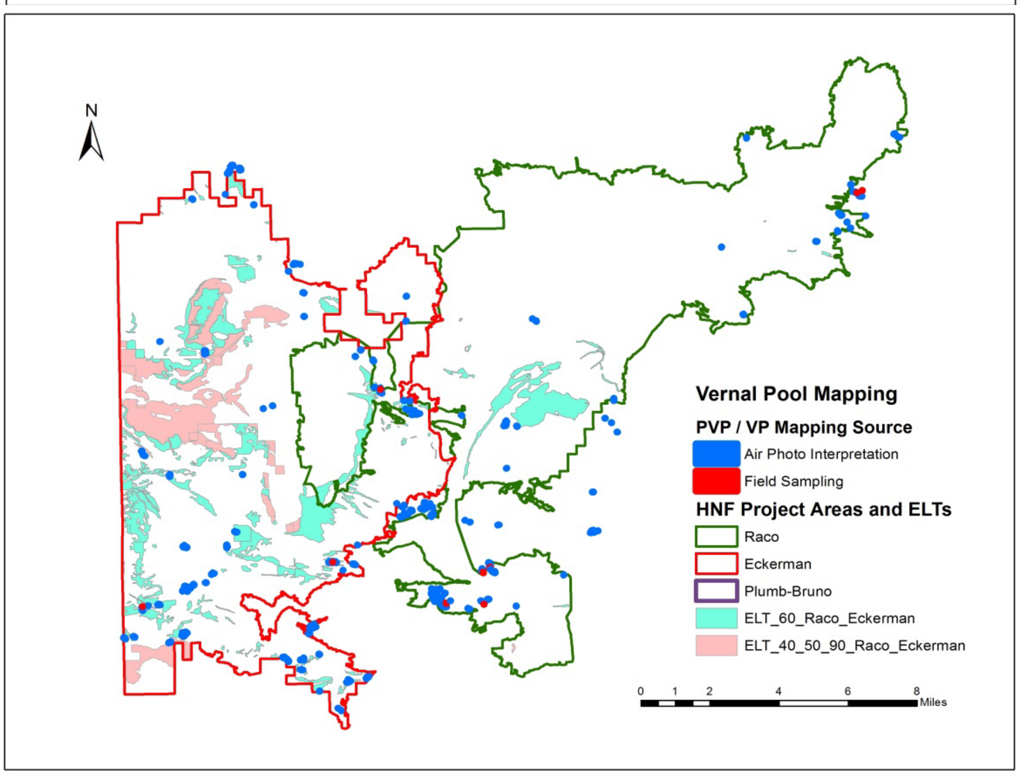


Figure 6. Maps showing the distribution of potential vernal pools (blue polygons) mapped from aerial photo interpretation and Ecological Landtypes (ELTs) 40-50-90 and ELT 60 within the Plumb-Bruno Project Area (top) and the Raco-Eckerman Project Area (bottom) in the Hiawatha National Forest in the eastern Upper Peninsula.

Table 5. Summary of potential vernal pools identified and mapped from aerial photograph interpretation (API) that were surveyed in the field in 2015.

Hiawatha National Forest Vernal Pool Project Area	Total Number of API Potential Vernal Pools Mapped in 2015	Total Number & Percentage of API Potential Vernal Pools Surveyed in 2015	Total Number of Additional Vernal Pools Surveyed in 2015	Total Number of Potential Vernal Pools & Additional Pools Surveyed in 2015
Plumb-Bruno	201	47 (23%)	13	60
Raco-Eckerman	218	46 (21%)	12	58
Total	419	93 (22%)	25	118

Of the 118 potential or new vernal pools that were surveyed in 2015, a total of 74 (63%) were verified as active vernal pools (H2O-VP) (Table 6). An additional 15 pools (13%) were identified as potential or likely vernal pools (H2O-VP?) but their status is uncertain at this time, and additional data are needed for final designation of their status. If these pools are confirmed and included as verified vernal pools, this would result in a total of 89 (75%) vernal pools verified within the project areas in 2015. A total of 29 (25%) of the potential or new vernal pools surveyed in 2015 were verified as not being vernal pools in the field. Of these, 16 (14%) were other types of natural or artificial wetlands (H2O-NVP), and 13 (11%) were areas that were dry (i.e., no water present) (H2O-None) and did not appear to regularly hold water for extended periods of time.

Table 6. Summary of field sampling results in terms of total numbers of vernal pools or potential/likely vernal pools verified in the field and potential vernal pools that were verified as not being vernal pools (i.e., either another type of wetland or were dry and not wetlands at all).

HNF Vernal Pool Project Area	Total Number of API and Field Identified Potential/New Vernal Pools Surveyed in 2015	Total Number Vernal Pools Verified as Vernal Pools in the Field (H2O-VP)	Total Number of Verified Potential or Likely Vernal Pools – Status Uncertain (H2O-VP?)	Total Number Verified as Not Vernal Pools – Other Wetland Types (H2O-NVP)	Total Number Verified as Not Vernal Pools – Dry (H2O-None)
Plumb-Bruno	60	34	2	13	11
Raco-Eckerman	58	40	13	3	2
Total	118	74	15	16	13

Verified Vernal Pools Identified from Aerial Photo Interpretation

Of the 93 potential vernal pools (PVPs) identified and mapped from aerial photos that were surveyed in 2015, 55 (59%) were verified in the field as active vernal pools (Table 7). These included pools that were wet as well as pools that were dry but had sufficient evidence that the basin regularly holds water for part of the year (e.g., black, stained, matted leaf litter in pool basin; water marks at base of tree trunks; presence of wetland plants; presence of vernal pool indicator species; presence of hydric or organic/muck soils) (Figure 7). Of the remaining PVPs identified and mapped from aerial photos, 11 pools were identified as potential or likely vernal pools but their status is uncertain at this time and additional data are needed for final verification of these wetlands (Table 7). Combining the field verified active vernal pools and potential or likely vernal pools would result in a total of up to 66 (71%) verified or likely vernal pools that had been mapped as potential vernal pools from aerial photo interpretation.

All of the potential vernal pools that need additional information to verify their status were surveyed in the fall when they were dry. They had some indications that they held water in the field, but this needs to be verified in the spring when they are wet and for how long (Figure 7). Most of these potential or likely vernal pools also contained a significant amount of herbaceous or graminoid vegetation and/or were part of other wetlands. Some of these potential pools were potentially or likely intermittent wetlands or part of intermittent wetlands, which could be or could function like vernal pools. These potential pools could be marshy vernal pools or emergent wetlands, and need to be revisited in the spring when the pools are full to clarify their status (Figure 7).

Of the 93 PVPs surveyed in 2015, 28 (30%) were verified as not being vernal pools, of which 15 were other types of wetlands, and 13 were dry land and did not appear to regularly hold water for extended periods of time (Table 7). Most of the PVPs that were actually other types of wetlands were bogs, muskegs, and/or intermittent wetlands that did not dry up in the fall, were fairly large/ in size, and/or had abundant shrubs and/or emergent vegetation such as leatherleaf, willow, grasses, and sedges (Figure 8). Two of the potential vernal pools turned out to be permanent pools or ponds. Areas that were dry and had little to no evidence of water pooling at the site for an extended period of time or lacked a distinct basin or depression primarily consisted of small, young upland forest stands (e.g., clump of red maple seedlings), small openings and clearings in upland forests, old two-track roads and small dry depressions that appeared to be artificially created (Figure 8).

Verified Vernal Pools Identified from Field Sampling

Of the 25 new or potential vernal pools encountered in the field in 2015, 19 were verified and mapped as active vernal pools, 5 were designated as potential or likely vernal pools that need additional information to make a final determination of their status, and 1 was not a vernal pool but another wetland type (Table 8). The potential or likely vernal pools that needed additional information to determine their status again consisted of areas that were dry, and need to be revisited in the spring to verify pool status and condition when the pool is wet.

Table 7. Summary of aerial photo interpreted (API) potential vernal pools that were surveyed in 2015 and designated as verified vernal pools, potential or likely vernal pools/status uncertain, not vernal pools but other wetland types, and not vernal pools and dry.

HNF Project Areas	Number of API Potential Vernal Pools Surveyed in 2015	Number Verified as Vernal Pools (H2O-VP)	Number Verified as Potential/Likely Vernal Pools (H2O-VP?)	Number Verified as Not Vernal Pools – Other Wetlands (H2O-NVP)	Number Verified as Not Vernal Pools – Dry (H2O-None)
Plumb-Bruno	47	22	1	13	11
Raco-Eckerman	46	33	9	2	2
Total	93	55	10	15	13

Table 8. Summary of field-identified new or potential vernal pools that were surveyed in 2015 and verified as vernal pools, potential/likely vernal pools/status uncertain, and not vernal pools.

HNF Project Areas	Number of Field Identified New/Potential Vernal Pools Surveyed in 2015	Number Verified as Vernal Pools (H2O-VP)	Number Verified as Potential / Likely Vernal Pools (H2O-VP?)	Number of Verified as Not Vernal Pools – Other Wetlands (H2O-NVP)	Number Verified as Not Vernal Pools-Dry (H2O-None)
Plumb-Bruno	13	12	1	0	0
Raco-Eckerman	12	7	4	1	0
Total	25	19	5	1	0

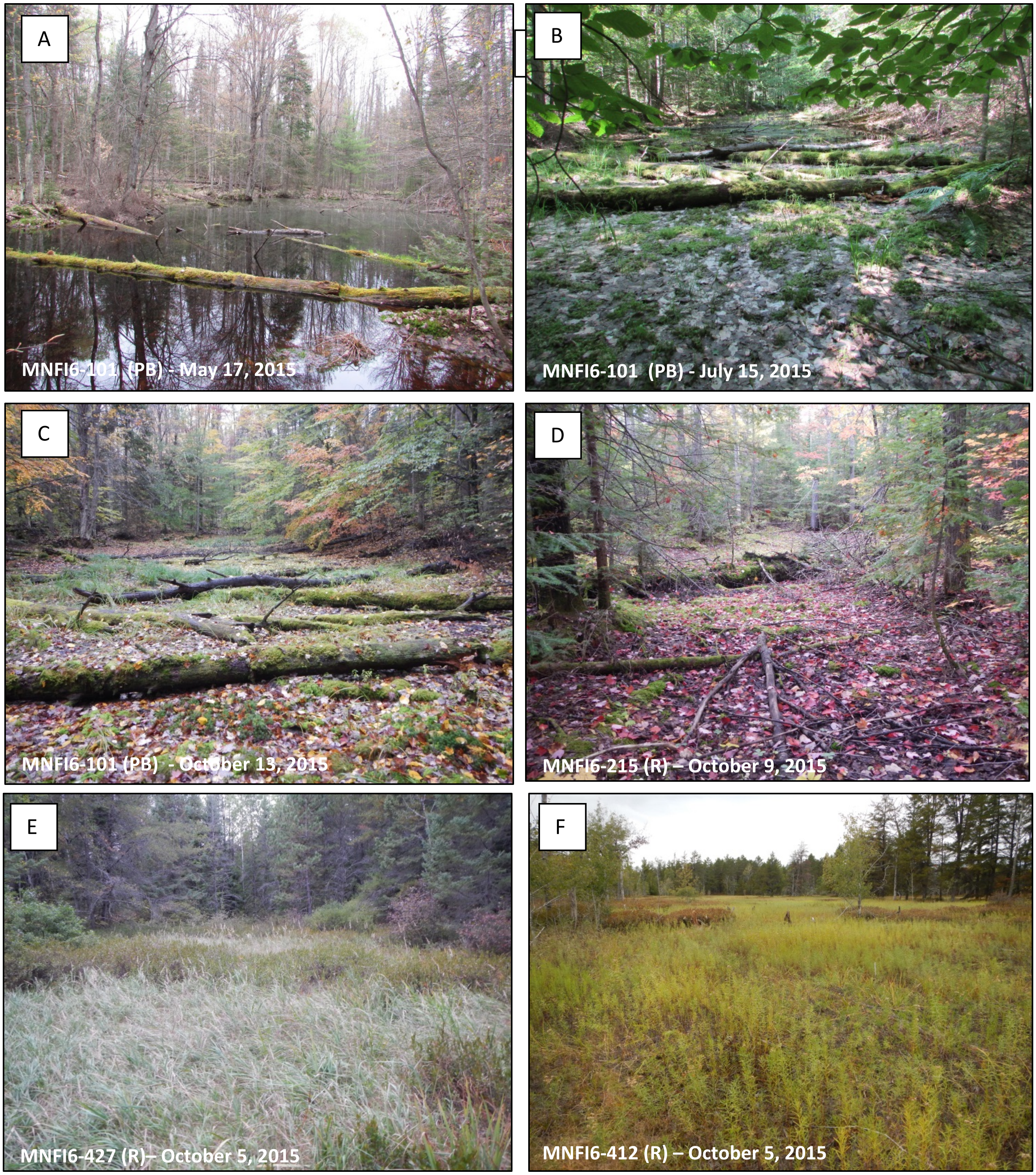


Figure 7. Examples of verified and potential or likely vernal pools that were observed in the field in the Hiawatha National Forest in 2015: (A) verified wet vernal pool when wet; (B) and (C) same verified vernal pool when drying/dry; (D) verified dry vernal pool with clear signs of regularly holding water during part of the year; (E) potential or likely vernal pool that was dry and needs to be revisited in the spring to verify flooding and if either a marsh pool or emergent wetland; and (F) potential vernal pool that was dry that is potentially an intermittent wetland and may be a marshy vernal pool but needs additional information to verify. All photos were taken by Yu Man Lee.

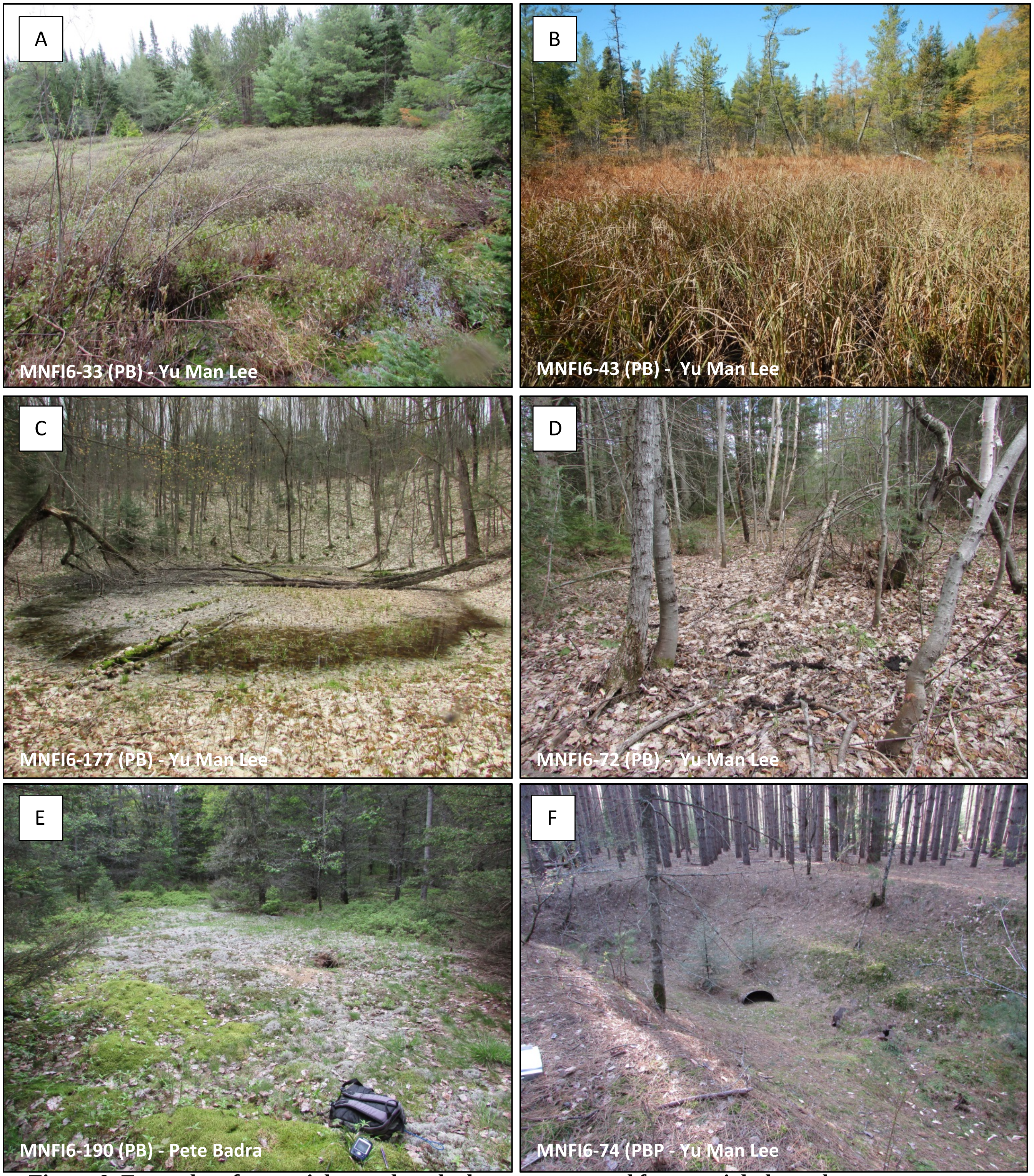


Figure 8. Examples of potential vernal pools that were mapped from aerial photos but were surveyed and verified to not be vernal pools in the field: (A) leatherleaf bog; (B) muskeg or emergent wetland; (C) moat around bog that did not dry up in the fall (had VP indicator species); (D) forest stand with no standing water or signs that area regularly holds water for extended time; (E) opening in upland forest; and (F) artificially created depression.

Vernal Pool Characteristics

Most of the vernal pools verified during surveys in 2015 were categorized as open, sparsely vegetated, or marsh pools, followed by shrubby pools (Figure 9). About 40% of the verified vernal pools were categorized as open or sparsely vegetated. About 22% of the verified vernal pools were categorized as marsh pools, followed by about 15% categorized as shrubby pools. Only three vernal pools were categorized as forested pools. A number of pools (~13) also were classified as a mixed pool type such as open and marsh pool or shrubby and marsh pool (Figure 9). A couple of the pools were open pools within emergent wetlands (Figure 9). Additionally, a number of the potential or likely vernal pools that need additional information to make a final designation on their status were marsh or shrubby pools.

Figure 9. Examples of different vernal pool types encountered in the field during vernal pool surveys on the Hiawatha National Forest in the eastern Upper Peninsula – (A) Open Pool; (B) Marsh Pool (in May); (C) Shrubby-Marsh Pool (in October); and (D) Forested Pool.

Water levels in the vernal pools surveyed in 2015 appeared to be typical of water levels expected during the spring, summer, and fall. Most (~70%) of the vernal pools surveyed in the spring (i.e., May) were full/mostly full (75-100% full) or partially full (50-74% full). Most (~90%) of the vernal pools surveyed in the summer (i.e., July) were partially full or less than half full (25-49% full). All of the vernal pools and almost all of the potential vernal pools surveyed in the fall (i.e., October) were dry/mostly dry (0-24% full).

Most of the verified vernal pools were isolated and did not have any inlet or outlet channels. Of the 74 verified vernal pools identified during surveys in 2015 (combining pools identified from air photos and in the field), 54 (73%) of the pools were isolated, and 18 (24%) of the pools were not isolated and were connected to or part of other vernal pools or other wetlands. A total of 69 (93%) of these vernal pools did not have any inlets or outlets, and only 2 (3%) of them had temporary inlets or outlets.

The verified vernal pools in the study areas were very small. Size of the verified vernal pools ranged from 0.003 acre to about 1 acre (0.001 ha – 0.44 ha), with a mean vernal pool area of 0.18 acre (0.07 ha). Total area summed for all the verified vernal pools across the Plumb-Bruno and Raco-Eckerman project areas was only 13 acres (~5 ha). These estimates may or will likely change with the addition of at least some of the potential or likely vernal pools that need additional data to verify their status.

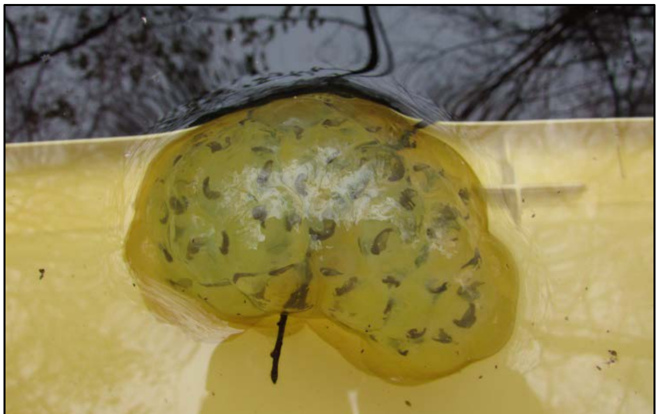
Presence of vernal pool obligate or indicator species was documented in only 14 of the 74 vernal pools verified during field sampling in 2015 (Table 9). However, only 38 of these were surveyed in the spring and/or summer of 2015 when vernal pool indicator species would have been observed if present. Thus, vernal pool indicator species were documented in 37% of these pools. These were all located in the Plumb-Bruno Project Area. Vernal pool indicator species also were documented in one additional wetland that was not classified as a vernal pool (i.e., a moat around a kettlehole bog that did not dry up in 2015). Vernal pool indicator species that were documented include fairy shrimp, wood frog tadpoles, blue-spotted salamander egg masses and larvae, and spotted salamander egg masses and larvae (Figure 10).

