Identifying and Mapping Vernal Pools on State Forest Lands in Michigan's Upper Peninsula

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Center photo - Vernal pool, Crystal Falls State Forest Area, Iron County, MI. Photo by Pete Badra and Nick Scobel, MNFI.

EXECUTIVE SUMMARY

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. This project represents a unique collaboration between Verso Paper Corporation, the Michigan Department of Natural Resources, the Michigan Forest Products Council and the Michigan Natural Features Inventory. This collaborative project conducted a targeted effort to identify and map vernal pools on state forest lands in the western Upper Peninsula of Michigan. Information on the locations and ecological characteristics of vernal pools compiled as part of this project were added to a statewide spatial database of vernal pools in Michigan. This project included efforts to evaluate the effectiveness of aerial photograph interpretation and radar for identifying and mapping vernal pools remotely.

A total of 1,332 potential vernal pools were identified and mapped within the project's study areas using aerial photograph interpretation. The study areas were located within the Baraga State Forest Area in Houghton County and Crystal Falls State Forest Area in Iron and Dickinson Counties. An additional 156 potential vernal pools were identified and mapped from aerial photograph interpretation within the Crystal Falls State Forest study area as part of the MNFI's previous vernal pool study (Lee et al. 2014), resulting in an overall total of 1,488 potential vernal pools mapped across both study areas. Approximately 115-120,000 acres of state forest lands across both study areas were reviewed for potential vernal pools using aerial photo interpretation.

MNFI staff surveyed a total of 207 potential and new vernal pools in the field in 2014. Of these, 173 were potential vernal pools that had been identified and mapped from aerial photograph interpretation, and 34 were new or potential vernal pools identified in the field that had not been mapped during aerial photo interpretation. Of the 207 potential or new vernal pools surveyed, a total of 112 (54%) were verified as vernal pools. An additional 22 pools (11%) 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. If these pools are confirmed and included as verified vernal pools, this would result in a total of 134 (65%) vernal pools identified and mapped within the study areas in 2014. A total of 73 (35%) of the potential or new vernal pools surveyed in 2014 were verified as not being vernal pools in the field. Of these, 31 (15%) were other types of

natural or artificial wetlands, and 42 (20%) were areas that were dry and did not appear to regularly hold water for extended periods of time. Most of the vernal pools verified in 2014 were categorized as open, sparsely vegetated, or forested pools, although some marsh and shrubby pools also were documented.

The overall accuracy rate for correctly identifying vernal pools from aerial photograph interpretation was moderate. Of the 173 potential vernal pools that were identified from aerial photos and surveyed in the field in 2014, 83 (48%) were verified as vernal pools in the field, and an additional 18 (10%) were identified as potential or likely vernal pools that need additional information to confirm their status. Combining the verified and potential/likely vernal pools resulted in a total of 101 vernal pools identified in the field, which would result in an overall vernal pool mapping accuracy rate of 58% for aerial photo interpretation across both study areas. 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 72 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). This resulted in an overall commission error rate of 42%.

For this project, Michigan Tech Research Institute conducted a small pilot project to assess the use of C-Band SAR (synthetic aperture radar) to map vernal pools in a small area in the western Peninsula and two other areas in southeast Michigan with data collected from Radarsat-2 in the spring and summer of 2014. Michigan Tech Research Institute used a similar methodology that they developed for MNFI's previous vernal pool project (Lee et al. 2014). However, the Radarsat-2 images for the western UP study area were not able to exhibit enough variability between data collected in the spring and summer for field identified vernal pools to be detected.

While mapping potential vernal pools using aerial photo interpretation can be time consuming and has been only moderately accurate in the western UP, aerial photo interpretation is currently still the most effective method we have for identifying and mapping vernal pools remotely. 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). This project added a significant number of potential vernal pools identified and mapped in the western UP, nearly quadrupling the number of potential vernal pools identified and mapped from aerial photos from about 460 to almost 1,800. 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 173 active vernal pools on the ground, of which 112 were documented during this study.

The results of this project will greatly assist Verso, the MDNR, the MFPC, and their partners with forest planning and harvesting efforts, and help facilitate sustainable forest management practices including efforts to protect vernal pools. 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 identify, manage and conserve them.

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INTRODUCTION

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 animal species have been documented in vernal pools in northeastern America (Colburn 2004). 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. 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 2004). 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 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 identifying, mapping, monitoring, and protecting these small but valuable wetlands in Michigan and other states. 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). However, 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. 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. In general, little information is currently available on the status, distribution, and ecology of vernal pools in Michigan. This information is critical for developing and implementing appropriate management of these wetlands.

This project represents a unique collaboration between Verso Paper Corporation, the Michigan Department of Natural Resources (MDNR), the Michigan Forest Products Council, (MFPC) and the Michigan Natural Features Inventory (MNFI), a program of Michigan State University Extension (MSUE). This collaborative project conducted a targeted effort to identify and map vernal pools on state forest lands in Michigan's Upper Peninsula on which Verso Paper Corporation procures wood. Information on the locations and ecological characteristics of vernal pools compiled as part of this project were added to a statewide spatial database of vernal pools in Michigan, and provided to project partners.

This project also included efforts to evaluate different approaches for identifying and mapping vernal pools remotely. Currently, the most common and effective way to inventory and map vernal pools remotely is through aerial photograph interpretation (Colburn 2004). While this method can be fairly accurate in identifying and mapping vernal pools, it also is very time-consuming and labor-intensive (Colburn 2004, Lee et al. 2014). The accuracy rate of aerial photograph interpretation also can vary depending on forest landscape characteristics, pool type and size, timing and scale of the aerial photos, and photo interpreter experience (Brooks et al. 1998, Burne 2001, Calhoun et al. 2003, Colburn 2004, Lathrop et al. 2005, Burne and Lathrop 2008, Lee et al. 2014). New technologies, such as radar, may be able to enhance our ability to locate and map vernal pools, particularly in forested landscapes. This project further investigated the use and effectiveness of aerial photo interpretation and radar for identifying and mapping vernal pools remotely.

Verso Paper Corporation, the Michigan DNR, and the Michigan Forest Products Council promote protection and encourage their partners to protect vernal pools as part of sustainable forestry practices. The results of this project will greatly assist Verso, the MDNR, the MFPC, and their partners with forest planning and harvesting efforts, and help facilitate sustainable forest management practices including efforts to protect vernal pools on lands on which Verso procures wood. This project also complements and builds upon a vernal pools project recently completed by the MNFI in collaboration with the Michigan Department of Environmental Quality (MDEQ), MDNR, and other partners (Lee et al. 2014). This project 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 identify, manage and conserve them.

PROJECT OBJECTIVES

This project addressed the following objectives:

1) Identify and map potential vernal pools across at least approximately 15,000 acres of state forest land in Michigan's Upper Peninsula using remote sensing (i.e., air photos and/or radar/LiDar) and/or ecological modeling using GIS. Project will focus on lands under active forest management.

2) Verify and map actual vernal pools in the field across a portion of the study area (at least 250 acres). This will include verifying potential vernal pools mapped remotely and additional vernal pools encountered during field sampling. Collect some initial information on the physical/biological characteristics of vernal pools identified in the field.

3) Evaluate the effectiveness of identifying and mapping vernal pools remotely using different approaches. Examine if and how forest type, soil type, and/or vernal pool type impact the effectiveness of identifying vernal pools remotely.

4) Compile information on the locations and some initial physical/biological characteristics of vernal pools identified and mapped for this project in a spatial database.

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

METHODS

Study Areas

The project's study areas targeted state forest lands in the western Upper Peninsula in Houghton, Iron, and Dickinson counties (Figure 1). These lands are located within the Baraga and Crystal Falls State Forest Areas, and are owned and managed by the Michigan Department of Natural Resources. These forests are under active forest management. Total acreage of state forest lands that were included in the study areas was approximately 125,000 acres (~51,000 ha).

To select specific study areas for this project, we examined and considered several factors. We first conducted a cursory visual assessment of aerial imagery of state forest lands in the western Upper Peninsula and looked for areas that appeared to have greater potential for vernal pools. In Michigan, vernal pools occur in forested settings throughout the state but are generally more abundant in areas where the water table is high and/or where bedrock or fine-textured soils such as clay are present and closer to the surface to hold water temporarily. We focused on areas with larger, more contiguous tracts of state forest lands to increase efficiency in the mapping and survey components of the project. We were interested in working in the same general area in which MNFI had previously mapped vernal pools to contribute data and build on efforts that had been initiated as part of MNFI's earlier project on vernal pools. We also initially thought that we were limited to areas for which radar data were available for identifying potential vernal pools (i.e., for spring/flooded and summer/not flooded conditions). These considerations resulted in the study areas that were selected.

We also were interested in mapping and collecting data on vernal pools in different ecological settings. As a result, the study areas were located in several physiographic regions within the Superior Bedrock Uplands major physiographic region (Figure 2), although vernal pool mapping in the field focused on the Michigamme Bedrock Terrain and Sturgeon Incised Terrain physiographic regions (Figure 2 and Table 1) (Schaetzl et. al 2009). Similarly, the study areas were located in several regional landscape ecosystems or ecoregions, primarily the Baraga (Sub-subsection IX.6.3) and the Winegar Moraine (Sub-subsection IX.3.2) ecoregional sub-subsections (Albert 1995) (Figure 3 and Table 1). Albert (1995) and Schaetzl et al. (2009) provide additional detailed information about the characteristics of these ecoregions and physiographic regions.

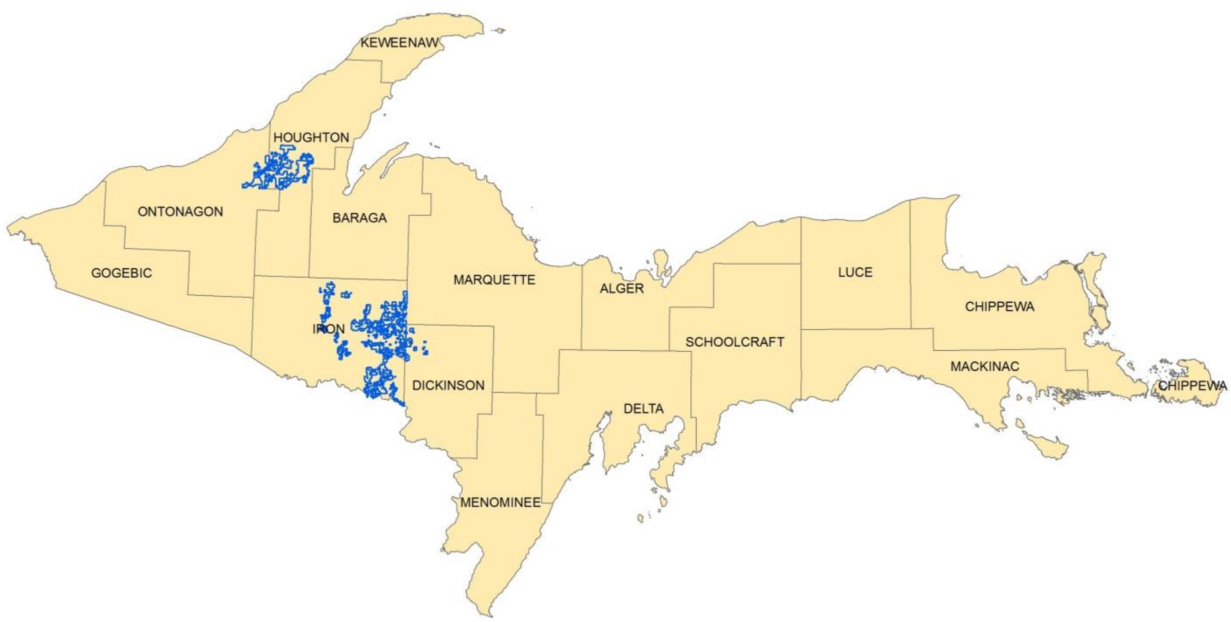


Figure 1. Map showing the general locations of project study areas within the Baraga State Forest Area in Houghton County and Crystal Falls State Forest Area in Iron and Dickinson counties in the western Upper Peninsula of Michigan.

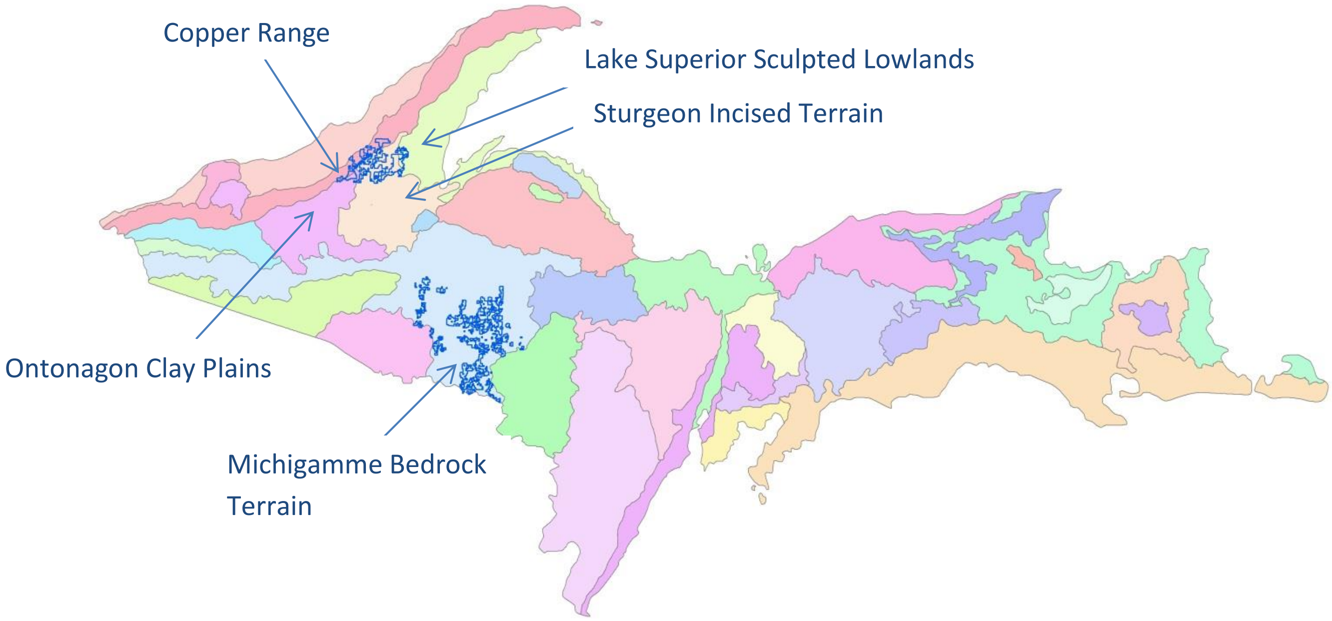


Figure 2. Map showing the physiographic regions in which the project study areas were located within the Baraga and Crystal Falls State Forest Areas in Michigan's western Upper Peninsula.