In addition to vernal pool indicator species, a number of other invertebrate and amphibian species commonly associated with vernal pools were found in a number of pools. Invertebrate species included mosquito larvae (Culicidae), springtails (Collembola), water fleas (Cladocera/Daphnia), copepods (Copepoda), phantom midges (Chaoboridae), chironomids or non-biting midge larvae (Chironomidae), water boatmen (Corixidae), water striders (Gerridae), water mites (Hydrachnidiae), caddisfly larvae (Trichoptera: Limnephilidae), clubtail dragonfly larvae (Gomphidae), Megaloptera (alderflies, dobsonflies, and fishflies) larvae, horsehair worms (Nematomorpha), predacious diving water beetles (Dytiscidae), whirligig beetles (Gyrinidae), other aquatic beetles (Coleoptera), bladder snails (Physidae), and fingernail clams (Veneroida: Sphaeriidae). Other amphibians and reptiles that were documented in or along the vernal pools surveyed in 2015 included a Painted Turtle (Chrysemys picta), Spring Peeper (*Pseudacris crucifer*) tadpoles and adults, Western Chorus Frog (*Pseudacris triseriata triseriata*) tadpoles, an American Toad (*Anaxyrus americanus*), and Green Frogs (*Lithobates clamitans*). This should be considered a preliminary list of species occurring in the vernal pools since limited surveys for other species were conducted in 2015.

Table 9. Summary of vernal pools and other wetlands in which vernal pool indicator species were found during surveys in the Plumb-Bruno Project Area in the Hiawatha National Forest in the eastern Upper Peninsula in 2015.

Pool ID	Pool Type	Fairy Shrimp (Y)	Wood Frog Egg Masses (E), Tadpoles (T), and/or Breeding Adults (A)	Spotted Salamander Egg Masses (E), Larvae (L), and/or Breeding Adults (A)	Blue-spotted Salamander Egg Masses (E), Larvae (L), and/or Breeding Adults (A)
MNFI6-65	Open			E	
MNFI6-69	Shrubby			E	
MNFI6-73	Marshy			E	(E?)
MNFI6-83	Marshy			L	
MNFI6-84	Marshy			L	L
MNFI6-97	Open			E	E
MNFI6-98	Open			E	E
MNFI6-101	Open		T	E, L	(E?)
MNFI6-177*	Bog			E, L	E, L
MNFI6-178	Open				E
MNFI6-187	Shrubby		T		
MNFI6-188	Open			E	
MNFI6-208	Open	Y			
MNFI6-209	Sparsely Vegetated			E	
MNFI6-210	Sparsely Vegetated/ Marshy			(E?)**	(E?)**
TOTAL NUMBER OF POOLS		**1**	**2**	**11 (12)**	**5 (8)**

*MNFI6-177 was a moat around a bog and did not dry up by October 2015, so was categorized as not a vernal pool.
**MNFI6-210 – An Ambystomatid salamander egg mass was found but was not able to be identified to species.



MNFI6-101 - Spotted Salamander Egg Mass

MNFI6-177 – Blue-spotted Salamander Egg Masses

MNFI6-101 – Spotted Salamander Larva (fine-scale blotching/speckling on tail)

MNFI6-84 – Blue-spotted Salamander Larva (large blotches on tail)

MNFI6-208 – Fairy Shrimp

MNFI6-208 – Close-up of fairy shrimp

Figure 10. Examples of vernal pool indicator species found in vernal pools in the Plumb-Bruno Project Area in the Hiawatha National Forest in the eastern Upper Peninsula of Michigan in 2015.

Vernal Pool Results by Land Type Association (LTA) and Ecological Land Type (ELT)

Plumb-Bruno Project Area

Vernal pool field sampling in the Plumb-Bruno Project Area focused on the Steuben Segment and Lake Stella Complex Land Type Associations (LTAs) (Table 10). Forty potential vernal pools identified from aerial photos or in the field were surveyed in the Steuben Segment LTA, of which 24 (60%) were verified as vernal pools (Table 10). Vernal pool indicator species were documented in 13 (54%) of the 24 verified vernal pools in this LTA. Sixteen potential vernal pools were surveyed in the Lake Stella Complex LTA, of which six (37.5%) were vernal pools, and two were classified as potential or likely vernal pools that need additional information to confirm their status (Table 10). Vernal pool indicator species were not observed in any of these pools. One potential vernal pool in the Steuben Outwash LTA was surveyed and verified as a vernal pool with vernal pool indicator species.

Of the 60 potential vernal pools surveyed in the Plumb-Bruno Project Area, 29 were located in the ELT 40-50-90 stands, and 11 were located in the ELT 60 stands (Table 11). Of the 29 PVPs surveyed in the ELT 40-50-90 stands, 17 (58%) were verified as vernal pools, and vernal pool indicator species were found in 7 of these pools. Of the 11 PVPs surveyed in the ELT 60 stands, 5 (45%) were verified as vernal pools, and 2 were categorized as potential vernal pools that need additional information to confirm their status (Table 11). Vernal pool indicator species were not found in the pools surveyed in the ELT 60 stands.

Raco-Eckerman Project Area

Field sampling was conducted in 6 of the 11 LTAs in the Raco-Eckerman Project Area, and vernal pools were verified in 5 of the 6 LTAs surveyed (Table 10). Twenty-four potential vernal pools identified from aerial photos or in the field were surveyed in the Raco Sand Plains South LTA, of which 14 (58%) were verified as vernal pools and 6 additional pools were designated as potential vernal pools that need additional information to confirm their status (Table 10). Ten potential vernal pools were surveyed in the Wilwin Wetlands LTA, of which 6 (60%) were verified as vernal pools and the remaining 4 pools were potential vernal pools that need additional information to verify their status. A total of nine potential vernal pools was surveyed in the Lake Superior Highlands LTA, of which eight (89%) were verified as vernal pools and one was a potential vernal pool that needs additional information (Table 10). Eight potential vernal pools were surveyed in the Sand/Day Transition-North LTA, and seven of these were verified as vernal pools in the field. Six potential vernal pools were surveyed in the Interior Wetlands LTA, of which five were verified as vernal pools (Table 10).

Because a majority of the potential vernal pools identified and mapped from aerial photos and in the field in the Raco-Eckerman Project Area were not located in the ELT 40-50-90 or ELT 60 stands, only a small number of potential vernal pools were surveyed in these landtypes. Of the 15 potential vernal pools mapped in the ELT 60 stands in this project area, only seven were surveyed, of which four were verified as vernal pools (Table 11). There was only one potential vernal pool mapped in the ELT 40-50-90 stands in this project area, and it was not surveyed in 2015. Most of the vernal pools verified in the Raco-Eckerman Project Area were located in other ELTs.

Table 10. Summary of vernal pool sampling results by Land Type Association (LTA) in the Plumb-Bruno and Raco-Eckerman project areas in the Hiawatha National Forest in the eastern Upper Peninsula in 2015.

Land Type Association (LTA)	Potential Vernal Pools Mapped in 2015	Potential Vernal Pools Surveyed in 2015	Verified Vernal Pools (Percent of PVPs Surveyed)	Verified Potential Vernal Pools –Status Uncertain	Not a Vernal Pool – Another Type of Wetland	Not a Vernal Pool – Dry/ No Water
Plumb Bruno						
Steuben Segment	112	40	24 (60%)	0	6	10
Lake Stella Complex	43	16	6 (38%)	2	7	1
Steuben Outwash	7	1	1 (100%)	0	0	0
Beaton Lake Outwash*	7	3	3 (100%)	0	0	0
Raco-Eckerman						
Raco Sand Plains South	66	24	14 (58%)	6	3	1
Wilwin Wetlands	65	10	6 (60%)	4	0	0
Lake Superior Highlands	21	9	8 (89%)	1	0	0
Sand/Day Transition - North	15	8	7 (88%)	1	0	0
Interior Wetlands	7	6	5 (83%)	1	0	0
Raco Sand Plains North	17	1	0 (0%)	0	0	1
TOTAL	**360****	**118**	**74**	**15**	**16**	**13**

*LTA outside but adjacent to the project area boundary. **Total does not include all mapped PVPs.

Table 11. Summary of vernal pool sampling results by Ecological Land Type (ELT) 40-50-90 and ELT 60 in the Plumb-Bruno and Raco-Eckerman project areas in the Hiawatha National Forest in the eastern Upper Peninsula in 2015.

Ecological Land Type (ELT)	Potential Vernal Pools Mapped in 2015	Potential Vernal Pools Surveyed in 2015	Verified Vernal Pools (Percent of PVPs Surveyed)	Verified Potential Vernal Pools –Status Uncertain	Not a Vernal Pool – Another Type of Wetland	Not a Vernal Pool – Dry/ No Water
Plumb Bruno						
ELT 40-50-90	87	29	17 (59%)	0	6	6
ELT 60	25	11	5 (45%)	2	3	1
Other ELTs	89	20	12 (60%)	0	4	4
Raco-Eckerman						
ELT 40-50-90*	1	0	0	0	0	0
ELT 60	14	7	4 (57%)	3	0	0
Other ELTs	203	51	36 (71%)	10	3	2
TOTAL	**419**	**118**	**74**	**15**	**16**	**13**

*Only one potential vernal pool identified and mapped from aerial photo interpretation in this ELT.

Accuracy Assessment for Aerial Photo Interpretation

The overall accuracy rate for correctly identifying vernal pools from aerial photograph interpretation was moderate. Of the 93 potential vernal pools that were identified and mapped from aerial photos and surveyed in the field across both project areas in 2015, 55 (59%) were verified as vernal pools in the field. An additional 10 (11%) were identified as potential or likely vernal pools that need additional information to confirm their status. Combining the verified and potential/likely vernal pools would result in a total of 65 vernal pools identified in the field, which would result in an overall vernal pool mapping accuracy rate of 70% for aerial photo interpretation across both project areas.

The vernal pool accuracy rate varied between the two project areas, with the Plumb-Bruno Project Area having an accuracy rate of 47% (22 verified vernal pools of 47 potential vernal pools mapped from aerial photos and surveyed) and the Raco-Eckerman Project Area having an accuracy rate of 72% (33 of 46). When the potential or likely vernal pools that need additional information to confirm their status were included in the total number of vernal pools verified in the field, the accuracy rate for the Plumb-Bruno Project Area increased to 49% while the accuracy rate for the Raco-Eckerman Project Area increased to 91%.

Commission error, in terms of identifying potential vernal pools from aerial photo interpretation that turned out to not be vernal pools in the field, was fairly high. A total of 28 potential vernal pools identified from air photos were surveyed and verified as not being vernal pools in the field (i.e., other types of wetlands or dry land). This resulted in an overall commission error rate of 30% (i.e., 28 of 93 PVPs) for mapping vernal pools using aerial photo interpretation across both project areas. Again, this varied by project area, with the Plumb-Bruno Project Area having a commission error rate of 51% (i.e., 24 of 47 PVPs) and the Raco-Eckerman Project Area having a commission error rate of only 9% (i.e., 4 of 46 PVPs).

As mentioned earlier, omission error, in terms of not mapping vernal pools from aerial photo interpretation that actually exist in the field, cannot be truly estimated because areas that did not have potential vernal pools mapped were not targeted for field sampling, and project areas were not systematically surveyed for vernal pools. However, we may be able to provide a proxy estimate of omission error in terms of the number of verified vernal pools identified in the field that were not mapped as potential vernal pools relative to the total number of vernal pools documented in the field. Of the 74 vernal pools verified in the field across both project areas, 19 of these were found in the field and were not mapped during aerial photo interpretation. These 19 pools represent about 26% of the total number of verified vernal pools that were found in the field across both project areas. As with the accuracy rate and commission error, this also varied by project area. Twelve (35%) of the 34 vernal pools verified in the field in the Plumb-Bruno Project Area were not mapped during aerial photo interpretation, but only 7 (18%) of the 40 vernal pools verified in the field in the Raco-Eckerman Project Area were not mapped during aerial photo interpretation. However, these estimates should be viewed with caution though for reasons mentioned earlier.

We examined whether vernal pool mapping accuracy using aerial photo interpretation varied by Land Type Association or Ecological Land Type. The accuracy rate for identifying and mapping vernal pools did vary to some degree among LTAs within both project areas although sample sizes, in terms of the number of potential vernal pools that were surveyed, were uneven and fairly small for some of the LTAs (Table 10). Vernal pool mapping accuracy rates also appeared to vary slightly between ELT 40-50-90 and ELT 60 within the Plumb-Bruno Project Area (Table 11), but again, sample sizes were uneven and fairly small. Additional data and analyses are needed to further evaluate the impact of LTA and/or ELTs on the effectiveness of mapping vernal pools using aerial photo interpretation.

Vernal Pool Training

On July 16, MNFI conducted a vernal pool training for HNF staff. The training included an indoor portion during which basic information on vernal pool ecology was presented, and a field component in which HNF staff were able to visit and see several vernal pools and some associated amphibians and invertebrates in the field. The indoor portion of the training was held at the Munising District Office, and the field component was conducted about 10-13 miles south of Munising in the Plumb-Bruno Project Area at vernal pools northwest of Thornton Lake and north of McKeever Lake. During the indoor and outdoor components of the training, we reviewed and discussed how to identify vernal pools in the field, the vernal pool survey and monitoring protocol and field form, and potential management of vernal pools. We also provided HNF staff with some basic reference materials on vernal pools. Approximately 12 HNF staff from both the West and East Zones of the Forest attended the training.

DISCUSSION

Aerial Photograph Interpretation

We identified and mapped a fairly large number of potential vernal pools (i.e., 419) from aerial photo interpretation across the Plumb-Bruno and Raco-Eckerman project areas within the Hiawatha National Forest (HNF) in 2015. We were able to exceed our initial goal of reviewing and mapping potential vernal pools of at least 100,000 acres and primarily within the ELT 40-50-90 and ELT 60 forest stands in the two project areas. We reviewed and mapped potential vernal pools across both project areas regardless of ELT, which totaled approximately 234,110 acres (94,741 ha). This was accomplished over approximately a one-week (5-7-day) time period.

Vernal pool mapping results from this project also are significant from a statewide perspective because previous vernal pool mapping efforts (e.g., Lee 2014, Lee et al. 2014) focused mainly on national and state forest lands in the western Upper Peninsula of Michigan. This project has contributed the first set of potential and verified vernal pools in the eastern Upper Peninsula to Michigan's statewide vernal pool database (MNFI 2016). Vernal pools have been identified and mapped in the eastern Upper Peninsula prior to this project, but past efforts have been conducted on a project-by-project basis and have been fairly limited in scope (e.g., Pictured Rocks National Lakeshore, Previant and Nagel 2014). Vernal pool locations from these other efforts also have not been submitted and incorporated into the statewide vernal pool database yet. Having information on vernal pools in the eastern Upper Peninsula will contribute greatly to our knowledge and understanding of vernal pools and will aid in their conservation and management across the state.

The amount of area that can be reviewed and mapped for potential vernal pools in a given amount of time depends on the number of potential vernal pools in the area and the availability and quality of aerial photo imagery, particularly high resolution, leaf-off aerial imagery taken in the spring. The amount and type of forest cover around vernal pools (e.g., deciduous or coniferous forest) and pool type and size also can potentially affect vernal pool mapping efficiency and amount of area that can be reviewed and mapped for potential vernal pools. We were able to review and map potential vernal pool across over 234,000 acres for this project compared to 115,000 to 120,000 acres of state forest lands in the western Upper Peninsula for another project during the same amount of time as this project (i.e., 5-7 days) (Lee 2014). This may have been due, at least in part, to fewer potential vernal pools identified in the Plumb-Bruno and Raco-Eckerman project areas compared to the study areas for the project in the western U.P. (i.e., 419 compared to 1,332 PVPs, respectively). We also had more recent and higher resolution aerial imagery for this project (i.e., 2007 leaf-off, color infrared (CIR) aerial imagery) which also likely increased our efficiency at mapping potential vernal pools. For the previous project in the western U.P. and MNFI's earlier vernal pool mapping efforts, 1998 CIR aerial photo imagery was primarily used to map potential vernal pools, although we were able to find and use some more recent, high resolution, leaf-off natural color aerial imagery of the western U.P. study areas.

The accuracy rate for mapping vernal pools from aerial photo interpretation for this project was moderate. Our overall accuracy rate for correctly identifying vernal pools from aerial photo interpretation across both project areas was 59% based on verified vernal pools, and potentially 70% if potential/likely vernal pools that need additional information to verify their status were included. These accuracy rates are slightly higher than those obtained during MNFI's previous vernal pool mapping efforts in the western Upper Peninsula (Table 12). Lee (2014) reported vernal pool mapping accuracy rates of 48% based on verified vernal pools only, and 58% based on verified and potential/likely vernal pools on state forest lands in Houghton, Iron, and Dickinson counties in the western Upper Peninsula (Table 12). An earlier vernal pool mapping effort conducted in 2012 and 2013 included mapping potential and verified vernal pools on national and state forest lands in Baraga, Houghton, and Iron counties in the western Upper Peninsula using aerial photo interpretation and field sampling. This effort yielded vernal pool mapping accuracy rates of 50% for verified vernal pools only, and 58% for verified and potential/likely vernal pools, based on individual pools (Lee et al. 2014) (Table 12).

The commission error rate for this project was similar to or slightly lower than those for previous vernal pool mapping efforts in the western Upper Peninsula. The commission error rate for this project was 30%, which is lower than the 42% commission error rate reported by Lee (2014) for vernal pool mapping on state forest lands in the western U.P. (Table 12). The commission error rate for Lee et al. (2014) was 31% based on individual vernal pools, and 40% based on vernal pools mapped and surveyed in randomly selected sample test cells (Table 12). Omission or proxy omission error rates were surprisingly similar across the projects. The proxy omission error rate for this project was 26%, and was about 25% in Lee (2014) (Table 12). Lee et al. (2014) reported an omission error rate of 25% for surveyed test cells (Table 12).

Vernal pool mapping accuracy was higher for this project compared to earlier vernal pool mapping efforts in the western Upper Peninsula (Lee 2014, Lee et al. 2014) for a couple of potential reasons. Utilizing more current and higher resolution leaf-off CIR aerial imagery to map vernal pools for this project is most likely the primary reason for the higher vernal pool mapping accuracy for this project. Additionally, many of the vernal pools verified in the field for this project were marshy and/or shrubby pools with open canopy cover, particularly in the Raco-Eckerman Project Area. It may have been easier to see and identify these vernal pools on the aerial imagery because of the open canopy. Enhanced photo interpreter skill or experience with identifying and mapping vernal pools from aerial imagery also may have contributed to higher vernal pool mapping accuracy for this project compared to earlier vernal pool mapping efforts. However, even with more recent, higher resolution leaf-off CIR aerial imagery, some vernal pools could still not be readily identified from aerial imagery (Figure 11). This may have been due to their small size and/or shallow water depth, the vegetation present in the pools, and/or timing of the photos (e.g., pools may not have filled with water yet or were dry that year). Although the vernal pool mapping accuracy rate for this project was higher than accuracy rates for previous vernal pool mapping efforts in the western Upper Peninsula, the accuracy rate for this project was still lower than those obtained for vernal pool mapping efforts in targeted study areas in northeastern, southeastern, and southwestern Lower Peninsula (Table 12). More extensive forested cover across the landscape and greater prevalence of coniferous trees in the forests in the western and eastern U.P., combined with the small and shallow nature of vernal pools, likely make it more challenging to identify vernal pools under forest canopy in the U.P. than in other parts of the state. Additionally, on average, vernal pools in the U.P. may be shallower and smaller than vernal pools in other parts of the state, which may make them even more challenging to identify and map from aerial photos. The study areas for MNFI's previous vernal pool mapping projects in the western U.P. were located in bedrock-controlled physiographic regions, where the bedrock is close to the surface in many areas (Schaetzl et al. 2013). The eastern Upper Peninsula is characterized by low elevation, low relief landscapes with sandy, sandy loam, and/or loamy soils underlain by varying depths of glacial drift or bedrock (Schaetzl et al. 2013). Because of the landform, geology, and soils in the eastern and western U.P., many of the vernal pools we encountered in these areas tended to be very small and shallow. Most of the vernal pools we surveyed in the Hiawatha National Forest in the spring of 2015, when water levels in the pools were full or mostly full, were less than 1 - 2 feet deep. Additional efforts to identify and map vernal pools using aerial photos and to assess the accuracy of these efforts should be conducted to improve our ability to identify vernal pools using aerial photo interpretation in the Upper Peninsula.