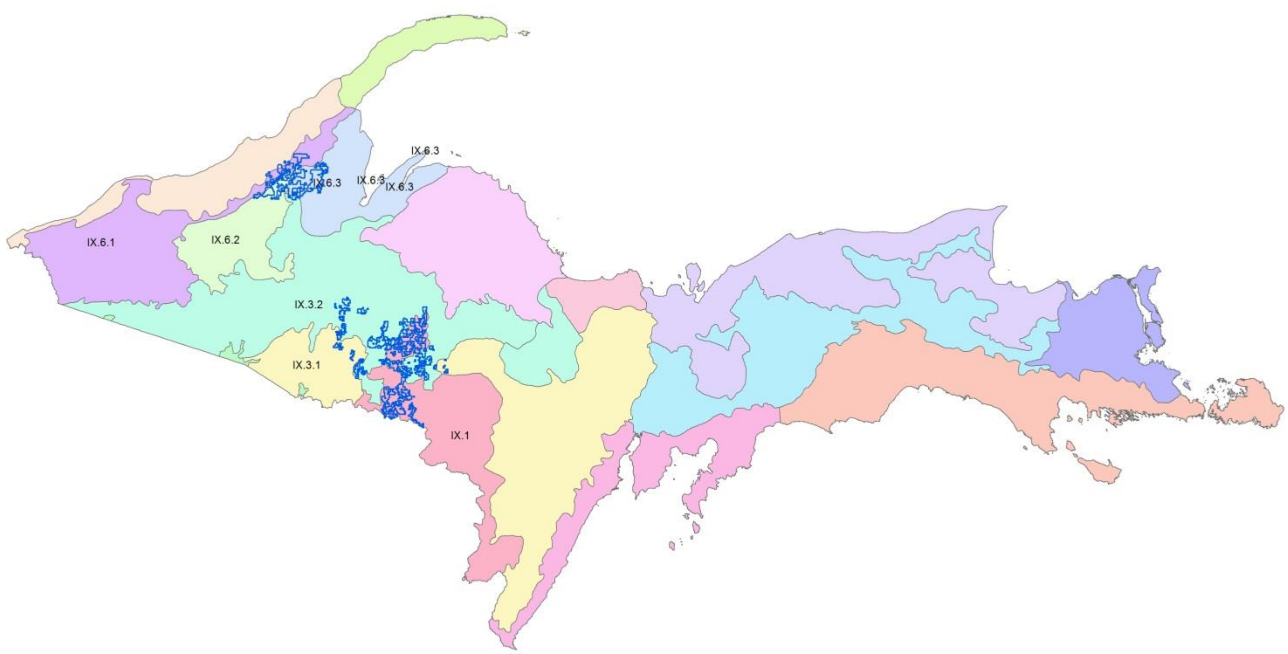


Figure 3. Map showing the regional landscape ecosystems in which the project study areas were located within the Baraga and Crystal Falls State Forest Areas in Michigan's western Upper Peninsula.

Table 1. Summary and brief descriptions of the two main physiographic regions and ecoregions in which the study areas and vernal pool mapping for this project were located within the Baraga and Crystal Falls State Forest Areas in the western Upper Peninsula.

Study Area	**County(ies)**	**Physiographic Region**	**Physiographic Region - General Description, Soils, and Presettlement Vegetation (Information from http://www.physiomap.msu.edu/)**	**Ecological Region - Subsection/ Sub-Subsection Number**	**Ecological Region - Subsection / Sub-Subsection**	**Ecological Region – Landforms & Soils**
Baraga State Forest Area	Houghton	Superior Bedrock Uplands - Sturgeon Incised Terrain	High elevation, largely bedrock-controlled landscapes that have been modified by glacial scour and deposition, with areas of high hills and low mountains formed on bedrock. Upland, moderate-high relief landscape with dendritically incised stream channels and valleys; many are deep and/or steep-sided. Thick, sandy drift. Well drained and drier soils on uplands and on valley sides. Soils are sandy loam and similar coarse textures. Tills and glaciofluvial sediments form the parent materials. Sugar maple-hemlock-yellow birch forest on uplands; some pine on sandy areas.	IX.6.3	Bergland - Baraga	End Moraines of Coarse-Textured Till; Coarse-Textured Glacial Till. Broad, ground-moraine ridges (150 to 500 feet high) of well-drained sands and sandy loam soils. Poorly drained soils restricted to stream edges and occasional depressions between large moraine ridges.
Crystal Falls State Forest	Iron, Dickinson	Superior Bedrock Uplands – Michigamme Bedrock Terrain	High elevation, largely bedrock-controlled landscapes that have been modified by glacial scour and deposition, with areas of high hills and low mountains formed on bedrock. Hummocky and incised plains with moderate relief. Drift is sandy, thin in many places but can be locally thick. Many areas could be bedrock-influenced ground moraine. Moderately well drained soils on uplands; poorly drained soils, and Histosols, in lowland swamps. Sugar maple-hemlock-yellow birch forest on uplands; some pine on sandy areas.	IX.3.2	Upper Wisconsin/ Michigan Moraines - Winegar Moraine	End Moraines of Coarse-Textured Till; Coarse-Textured Glacial Till; Ground Moraine, and Outwash. Irregular lobes of end moraine – numerous kettle lakes and steep ridges. Sandy loam or loamy sand.

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 2) 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 considered natural features within natural communities and not distinct natural communities, although some vernal pools can be classified as a natural community (e.g., inundated shrub swamp, northern hardwood swamp). 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 2. 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 3 and Appendix 1). 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.

Table 3. Vernal pool types and definitions used to categorize vernal pools identified and mapped on state forest lands in the western 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 fall of 2014 to identify and map potential vernal pools (PVPs) within the study areas. We reviewed aerial photo imagery and mapped potential vernal pools across nearly all the state forest lands included in the study areas (approximately 115-120,000 acres, mainly in Houghton and Iron counties).

Aerial photograph interpretation consisted of using ESRI ArcGIS software to visually examine available aerial imagery and other available imagery and maps of the study area on a computer screen. Aerial imagery that were available for the study areas and inspected for this project included statewide color infrared aerial imagery from the spring of 1998 and natural color aerial imagery from the summer of 2005, 2010, and 2012 (NAIP 2005, NAIP 2010, and NAIP 2012 True Color). Additionally, high-resolution, leaf-off, natural color imagery of parts of the study areas was found and utilized during aerial photo interpretation conducted in the fall. Topographic maps, land cover data (C-CAP 2006), 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 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 area to provide consistency in interpretation across the study area. 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.

Investigating the Use of Radar to Map Potential Vernal Pools

The detection and mapping of vernal pools can be hindered by forest canopy cover, making the utility of optical imagery alone limiting and challenging, particularly in forests dominated by coniferous trees. In an attempt to enhance our effectiveness and efficiency at mapping potential vernal pools, we evaluated the use of satellite-based radar data for detecting and mapping potential vernal pools within the study area. We conducted a pilot project with Michigan Tech Research Institute (MTRI) of Michigan Technological University to investigate the use of radar for identifying and mapping vernal pools as part of MNFI's previous vernal pool project (Lee et al. 2014). This project provided an opportunity for MTRI to conduct a small pilot to test this method in the western Upper Peninsula since the radar data needed to map potential vernal pools were not available during MNFI's earlier study.