Vernal pool mapping accuracy rates obtained for this project in the eastern Upper Peninsula and during earlier mapping efforts in the western U.P. also are lower than those reported for vernal pool mapping efforts in other states (e.g., Burne 2001 in Massachusetts, Lathrop et al. 2005 in New Jersey) (Table 12). Differences in accuracy and error rates between our study and studies in other states could have resulted from differences in forest structure and composition, quality or resolution of the aerial photo imagery, study design, timing of the aerial photos, and photo interpreter skill and experience. However, accuracy rates for mapping vernal pools in northeastern and southeastern Lower Peninsula were comparable to accuracy rates obtained by these studies in other states (Table 12). Other factors mentioned earlier regarding the small, shallow, and forested nature of the vernal pools in the eastern and western U.P. also may have contributed to lower vernal pool mapping accuracy rates in the U.P. compared to mapping efforts in other parts of the country.

Table 12. General comparison of accuracy and error rates for identifying and mapping vernal pools from aerial photograph interpretation across various studies in Michigan and other states. It is important to note that these are general comparisons and not direct comparisons since study designs and methods varied among projects. *PB = Plumb-Bruno, RE = Raco-Eckerman.

State and Project Area/Study	Accuracy Rate (True Positives)	Accuracy Rate (True Negatives)	Commission Error (False Positives)	Omission Error (False Negatives)
MI – E. Upper Peninsula (Lee 2016, current study, based on individual pools	59%[1] (47% for PB*) (72% for RE*)	-	30%[2] (9% for RE*) (51% for PB*)	(26%)[3]
MI – W. Upper Peninsula (Lee 2014, based on individual pools)	48%[1]	-	42%[2]	(~25%)[3]
MI – W. Upper Peninsula (Lee et al. 2014 – based on individual pools / test cells)	47%[1] / 60%[4]	- / 75%[5]	31%[2] / 40%[6]	- / 25%[7]
MI – NE Lower Peninsula (Lee et al. 2014 – individual pools / test cells)	84%[1] / 85%[4]	- / 97%[5]	7%[2] / 15%[6]	- / 3%[7]
MI – SE Lower Peninsula (Lee et al. 2014 – based on individual pools / test cells)	77%[1] / 73%[4]	- / 88%[5]	25%[2] / 27%[6]	- / 12%[7]
MI – SW Lower Peninsula (Cohen et al. *In prep* – based on individual pools)	88%[1]	-	-	(19%)[3]
MA – various studies (Burne 2001)	>80-90%[1]	-	<3-5%[2]	-
NJ - statewide (Lathrop et al. 2005)	88%[1]	-	12%[2]	30%[7]

[1]Accuracy rate (true positives) was calculated based on the number of field verified vernal pools compared to the total number of potential vernal pools identified from aerial photo interpretation.
[2]Commission error (false positives) was calculated based on the number or percentage of individual vernal pools that had been mapped as potential vernal pools from aerial photo interpretation but were verified to not be vernal pools in the field (i.e., other wetland type or dry/no water present).
[3]These omission error estimates were based on the number of individual vernal pools verified in the field that had not been mapped during aerial photo interpretation compared to the total number of vernal pools verified in the field. These are considered pseudo- or proxy estimates of omission error.
[4]Accuracy rate (true positives) was calculated based on the number of test cells with vernal pools verified in the field compared to the number of test cells surveyed that contained potential vernal pools identified from aerial photo interpretation.
[5]Accuracy rate (true negatives) was calculated based on the number of test cells surveyed that did not have vernal pools identified in the field compared to the number of test cells surveyed that did not contain potential vernal pools identified from aerial photo interpretation.
[6]Commission error (false positives) was calculated based on the number or percentage of sampled test cells that contained potential vernal pools identified from aerial photo interpretation but were verified as not containing vernal pools in the field.
[7]Omission error (false negatives) was calculated based on the number of test cells that contained vernal pools/possible vernal pools identified in the field compared to the number of test cells that were sampled that did not contain potential vernal pools identified from aerial photo interpretation.

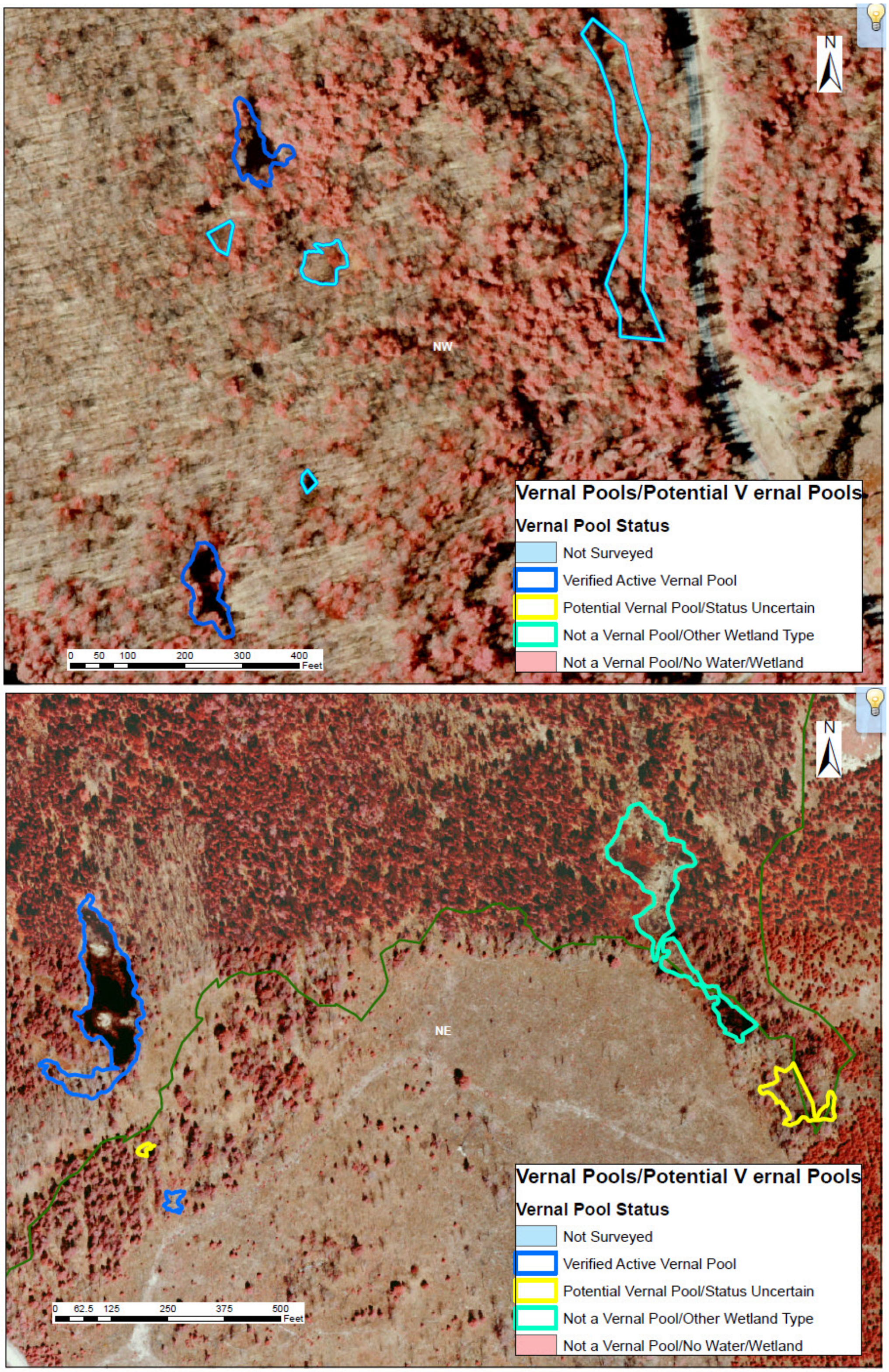


Figure 11. Examples of vernal pools verified in the field in 2015 that did not have obvious signs of standing water in the spring (i.e., black coloration) on the CIR leaf-off aerial imagery and, hence, were not identified as potential vernal pools in the Plumb-Bruno Project Area (top, shown in light blue) and Raco-Eckerman Project Area (bottom, shown in yellow and small dark blue polygon).

Several factors likely contributed to commission error (i.e., false positives) in addition to the type and quality of aerial photo imagery used in vernal pool mapping. Casting of shade by canopy trees can appear very similar to wetlands/vernal pools, and likely contributed to commission error. Viewing aerial photos on the computer screen and not using stereoscopes which would allow us to see the topographic variations in the terrain better also may have contributed to commission error. We also tended to be conservative and erred on the side of being inclusive in our mapping of potential vernal pools, which also likely contributed to higher commission error. Burne (2001) also reported similar sources of commission error.

A number of factors likely contributed to omission error. As reported in other studies, very small pools are generally difficult to identify and map, and cannot be identified and mapped with great reliability using aerial photos. Burne (2001) found that pools smaller than 50-60 ft (15–18 m) in diameter could not be reliably identified from aerial photos at a scale of 1:12,000, and pools between 60 and 125 ft (18 and 38 m) in diameter were easily confused with tree shadows and some types of man-made features. Burne (2001) found that pools at least 100 ft (30 m) in diameter could be more reliably detected using aerial photos at 1:12,000 scale. Lathrop et al. (2005) found that pools with perimeters less than 131 ft (40 m) or areas less than 0.03 acre (120 m^2 / 0.01 ha) are difficult to reliably identify and map with aerial photos, but pools with perimeters greater than approximately 165 ft (50 m) and areas greater than approximately 0.05 acre (0.02 ha) in size (assuming a roughly circular shape) can be reliably mapped at 1:5000 scale. The verified vernal pools for this project ranged in size from 0.003 acre to about 1 acre, with a mean pool area of 0.18 acre. As mentioned earlier, identification of vernal pools in areas dominated by coniferous vegetation is challenging since it is difficult or impossible to see the forest floor (Burne 2001). Small vernal pool size and coniferous tree cover likely contributed to omission error for vernal pool mapping for this project.

Results from this project also suggest that other factors such as physiographic region, land type association (LTA), ecological land type (ELT), and/or vernal pool type may impact the accuracy and effectiveness of mapping potential vernal pools using aerial photo interpretation. Different physiographic regions or land types are characterized by different landforms, soils, hydrology, and vegetation, which can impact vernal pool size, depth, and vegetation within and around the pool, and in turn, impact the ability to see vernal pools in aerial photos. The vernal pool sampling results suggest there may be differences in vernal pool mapping accuracy among land type associations or ecological land types (see Tables 10 and 11). For example, in the Plumb-Bruno Project Area, vernal pool mapping using aerial photos appeared to be more accurate potentially in the Steuben Segment LTA and ELT 40-50-90 than in the Lake Stella Complex LTA and ELT 60 (Tables 10 and 11). However, sample sizes for this analysis were small, and additional data are needed to further investigate this. Vernal pool mapping accuracy varied between the two project areas, with higher accuracy rates and lower commission and omission error rates in the Raco-Eckerman Project Area than in the Plumb-Bruno Project Area (Table 12). This may have been due to improved photo interpreter skill or experience. Potential vernal pools were identified and mapped in the Raco-Eckerman Project Area after vernal pools had been mapped and surveyed in the Plumb-Bruno Project Area. We were able to get a better idea of what verified vernal pools look like on the aerial imagery we used for the project. Also, many of the vernal pools in the Raco-Eckerman Project Area had little to no forest canopy cover, which likely made it easier to identify them on the aerial imagery.

Field Sampling

While field surveys to verify and map vernal pools can be time intensive and expensive, it is essential for validating the presence and type of vernal pools as well as associated indicator and/or other targeted species (Brown and Jung 2005). Field surveys for this project verified and mapped 74 vernal pools across the two project areas in Hiawatha National Forest in the eastern U.P. Field sampling or validation is especially warranted given the moderate to low accuracy and error rates for mapping vernal pools from aerial photos in the eastern U.P. that were estimated for this project and for MNFI's previous vernal pool mapping efforts in the western U.P. For example, if the omission error rate for the vernal mapping across the two project areas is potentially 26%, this means that field surveys could reveal as many as 26% more pools on the landscape than identified from aerial photographs alone.

The physical and landscape characteristics of the verified vernal pools in the two project areas in the Hiawatha National Forest in 2015 were similar to those of vernal pools found in other parts of Michigan and other states in the glaciated Northeast. For example, vernal pools are generally isolated basins or depressions, and have no continuous surface-water connections to permanently flooded water bodies (Colburn 2004). Most (73%) of the vernal pools verified in the two project areas in 2015 were isolated basins or depressions, and almost all of them (93%) had no inlet or outlet. Similar results were reported for vernal pools that were verified in study areas in the western U.P. and in several state game areas in southern Michigan, with 69% to 93% of the vernal pools in these study areas occurring in isolated basins or depressions (Lee 2014, Cohen et al. 2015a and 2015b, Cohen et al. *In prep*). Although most of the verified vernal pools in the two project areas occurred in isolated basins or depressions, many of the pools were located in clusters or in the general vicinity of other vernal pools or other wetlands and water bodies.

Another key characteristic of vernal pools is that they are generally small and shallow (Colburn 2004). Verified vernal pools across the two project areas in the eastern U.P. ranged in size from 0.003 acre to about 1 acre (0.001 ha – 0.40 ha), with a mean pool area of 0.18 acre (0.07 ha). Shrank et al. (2015) reported vernal pools in the Pictured Rocks National Lakeshore ranged in surface area from 0.02 acre to 1.4 acre (0.008 ha – 0.57 ha), with an average area of 0.31 acre (0.13 ha). Lee (2014) reported verified vernal pools in the project's study areas in the western U.P. ranging from about 0.001 acre to about 4 acres (0.0004 ha – 1.6 ha), with mean vernal pool area about 0.23 acre (0.09 ha). Vernal pools documented in targeted survey areas in the western U.P. and northeastern and southeastern Lower Peninsula ranged in area from <0.001 acre – 1.34 acres (<0.0004 ha – 0.5 ha), with a mean pool area of 0.15 acre (0.06 ha) (Lee et al. 2014). Similarly, verified vernal pools in the Flat River State Game Area (SGA) in southwestern Lower Peninsula ranged in size or area from 0.01 acre to 3.6 acres (0.004 ha – 1.46 ha), and averaged 0.3 acre (0.12 ha) in area (Cohen et al. *In prep*). These results support the vernal pool definition that most vernal pools in Michigan are smaller than 2.5 acres (1 ha), with a majority of vernal pools less than 0.5 ac (0.20 ha) in size.

Vernal pool types documented during this project were similar to vernal pool types found during other vernal pool mapping efforts, but the abundance of certain pool types did differ slightly. Most (40%) of the vernal pools verified across the two project areas in 2015 were categorized as open or sparsely vegetated pools. Other vernal pool mapping efforts in Michigan and other studies in the northeast U.S. have reported open or sparsely vegetated vernal pools to be the most common types of vernal pools in an area, followed by forested pools (Colburn 2004, Lee 2014, Cohen et al. 2015a and 2015b, Cohen et al. *In prep*). Lee (2014) found that half of the vernal pools verified in the project's study area in the western U.P. in 2014 were open or sparsely vegetated pools, and about one-third of the pools were forested pools. Most (69%) of the vernal pools verified in the Flat River SGA in southeast Michigan were classified as open or sparsely vegetated vernal pools with little to no vegetation growing in the pools, and six pools (23%) were classified as forested vernal pools (Cohen et al. *In prep*). Similarly, Cohen et al. (2015a and 2015b) reported that 79% and 70% of the verified vernal pools in Middleville SGA and Lost Nation SGA in southwest and southeast Michigan, respectively, were classified as open or sparsely vegetated pools.

Although open or sparsely vegetated pools were most prevalent, shrubby and marsh pool types also were fairly common in the two project areas in the Hiawatha National Forest (HNF), and more common than in some of the other vernal pool study areas . About 22% of the verified vernal pools in the two project areas in the HNF were categorized as marsh pools, and about 15% were categorized as shrubby pools, for a total of 37% of the verified vernal pools. Shrank et al. (2015) also documented a number of marshy vernal pools in the Pictured Rocks National Lakeshore, which they classified as "classic vernal pools." These included "classic sedge pools" dominated by sedges and fern such as knotsheath sedge (*Carex retrorsa*) and sensitive fern (*Onoclea sensibilis*); "classic mudflat/graminoid pools" dominated by grasses, sedges, and ferns such as soft rush (*Juncus effusus*) and wool grass (*Scirpus cyperinus*); and "classic grass pools" dominated by grasses such as bluejoint grass (*Calamagrostis canadensis*) and bladder sedge (*Carex vesicaria*) (Shrank et al. 2015). In contrast, shrubby and marshy pools comprised only 5 and 10% of verified vernal pools, respectively, in a study area in the western U.P. (Lee 2014). Shrubby and marshy vernal pools may be more common in certain regions of the state, such as the eastern U.P. Many of the shrubby and marshy vernal pools were in the Raco-Eckerman Project Area. Some of these may be intermittent wetland natural communities, which we have not encountered or documented as vernal pools during previous vernal pool mapping efforts. Further investigation is needed to determine if some of the vernal pools or potential vernal pools are intermittent wetlands and if they should be considered vernal pools. Additional work also should include collecting data on the vegetation within and surrounding vernal pools to help classify the pools and understand their ecological values.

Vernal pools provide critical habitat for wood frogs, blue-spotted salamanders, spotted salamanders, and fairy shrimp, which are considered vernal pool obligate or indicator species in Michigan, but these species don't occur in all vernal pools. Vernal pool surveys in 2015 were able to document vernal pool indicator species in 14 (37%) of 38 vernal pools surveyed in the spring and early summer when indicator species could be in the pools. Use of vernal pools by these indicator species for breeding and reproduction appears to vary among studies/study areas, and also can vary among individual pools and years (e.g., species may breed in some pools/years and not others) (Colburn 2004, Calhoun and deMaynadier 2008). For example, wood frog and/or blue-spotted, and/or spotted salamander adults, larvae, and/or metamorphs were documented in 20% to 55% of vernal pools surveyed in several study areas in southern Michigan (Lee et al. 2014, Cohen et al. 2015a and 2015b, Cohen et al. *In prep*). Lee et al. (2014) found vernal pool indicator species in 50% and 78% of vernal pools surveyed in study areas in northeastern Lower Peninsula and western Upper Peninsula, although sample sizes were fairly small. Similar occupancy rates for vernal pool indicator species (e.g., 22% in general, 70-90% for wood frogs, and 62% for blue-spotted salamanders) have been documented in studies in the northeastern and Midwestern U.S. (Calhoun et al. 2003, Egan and Paton 2004, Skidds and Golet 2005, Baldwin et al. 2006, Brodman 2010).

Spotted salamanders were the most prevalent vernal pool indicator species documented, with egg masses and/or larvae confirmed in 10 (71%) of the 14 vernal pools surveyed in the spring and early summer in 2015 (Table 9). Blue-spotted salamander egg masses and/or larvae were documented in at least 4 and up to 7 of the pools, and wood frog tadpoles were observed in only two of the pools (Table 9). Some studies have reported lower vernal pool occupancy rates for spotted salamanders compared to those of wood frogs (e.g., 27% compared to 43%, respectively, Porej et al. 2004) and blue-spotted salamanders (e.g., 22% compared to 62%, respectively, Brodman 2010), although other studies have reported much higher or similar vernal pool occupancy rates to those of wood frogs and blue-spotted salamanders (e.g., 80-90%, Baldwin et al. 2006). Timing of the surveys might have affected detection of wood frog eggs and/or tadpoles. Potential exists for these indicator species to occur in other vernal pools in both the Plumb-Bruno and Raco-Eckerman project areas.

While wood frogs, blue-spotted, and spotted salamanders can use a variety of vernal pools, several factors strongly influence occupancy and successful reproduction in vernal pools by these species. These include pool hydroperiod (i.e., length of time a pool holds water), canopy closure, and landscape composition and structure surrounding vernal pools. These species generally require vernal pools that hold water from March or early April to at least early July so that their larvae can complete metamorphosis before the pool dries (Harding 1997, Colburn 2004). Several studies have found that wood frog and spotted salamander breeding populations in vernal pools are positively correlated with longer hydroperiods (e.g., >16 or 18 weeks) (Calhoun et al. 2003, Babbitt 2005, Baldwin et al. 2006, Green et al. 2013). These species also are more prevalent in densely shaded, closed-canopy pools (Skelly et al. 1999, Colburn 2004, Calhoun and deMaynadier 2008). Because these species spend most of their life cycle outside of the breeding season in forested terrestrial habitats, these species are associated with vernal pools that are primarily surrounded by forests, and are unlikely to utilize vernal pools surrounded by large areas of open habitat (Calhoun and deMaynadier 2008). Wood frog, spotted salamander, and blue-spotted salamander occupancy in vernal pools have been positively associated with forest cover or amount of forest within a 1-km radius around the pools (Guerry and Hunter 2002). Additionally, critical thresholds in forest cover or amount of forest around vernal pools have been documented for these species. Studies have reported spotted salamanders only occurring in vernal pools that had forest cover/forested habitat in at least 20-35% of the surrounding area within 100 to 300 m of the pool (Porej et al. 2004, Homan et al. 2004). For wood frogs, thresholds of about 10-30% forest cover within 100 to 300 m, and 15% forest cover within 200 m to 1 km of vernal pools have been reported (Porej et al. 2004, Homan et al. 2004). Gibbs (1998) also reported critical thresholds of about 30% forest cover around vernal pools for both these species.

The number or density of vernal pools and/or other wetlands as well as the diversity of these wetlands (e.g., wetlands with different hydroperiods) also can impact the presence and abundance of these species (Gibbs 1993, Calhoun and deMaynadier 2008, Brodman 2010).

Brodman (2010) found that sites with greater number of wetlands and hydroperiod classes had higher species richness, abundance, and occupancy of pond-breeding salamanders including spotted and blue-spotted salamanders. He found that wetland clusters with 14 or more wetlands had significantly greater species richness and percentage occupancy than wetland clusters with 2-13 wetlands (Brodman 2010). Isolated wetlands had significantly lower species richness, occupancy, and abundance than sites with two or more wetlands (Brodman 2010). Additionally, wetland clusters with three hydroperiod classes had significantly greater species richness, abundance, and occupancy of salamanders than sites with two hydroperiod classes, and sites with one hydroperiod class had significantly lower abundance and occupancy than sites with two hydroperiod classes) (Brodman 2010). However, other studies have found that these species may disproportionally use partially isolated pools in some areas because of fewer available options and as stepping stones for dispersal between wetland clusters (Gibbs 2000, Calhoun et al. 2003, Baldwin et al. 2006). These species also have high site fidelity, with all or most adults returning to their natal pools and the same pools to breed in year after year (Colburn 2004).

Fairy shrimp were only documented in one of the vernal pools surveyed in the spring in 2015. This may have been due to timing of the surveys in 2015. Fairy shrimp (*Eubranchipus* spp.) are mainly found in flooded vernal pools in early spring until mid to late May, or when water temperatures reach 68°F to 72°F (20°C to 22°C), which can vary in terms of the timing depending on local weather conditions in the spring (Colburn 2004). Fairy shrimp also may not be observed every year in a given pool (Colburn 2004, Calhoun and deMaynadier 2008). Previous surveys conducted by MNFI documented fairy shrimp in a small number of vernal pools in southeastern and northeastern Lower Peninsula, but did not document fairy shrimp in any of the vernal pools surveyed in the western U.P., likely due to timing of the surveys (Lee 2014, Lee et al. 2014). This is the first documentation of fairy shrimp in a vernal pool in the Upper Peninsula during recent surveys conducted by MNFI. Additionally, MNFI's previous vernal pool surveys documented only one species of fairy shrimp, the knobbedlip fairy shrimp (*Eubranchipus bundyi*) (Lee et al. 2014). This species is known from states and provinces throughout the western, northern, and northeastern U.S. and Canada, and has been ranked as globally secure (G5) but its conservation status has not yet been ranked in the states and provinces in which it occurs (NatureServe 2016). The status of this species in Michigan is unknown since we have little to no information about this species in the state. Additionally, two other species of fairy shrimp, neglected fairy shrimp (*Eubranchipus neglectus*, G5) and springtime fairy shrimp (*Eubranchipus vernalis*, G4) have potential to occur in Michigan (NatureServe 2016). Potential exists for fairy shrimp, and potentially multiple species, to occur in additional vernal pools in the Plumb-Bruno and Raco-Eckerman project areas.

Some of the common species associated with vernal pools were found in a number of pools surveyed in 2015, but these results should be considered preliminary since surveys were limited and cursory. Additional species have potential to occur in vernal pools in the Plumb-Bruno and Raco-Eckerman project areas. Vernal pool surveys conducted by MNFI in 2013 documented a total of 104 invertebrate taxa and between 3-28 different invertebrate taxa per pool across all vernal pools surveyed in southeastern and northeastern Lower Peninsula and western Upper Peninsula (Lee et al. 2014). However, vernal pools in the Upper Peninsula may not be as diverse as pools in southern Michigan. The average number of invertebrate taxa was higher in vernal pools in southeastern Lower Peninsula (n=16) than in the northeastern Lower Peninsula (n=8) and the western Upper Peninsula (n=8) (Lee et al. 2014).

Recommendations for Future Vernal Pool Inventory, Monitoring, and Research

The following recommendations are provided to help the Hiawatha National Forest develop a vernal pool research and monitoring strategy for the Forest:

1) Follow-up Surveys for Vernal Pools in Plumb-Bruno and Raco-Eckerman Project Areas

Information on the status and locations of potential and field verified vernal pools compiled as a result of this project will help Hiawatha National Forest biologists and managers manage and protect vernal pools in support of sustainable forest management. Surveys in 2015 were able to verify a number of vernal pools in the field in the Plumb-Bruno and Raco-Eckerman project areas. However, some of the vernal pools that were surveyed need additional information to confirm their status (i.e., whether they are vernal pools or not). These primarily consist of potential vernal pools that were surveyed in the fall when the pools were dry and there was a substantial amount of vegetation within the pool basin, particularly in the Raco-Eckerman Project Area. Some of these potential vernal pools are fairly large in area compared to other vernal pools, and may be intermittent wetland natural communities. Follow-up surveys of potential vernal pools that need additional information to confirm their status should be conducted to make a final determination on the status of these pools. Follow-up surveys of vernal pools that were only surveyed in the fall when the pools were dry also should be conducted when possible to confirm the status of the pools, more accurately map the pools, and collect additional information about the physical and ecological characteristics of the pools. Given the vernal pool mapping accuracy rates and commission and omission error rates, additional surveys also are needed to verify vernal pools mapped from aerial photos and additional vernal pools that may not have been mapped from aerial photos.

2) Additional Surveys for Vernal Pool Indicator Species and Other Plants and Animals in Vernal Pools in Plumb-Bruno and Raco-Eckerman Project Areas

Vernal pools provide essential habitat for a host of plant and animal species, particularly amphibians and invertebrates, including species that require and are specialized for life in vernal pools such as fairy shrimp, wood frogs, blue-spotted salamanders, and spotted salamanders. A number of other wildlife species and diverse taxa utilize vernal pools for foraging, breeding, drinking, refuge, and dispersal, including some rare species in Michigan. Information on the species using vernal pools for breeding and other purposes can help guide and ensure appropriate management and protection of these unique and diverse wetlands. This information also can be used to help prioritize vernal pools for management and protection. The use of vernal pools for breeding by vernal pool indicator species and other species can vary from year to year and within a single year though, depending on local site conditions (e.g., water levels, weather), local population dynamics, etc. As a result, a single field survey may be inconclusive. Ideally, multi-year surveys at multiple intervals over the breeding season are needed to identify vernal pools that are used for breeding and other purposes and conclusively rule out pools that are not serving as viable breeding habitat for vernal pool indicator species and other species.

Because surveys in 2015 focused on identifying and verifying vernal pools, surveys for vernal pool indicator species and other amphibians and invertebrates in verified vernal pools were fairly limited and cursory. Additional surveys to document vernal pool indicator species and other biodiversity, particularly amphibians and invertebrates, in verified vernal pools should be conducted in the Plumb-Bruno and Raco-Eckerman project areas. Additional surveys are particularly warranted to determine the presence, status, and distribution of fairy shrimp to obtain more complete and accurate information on the ecology of vernal pools in the HNF, and increase our knowledge of the statewide status and distribution of fairy shrimp in Michigan since we have so little information on these species and given their complete reliance on vernal pools. Surveys should focus not only on documenting presence of fairy shrimp but also identifying the species present since only one species of fairy shrimp has been documented during MNFI's previous surveys. Surveys also could help to identify the presence of rare species, and have the potential to document invertebrate species previously not documented in vernal pools and/or the state. For example, a species of clam shrimp (*Caenestheriella* sp.) new to Michigan was found in small pool of water in a two-track during MNFI's vernal pool surveys in 2013 (Lee et al. 2014).

3) Vernal Pool Mapping and Surveys in Other Areas of the Hiawatha National Forest

Additional efforts to identify and map potential vernal pools and verify vernal pools in the field in other areas within the Hiawatha National Forest (HNF) would provide more complete baseline information on the locations and distribution of vernal pools in the HNF to facilitate sustainable forest planning and management. Vernal pools are not evenly distributed across Michigan (Thomas et al. 2010), and they are not located everywhere in the state. The presence of a vernal pool requires the right combination of topography, water sources, soils, cover, and climate (Thomas et al. 2010). Vernal pools are potentially lacking in some areas simply because closed-contour concave depressions are scarce, or the area is too wet or too dry (Thomas et al. 2010). Lee et al. (2014) found vernal pools in only 115 (28%) of the 402 1-ha test cells sampled across three study areas in the southeastern and northeastern Lower Peninsula and western Upper Peninsula. This suggests that vernal pools may not be very common or occur very frequently across the landscape, although they can be locally abundant or dense in some areas. Vernal pool mapping and survey results from the Plumb-Bruno and Raco-Eckerman project areas in 2015 also demonstrated that vernal pools are not evenly distributed across the HNF. Results from 2015 also indicated that vernal pools may be more abundant and/or vernal pool mapping using aerial photo interpretation may be more accurate in certain physiographic regions and/or land type associations within the HNF. Additional vernal pool mapping and surveys could focus on priority physiographic regions and/or LTAs that have greater potential for vernal pools. Surveys for vernal pool indicator species also would help inform forest planning and management efforts.

4) Investigate Remote Sensing Methods to Increase Mapping Efficiency and Accuracy

Aerial photo interpretation is currently still the most effective method we have for identifying and mapping vernal pools remotely. While previous efforts to map vernal pools in the Upper Peninsula have only been moderately accurate using aerial photo interpretation, we were able to get higher vernal pool mapping accuracy rates during this project, particularly in the Raco-Eckerman Project Area, likely due, at least in part, to the availability of more recent and higher resolution, color-infrared, leaf-off aerial imagery. We were able to identify and map a fairly large number of potential vernal pools across an extensive area over a relatively short period of time using aerial photo interpretation. One advantage of this method is that aerial imagery is already available for the entire state, and higher resolution, CIR, leaf-off aerial imagery is available for some parts of the state. Accuracy rates for mapping vernal pools from aerial imagery also may increase over time as higher resolution imagery become available, and as photo interpreters become more experienced at mapping vernal pools from aerial imagery.

While aerial photo interpretation and field surveys can be fairly effective in identifying and mapping vernal pools, these approaches also are time- and labor-intensive and costly (Colburn 2004). The accuracy of aerial photograph interpretation varies depending on landscape characteristics, surrounding forest cover, pool type and size, timing of the air photos, photograph scale, and photo interpreter skill/experience (Brooks et al. 1998, Burne 2001, Calhoun et al. 2003, Colburn 2004, Lathrop et al. 2005, Burne and Lathrop 2008). Also, leaf-off aerial imagery is required for mapping vernal pools in forested landscapes, and this approach is limited to non-coniferous canopy and relies on wet spring conditions. These limitations have led researchers and managers to investigate other methods for detecting and mapping potential vernal pools, such as using radar and/or LiDAR data (Lee et al. 2014, Wu et al. 2014, Faccio pers. comm.).

MNFI working with researchers from Michigan Tech Research Institute (MTRI) have investigated the use of radar and LiDAR data for mapping potential vernal pools (Lee et al. 2014). Radar sensors (synthetic aperture radar – SAR) are low frequency active systems that collect data from onboard satellite platforms. These sensors provide their own energy source that allows data collection regardless of cloud cover or daylight, and thus expands the timing of their use beyond optical sensors. Their low frequency also allows for penetration of a canopy cover to detect the presence of standing water. Characteristic enhanced (bright) radar signatures are observed, with high energy reflected from the forests in the flooded condition due to a "double-bounce effect" (Figure 12, Lee et al. 2014). The incoming energy bounces from the tree trunks to the smooth, high dielectric water surface and back to the sensor, with less energy absorbed than from a non-flooded forest. In the dry state, the reflected signatures are typically moderate, with a gray appearance in the image.

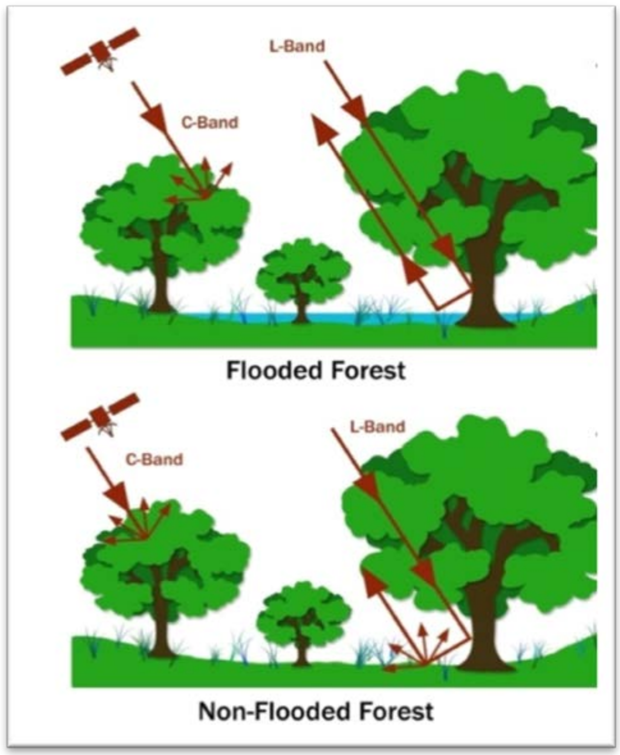


Figure 12. Schematic showing the theoretical scattering of L-band (~24 cm wavelength) SAR from flooded versus non-flooded forests (MTRI 2014).

LiDAR sensors also are active systems that use visible light as their energy source. LiDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth (National Oceanic and Atmospheric Administration (NOAA) 2016). LiDAR sensors transmit thousands of pulses per second, which return to the sensor and are processed into point clouds. These light pulses, combined with other data recorded by the airborne systems, generate precise, three-dimensional information about the shape of the Earth and its surface characteristics (NOAA 2016). The point clouds are typically used to derive high resolution digital elevation models. In some cases, the point clouds also contain intensity information, relating not only the location of the pulse at the point it was returned to the sensor, but also the intensity of the pulse (Bourgeau-Chavez pers. comm.). This can be useful for determining inundation because the light emitted by the LiDAR sensor is absorbed by water (Bourgeau-Chavez pers. comm.).

Using a temporal set of signatures characteristic of vernal pools, a method was developed to find areas of "potential vernal pools" (Lee et al. 2014). Satellite-based radar data were evaluated to determine if the 10 m resolution Japanese ALOS PALSAR FBS (fine beam single) radar imagery (circa 2006-2011) could be used to effectively detect potential vernal pools (Lee et al. 2014). Using the definition criteria of a vernal pool (that they are flooded in the spring and dry in the summer), two seasons of radar imagery were used to try to capture these hydrological differences. A spring/summer image pair of PALSAR was used for detection of potential vernal pools by subtracting the summer scene or radar signals from the spring scene/radar signals, and areas of high return were extracted and assigned a value of 1. Subtracting the two dates/scenes is important because it highlights those areas that were wet (bright) in the spring, and dry (darker) in the summer. This method resulted in a map showing the probability of how likely an area is to contain a vernal pool (Figure 13). We also investigated the use of the 10 m L-band PALSAR data in combination with LiDAR data and Digital Elevation Model (DEM) data to improve mapping capability (Lee et al. 2014).

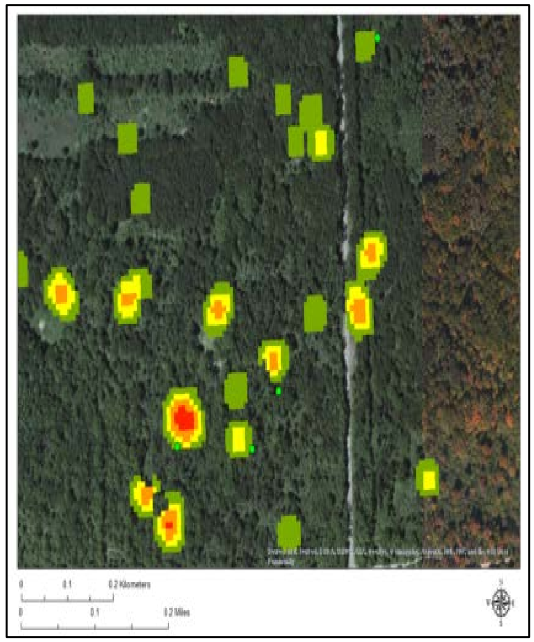


Figure 13. PALSAR probability map of vernal pools (red is highest probability, green is lowest). Green points indicate vernal pools verified in the field. (MTRI 2014)

The use of radar to identify and map potential vernal pools appears promising, at least in southeast and northeast Michigan, but additional work is needed to increase the accuracy and demonstrate the effectiveness of this method for mapping vernal pools across the state remotely. The use of radar and/or LiDAR should be further investigated to try to increase vernal pool mapping efficiency and accuracy, particularly in the Upper Peninsula, and reduce costs. MNFI is interested in working with MTRI, HNF, and other partners to further investigate this. Researchers in Vermont also are currently investigating the use of radar and LiDAR data for mapping vernal pools in the Northeast (Faccio pers. comm.). Wu et al. (2014) were able to successfully detect over 2,000 potential vernal pools in a 37,000-ac (150 km^2) area in eastern Massachusetts by combining the use of high-resolution LiDAR data (i.e., 1-m LiDAR DEM), CIR aerial imagery, stochastic depression analysis, and additional geospatial analysis. However, radar and high-resolution LiDAR data are currently still not available for the entire state, including spring and summer radar data taken during appropriate times of year for identifying potential vernal pools. We can start investigating the use of these data for mapping vernal pools where these data are currently available though, and work with partners to seek funding to obtain these data for other areas. Radar and high-resolution LiDAR are becoming increasingly available, and the State, HNF, and other partners are interested in acquiring and using these data for other purposes as well.

Combining aerial photo interpretation with other methods (e.g., radar and/or GIS modelling) also may help increase the efficiency and cost-effectiveness of mapping potential vernal pools across the state. For example, GIS modelling and/or radar data could be used to identify general regions or areas in the state that have the greatest potential or probability for occurrence of vernal pools, particularly areas that have potential for higher densities of vernal pools. These areas could then be prioritized for mapping individual potential vernal pools using radar, LiDAR, and/or aerial photo interpretation, and verifying vernal pools in the field. Previous efforts to map vernal pools using radar data resulted in high commission error (i.e., high rate of false positives) (Lee et al. 2014). Aerial photo interpretation of radar-mapped potential vernal pools could help reduce commission error and increase mapping accuracy in some cases. In terms of verifying and mapping vernal pools in the field, the use of new technology, such as drones or UAVs (unmanned aerial vehicles), and/or citizen scientists could be investigated to provide assistance with verifying and monitoring vernal pools in the field in the HNF.

5) Contribute and Access Information through the Michigan Vernal Pool Database

Vernal pool locations and data that have been documented as part of this and other projects in the future have been and will be compiled in the Michigan Vernal Pool Database, a statewide vernal pool database with information on the locations, basic ecological characteristics, and source of potential and verified vernal pools that have been mapped, which is currently housed and managed by MNFI. This information could be accessed and integrated into the HNF forest inventory/planning database(s). Locations of additional vernal pools identified in the field should be submitted and added to the statewide vernal pool database. This database will be used to help assess and determine the status and distribution of vernal pools across Michigan, and inform conservation and management of these wetlands.