For this project, Michigan Tech Research Institute assessed the use of C-Band SAR (synthetic aperture radar) to map vernal pools with data collected from Radarsat-2 in the spring and summer of 2014. Previous work by Townsend *et* al. (2001, 2002) showed 5.7 cm C-band data from Radarsat-1 as useful for detection of inundation beneath a forest canopy. As a result, MTRI evaluated the effectiveness of this shorter wavelength for vernal pool detection in the western Upper Peninsula. They also included the Pinckney State Recreation Area in southeast Michigan, which was one of the study areas in the previous vernal pool project, in this evaluation with other project funds.

Michigan Tech Research Institute used a similar methodology with the C-Band data that they developed for MNFI's previous vernal pool project using satellite-based radar data (i.e., 10-m resolution Japanese ALOS PALSAR FBS (fine beam single) L-Band SAR imagery for that study) to detect potential vernal pools in two of the three study areas for that project (Lee et al. 2014). Radar sensors (synthetic aperture radar – SAR) are low frequency active systems which also allows for penetration of canopy cover to detect the presence of standing water (Lee et al. 2014). Since vernal pools by definition are only inundated in the spring and dry in the summer, two seasons of radar imagery were evaluated to capture these hydrological differences and help map potential vernal pools. Using a differencing technique of spring (wet) minus summer (dry) conditions, it was hypothesized that vernal pools could be differentiated from "wetlands" that have a longer hydroperiod and uplands that don't exhibit the bright radar signature for flooded conditions in spring (MTRI pers. comm). The radar data were combined with digital elevation data (e.g., LiDar or USGS DEM) to improve mapping of potential vernal pools (Lee et al. 2014). Potential vernal pools identified and mapped using radar imagery and DEM data were compared to vernal pool data from the field to assess the effectiveness of this method.

Radarsat-2 data collections were tasked for spring (when inundated) and summer (when dry) 2014 for the western Upper Peninsula (i.e., Radarsat-2 FQ1 June 1 and August 11) and Pinckney (i.e., Radarsat-2 FQ5 April 24 and July 29) study areas. MTRI staff visited field sites in the western Upper Peninsula and Pinckney Recreation Area study areas in spring and/or fall 2014. Twenty vernal pools were sampled in the western UP, and six vernal pools were sampled in the Pinckney Recreation Area. Data were collected on vegetation and indicator faunal species. Pool extent was recorded in the field using GPS units.

Field Sampling to Identify and Map Vernal Pools

MNFI staff conducted field sampling in the study areas in early summer and fall of 2014 to identify, map, and assess vernal pools on the ground. Field sampling consisted of two teams of 1-2 surveyors visiting potential vernal pools mapped using aerial photo interpretation within the study areas. Potential vernal pools were located 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 2). 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 two different time periods in 2014. We conducted field sampling in early summer of 2014 (i.e., early season sampling) to identify vernal pools when they are typically filled with water. Early season sampling was conducted from 8-12 July. We conducted field sampling in early fall of 2014 from 5-13 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 4). 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 2). 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 2014.

Table 4. Categories used to designate potential vernal pools sampled in the field in the study areas on state forest lands in the western 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, we conducted an accuracy assessment of these methods by comparing vernal pool mapping results from the aerial photograph interpretation to field sampling results from 2014. 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 5). Commission error could come in two forms: (1) features that were bodies of water 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). An estimate of omission error in terms of the number of vernal pools found in the field but were not mapped from aerial photographs (also known as false negatives) also was generated. But this does not represent an accurate or 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, which would be difficult to quantify.

Table 5. Summary of comparisons for accuracy assessment for vernal pool mapping on state forest lands in the western 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

We had originally proposed examining if and how forest type, soil type, and/or vernal pool type impact the effectiveness of identifying vernal pools remotely. However, due to limited time and availability in terms of the type and scale of forest and soil data needed for this analysis, we were not able to examine these factors at this time. We were able to generally examine differences in effectiveness due to vernal pool type and physiographic region between the two general study areas. We evaluated the whether physiographic region impacted the effectiveness of identifying vernal pools from aerial photo interpretation by comparing the accuracy rates based on the number and percentage of potential vernal pools verified as vernal pools in the field between the two physiographic regions included in the study. For this project, we evaluated whether vernal pool type impacted the effectiveness of identifying vernal pools remotely by examining the relative abundance of the different types of vernal pools that were documented in the field of the potential vernal pools that were surveyed and verified as vernal pools. We also looked at the potential vernal pools that were surveyed and identified as other wetland types.

RESULTS

Aerial Photograph Interpretation

A total of 1,332 potential vernal pools was identified and mapped within the study areas using aerial photograph interpretation. Of these, 250 were mapped within the Baraga State Forest Area, and 1,082 were in the Crystal Falls State Forest Area. An additional 156 potential vernal pools were identified and mapped from aerial photograph interpretation within the Crystal Falls

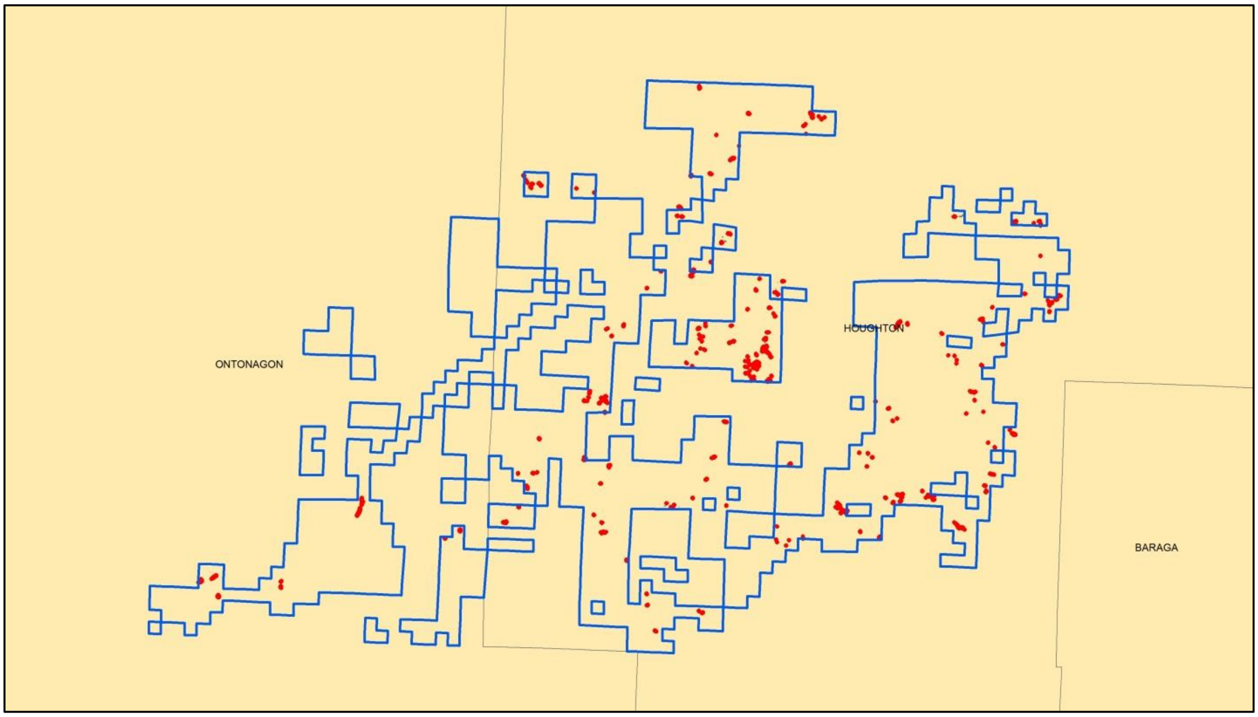
State Forest study area as part of the MNFI's previous vernal pool study. These potential vernal pools were included as part of this project. This resulted in a total of 1,238 potential vernal pools within the Crystal Falls study area, and an overall total of 1,488 potential vernal pools across both study areas.