6) Assess Management and Protection of Vernal Pools in the HNF

Although vernal pools are very small and may not be very abundant across the landscape except in certain areas, vernal pools are recognized as small natural features with large ecosystem functions. They provide critical breeding habitat for a number of amphibians and invertebrates, which represent significant biomass and provide an important source of food and nutrients for other animals, plants, and the forest ecosystem (Burton and Likens 1975). Because of the abundance of life in these small wetlands, vernal pools have been referred to by some as "hatcheries of the forest" and "coral reefs of Northeastern forests." Alterations to the pool basin and surrounding habitat can significantly impact the hydrology, ecological processes, and plants and animals that occur within and around vernal pools (Colburn 2004). These impacts can include changing the input of leaves in the fall, altering the nutrient content of the water and leaves within the pool basin and inflowing surface and ground water, changing the flow of water into or out of the pool, increasing the amount of sunlight reaching the pool, increased algal production, higher water temperatures, increased sedimentation, and alteration or removal of upland habitat for amphibians (Semlitsch et al. 1988; deMaynadier and Hunter 1995, 1998, 1999; Waldick et al. 1999; Colburn 2004). Forest management activities or best management practices designed to minimize disturbance to the pool basin and forest's organic layer, maintain adequate canopy cover and shade over the pool, and provide adequate leaf litter and woody debris of various sizes and decay classes would reduce impacts to pond-breeding amphibians that occur in and around vernal pools.

Management of vernal pools should keep in mind that wood frogs, blue-spotted salamanders, spotted salamanders, and other amphibians that breed in vernal pools utilize them during a specific period of time, and spend most of the year in the surrounding forests, with some species migrating quite a distance from their breeding pools (Colburn 2004). Avoiding or minimizing management activities that disturb soils or forest canopy around vernal pools, particularly during breeding, egg-laying, and larval development periods for pond-breeding amphibians (i.e., March/April through July/early August), would reduce adverse impacts to these species (Thomas et al. 2010). The State of Michigan's sustainable soil and water quality practices for forest lands recommend no disturbance within the vernal pool depression, limiting use of heavy equipment within 30 meters (100 ft) or at least one tree length of the pool to avoid creating deep ruts, and maintaining at least 70% canopy closure within the 30-m (100 ft or 1.4 ac) buffer (Michigan DNR and Michigan DEQ 2009). However, many of the vernal pool-breeding amphibian species, such as wood frogs and spotted salamanders, migrate, on average, about 119 m to 193 m (390 ft – 633 ft) from the vernal pools in which they breed into the surrounding forest (Semlitsch and Skelly 2008). The occurrence of these species also have been found to be positively associated with forest cover up to 300 m (984 ft) and, in some cases, up to 1-km (0.6 mi) from vernal pools (Guerry and Hunter 2002, Porej et al. 2004, Homan et al. 2004). As a result, maintaining a larger buffer of forest habitat (e.g., up to 400 ft/ 122 m) with at least 50% canopy cover around vernal pools and providing abundant cover on the forest floor (i.e., leaf litter and coarse woody debris) has been proposed in some forest management guidelines to protect terrestrial habitat for vernal pool-dependent amphibians and invertebrates (Calhoun and deMaynadier 2004 and 2008). Dramatic shifts in forest cover type also may adversely impact forest-dwelling amphibians as they are sensitive to changes in leaf litter composition and chemistry (deMaynadier and Hunter 1995, Waldick et al. 1999). Construction of roads and landings and applications of chemicals (e.g., herbicides and/or pesticides) should be avoided within the 30-meter buffer around a vernal pool, and minimized within the larger buffer if possible (Calhoun and deMaynadier 2008). Maintaining forest cover and wetland density and diversity across the landscape would facilitate species dispersal among vernal pools and other wetlands, and would likely maximize protection of biodiversity within the pools (Calhoun and deMaynadier 2008). Rutting and scarification of the forest floor may create barriers and prevent salamanders from travelling to breeding pools (Means et al. 1996).

7) Refine and Adapt Management based on Research and Monitoring

Information on the status, distribution, and ecology of vernal pools in the HNF is essential to help ensure that vernal pool management and protection efforts are effective and to adapt management as needed. Each vernal pool is the result of a complex interplay between climate, weather, landform, geology, hydrologic processes, water and soil chemistry, soil type, pool geometry, vegetation, fauna, and the surrounding environment (Thomas et al. 2010). Because all these factors tend to vary across the landscape, vernal pools are unique and highly variable (Colburn 2004, Thomas et al. 2010). As some of these factors change over time due to natural and anthropogenic causes, the ecology of vernal pools will likely also change over time.

Research and monitoring can help assess current and future status of vernal pools, clarify their specific ecological roles and contributions within forest ecosystems, identify and evaluate threats facing vernal pools, and help determine appropriate management needed and whether management is effective or needs to be adapted.

Some specific research and monitoring questions might include the following:

- Do vernal pools vary in ecologically meaningful or significant ways across the HNF, and if so, how? What are the main ecological differences and drivers for these differences?
- How do vernal pools specifically help maintain and contribute to the healthy forest ecosystems within the HNF?
- What factors or threats are impacting vernal pools and their ecological functions and values?
- Are current planning and management efforts effective at protecting vernal pools and maintaining their ecological values and contributions to healthy forest ecosystems? How can we adequately protect vernal pools while also managing for other forest values?
- Are there key ecological attributes that we can measure and monitor to assess and track the status and condition of vernal pools over time and potential impacts from land use and management activities and other factors?
- How will climate change impact vernal pools, associated species and ecological values, and efforts to manage and protect them within and outside the HNF?

Researchers in other states (e.g., Wisconsin) have been investigating some of these questions. We may be able to apply information from these other studies to vernal pools in Michigan. Research is needed to identify and compile information from other studies.

In summary, this project represents an initial effort to obtain baseline information on the distribution and ecology of vernal pools in the Hiawatha National Forest. These results will help inform management and protection of vernal pools and provide the foundation for future vernal pool research and monitoring efforts in the Forest. This information will assist the Hiawatha National Forest with forest management and planning efforts, and help facilitate sustainable forest management practices, ensuring the long-term productivity and the overall health of Michigan's forest ecosystems. This project also complements and builds upon recent efforts to identify, map, and assess vernal pools in the Upper Peninsula and statewide. Recent efforts to assess and map vernal pools have been conducted mainly in the western Upper Peninsula, so this project provides new information regarding vernal pools in the eastern Upper Peninsula. This project also provides additional information that will help develop an effective and efficient approach for identifying and mapping vernal pools, and enhance our understanding of their distribution and ecology in Michigan and how to effectively manage and conserve them.

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APPENDICES

Appendix 1. Summary and brief descriptions of the primary Land Type Associations (LTAs) encompassed in the Plumb-Bruno and Raco-Eckerman project areas in the Hiawatha National Forest in the eastern Upper Peninsula. Information in this table from the U.S. Forest Service and The Nature Conservancy of Michigan's 2011 report on LTAs of the Hiawatha National Forest.

Project Area	LTA Name	Brief Description	Landforms	Soil Complexes	Vegetative Communities
Plumb-Bruno	Lake Stella Complex	Outwash plains of sandy or sandy-skeletal soils. Lowland coniferous forests dominant.	Outwash plain - Outwash deposits of sand and gravel in well-stratified layers	Texture: Peat (52%); sand (31%) Particle Size: Sandy or sandy-skeletal (69%); sandy (31%) Drainage Class: Very poorly drained (69%); somewhat excessively drained (31%)	Lowland Coniferous Forest (40%); Lowland Shrub (12%); Northern Hardwood Association (11%); Lowland Deciduous Forest (9%); Mixed Non-Forest Wetland (7%); Pines (5%)
Plumb-Bruno	Steuben Segment	Disintegration moraines and outwash moraines with sandy soils. Northern hardwoods dominant.	Disintegration Moraine; Outwash plain - Randomly oriented chaotic mounds and pits; Outwash deposits of sand and gravel in well-stratified layers	Texture: Sand (69%); sandy loam (15%); muck (12%) Particle Size: sandy (84%); sandy or sandy skeletal (16%) Drainage Class: Somewhat excessively drained (80%); Very poorly drained (16%)	Northern Hardwood Association (43%); Lowland Coniferous Forest (11%); Upland Mixed Forest (10%); Aspen Association (8%)
Plumb-Bruno	Steuben Outwash	Disintegration moraine of sandy soils. Pine forests and herbaceous openlands dominant.	Disintegration moraine ; pitted outwash plain - Randomly oriented chaotic mounds and pits; outwash plains marked by many irregular depressions such as kettles and shallow pits	Texture: Sand (95%) Particle Size Class: Sandy (96%) Drainage Class: Excessively drained (79%); somewhat excessively drained (17%) Infiltration Rate: High (96%)	Pines (37%); Herbaceous Openland (14%); Upland Mixed Forest (10%); Northern Hardwood Association (9%); Water (6%); Lowland Coniferous Forest (6%)
Plumb-Bruno	Ridge-swale Complex	Dune-capped lake plains of sandy or sandy-skeletal soils. Lowland coniferous forests dominant.	Dune-capped lake plain & lake plain: Sandy lake-bed deposits with wind-worked sand bars or dunes; nearly level plains	Texture: Peat (78%); sand (14%) Particle Size Class: Sandy or sandy-skeletal (85%) Drainage Class: Very poorly drained (86%)	Lowland Coniferous Forest (35%); Upland Mixed Forest (13%); Pines (10%); Lowland Shrub (10%); Mixed Non-Forest Wetland (7%); Lowland Deciduous Forest (7%)

Project Area	LTA Name	Brief Description	Landforms	Soil Complexes	Vegetative Communities
Raco-Eckerman	East Tahqua-menon Drainage	Nearly level lake plains of sandy or sandy-skeletal soils. Lowland coniferous forests dominant.	Lake plain - Nearly level plains	Texture: Peat (67%); sand (16%) Particle Size: Sandy or sandy-skeletal (67%); sandy (27%) Drainage Class: Very poorly drained (67%); excessively drained (16%)	Lowland Coniferous Forest (44%); Lowland shrub (23%); Pines (12%); Mixed Non-Forest Wetland (10%)
Raco-Eckerman	Lake Superior Highlands	Outwash plains of sandy or sandy-skeletal soils in well-stratified layers. Northern hardwoods and pine forests.	Outwash plain; bedrock-controlled ground moraine; lake plain; outwash plain (lowlands) - Sand and gravel deposits in well-stratified layers; rock outcrops and small outwash filled channels; nearly level plains	Texture: Sand (61%); fine sand (11%); peat (9%) Particle Size: Sandy (77%); sandy or sandy-skeletal (9%) Drainage Class: Excessively drained (37%); somewhat excessively drained (30%); very poorly drained (15%)	Northern Hardwood Association (46%); Pines (15%); Aspen Association (12%); Lowland Coniferous Forest (10%)
Raco-Eckerman	Tahqua-menon River Drainage	Lake and lowland outwash plains of sandy or sandy-skeletal soils. Lowland coniferous forests dominant.	Lake plain; outwash plain (lowlands) - Nearly level plains; outwash deposits found over old lake plains	Texture: Muck (62%); peat (23%); very fine sandy loam (12%) Particle Size: Undefined (61%); sandy or sandy-skeletal (23%); fine-loamy (12%) Drainage Class: Very poorly drained (84%); somewhat poorly drained (12%)	Lowland Coniferous Forest (41%); Lowland Shrub (26%); Mixed Non-Forest Wetland (21%); Aspen Association (3%); Pines (3%)
Raco-Eckerman	Wilwin Wetlands	Lowland outwash plain of sandy or sandy-skeletal soils. Lowland coniferous forests dominant.	Outwash plain (lowlands) - Outwash deposits found over old lake plains	Texture: Peat (84%) Particle Size Class: Sandy or sandy-skeletal (84%) Drainage Class: Very poorly drained (84%)	Lowland Coniferous Forest (41%); Mixed Non-Forest Wetland (28%); Lowland Shrub (18%)

Project Area	LTA Name	Brief Description	Landforms	Soil Complexes	Vegetative Communities
Raco-Eckerman	Betchler Marsh	Lowland outwash plains of sandy or sandy-skeletal soils. Lowland shrubs and mixed non-forest wetlands dominant.	Outwash plain (lowlands); outwash plain - Outwash deposits found over old lake plains; outwash deposits of sand and gravel in well-stratified layers	Texture: Peat (97%) Particle Size: Sandy or sandy-skeletal (97%) Drainage Class: Very poorly drained (97%)	Lowland Shrub (44%); Mixed Non-Forest Wetland (25%); Lowland Coniferous Forest (18%)
Raco-Eckerman	Raco Sand Plains South	Outwash plains of sandy soils. Pine forests dominant.	Outwash plain; outwash plain (lowlands) - Outwash deposits of sand and gravel in well-stratified layers; outwash deposits found over old lake plains	Texture: Sand (64%); peat (36%) Particle Size: Sandy (64%); sandy or sandy-skeletal (36%) Drainage Class: Excessively drained (64%); very poorly drained (36%)	Pines (38%); Mixed Non-Forest Wetland (15%); Lowland Shrub (13%); Herbaceous Openland (12%); Lowland Coniferous Forest (11%)
Raco-Eckerman	Raco Sand Plains North	Outwash plains of well-stratified sandy soils. Northern hardwoods and pine forests/barrens dominant.	Outwash plain; Outwash plain (lowlands) - Outwash deposits of sand and gravel in well-stratified layers; Outwash deposits found over old lake plains	Texture: Sand (98%) Particle Size: Sandy (98%) Drainage Class: Very poorly drained (84%), Somewhat poorly drained (12%)	Pines (45%); Herbaceous Openland (23%); Aspen Association (7%); Upland Shrub/ Low-Density Trees (7%)
Raco-Eckerman	Strongs Road Outwash Hills	Outwash plains of sandy soils. Pine forests dominant.	Outwash plain - Outwash deposits of sand and gravel in well-stratified layers	Texture: Sand (93%) Particle Size: Sandy (93%) Drainage Class: Excessively drained (93%)	Pines (57%); Upland Shrub/Low-Density Trees (11%); Herbaceous Openland (11%)

Appendix 2. Summary and brief descriptions of the main physiographic regions and ecoregions in which the Plumb-Bruno and Raco-Eckerman project areas within the Hiawatha National Forest are located in the eastern Upper Peninsula. Information in this table is from Albert (1995), Schaetzl et al. (2009), and Michigan Geological Survey (2016).

Project Area	County(ies)	Major Physiographic Region – Physiographic Region	Physiographic Region - General Description, Soils, and Presettlement Vegetation (Information from Michigan Geological Survey 2016 - http://www.physiomap.msu.edu/)	Ecological Region - Subsection/ Sub-Subsection Number	Ecological Region - Subsection / Sub-Subsection	Ecological Region – Geology, Landforms & Soils
Plumb-Bruno	Alger, Delta, Schoolcraft	Eastern Upper Peninsula Lowlands – Escanaba Sandy Plains	Low elevation, low relief landscapes that have been variously influenced by glacial deposition, glacial meltwater, and post-glacial lacustrine and eolian processes. A few small dunes and beach ridges. Region is primarily low and flat, with a few isolated hills. Mostly somewhat poorly drained soils or wetter, formed in sandy beach, lacustrine and outwash deposits. Large patches of Histosols in some areas. Swampy landscape on wet sandy sediment. Several major streams cross the region, flowing into Lake Michigan. Lakes common in some areas. Presettlement vegetation: Wide expanses of conifer and cedar swamp. Hemlock and white pine on low, sandy rises. Beech-sugar maple-hemlock forest on low, sandy uplands.	VIII.2.1	Northern Lacustrine-influenced Upper Michigan and Wisconsin - Seney Sand Lake Plain	Glacial outwash sand and gravel; postglacial alluvium; proglacial outwash; and peat and muck. Contains the largest expanses of wetland in the State. Bedrock covered by 100 to 200 feet of glacial drift, but near the surface along western edge. Landforms of lacustrine origin. Broad, poorly drained embayments contain beach ridges and depressions (swales), sand spits, transverse sand dunes, and sand bars. Peats, poorly drained sands, excessively drained sands.
Plumb-Bruno	Alger, Delta, Schoolcraft	Eastern Upper Peninsula Lowlands – Hiawatha Sandy Uplands	Low elevation, low relief landscapes that have been variously influenced by glacial deposition, glacial meltwater, and post-glacial lacustrine and eolian processes. Generally dry, sandy upland of moderate relief. Hummocky terrain in places, densely pitted outwash in others. Sand textures dominate, on outwash-derived soils. Most soils are excessively or somewhat excessively drained. Little surface flowing water. Many kettles, some large, and many holding permanent water. Presettlement vegetation: Mainly beech-sugar maple-hemlock-white pine on sandy uplands.	VIII.2.2	Northern Lacustrine-influenced Upper Michigan and Wisconsin - Grand Marais Sandy End Moraine and Outwash	Glacial outwash sand and gravel; postglacial alluvium; proglacial and ice-contact outwash; end moraines of coarse-textured till; and coarse-textured glacial till. Sandy ridges of end moraine and pitted outwash. Lacustrine deposits of glacial and postglacial origin also located along NE edge. Bedrock is locally exposed, but drift can be at least 200 feet thick. Mostly well-drained, sandy soils.

Project Area	County(ies)	Major Physiographic Region – Physiographic Region	Physiographic Region - General Description, Soils, and Presettlement Vegetation (Information from Michigan Geological Survey 2016 - http://www.physiomap.msu.edu/)	Ecological Region - Subsection/ Sub-Subsection Number	Ecological Region - Subsection / Sub-Subsection	Ecological Region – Geology, Landforms & Soils
Raco-Eckerman	Chippewa	Eastern Upper Peninsula Lowlands – Algonquin-Minong Lake Plain	Low elevation, low relief landscapes that have been variously influenced by glacial deposition, glacial meltwater, and post-glacial lacustrine and eolian processes. Low to moderate relief, glacial lake plain with complex bed forms, various beach ridge complexes, islands, and sandy-to-silty sediment textures on lake floor. Many small islands and incised channels. Soils formed in silty and sandy lacustrine deposits. Highly variable soil drainage classes, but large areas are very poorly drained, with thick Histosols. Broad expanses of swamp and bog; sluggish streams. Numerous lakes. Presettlement: Swamp, bog and marsh on flat lacustrine plains. Beech-sugar maple-hemlock forest on upland areas; sandiest areas were pine forest. Land Use: Wetland and forest. Areas of open land occur on sandy uplands.	VIII.2.1	Northern Lacustrine-influenced Upper Michigan and Wisconsin - Seney Sand Lake Plain	Peat and muck; lacustrine sand and gravel; lacustrine fine; and lacustrine coarse. Contains the largest expanses of wetland in the State. Bedrock covered by 100 to 200 feet of glacial drift, but near the surface along western edge. Landforms of lacustrine origin. Broad, poorly drained embayments contain beach ridges and depressions (swales), sand spits, transverse sand dunes, and sand bars. Peats, poorly drained sands, excessively drained sands.
Raco-Eckerman	Chippewa	Eastern Upper Peninsula Lowlands – Hulbert Island	Low elevation, low relief landscapes that have been variously influenced by glacial deposition, glacial meltwater, and post-glacial lacustrine and eolian processes. Low-moderate relief, sandy upland within Glacial Lake Algonquin plain. Somewhat excessively and excessively drained sandy soils across most of the region. Some areas have a thin, silty, eolian cap. Mostly a dry upland; has a few kettle lakes. Wetter in SE part of region. Presettlement: Varies by elevation. Driest upland areas were pine barrens. Beech-sugar maple-hemlock forest occurs, along with swamp forest. Land use: Upland forest and lowland swamp. Considerable amounts of open land on driest sites.	VIII.2.2	Northern Lacustrine-influenced Upper Michigan and Wisconsin - Grand Marais Sandy End Moraine and Outwash	End moraines of coarse-textured till; glacial outwash sand and gravel; postglacial alluvium; peat and muck; ice-contact outwash; ice-marginal till; proglacial outwash; and lacustrine fine. Sandy ridges of end moraine and pitted outwash. Lacustrine deposits of glacial and postglacial origin also located along NE edge. Bedrock is locally exposed, but drift can be at least 200 feet thick. Mostly well-drained, sandy soils.

Appendix 3. Informational handout on vernal pool types, their definitions, and photos of examples.

VERNAL POOL TYPES

1) **Open Pool –** "Classic" vernal pool with trees, shrubs, and herbaceous (non-woody) plants covering less than 10% of the ground within the pool when the pool is flooded or wet. Herbaceous plants are plants whose stems and leaves die at the end of the growing season and have no woody stems above ground.


2) **Sparsely Vegetated Pool –** Trees, shrubs, and non-woody herbaceous plants covering 10% to less than 30% of the ground within the pool when the pool is flooded or wet.


3) **Shrubby Pool –** Pool is dominated by shrubs, with shrubs covering 30% or more of the ground within the pool when it is flooded or wet, and representing the tallest vegetation layer within the pool.


4) **Forested Pool –** Pool is dominated by trees with rooted, live trees covering 30% or more of the ground within the pool when it is flooded or wet, and representing the tallest vegetation layer within the pool. For example, a forested swamp pool, pool within a larger forested swamp, and a floodplain pool.

5) **Marsh Pool –** Pool dominated by non-woody herbaceous plants, including emergent plants which are plants that grow in water and stick up out of the water. Non-woody herbaceous and emergent plants cover 30% or more of the ground within the pool when it is flooded or wet, and represent the uppermost vegetation layer within the pool. Trees and shrubs may be present but cover less than 30% of the pool.

Appendix 4. Vernal Pool Survey and Monitoring Data Form.

Michigan Vernal Pools Project

Volunteer Vernal Pool Monitoring Form

http://mnfi.anr.msu.edu/vernalpools/ - Contact MNFI at (517) 284-6200

QC Date: ______
QC Initials: ______
Date Entered: ______

1a) Observer Information ☐ Visit 1 ☐ Visit 2 ☐ Visit 3 Time: from ______ ☐AM ☐PM to ______ ☐AM ☐PM

Name(s): ______ Date: ______

1b) Property Information Ownership? ☐ Public ☐ Private Landowner/Manager Name: ______

Site name: ______ Address: ______

Plot # ______ City: ______ State: ______ Zip: ______

2a) Vernal Pool Location Was pool mapped as a Potential Vernal Pool (PVP)? ☐ Yes ☐ No

Pool ID #: ______ New Pool ID #: ______

Enter coordinates in Decimal Degrees (e.q. Latitude: 44.764322 Longitude: -72.654222)

Latitude: ______ Longitude: ______

Township/Range/Section/1/4 info : ______

County: ______

For verification of PVP's location please enter names and coordinates for the nearest crossroads. Record as Decimal Degrees as shown above.

Method for locating pool?

Latitude: ______ Longitude: ______

☐ GPS ☐ Topo Map ☐ Google Earth ☐ Air Photo

Crossroad names: ______

2b) Brief Site Directions to Pool **

**** Written site directions to pool** (This should include: (1) description of a logical starting point; (2) the distance from the starting point to pool; (3) the direction of travel; and (4) distinctive landmarks and water bodies.): For example 'Enter Robinhood Park on the trailhead at Jordan Road. Follow the trail west approximately 1/2 mi. This is the first pool on your left, just behind a low stone wall.'

3a) Pool Type Is this a Vernal Pool? ☐ Yes ☐ No ☐ Not Sure Pool Photo Numbers: ______

☐ Open Pool ☐ Sparsely Vegetated Pool ☐ Shrubby Pool

☐ Forested Pool ☐ Marsh Pool ☐ Other (describe): ______

3b) Presence of Inlet or Outlet

Is this pool connected to or part of another water feature? ☐ culvert ☐ lake ☐ open/emergent/shrubby wetland

☐ No, pool is isolated ☐ Yes, pool is connected to: (check **ALL** that apply) ☐ stream ☐ ditch ☐ forested wetland ☐ vernal pool

If inlet/outlet is present, indicate type: ☐ permanent ☐ temporary ☐ do not know ☐ none

3c) Surrounding Habitat (within 100 feet of pool) (check **ALL** that apply)

☐ Upland Deciduous Forest ☐ Lowland Deciduous Forest

☐ Upland Coniferous Forest ☐ Lowland Coniferous Forest

☐ Upland Mixed Forest ☐ Lowland Mixed Forest

☐ Floodplain ☐ Grassland or open

☐ Emergent Wetland (marsh, bog)

Disturbances:

☐ Agriculture

☐ Road/driveway

☐ paved

☐ dirt/gravel

☐ Powerline right-of-way ☐ Other: ______

☐ Light development (<25%) ☐ No disturbances

☐ Intensive development (>25%)

☐ Minor logging (> or = 70% canopy remaining)

☐ Major logging (< or = 70% canopy remaining)

4a) Approximate Maximum Pool Depth

☐ Ankle-deep (<6") ☐ Hip-deep (2-3 ft)

☐ Shin-deep (6-12") ☐ Chest-deep (3-4 ft)

☐ Knee-deep (12-24") ☐ Deeper than 4 ft

4b) Water Level at Time of Survey (check one)

☐ Full/Nearly full 75-100% ☐ Less than half 25-49%

☐ Partially full 50-74% ☐ Dry/mostly dry 0-24%

4c) Water temperature (*F): ______

4d) Approximate Size of Pool (at maximum capacity - at widest and longest points)

Width: ______ feet

Length: ______ feet

Size determined by: ☐ Pacing ☐ Measuring ☐ Using GPS

4e) Substrate (when dry - check **ALL** that apply)

☐ Leaf litter ☐ Sand - Gravel ☐ Unknown

☐ Bedrock ☐ Muck - Peat ☐ Other: ______

☐ Loam ☐ Silt - Clay

Funding for this project was provided by the US Environmental Protection Agency along with the Michigan Department of Environmental Quality

4f) Vegetation in Pool

Are trees (trees = or > 4" in diameter) present in the basin? (check one)

☐ No ☐ Yes, within pool basin ☐ Yes, but only at the edge

# of trees only within the pool basin? ________ ☐ live and/or ☐ dead/snags

% Cover within the pool (check one):

Floating vegetation: ☐ 0% ☐ 1 to 9% ☐ 10 to 25% ☐ 26 to 50% ☐ >50%

Emergent vegetation: ☐ 0% ☐ 1 to 9% ☐ 10 to 25% ☐ 26 to 50% ☐ >50%

Shrubs: ☐ 0% ☐ 1 to 9% ☐ 10 to 25% ☐ 26 to 50% ☐ >50%

4h) Cover (Any material in the pool that can provide egg attachment sites and offer concealment to adults and/or larvae; check all that apply):

☐ Shrubs ☐ Submergent vegetation

☐ Branches, twigs ☐ Logs or large woody debris

☐ Sphagnum moss ☐ Emergent vegetation (grasses, cattails)

☐ Algae ☐ Other: ____________

☐ Leaf litter

Tree canopy over pool basin (when leaves are fully out): ☐ 0% ☐ 1 to 9% ☐ 10 to 25% ☐ 26 to 50% ☐ >50%

4g) Pool Disturbance (in pool, immediately adjacent or along shore of pool - check all that apply)

☐ Dumping - Refuse ☐ Filling ☐ Invasive Species Present

☐ Ditching - Draining ☐ Sediment ☐ Purple loosestrife ☐ Garlic mustard

☐ Agricultural runoff ☐ Vehicle ruts ☐ Reed canary grass ☐ Other: ____________

☐ Cultivation - Livestock ☐ Presence of rock pile or other anthropogenic disturbance ☐ No disturbances

5) Indicator Species and Additional Species (if other species are observed please list below in blank fields under Fingernail Clams)

Provide a photograph of each indicator species (adults, juveniles/larvae, or egg masses) observed. **Photos of species observed are required.**

Species Observed	Adults	Tadpoles/Larvae	Egg Masses			Photo? Yes	Notes/Photo ID#
			Number	Estimated	Counted		
Wood Frog				☐	☐	☐	
Spotted Salamander				☐	☐	☐	
Blue-spotted Salamander				☐	☐	☐	
Fairy Shrimp							
Fingernail Clams							
				☐	☐	☐	
				☐	☐	☐	
				☐	☐	☐	
				☐	☐	☐	
				☐	☐	☐	
				☐	☐	☐	
				☐	☐	☐	

Were any of the following observed? (check **ALL** that apply)

☐ Fish: (indicate all lengths observed) ☐ ≤ 3" ☐ > 3" ☐ Green frogs: ☐ tadpoles ☐ adults

☐ Bullfrogs: ☐ tadpoles ☐ adults ☐ Other: ____________

Comments:

Draw diagram of pool (include landmarks, location of indicated species, north arrow and area surveyed if entire pool was not surveyed)**:**

Funding for this project was provided by the US Environmental Protection Agency along with the Michigan Department of Environmental Quality

Appendix 5. MNFI Abstract on Vernal Pools.

Vernal Pool

Overview: Vernal pools are small, isolated wetlands that occur in forested settings throughout Michigan. Vernal pools experience cyclic periods of water inundation and drying, typically filling with water in the spring or fall and drying during the summer or in drought years. Substrates often consist of mineral soils underlain by an impermeable layer such as clay, and may be covered by a layer of interwoven fibrous roots and dead leaves. Though relatively small, and sometimes overlooked, vernal pools provide critical habitat for many plants and animals, including rare species and species with specialized adaptations for coping with temporary and variable hydroperiods. Vernal pools are also referred to as vernal ponds, ephemeral ponds, ephemeral pools, temporary pools, and seasonal wetlands.

Introduction and Definitions: Temporary water pools can occur throughout the world wherever the ground or ice surface is concave and liquid water gains temporarily exceed losses. The term "vernal pool" has been widely applied to temporary pools that normally reach maximum water levels in spring (Keeley and Zedler 1998, Colburn 2004). In northeastern North America, *vernal pool* and similar interchangeable terms have focused even more narrowly upon pools that are relatively small, are regularly but temporarily flooded, and are within wooded settings (Colburn 2004, Calhoun and deMaynadier 2008, Wisconsin DNR 2008, Ohio Vernal Pool Partnership 2009, Vermont Fish & Wildlife Department 2004, Tesauro 2009, New York Natural Heritage Program 2009, Commonwealth of Massachusetts Division of

Michigan Natural Features Inventory
P.O. Box 30444 - Lansing, MI 48909-7944
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Fisheries and Wildlife 2009, Maine Department of Environmental Protection Bureau of Land & Water Quality 2009, Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission 2005, Sullivan 2009).

Unlike vernal pools, which occur in forested settings, seasonally inundated wetlands in open settings typically acquire well-developed and distinct floristic compositions and therefore are classified as one of several different non-forested wetland communities such as emergent marsh, southern wet meadow, coastal plain marsh, and so forth (see Kost et al. 2007 for list and descriptions of wetland community types). Remnants of former vernal pools can be observed where forests have been cleared and non-native vegetation has become dominant such as in old fields, golf courses, subdivisions, etc. Though forested vernal pools and non-forested seasonally inundated wetlands share many attributes, the vegetation of forested vernal pools varies greatly among occurrences. The lack of a consistent assemblage of vegetation, along with their small size, make it difficult to classify vernal pools as a separate type of natural community. Instead, vernal pools are considered to be an integral component of a variety of upland and lowland forested natural communities throughout Michigan (see Kost et al. 2007).

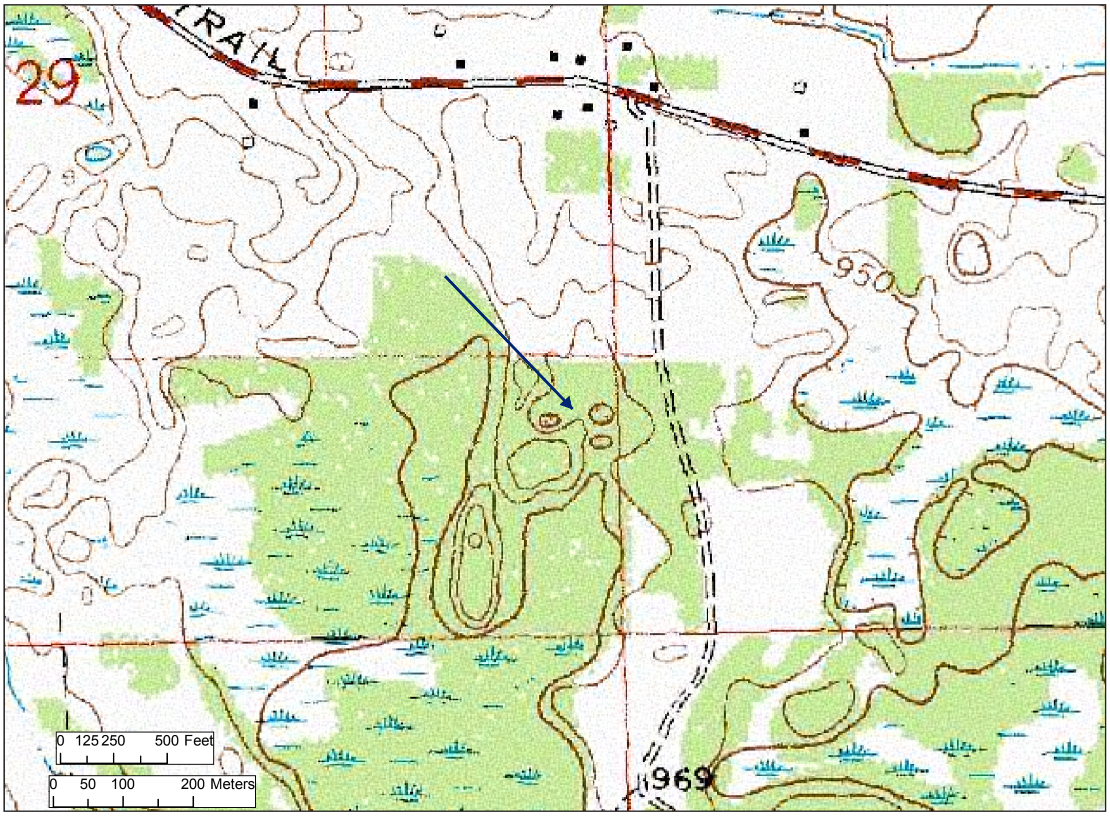
To distinguish vernal pools from briefly puddled upland depressions, true ponds, flowing waterbodies, and a variety of open wetland types, their definition can be further narrowed to sites that meet the following criteria:

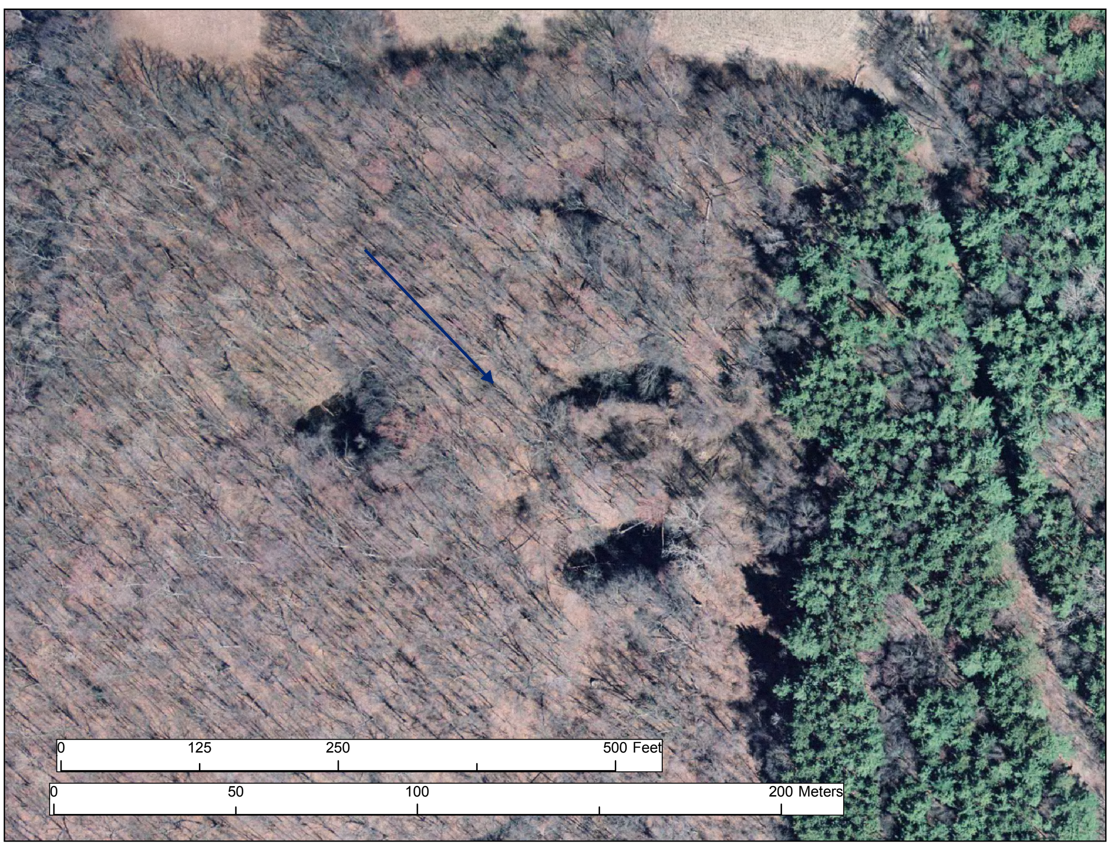
- flooded long enough and frequently enough, *and* dried out long enough and frequently enough to harbor flora and/or fauna that have specialized adaptations or life cycles for coping with both inundation and water drawdown. Notably, permanent fish populations do not occur in vernal pools because they cannot survive prolonged drawdown.
- small enough and/or shaded enough that recognized open-structure natural community types (see Kost et al. 2007) such as submergent marsh, emergent marsh, southern wet meadow, wet prairie, and so forth, do not become well established.
- lack permanent surface water connection to other water bodies.

Range: Vernal pools with physical attributes most similar to those in Michigan occur in other forested and recently glaciated portions of the northeastern U.S. and eastern Canada. This includes an area stretching from approximately New Jersey to Missouri to northern Manitoba to Newfoundland (Calhoun and deMaynadier 2008).

In Michigan, vernal pools occur in forested settings throughout the state but are most abundant where water tables are high and/or where bedrock or fine-textured soils such as clay impede surface water infiltration. Although there has not been a systematic study of the distribution of vernal pools in Michigan, landscape ecoregions that are likely to support an abundance of vernal pools because of the presence of near-surface bedrock, fine-textured soils, or high water tables include the following: Southern Lower Michigan (Section VI), Arenac (Subsection VII.1), Manistee (Subsection VII.4), Traverse City (Sub-subsection VII.5.2), Onaway (Sub-subsection VII.6.1), Cheboygan (Sub-subsection VII.6.3), and the Eastern and Western Upper Peninsulas (Sections VIII and IX) (Albert 1995).

Landscape Context: Vernal pools hold standing water, which means they are restricted to geometrically concave locations. While vernal pools are relatively small as defined by their high water mark, the concave landform in which they occur can be far larger. For example, a 0.04-hectre (0.1-acre) vernal pool may occupy the lowest point within a 2-hectare (5-acre) landscape depression. Vernal pools lack permanent overland connections to other water bodies, although small or shallow temporary drainage paths into or out of vernal pools may be present (Wiggins et al. 1980). Thus, vernal pools are found outside the boundaries of





Topographic map (top) and aerial photograph (bottom) with arrows indicating locations of vernal pools.

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typical flow levels of perennial streams and rivers. Vernal pools can form without the direct support of a regional water table when water inputs exceed infiltration capacity of the soil—forming what is often termed a "perched" water table (Colburn 2004). Perched conditions occur more commonly on or just above bedrock, or on fine-textured ground moraine and glacial lake-plain landforms (Calhoun and deMaynadier 2008). Vernal pools can also be directly supported by a regional water table; this occurs where groundwater levels intersect pool bottoms. These groundwater-supported vernal pools are more frequent in floodplains and on landforms with coarse-textured soils such as kettles within glacial outwash plains and moraines (Calhoun and deMaynadier 2008).

Water depth in vernal pools can vary greatly but is generally very shallow. Even at their maximum water levels, some vernal pools are only about 10 cm deep (4 in). In contrast, vernal pools that are more than one meter deep (at least temporarily) are not unusual in Michigan, but maximum depth is naturally limited by the fact that steep depressions eventually fill in with eroded material and larger wet depressions become permanent lakes, ponds, or other wetland natural communities such as emergent marsh.

Vernal pools vary greatly in size. The smallest pools may be only a few square meters in area, created through local events such as tree tip-ups or bole-rot cavities. In the northeastern U.S. including Michigan, most vernal pools are less than 1 hectare

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Vernal pool in early spring.

(2.47 acres) in size (Calhoun and deMaynadier 2008) and the vast majority are less than .4 hectare (1 acre) in size. The upper size range of vernal pools is limited because they tend to acquire the vegetation of particular natural community types such as wet prairie or southern hardwood swamp as their size increases and therefore are not considered vernal pools by most definitions. In comparison to smaller pools, larger pools tend to be deeper with larger volumes of water and have longer hydroperiods (i.e., the length of time standing water is present) (Colburn 2004, Calhoun and deMaynadier 2008). Pool size affects hydrology, chemistry, and biology. Larger pools tend to have a lower edge-to-interior ratio (Calhoun and deMaynadier 2008), which allows more sunlight entry, as trees and their canopies are often restricted to pool edges. Wet periods and dry periods are both critical to a vernal pool's biological, physical, and chemical character. Therefore, from a conservation perspective, a vernal pool's boundaries are usually defined by its high water mark even when it is completely dry.

Vernal pools are completely or partially surrounded by forests, woodlands, or savannas (Colburn 2004). This sets them apart from pools in open landscapes that typically harbor species assemblages of emergent marsh, wet prairie, wet meadow, and so forth. They can occur within either upland or wetland forest contexts. Also, while many individual vernal pools contain numerous indicators of wetland conditions, because of the temporary nature of water pooling and the resulting vegetation (or lack thereof), some vernal pools may temporarily or periodically lack positive indicators of wetland soil, hydrology, or vegetation (USACE, 2008).