Based on all the potential vernal pool polygons mapped within the study areas from this project and MNFI's previous project, the potential vernal pool polygons ranged in size from less than 0.01 acre to about 10 acres (<0.01 ha to ~4 ha), with mean area of the polygons about 0.2 acres (~0.07 ha). The total acreage for all the potential vernal pool polygons was about 256 acres (~104 ha), which represented approximately 0.2% of the study area (based on an estimate of about 115,000 -120,000 acres of the study area reviewed for potential vernal pools).

The potential vernal pools that were mapped were distributed throughout the study areas within the Baraga and Crystal Falls State Forest Areas, but they were not evenly distributed throughout the study areas and appeared to be clustered or more prevalent in certain areas (Figure 4). This seemed to be particularly the case in the Baraga State Forest study area. There also appeared to be a lower density of potential vernal pools identified and mapped in the Baraga State Forest study area in general (Figure 4).

Field Sampling

MNFI staff surveyed a total of 207 potential and new vernal pools in the field within the Baraga and Crystal Falls study areas in 2014. Of the 207 pools surveyed, 173 were potential vernal pools that had been identified and mapped from aerial photograph interpretation (API) (i.e., as part of this project and previous MNFI project), and 34 were new or potential vernal pools identified in the field that had not been mapped during aerial photo interpretation. The 173 potential vernal pools surveyed in the field represents about 12% of the 1,488 total potential vernal pools included in the study. Of the 173 potential vernal pools identified surveyed in the field, 46 were located in the Baraga State Forest Area, and 127 were located in the Crystal Falls State Forest Area (Table 6). Of the 173 potential vernal pools surveyed in the field in 2014, 81 were surveyed only during the early season sampling period (i.e., early July), 64 were surveyed during both the early and late seasons (i.e., early October), and 28 were surveyed only during the late season (Table 6). Of the 34 new or potential pools that were identified and surveyed in the field in 2014, 20 were located in the Baraga State Forest Area, and 14 were located in the Crystal Falls State Forest Area (Table 7). Of these, only 3 were surveyed only during the early season, 16 were surveyed during both the early and late seasons, and 15 were surveyed only during the late season (Table 7).



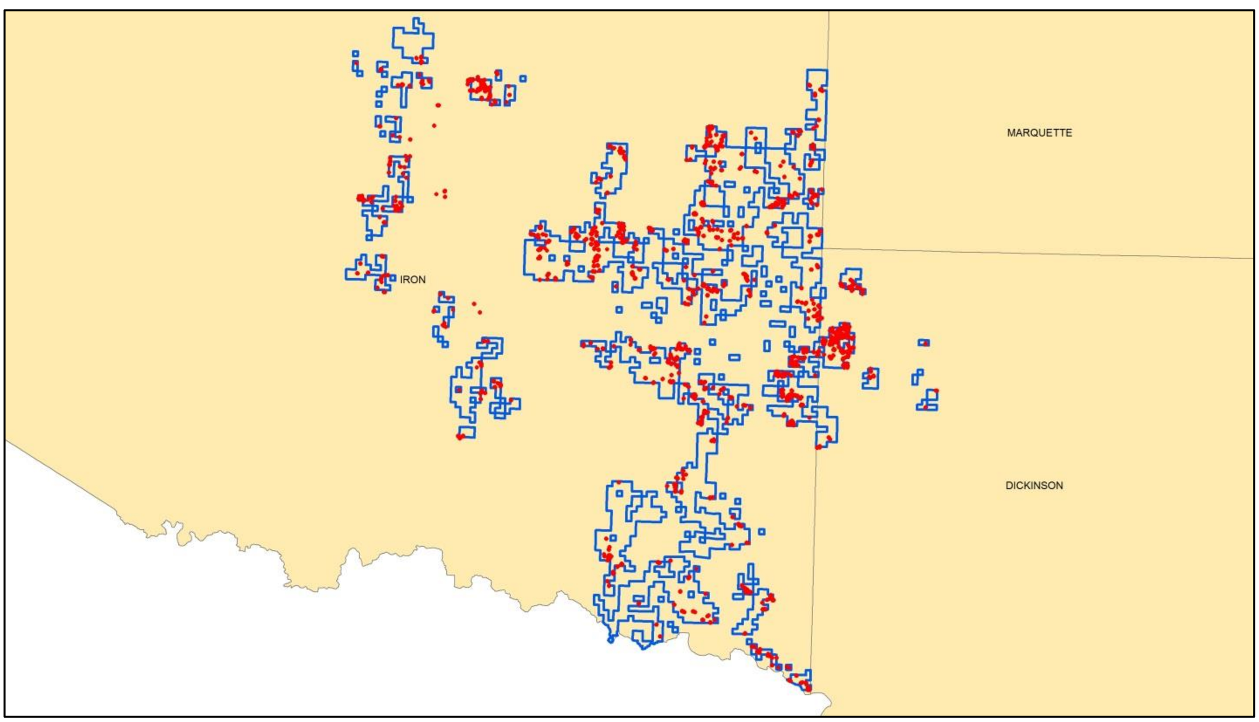


Figure 4. Maps showing the distribution of potential vernal pools (red dots) mapped from aerial photo interpretation within the Baraga State Forest study area (top map, study area outlined in blue) and the Crystal Falls State Forest study area (bottom map) in the western Upper Peninsula. Note: Several of the compartments or areas outlined in blue were not reviewed for potential vernal pools.

Table 6. Summary of potential vernal pools identified and mapped from aerial photograph interpretation (API) that were surveyed in the field in 2014.

State Forest Area	Number of API Potential Vernal Pools Surveyed in 2014	Number of API Potential Vernal Pools Surveyed only during Early Season 2014	Number of API Potential Vernal Pools Surveyed during Early and Late Seasons 2014	Number of API Potential Vernal Pools Surveyed only during Late Season 2014
Baraga	46	19	22	5
Crystal Falls	127	62	42	23
Total	173	81	64	28

Table 7. Summary of new or potential vernal pools identified and surveyed in the field in 2014.

State Forest Area	Number of New/Potential Vernal Pools Identified and Surveyed in Field in 2014	Number of New/Potential Vernal Pools Identified and Surveyed in Field only during Early Season 2014	Number of New/Potential Vernal Pools Identified and Surveyed in Field during Early and Late Seasons 2014	Number of New/Potential Vernal Pools Identified and Surveyed in Field only during Late Season 2014
Baraga	20	0	12	8
Crystal Falls	14	3	4	7
Total	34	3	16	15

Of the 207 potential or new vernal pools that were surveyed in 2014, a total of 112 (54%) were verified as active vernal pools (H2O-VP) (Table 8). An additional 22 pools (11%) 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 134 (65%) vernal pools identified and mapped within the study areas in 2014. A total of 73 (35%) of the potential vernal pools surveyed in 2014 were verified as not being vernal pools in the field. Of these, 31 (15%) were other types of natural or artificial wetlands (H2O-NVP), and 42 (20%) 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 8. 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 and were either other wetland types or were dry and not wetlands at all.

State Forest Area	Total Number of API and Field Identified Potential/New Vernal Pools Surveyed in 2014	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)
Baraga	66	34	9	14	9
Crystal Falls	141	78	13	17	33
Total	207	112	22	31	42

Of the 173 potential vernal pools (PVPs) identified and mapped from aerial photos that were surveyed in 2014, 83 were verified in the field as active vernal pools (Table 9). 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 5). An additional 18 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 9). These included four potential vernal pools that were located in lowland forest or forest swamps that were dry and had some indications that they held water in the field but need to be verified in the spring when they are wet and for long (Figure 5). Ten of these potential or likely vernal pools could be marsh pools or emergent wetlands, and need to be revisited in the spring when the pools are full and in late summer or fall to verify drying (Figure 5). Four of these potential or likely vernal pools could be semi-permanent or permanent pools and need to be revisited in late summer or fall to verify drying. Combining the field verified active vernal pools and potential or likely vernal pools resulted in a total of 101 verified or likely vernal pools that had been mapped as potential vernal pools from aerial photo interpretation.

Of the 173 PVPs surveyed in 2014, 72 were verified as not vernal pools, of which 30 were other types of wetlands, and 42 were dry and did not appear to regularly hold water for extended periods of time (Table 9). Other types of wetlands that were mapped as potential vernal pools included hardwood or coniferous swamp forest stands with no open water or a few very small pools of water, bogs, emergent wetlands, shrub swamps or shrub thickets that contained permanent water or did not have any open water, and artificial pools along active or old roads that appear to be permanently flooded. 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 upland forest stands and small openings and clearings in upland forests as well as old two-track roads and small dry depressions that appeared to be artificially created.

Of the 34 new or potential vernal pools encountered in the field in 2014, 29 were verified and mapped as active vernal pools, 4 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 10). 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 inundation. These also included several wetlands that still contained quite a bit of water and need to be revisited in late summer or fall to verify drying.

Table 9. Summary of aerial photo interpreted (API) potential vernal pools that were surveyed in 2014 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.

State Forest Area	**Number of API Potential Vernal Pools Surveyed in 2014**	**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)**
Baraga	46	19	5	13	9
Crystal Falls	127	64	13	17	33
Total	173	83	18	30	42

Table 10. Summary of field-identified new or potential vernal pools that were surveyed in 2014 and verified as vernal pools, potential/likely vernal pools/status uncertain, and not vernal pools.

State Forest Area	**Number of Field Identified New/Potential Vernal Pools Surveyed in 2014**	**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)**
Baraga	20	15	4	1	0
Crystal Falls	14	14	0	0	0
Total	34	29	4	1	0

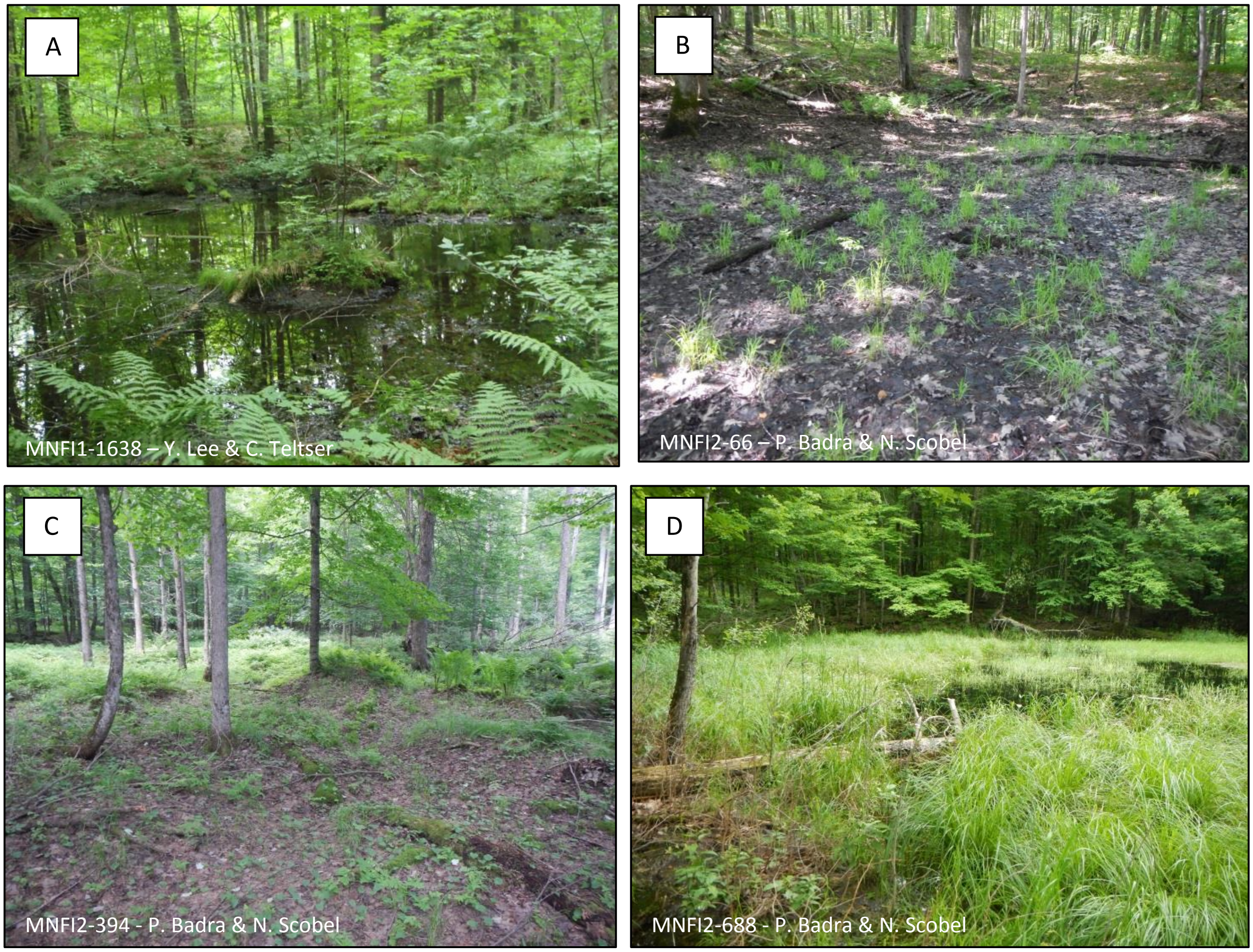


Figure 5. Examples of verified and potential or likely vernal pools that were observed in the field in 2014: (A) verified wet vernal pool; (B) verified dry vernal pool with clear signs of regularly holding water during part of the year; (C) potential or likely vernal pool that was dry and needs to be revisited in the spring to verify flooding; and (D) potential or likely vernal pool that is either a marsh pool or a permanently flooded emergent wetland.

Most of the vernal pools verified during the surveys in 2014 were categorized as open, sparsely vegetated, or forested pools, although marsh and shrubby pools also were documented (Figure 6). About half of the verified vernal pools were categorized as open or sparsely vegetated. About one-third of the verified vernal pools were categorized as forested pools. These included small, isolated forested swamp depressions in upland forests as well as pools within larger forested swamp complexes. Shrubby and marsh pools comprised much smaller percentages of the verified vernal pools (about 5 - 10% respectively). However, a number of the potential or likely vernal pools that needed additional information to make a final designation on their status were marshy or shrubby pools. Thus, if these pools are later verified as vernal pools, the number of marsh and shrubby pools would increase, although they would still remain a much smaller percentage of the verified vernal pools than open, sparsely vegetated, and forested pools.