Soils within vernal pools have not been extensively studied (Colburn 2004), but soils within a given pool tend to reflect the local soil types and intrinsic hydrology. Soils in perched situations tend to overlay shallow bedrock or contain fine materials, such as clay, silt, and muck (Calhoun and deMaynadier 2008). Vernal pools that are strongly connected to the water table tend to have coarse soils such as sand or gravel (Calhoun and deMaynadier 2008). Vernal pool soils often contain indicators of prolonged inundation, including low chroma horizons, mottling, and anoxic decay odors. Layers of coarse or fine peat can overlay mineral soils in vernal pools, but they are more characteristic of pools, or areas within pools, that have the long periods of inundation required for organic layer accumulation (Colburn 2004). Some vernal pool soils are covered by a partially decomposed, interwoven layer of fine roots. All pools receive an annual deposition of tree leaves, and leaf detritus plays an important role in maintaining the biota of vernal pools (Colburn 2004).

Vernal pools are not evenly distributed across Michigan. The presence of a vernal pool requires a supportive combination of topography, water sources, soils, cover, and climate. Vernal pools are potentially lacking is some areas simply because closed-contour concave depressions are scarce; this is the case along many hillsides where smooth, gentle slopes prevent water stagnation. Vernal pools are lacking in some wetland expanses (e.g. in many ponds, lakes, fens, and submergent marsh systems) because surface water is continually present, and does not recede frequently enough for vernal pool development. Conversely, vernal pools are scarce in areas with well-drained coarse-textured soils and high elevation relative to groundwater levels. These dry conditions occur on high dune features and across large portions of some outwash features such as the Highplains (Subsection VII.2), which occupies much of the central northern Lower Peninsula (Albert 1995). Within Michigan, vernal pools are especially numerous at wooded sites in glacial lake plains and till plains, such as the Maumee Lake Plain (Sub-subsection VI.1.1) and the Lansing Till Plain (Sub-subsection VI.4.1). Vernal pools also commonly occur in depressions and swales among forested dunes, in forested settings between drumlins, within kettles, and on forested floodplains.

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Vernal pool in late spring.

Vernal pools occur in all of Michigan's forested community types. In wetland forests they often occur in depressions between hummocks and are inseparable from the forest community as a whole. In upland forests, their vegetation (or lack thereof) and water often make them readily distinguishable from the forest matrix otherwise present. On a per-unit-area basis, vernal pools are probably most numerous in wet forest types with mineral soil such as wet-mesic flatwoods, floodplain forest, southern hardwood swamp, and northern hardwood swamp. Vernal pools are common features in mesic southern forest, northern mesic forest, and dry-mesic southern forest. They are less common in dry southern forest, dry-mesic northern forest, and dry northern forest because of the sandy texture and generally well-drained condition of their soils.

Natural Processes: The character of any given vernal pool is the result of a complex response to and interplay between climate, weather, hydrologic processes, water and soil chemistry, pool geometry, fire patterns, vegetation, fauna, and the surrounding environment. Because all these factors tend to vary across the landscape, each vernal pool is unique. Furthermore, as these factors vary through time, each vernal pool can be viewed as a dynamic feature that changes daily, seasonally, and yearly. As a vernal pool changes, so do its associated plant and animal species (Colburn 2004).

The hydrologic regime of a given vernal pool is controlled by water gains (inputs to the pool) and losses (outputs from the pool). Essentially, when water gains exceed losses, pool levels rise.

When water gains equal losses, pool levels are stable. When water gains are less than losses, pool levels fall. Water gains can occur directly from precipitation, overland via sheet flow or intermittent drainageways, through soil via drainage from higher elevations, from subsoil via groundwater input, and overland via flooding of streams, rivers, or lakes (Calhoun and deMaynadier 2008, Colburn 2004). Similarly, water losses can occur through evapo-transpiration, overland via sheet flow or intermittent drainageways (if the pool is spilling its banks), through soil via drainage to lower elevations, and through subsoil via loss to groundwater (Calhoun and deMaynadier 2008). The relative size of the different hydrologic gains and losses will vary by soil and subsoil textures, topography, groundwater elevations, river flood stages, and local temperatures (e.g. below freezing versus above freezing) (Calhoun and deMaynadier 2008). These factors vary across the landscape, so each vernal pool can be expected to have at least slightly different hydrologic controls. Hydrologic controls combine with pool geometry (the unique depth, width, and shape of each pool) such that each vernal pool has a unique hydrologic regime (Calhoun and deMaynadier 2008). For example, some vernal pools contain standing water during most months of most years, while others contain no standing water during most months of most years (Colburn 2004). The water levels in some vernal pools can fluctuate rapidly and dramatically, while others are relatively stable. For example, a vernal pool fed primarily by river flooding will fill rapidly during a single flood, whereas pools tied strongly to groundwater levels will usually experience slow, steady increases in water levels.

Vernal pool hydrology is also strongly tied to climate, which varies across Michigan. Overall Midwestern continental weather causes Michigan's cold winters and warm summers, but Great Lake effects skew this pattern by causing higher temperatures, cloud cover, and precipitation levels than would otherwise occur in fall and winter. Conversely, the lake effects reduce temperatures, cloud cover, and precipitation levels in spring and summer (Scott and Huff 1996, Eichenlaub et al. 1990). Lake effects upon weather are more prominent near and downwind of each Great Lake (Eichenlaub et al. 1990); thus it is likely vernal pools near to and downwind of Lake Michigan, Superior, Huron, or Erie experience much more lake-effect than those further inland and upwind. Because of their higher levels of dormant season precipitation, vernal pools located in areas of strong lake-effect likely receive more water in winter and spring than those further inland. However, overall summer lake-effect influences are less clear; while lower temperatures would reduce evaporation, lower cloud cover and precipitation would increase evaporation. Temperatures in Michigan are generally consistently higher in the south and lower in the north (Eichenlaub et al. 1990). This trend is important, because temperatures strongly influence evaporation rates, and thus annual (potential) evaporation rates from vernal pools in northern Michigan are likely to be substantially lower than those in southern Michigan (Dunne and Leopold 1978). The combination of localized lake-effects and broad climate differences from north to south suggest that there may be regional differences in vernal pool hydrology across Michigan.

Daily and seasonal weather events affect the water balance in any given vernal pool. Vernal pool water levels can rise following single precipitation events. While precipitation (the ultimate source of most vernal pool water) occurs somewhat consistently throughout the year in Michigan, evapo-transpiration reaches a maximum in warm months such as June, July, and August. Accordingly, vernal pools usually experience declining water levels in these three summer months (Calhoun and deMaynadier 2008). As evapo-transpiration declines in fall and reaches a minimum in the winter months, many vernal pools are recharged with water at this time (Calhoun and deMaynadier 2008). Finally, vernal pools are subject to broader weather fluctuations. Cold and snowy winters can lead to very high water levels as snow melts in spring. Especially wet and cool years (or groups of years) will tend to maximize the number of identifiable vernal pools and their water levels, while atypically dry and warm years (or groups of years) will tend to minimize the number of identifiable vernal pools and their water levels (Calhoun and deMaynadier 2008, Colburn 2004). In years of heavy precipitation, vernal pools that normally draw down can retain surface water throughout the year (Colburn 2004).

Water quality and chemistry in vernal pools is controlled by a large number of factors. Vernal pools in landscapes with (or derived from) igneous bedrock such as granite will tend to have lower cation concentrations and lower pH (i.e. higher acidity). Vernal pools in landscapes with (or derived from) sedimentary bedrock such as limestone have higher cation concentrations and higher pH (i.e. lower acidity) (Colburn 2004). The hydrologic regime and vegetation can also affect water quality and chemistry. For example, a high proportion of water inputs via groundwater results in higher salt concentrations, while the presence of sphagnum moss in a pool typically increases acidity. Dissolved oxygen levels fluctuate but are generally highest while algae and other organisms are photosynthesizing, when water temperatures are cold, when ice cover is not present, and when wind is causing water mixing (Colburn 2004). Studies of vernal pools in Michigan and southern Ontario have found relatively neutral and stable pH and relatively low dissolved oxygen levels (Kenk 1949, Wiggins et al. 1980). Water quality and chemistry

Yu Man Lee

By August, water levels in this vernal pool have dropped, stranding the duckweed that once covered its surface.

in a given pool also can vary through time (Colburn 2004). Water temperatures fluctuate diurnally, but they also fluctuate seasonally with the formation of ice in winter to highs near 30ºC (90º F) as vernal pools shrink in summer, (Kenk 1949, Colburn 2004). Dissolved mineral content and pH tend to be at a maximum in spring when water levels are high. Single rainfall events can alter pH. Vernal pools with large algal populations may have high dissolved oxygen levels during the day and low levels at night.

Vernal pools may often represent nutrient-rich environments. Observations on detrital processing in a vernal pool in southern Ontario suggest that detritus decomposes faster when exposed to air during fall and winter and has higher protein content upon spring flooding than when submerged continuously in permanent pools (Barlocher et al. 1978). However, only limited amounts of nutrients may be available in the water column because they may be trapped in the bottom sediments (Wiggins et al. 1980). Nutrients available in bottom sediments may be important for plant growth during the dry phase of vernal pools.

Vegetation surrounding and within vernal pools can differ markedly due to local soils, hydrology, climate, fire history, and other factors. The type and amount of plant cover present is important in influencing what animal species can survive within or utilize a given vernal pool (Colburn 2004). An important part of the food web in vernal pools is based upon leaf litter (Colburn 2004), so tree species and density along the edges or within a vernal pool can influence its fauna. Algae growth is an important component of the food chain in many vernal pools (Colburn 2004). Algae will receive more sunlight where plant canopies are sparse, and during the dormant season where deciduous trees, as opposed to evergreen trees, are dominant. Finally, temperature swings are moderated by tree cover. Vernal pools with higher levels of tree canopy cover are likely to experience less dramatic temperature swings in response to weather changes (Tesar et al. 2008, Millar et al. 1958).

Ground fires moving through forests and woodlands can affect vernal pools by occurring directly within them or by altering the conditions around them (Thomas 1998). Many of Michigan's savanna and forest community types are considered to be dependent upon a regular occurrence of ground fires (Kost et al. 2007). It is likely that vernal pools embedded in highly fire-dependent communities are more affected or more often affected by the occurrence of fires than those in communities with a very low fire frequency. One wide-reaching effect of fires is to reduce shrub and sapling cover and limit overstory tree density (Kost et al. 2007). This in turn allows increased levels of sunlight to reach the ground layer and affect ground flora composition. Vernal pools are normally wet in spring and incapable of burning, regardless of nearby fire intensity. However, many vernal pools are dry by fall, when most fires occurred prior to European settlement (McClain and Elzinga 1994). Thus, it is likely that many of the vernal pools in fire-prone landscapes were historically subject to fires, especially those with shorter hydroperiods. Whether they occur in or near vernal pools, fires are likely to impact the water quality and chemical cycling or balance within the pools, because fires tend to reduce litter and temporarily increase the availability of nutrients such as nitrogen, phosphorous, potassium, and calcium (Brady and Weil 1999; Tiedemann et al. 1979).

In summary, the character of any given vernal pool changes continually through time and is the result of a complex response to and interplay among climate, weather, hydrologic processes, water and soil chemistry, pool geometry, fire patterns, fauna, and vegetation. Because all of these factors tend to vary across the landscape, each vernal pool is assumed to be unique. This unique character may help to explain the variability in biotic communities among vernal pools.

Vegetation Description: Plants that grow in vernal pools are often tolerant of flooding, soil saturation, and drought. Many of these species are capable of initial growth during water recession and

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Vernal pool in September after water levels have dropped.

rapid growth thereafter to complete reproduction (Wiggins et al. 1980). High levels of shade and the absence of water in the summer can prevent establishment of typical marsh species in many vernal pools (Holland and Jain 1981). As in coastal plain marsh and intermittent wetlands (Kost et al. 2007), fluctuating water levels in vernal pools can promote the establishment of annual plant species (Holland and Jain 1981). Fluctuating water levels also can promote seedling establishment of perennial plants, but they are typically killed annually as high water levels return.

In Michigan, the vegetation in and along vernal pools usually has some similarity to that found in the surrounding landscape but also contains species adapted to wetter conditions. Common tree species of vernal pools may include: black ash (*Fraxinus nigra*), red ash (*Fraxinus pennsylvanica*), swamp white oak (*Quercus bicolor*), pin oak (*Quercus palustris*), bur oak (*Quercus macrocarpa*), black gum (*Nyssa sylvatica*), cottonwood (*Populus deltoides*), silver maple (*Acer saccharinum*), red maple (*Acer rubrum*), American elm (*Ulmus americana*), white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), northern white-cedar (*Thuja occidentalis*), and willow (*Salix spp.*). Common shrub species may include speckled alder (*Alnus rugosa*), buttonbush (*Cephalanthus occidentalis*), winterberry (*Ilex verticillata*), highbush cranberry (*Viburnum opulus var. americanum*), highbush blueberry (*Vaccinium corymbosum*), dogwood (*Cornus spp.*), and willow (*Salix spp.*). Common herbaceous species may include: small duckweed

(*Lemna minor*), jewelweed (*Impatiens capensis*), iris (*Iris spp.*), clearweed (*Pilea pumila*), marsh marigold (*Caltha palustris*), skunk cabbage (*Symplocarpus foetidus*), sensitive fern (*Onoclea sensibilis*), blue-joint grass (*Calamagrostis canadensis*), rushes (*Juncus spp.*), and sedges (*Carex spp.*, including but not limited to *C. tuckermanii*, *C. squarrosa*, *C. bromoides*, *C. lupulina*, *C. lupuliformis*, and *C. muskingumensis*).

Special Plants: Rare plant species known to be associated with vernal pools in Michigan, include Shumard's oak (*Quercus shumardii*, state special concern), raven's-foot sedge (*Carex crus-corvi*, state endangered), squarrose sedge (*Carex squarrosa*, state special concern), and false hop sedge (*Carex lupuliformis*, state threatened).

Associated Fauna: Vernal pools contribute significantly to biodiversity in Michigan by providing critical habitat and food chain support for many animal species (Josselyn et al. 1990). As a group, vernal pools are highly variable and represent the juxtaposition of aquatic and terrestrial environments. These conditions support distinctive animal communities and organisms with special adaptations (Wiggins et al. 1980, Zedler 1987). For example, King et al. (1996) reported the discovery of 30 potentially new crustacean species during a 1992 survey of 58 vernal pools in California.

A wide variety of animals utilize vernal pools for all or specific stages of their life history (Colburn 2004, Calhoun and deMaynadier 2008). The hydrologic cycle of vernal pools (i.e., duration, size, and temporal pattern of inundation, drying, and water-depth change) is the most important physical factor determining the animal communities found in these habitats, although the surrounding landscape and habitats, water chemistry, temperature, and biological or species interactions also strongly influence animal occurrence and distributions in vernal pools (Colburn 2004). Species that inhabit or utilize vernal pools often have specific life history strategies that allow them to survive in these variable wetlands (Wiggins et al. 1980, Williams 1997, Colburn 2004, Calhoun and deMaynadier 2008). For example, species that utilize vernal pools for aquatic egg and larval development must reach their drought-resistant or drought-avoidance stage before the pool dries (Colburn 2004). Species that breed in vernal pools with shorter hydroperiods may need to develop faster than species that breed in pools with longer hydroperiods in order to avoid drought conditions (Colburn 2004). Because conditions in vernal pools can change from year to year, species that inhabit vernal pools need to have life history strategies that have a high degree of flexibility (Colburn 2004). Species that breed or reproduce in vernal pools also often have specific strategies for increasing or maximizing reproductive potential in these highly variable habitats. These include producing large numbers of eggs or young; producing fewer, larger eggs or young with parental brooding; longer adult life spans with multiple breeding events; short life spans in combination with rapid development and production of large numbers of drought-resistant eggs or cysts that hatch at different times; continuous breeding or multiple generations per year; and/or complex life cycles that depend on adult mobility and dispersal, precise timing of breeding, and drought-resistant eggs (Colburn 2004).

The life history strategies of animals that depend on or utilize vernal pools have been categorized in several ways. For example, vernal pool fauna can be categorized as migrants (breeders and non-breeders) versus permanent residents (Colburn 2004). Migrant breeders breed in vernal pools during the inundated stage but leave the pools when they start to dry and spend a significant part of their life cycle away from vernal pools. These include early spring migrants, spring-summer migrants, and fall migrants. Migrant non-breeders include a variety of species that do not breed in vernal pools but utilize them for feeding and other aspects of their life cycle. Permanent residents remain in or near vernal pools for their entire life cycle, and include species that have limited dispersal abilities, species with adults or juveniles that aestivate and become dormant when pools are dry, and species with drought-resistant eggs or cysts that hatch upon or after flooding (Colburn 2004).

Wiggins et al. (1980) classify animals of temporary pools into four categories according to strategies for avoiding or tolerating drought conditions. “Overwintering” or “year-round residents” are capable of passive dispersal only, and aestivate or overwinter in the dry pool basin either as drought-resistant eggs or cysts or as juveniles and adults that burrow into the substrate. “Overwintering spring recruits” aestivate and overwinter in the dry pool basin as eggs, larvae, or in a few beetle species as adults, but are capable of dispersal as adult insects. Dispersal and recruitment is limited to the spring, and oviposition occurs in the vernal pool in spring before surface water disappears. “Overwintering summer recruits” enter the pool basin and oviposit in the dry basin after surface water disappears because their oviposition is independent of water, and overwintering occurs in the egg or larval stages. Finally, “non-wintering spring migrants” enter temporary pools in spring because their oviposition requires water; adults of the subsequent generation(s) leave the pool before it dries out, overwintering mainly in permanent water or on land.

Williams (1983) classifies vernal pool fauna into five similar groups based on general life history patterns and timing of when species are active in vernal pools but does not take into account when species may be dormant or aestivating. “Persistent species” are species that are always present and active in the pools regardless of the presence or

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absence of water. "Emerge-on-flooding species" are species that often are present in the dry pool basin as eggs or cysts, hatch and become active within a few days after the pool fills with water, and typically complete their life cycle within four to six weeks. "Late spring species" appear in vernal pools two to five weeks after spring flooding and often complete their life cycles in about five weeks. "Drying-phase species" appear after the pool has started to dry within two to three weeks of complete drought, and often develop rapidly. "Dry phase species" are only found in vernal pools during the dry period (Williams 1983). Animals associated with vernal pools also can be categorized as either "obligate or indicator vernal pool species" or "facultative vernal pool species." Obligate or indicator vernal pool species rely on vernal pools for all or portions of their life cycle and are unable to successfully complete their life cycle without vernal pools. Conversely, facultative vernal pool species can use vernal pools for all or portions of their life cycle but also are able to successfully complete their life cycles in other water bodies (Calhoun and Klemens 2002, Ontario Vernal Pool Association 2010).

Invertebrates comprise the majority of animals, species, and biomass in vernal pools (Calhoun and deMaynadier 2008). Invertebrate groups that occur in or are commonly associated with vernal pools include large crustaceans such as fairy shrimp, clam shrimp, and tadpole shrimp; small crustaceans such as seed shrimp (ostracods), copepods, water fleas (cladocerans), isopods and amphipods; springtails (Collembola); crayfish; worms including flatworms, leeches and earthworm-like segmented worms, roundworms, and horsehair worms; rotifers and sponges; mollusks such as snails and fingernail clams; arachnids such as water mites and spiders; and aquatic insects including caddisflies, aquatic beetles, dragonflies and damselflies, water bugs, true flies, and mosquitoes (Eriksen and Belk 1999, Colburn 2004, Williams 2006, Calhoun and deMaynadier 2008). Fairy shrimp (Order Anostraca) and clam shrimp (Orders Laevicaudata, Brevicaudata, and Spinicaudata) are probably the most well-known invertebrates associated with vernal pools (Colburn 2004, Calhoun and deMaynadier 2008), and are good indicators of the presence of vernal pools. Fairy shrimp commonly found in Michigan and northeastern North America are in the genus *Eubranchipus* (e.g., knob-lipped fairy shrimp [*Eubranchipus bundyi*] and neglected fairy shrimp [*E. negectus*]) and the most common clam shrimp is *Lynceus brachyurus* (Colburn 2004, Calhoun and deMaynadier 2008). These species are restricted to fish-free, temporary waters, and are permanent or overwintering residents of vernal pools with drought-resistant eggs that aestivate and remain dormant in pool substrates until hatching is stimulated by flooding (Colburn 2004). Fairy shrimp eggs also may require drying and exposure to cold temperatures before hatching (Colburn 2004, Calhoun and deMaynadier 2008). Fairy shrimp can most readily be found in flooded vernal pools in early spring and sometimes in the fall and winter (Colburn 2004, Calhoun and deMaynadier 2008). In the Northeast, fairy shrimp are generally not found in vernal pools after the middle or end of May, or when water temperatures reach 68 to 72° F (20 to 22° C) (Colburn 2004). In comparison to fairy shrimp, clam shrimp tend to have more restricted distributions, develop faster, and have shorter life spans (Calhoun and deMaynadier 2008). Clam shrimp are usually found occupying vernal pools later in the season than fairy shrimp, when water temperatures are warmer, primarily from early May to mid-September (Colburn 2004, Calhoun and deMaynadier 2008).