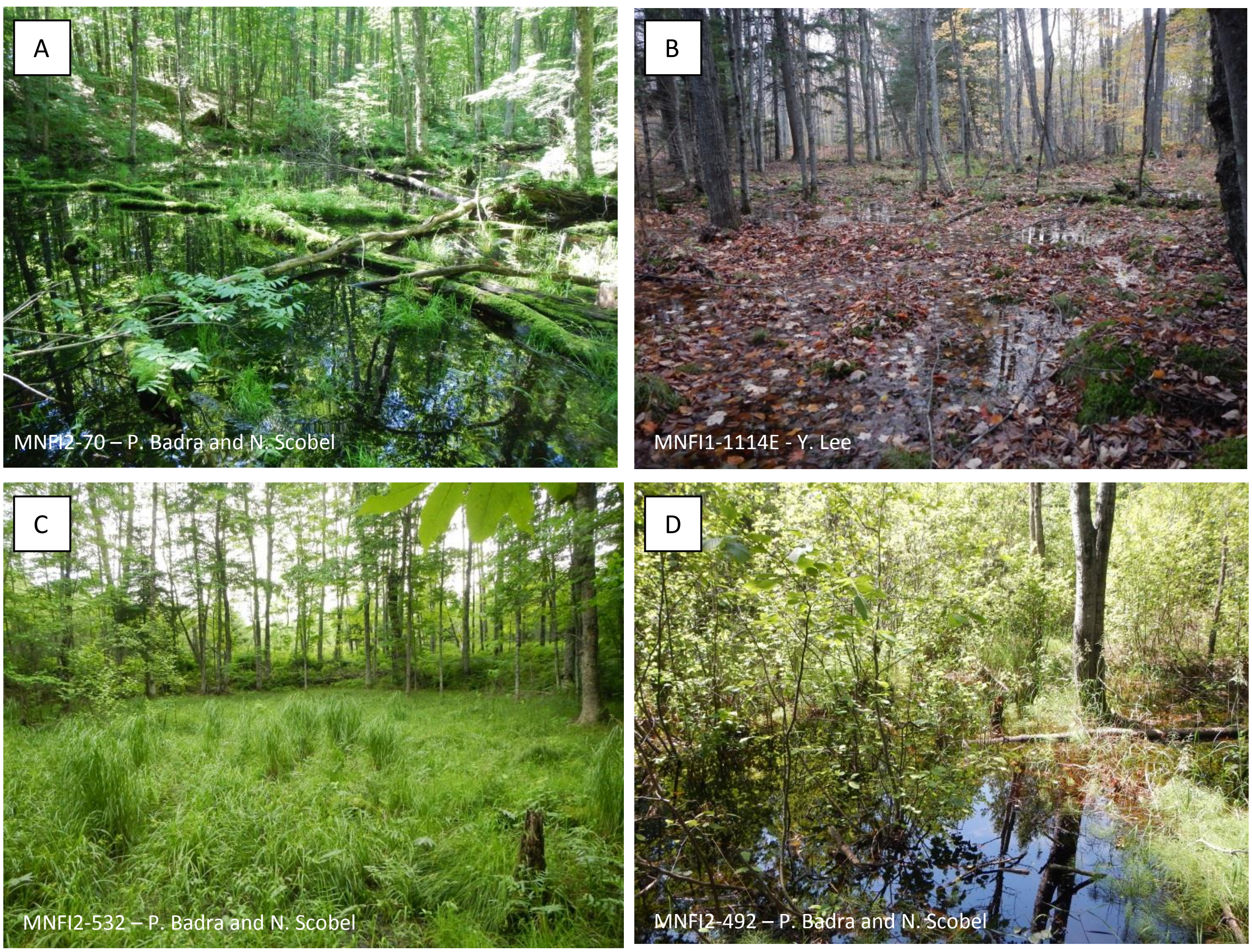


Figure 6. Examples of different vernal pool types encountered in the field during vernal pool surveys on state forest lands in the western Upper Peninsula – (A) Open / Sparsely Vegetated Pool; (B) Forested Pool; (C) Marsh Pool (in July); and (D) Shrubby Pool.

Water levels in the vernal pools were somewhat surprising during the early and late season sampling periods in 2014. Of the 99 verified or potential/likely vernal pools that were surveyed during the early season sampling period when the pools are typically wet or filled with water, only 26% of the pools were full (75-100% full) or partially full (50-74% full), 15% of the pools were less than half full (25-49% full), and 59% of the pools were dry or mostly dry (0-24% full). Of the 109 verified or potential/likely vernal pools sampled during the late season sampling period when the pools are typically dry or mostly dry, 19% of the pools were still full or partially full with water, and 30% of the pools were less than half full, which was higher than what was found during the early season. Only 50% of the pools were dry or mostly dry.

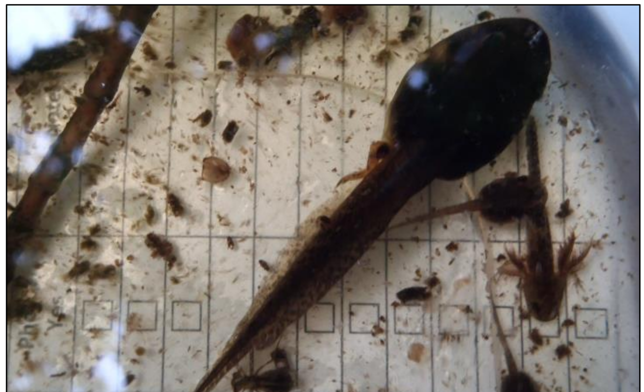
Most of the verified and potential/likely vernal pools were isolated and did not have any inlet or outlet channels. Of the 134 verified and potential/likely vernal pools identified during surveys in 2014 (combining pools were identified from air photos and in the field), 93 (69%) of the pools were isolated, and 42 (31%) of the pools were not isolated and were connected to or part of other vernal pools, forested wetlands, open/emergent/shrubby wetlands, and/or culverts. A total of 115 (86%) of these vernal pools did not have any inlets or outlets, and 17 (13%) of them had temporary inlet or outlet channels.

The verified vernal pools in the study areas were very small. Size of the verified vernal pools ranged from less than 0.001 ac to about 4 ac (<0.0001 ha - 2 ha), with mean vernal pool area ranging from 0.11 ac (0.04 ha) in the Crystal Falls study area to 0.35 ac (0.14 ha) in the Baraga study area. Total area summed for all the verified vernal pools was about 21 ac (~8 ha), with about 8.5 ac (3.5 ha) in the Crystal Falls study area and about 12 ac (4.8 ha) in the Baraga study area.

Presence of vernal pool obligate or indicator species was documented in only 8 (6%) of the 134 confirmed or likely vernal pools identified during field sampling in 2014. Vernal pool indicator species also were documented in 3 additional wetlands that were not classified as vernal pools (i.e., two were emergent wetlands, and one was an old two-track that was flooded due to beaver activity). Vernal pool indicator species that were documented included Wood Frog tadpoles, Blue-spotted Salamander egg masses and larvae, and Spotted Salamander egg masses and larvae (Figure 7). Adult Wood Frogs were observed in additional vernal pools that were surveyed in 2014. Fairy shrimp were not documented in any of the vernal pools, but it was too late in the season to observe the species during the early season surveys. Additionally, because many of the vernal pools encountered in the field were dry during the early season sampling period, this likely impacted the number of pools in which we could detect indicator species.