Small crustaceans such as water fleas or cladocerans (Class Branchiopoda, Order Anomala), copepods (Copepoda, Orders Calanoida, Cyclopoda, and Harpacticoida), and seed shrimp or ostracods (Ostracoda, Order Podocopida) are important and abundant components of vernal pool fauna worldwide (Colburn 2004). Most of these species also occur in other aquatic habitats and are not restricted to vernal pools except for several species such as cladoceran *Daphnia ephemeralis* and copepods *Cyclops haueri* and *Megacyclops latipes* (*D. ephemeralis* and *M. latipes* occur in

Michigan, and *C. haueri* is relatively rare but has been found in Connecticut and Ohio) (Kenk 1949, Wiggins et al. 1980, Schwartz and Hebert 1987, Higgins and Merritt 2001, Colburn 2004). Ostracods typical and indicative of vernal pools found in Michigan include *Candona inopinata*, *C. decora*, *Bradleystrandesia fuscata*, *Cypridopsis vidua*, *Cypris subglobosa*, and *Cypria ophthalmica* (Hoff 1942, Kenk 1949, Wiggins et al. 1980, Williams 1983, Colburn 2004). Cladocerans, copepods, and ostracods occurring in vernal pools are overwintering or permanent residents that use diapausing, drought-resistant eggs or cysts to withstand drying (i.e., the organism is surrounded by a structure or hard coating that protects it from drying and injury) (Colburn 2004). The diapausing eggs or cysts form an "egg bank" or pool of individuals, similar to a seed bank, in which development is halted until favorable environmental conditions are present to stimulate hatching or emergence, and not all eggs or individuals hatch or emerge with the same stimulus (Colburn 2004). Diapausing eggs and/or individuals can remain viable in the substrate for many years before hatching or emerging (Colburn 2004). A number of vernal pool species, including these species, fairy shrimp, and clam shrimp, utilize this strategy for avoiding or surviving drought or other adverse conditions in vernal pools (Colburn 2004). Some ostracod species (e.g., *Daphnia ephemeralis*) appear to be associated with cold water, and can be observed in pools in fall, winter or early spring before water temperatures start to warm (e.g., November – April/May), while others (e.g., *D. pulex*,) are generally found or reach peak abundance later in the season (e.g., April to June/ July) (Kenk 1949, Colburn 2004).

Aquatic insects are also one of the largest groups of animals in vernal pools in terms of numbers of species and individuals (Colburn 2004). They are important components of the energy cycle in vernal pools, serving as detritivores, herbivores, prey, and predators (Colburn 2004 Calhoun and deMaynadier 2008). Hundreds of species of aquatic insects occur in vernal pools, including caddisflies (Order Trichoptera), water beetles (Coleoptera), dragonflies and damselflies (Odonata), water bugs (Hemiptera), true flies (Diptera including midges, crane flies, and horseflies), and mosquitoes (Diptera) (Colburn 2004, Calhoun and deMaynadier 2008). Many of these aquatic insects are commonly observed in or near vernal pools, but very few species are restricted to this habitat (Colburn 2004). Caddisflies that occur in vernal pools are mainly from four families—Limnephilidae, Phryganeidae, Polycentropodidae, and Leptoceridae (Colburn 2004). Water beetles commonly found in vernal pools include predacious diving beetles (Dytiscidae), water scavenger beetles (Hydrophilidae), crawling water beetles (Haliplidae), and whirligig beetles (Gyrinidae) (Colburn 2004). Many species of dragonflies and damselflies require fishless waters, and some are found in vernal pools including several representatives of the darner and skimmer dragonflies (Families Aeshnidae and Libellulidae, respectively), and the spread-winged and pond damselflies (Families Lestidae and Coenagrionidae, respectively) (Colburn 2004). Water bugs from all the major aquatic Hemiptera families occur in vernal pools, including water boatmen (Corixidae), backswimmers (Notonectidae), giant water bugs (Belostomatidae), water striders (Gerridae, Veliidae, Hebridae, Mesoveliidae), and others (Colburn 2004). About 30 species of mosquitoes have been documented in vernal pools (see Colburn 2004). Some aquatic insects (e.g., some species of caddisflies, water beetles, spread-winged damselflies, and mosquitoes) have developed desiccation- or drought-resistant life stages or strategies that allow them to occur as overwintering, permanent residents of vernal pools. Most aquatic insects that occur in vernal pools are migratory breeders and can be classified as overwintering spring recruits, overwintering summer recruits, and/or non-wintering spring migrants (see Wiggins et al. 1980 and Colburn 2004 for more information). Some aquatic insect species (e.g., some species of water beetles and water bugs) are also migratory non-breeders and utilize vernal pools for feeding but breed elsewhere (Colburn 2004).

Two groups of freshwater mollusks regularly occur in vernal pools, fingernail clams (Family Sphaeriidae or Pisidiidae) and air-breathing snails (Families Lymnaeidae, Physidae, and Planorbidae) (Colburn 2004, Calhoun and deMaynadier 2008). Fingernail clams, also known as pea clams or pill clams, as adults are about the size and shape of a human fingernail. Five species of fingernail clams occur in vernal pools in northeastern North America, of which one species, the Herrington's fingernail clam (*Sphaerium occidentale*), is restricted to vernal pools that dry up annually (Kenk 1949, Wiggins et al. 1980, Colburn 2004). Other species of fingernail clams that occur in vernal pools include the swamp fingernail clam (*Musculium partumeium*), pond fingernail clam (*M. securis*), and pea clam (*Pisidium casertanum*) (Kenk 1949, Wiggins et al. 1980, Colburn 2004). Fingernail clams can survive drawdown conditions in vernal pools by burrowing into the substrate, aestivating (at different life stages), undergoing diapause in some species, and having flexible life history strategies (Colburn 2004). Nineteen species of air-breathing snails have been documented in vernal pools, and three of these species, the common stagnicola (*Stagnicola elodes*), the polished tadpole snail (*Aplexa elongata*), and the toothed planorbid (*Planorbula armigera*), are commonly found in vernal pools in Michigan and the glaciated northeast (Kenk 1949, Wiggins et al. 1980, Colburn 2004, Calhoun and deMaynadier 2008). Snails survive in vernal ponds by burrowing into the substrate and aestivating during dry, summer conditions, generally as juveniles but also as adults in some cases, and re-emerging to feed, grow, breed, and lay eggs when the pools refill with water (Colburn 2004, Calhoun and deMaynadier 2008).

Approximately 35 Midwestern amphibian species breed in or utilize vernal pools (Johnson 1998). The majority of amphibians in Michigan complete the transition from egg to larva to adult in one season, and prefer to breed in vernal pools and shallow wetlands where there is little or no threat to their larvae from fish predators. This strategy has its risks, however, since these water bodies may dry out before metamorphosis is complete. Amphibian species most dependent upon and most indicative of vernal pools in Michigan are wood frog (*Lithobates sylvaticus* [*Rana sylvatica*]), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*) and hybrid complex, marbled salamander (*Ambystoma opacum*, state endangered), and smallmouth salamander (*Ambystoma texanum*, state endangered) (Harding 1997, Conant and Collins 1998, Colburn 2004, Calhoun and deMaynadier 2008, Crother 2008). These species can be considered obligate or indicator vernal pool species (Massachusetts NHESP 2009, Ontario Vernal Pool Association 2010). Other amphibian species in Michigan that commonly breed in vernal pools but also can breed in other wetlands (i.e., facultative vernal pool species) include the eastern tiger salamander (*Ambystoma tigrinum*), western chorus frog (*Pseudacris triseriata*), boreal chorus frog (*Pseudacris maculata*), spring peeper (*Pseudacris crucifer*), gray treefrog (*Hyla versicolor),* Cope's gray treefrog (*Hyla chrysoscelis*), American toad (*Anaxyrus americanus* [*Bufo americanus*]), and Fowler's toad (*Anaxyrus fowleri* [*Bufo woodhousei fowleri*]) (Harding 1997, Colburn 2004, Calhoun and deMaynadier 2008, Crother 2008, Massachusetts NHESP 2009, Ohio Vernal Pool Partnership 2009, Ontario Vernal Pool Association 2010, Rhode Island Vernal Pool Website 2010). Eastern newts (*Notophthalmus viridescens*) and four-toed salamanders (*Hemidactylium scutatum*) can occasionally be found breeding in or along vernal pools (Colburn 2004). Green frogs (*Lithobates clamitans* [*Rana clamitans*]), northern leopard frogs (*Lithobates pipiens* [*Rana pipiens*]), pickerel frogs (*Lithobates palustris* [*Rana palustris*]), bullfrogs (*Lithobates catesbeianus* [*Rana catesbeiana*]), and Blanchard's cricket frogs (*Acris blanchardi* [formerly *Acris crepitans blanchardi]*) also can occasionally breed in or

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occur in vernal pools, but generally prefer to breed in open habitats or permanent waters and/or utilize vernal pools outside the breeding season (Colburn 2004). Eastern red-backed salamanders (*Plethodon cinereus*) can be found in dry vernal pool basins (Colburn 2004). Many of these amphibian species overwinter close to vernal pools; though some overwinter up to almost two kilometers (one mile) away. Amphibians contribute to the prey base for many reptiles, birds, mammals, and other amphibians. Thus, vernal pools support a critically important component of the food web that helps to maintain species diversity in and beyond their boundaries.

Many birds and a smaller number of reptiles and mammals also utilize vernal pools during the wet phase. These are all facultative vernal pool species that utilize these habitats for water, food, shelter, refuge from heat, and overwintering sites in some cases (Calhoun and deMaynadier 2008). Baker et al. (1992) documented 55 bird species in 11 vernal pools in California—primarily ducks, shorebirds, and grassland species of passerines as well as raptors and less frequently other bird species. They also found that bird species richness and abundance in vernal pools were positively correlated with pool area. Calhoun and deMaynadier (2008) has identified over 230 species of birds that may be observed at vernal pools during migration and breeding seasons, and 65 species of state-listed, rare and/or declining bird species associated with vernal pools in the Northeast. In Michigan, bird species that have often been observed using vernal pools or have high potential for using these habitats include wood duck (*Aix sponsa*), great blue heron (*Area herodias*), mallard (*Anas platyrhynchos*), American black duck (*Anas rubripes*), eastern screech owl (*Megascops asio*), barred owl (*Strix varia*), wild turkey (*Meleagris gallopavo*), American woodcock (*Scolopax minor*), black-capped chickadees (*Poecila atricapillus*), and warblers (Colburn 2004, Calhoun and deMaynadier 2008, Cuthrell pers. comm., Gehring pers. comm.). Calhoun and deMaynadier (2008) have identified additional bird species that may use vernal pools. It is important to note, however, that few studies have specifically examined bird communities near vernal pools (Calhoun and deMaynadier 2008). Therefore, additional bird species associated with vernal pools may be identified with further study.

Reptiles such as turtles can also be found in vernal pools but more often they utilize larger, more permanent water bodies such as ponds, lakes, and rivers. Spotted turtles (*Clemmys guttata*, state threatened) and Blanding's turtles (*Emydoidea blandingii*, state special concern) regularly use vernal pools for foraging, basking, and breeding (Harding 1997, Joyal et al. 2001, Milam and Melvin 2001, Colburn 2004, Calhoun and deMaynadier 2008). Painted turtles (*Chrysemys picta*) and snapping turtles (*Chelydra serpentina*) also utilize vernal pools opportunistically for foraging, basking, resting, and occasionally for overwintering (Harding 1997, Faccio 2001, Kenney and Burne 2000, Colburn 2004, Calhoun and deMaynadier 2008). Snakes such as common garter snakes (*Thamnophis sirtalis*), eastern ribbon snakes (*Thamnophis sauritus*), and northern water snakes (*Nerodia sipedon*) regularly use vernal pools for basking, shelter, and foraging. These snakes feed extensively on frogs and salamanders (i.e., adults, larvae/tadpoles, metamorphs, and/or eggs) (Conant and Collins 1998, Ernst and Ernst 2003, Kenney and Burne 2000, Colburn 2004, Calhoun and deMaynadier 2008).

A significant percentage of mammal species that occur in northeastern North America also utilize vernal pools (Calhoun and deMaynadier 2008). These include the little brown bat (*Myotis lucifugus*), big brown bat (*Eptesicus fuscus*), water shrew (*Sorex palustris*), masked shrew (*S. cinereus*), smoky shrew (*S. fumeus*), short-tailed shrew (*Blarina brevicauda*), star-nosed mole (*Condylura cristata*), meadow vole (*Microtus pennsylvanicus*), white-footed mouse (*Peromyscus leucopus*), woodland jumping mouse (*Napaeozapus insignis*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), mink (*Mustela vison*), white-tailed deer (*Odocoileus virginianus*), and moose (*Alces alces*, state special concern) (Vogt 1981, Whitaker and Hamilton 1998, Brooks and Doyle 2001, Faccio 2001, Brown and Jung 2005, Francl 2005, Calhoun and deMaynadier 2008).

Special Animals: Special animals in Michigan that utilize or depend on temporary pools include the smallmouth salamander, marbled salamander, boreal chorus frog, Blanchard's cricket frog, spotted turtle, Blanding's turtle, and moose (all noted previously) as well as the copperbelly water snake (*Nerodia erythrogaster neglecta*, federally threatened and state endangered), wood turtle (*Glyptemys insculpta*, state special concern), eastern box turtle (*Terrapene carolina carolina*, state special concern), and red-shouldered hawk (*Buteo lineatus*, state threatened) (Ernst et al. 1994, Kenney and Burne 2000, Kingsbury and Coppola 2000, Roe et al. 2003, Calhoun and deMaynadier 2008). Other state-listed or rare species that may be associated with or sometimes use vernal pools include the Indiana bat (*Myotis sodalis*, federally and state endangered), prothonotary warbler (*Protonotaria citrea*, state special concern), and ringed boghaunter dragonfly (*Williamsonia lintneri*, state special concern) (Calhoun and Klemens 2002, Calhoun and deMaynadier 2008). At the first sign of spring, smallmouth salamanders migrate from surrounding woods to breed in shallow bodies of water in floodplain forests, and often share vernal pools with other *Ambystoma* species. Their eggs hatch in three to eight weeks, and the larvae grow quickly and transform into terrestrial salamanders in two to three months (Harding 1997). In contrast to spring breeding salamander species, the marbled salamander migrates to autumnal pools to breed in the fall. The female lays eggs at the edge or bottom of a dry vernal pool and guards its eggs

until the nest is flooded. The eggs then hatch as the nest is inundated by rising water. The newly emerged larvae overwinter in the vernal pool and then undergo metamorphosis in late spring or early summer. The copperbelly water snake utilizes vernal pools during spring and moves to permanent waters as vernal pools begin to dry (Harding 1997). For most of the year, Blanding's turtles live in shallow, weedy waters such as ponds, marshes, and swamps but occasionally utilize vernal pools as well. As these habitats start to dry up during the summer, Blanding's turtles migrate overland to new bodies of water, or burrow under mud or vegetation and aestivate until conditions improve (Harding 1997). The red-shouldered hawk nests in mature, floodplain or upland hardwood forests but forages at nearby wetlands such as vernal pools. Indiana bats may forage around vernal pools (Calhoun and deMaynadier 2008). Prothonotary warblers breed in floodplain forests and forested swamps (Gibson 2007, MNFI 2007). Ringed boghaunter dragonflies breed in small wetlands including vernal pools (Maine Department of Inland Fisheries and Wildlife 2010).

Conservation/Management: In parts of North America, vernal pools have declined at an alarming rate. This loss includes a wide span—from California to Missouri to New England (Holland and Jain 1977, Zedler 1987, King et al. 1996; Johnson 1998; Preisser et al. 2000; Calhoun and deMaynadier 2008). Many of these vernal pools have been drained, filled, destroyed, or degraded by agricultural activities and urban development. In Michigan, large amounts of forest have been lost. Forests covered approximately 89% of

Michigan circa 1800 (Albert and Comer 2008) but now cover only about 45% of the state (NOAA Coastal Services Center 2006). Given that vernal pools were scattered throughout Michigan's forested lands, it is certain that a sizeable portion of Michigan's vernal pools have been destroyed or heavily altered. However, this loss is probably not distributed evenly. For example, in southern Lower Michigan, the southeastern glacial lakeplain and south central till plain have been cut over, heavily drained, converted to agriculture, and often developed, resulting in extensive loss of forests, vernal pools, and other wetlands (Comer 1996). The greatest losses of vernal pools have probably occurred in the following ecoregions of Southern Lower Michigan (Section VI): Maumee Lake Plain (Sub-section VI.1.1), Southern Lake Michigan Lake Plain (Sub-section VI.3.2), Lansing Till Plain (Sub-subsection VI.4.1), Sandusky Lake Plain (Sub-subsection VI.5.1), and Saginaw Bay Lake Plain (Subsection VI.6) (Albert 1995). In addition to direct conversion or destruction, vernal pools are also subject to degradation caused by urban drainage, off-road vehicles use, and landscape fragmentation.

Recommendations for the conservation and management of vernal pools include the following.
1) Become familiar with the characteristics of vernal pools and learn to identify them during all times of year.
2) Avoid or minimize activities that disturb soils or tree canopies in and near vernal pools, particularly during critical time periods for most amphibians (i.e., March through July). This is important because equipment use and canopy alteration can impact water quality and quantity and shift vegetation, resulting in changes to microhabitat that can pose serious problems for many amphibians (Semlitsch et al. 1988, deMaynadier and Hunter 1995, 1998, 1999, Waldick et al. 1999).
3) Maintain a buffer of native forest vegetation around vernal pools to protect them from land use activities and alterations to water quality (Calhoun and deMaynadier 2008). Recommended concentric forest harvest buffer zones are 30 m (100 ft) with very limited or no harvest and 120 m (400 ft) with limited harvest and protection practices for the forest floor and woody debris (Calhoun and deMaynadier 2008, Michigan DNR and Michigan DEQ 2009). Recommended buffers between roads and vernal pools are at least 100 m (330 ft) wide. Other buffer zones of up to 300 m (1,000 ft) in which land development can be held below certain densities have been recommended (Calhoun and deMaynadier 2008).
4) Maintain as much natural cover, wetland area, and drainage connection as possible between groups of vernal pools and between vernal pools and other wetlands, so that animals may continue to disperse between scattered vernal pools and wetlands (Calhoun and deMaynadier 2008).

Research Needs: More information is needed in order to understand, classify, and protect vernal pools in Michigan. Studies addressing the composition and ecology of plant and animal communities, hydrology, and water quality of vernal pools are warranted since little information has been systematically collected within Michigan. Additional investigation of vernal pool locations, biota, and physical properties are needed to determine if vernal pool subtypes exist. The information obtained through such studies would help to hone overall vernal pool conservation strategies.

Similar and Frequently Overlapping Natural Communities: Coastal plain marsh, intermittent wetland, inundated shrub swamp, lakeplain oak openings (wet variants), wet-mesic flatwoods, floodplain forest, southern hardwood swamp, and northern hardwood swamp.

Other Classifications:
Circa 1800 Vegetation: Vernal pools originally occurred in forests throughout Michigan. They may have been especially common in beech-sugar maple forests of the southern Lower Peninsula (Comer et al. 1995, Comer and Albert 1998).

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Other States:
MA: Vernal pool. (Commonwealth of Massachusetts Division of Fisheries and Wildlife 2009).

ME: Vernal pool (Maine Department of Environmental Protection Bureau of Land & Water Quality 2009).

NJ: Vernal pool (Tesauro 2009).

NY: Vernal pool (Edinger et al. 2002).

OH: Vernal pool (Ohio Department of Natural Resources 2010).

PA: Herbaceous vernal pond (Fike 1999); Seasonal Pool (see Seasonal Pool Registry Program operated by The Western Pennsylvania Conservancy).

VT: Vernal pool (Thompson and Sorenson 2005).

WI: Ephemeral pond (Epstein et al. 2010).

Related Abstracts: coastal plain marsh, dry-mesic southern forest, floodplain forest, hardwood-conifer swamp, intermittent wetland, inundated shrub swamp, lakeplain oak openings, mesic northern forest, mesic southern forest, northern hardwood swamp, southern hardwood swamp, wet-mesic flatwoods, Blanding's turtle, spotted turtle, wood turtle, eastern box turtle, copperbelly water snake, Blanchard's cricket frog, marbled salamander, smallmouth salamander, Indiana bat, red-shouldered hawk, prothonotary warbler.

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