Although vernal pool obligate or indicator species were found in only several pools, other species commonly associated with vernal pools were found in a number of pools. These include fingernail clams, caddisfly larvae, dragonfly larvae, dobsonfly larvae, phantom midges, water boatmen, and snails. Other amphibians, and reptiles also were documented in or near the vernal pools and other wetlands surveyed in 2014 including Eastern Newt (*Notophthalmus viridescens*) larvae, Spring Peeper (*Pseudacris crucifer*) tadpoles, Western Chorus Frog (*Pseudacris triseriata triseriata*) tadpoles, American Toads (*Anaxyrus americanus*), Green Frogs (*Lithobates clamitans*), and Eastern Garter Snake (*Thamnophis sirtalis sirtalis).* Small fish were found in one of the wetlands.

Spotted Salamander Egg Mass – Y. Lee & C. Teltser



Spotted salamander larva, green frog tadpole, wood frog tadpoles,& dragonfly larva– Y. Lee & C. Teltser

Blue-spotted salamander larva, green frog tadpole & wood frog tadpole – Y. Lee & C. Teltser

Caddisfly Case – Y. Lee & C. Teltser

Figure 7. Examples of vernal pool indicator species and other associated species found on July 11, 2014 in a sparsely vegetated vernal pool (MNFI2-294) in the Baraga State Forest Area in Houghton County in the western Upper Peninsula of Michigan.

Accuracy Assessment

The overall accuracy rate for correctly identifying vernal pools from aerial photograph interpretation was moderate. Of the 173 potential vernal pools that were identified from aerial photos and surveyed in the field in 2014, 83 (48%) were verified as vernal pools in the field, and an additional 18 (10%) 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 101 vernal pools identified in the field, which would result in an overall vernal pool mapping accuracy rate of 58% for aerial photo interpretation across both study areas.

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 72 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). This resulted in an overall commission error rate of 42% for aerial photo interpretation for mapping vernal pools across both study areas.

As mentioned earlier, omission error, in terms of the aerial photo interpretation not mapping and missing vernal pools that actually exist in the field, cannot be accurately estimated because areas that did not have potential vernal pools mapped were not targeted for field sampling. However, we may be able to provide a general or pseudo-estimate of omission error in terms of the number of verified and likely 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 134 total verified and likely vernal pools identified in the field, 33 (i.e., 29 verified and 4 potential/likely vernal pools) of them were not mapped during aerial photo interpretation. These 33 pools represent about 25% of the total number of verified and likely vernal pools that were found in the field. This estimate should be viewed with caution though given the reasons mentioned earlier.

We examined whether physiographic region and vernal pool type impacted the effectiveness of mapping vernal pools remotely using aerial photo interpretation. The accuracy rate for identifying and mapping vernal pools was slightly higher for the Crystal Falls State Forest study area located within the Michigamme Bedrock Terrain physiographic region than the accuracy rate for the Baraga State Forest study area located within the Sturgeon Incised Terrain physiographic region. The Crystal Falls study area had 77 (61%) of the 127 potential vernal pools surveyed in the study area verified as vernal pools or likely vernal pools, compared to the Baraga State Forest study area which had 24 (52%) of the 46 potential vernal pools surveyed in the study area verified as vernal pools or likely vernal pools. In terms of vernal pool type, of the 83 potential vernal pools that were surveyed and verified as vernal pools, most were open/sparsely vegetated and forested vernal pools, comprising 43% and 31% of the field-verified vernal pools, respectively. Marsh and shrubby pools comprised only 19% and 4% of the field-verified vernal pools, respectively. Additionally, most of the potential or likely vernal pools that needed additional information to finalize their designation and most of the potential vernal pools that turned out to be other wetland types were marsh or shrubby pools.

Radar

The results and discussion sections for the radar component of the study were provided by Michigan Tech Research Institute. The Radarsat-2 data were not as useful for detecting vernal pools in the western Upper Peninsula study area compared to the Pinckney Recreation Area study area. The Radarsat-2 images for the western UP study area were not able to exhibit enough variability between data collected in the spring and summer for field identified vernal pools to be detected. Figure 8 shows subsets of the spring and summer Radarsat-2 collections near several field verified vernal pools near Bob Lake in the Western UP.

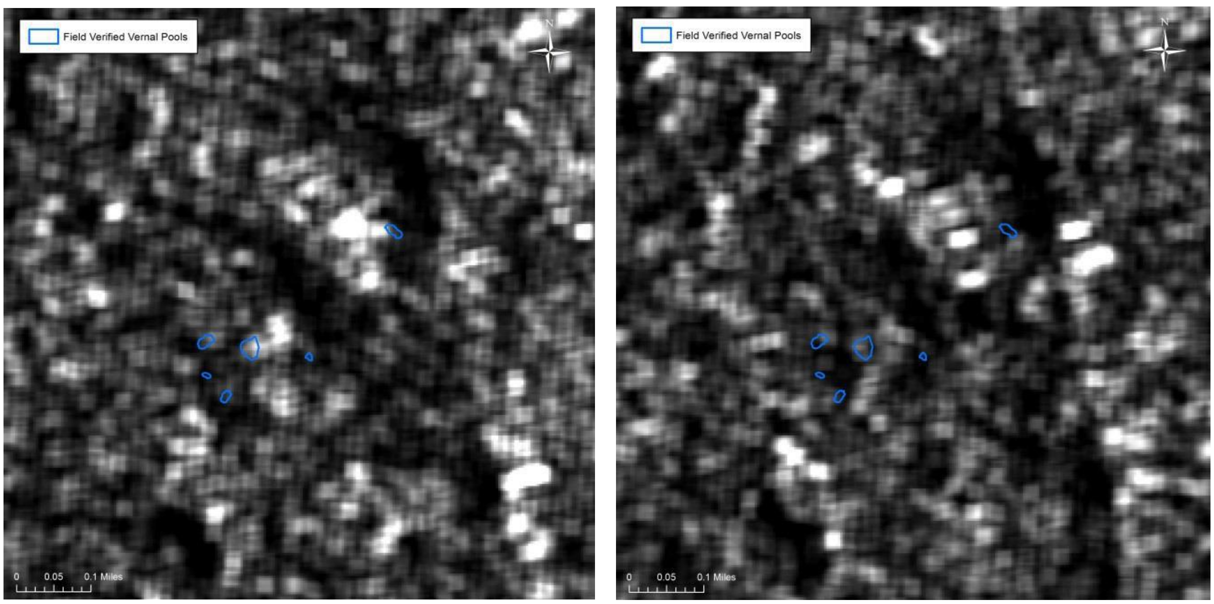


Figure 8. The June 1 (left) and August 11 (right) Radarsat-2 images around several field verified vernal pools near Bob Lake in the western Upper Peninsula. 6 of the 20 field-verified vernal pools from this study area are outlined in blue in the images.

For the Pinckney Recreation Area study area, spring radar data collected in April were ideal for capturing the inundation condition before full leaf flush. Figure 9 shows that the data proved to be useful for detecting wetlands and vernal pools in spring. Of the six field verified vernal pools, four were detected with Radarsat-2. One of the undetected vernal pools was “open”, and therefore would not be picked up by the differencing technique which is looking for SAR backscatter to go from bright to darker conditions. For an open area, the double bounce (strong SAR return) characteristic of inundated trees would not occur. Figure 9 shows the spring (wet) and summer (dry) Radarsat-2 images in addition to a map showing the locations of significant decreases in backscatter overlaid with a map of isolated depressions derived from a DEM (digital elevation model). Integrating the SAR with the DEM has been found to be more useful than either one alone for the L-band dataset that was used for the earlier study.

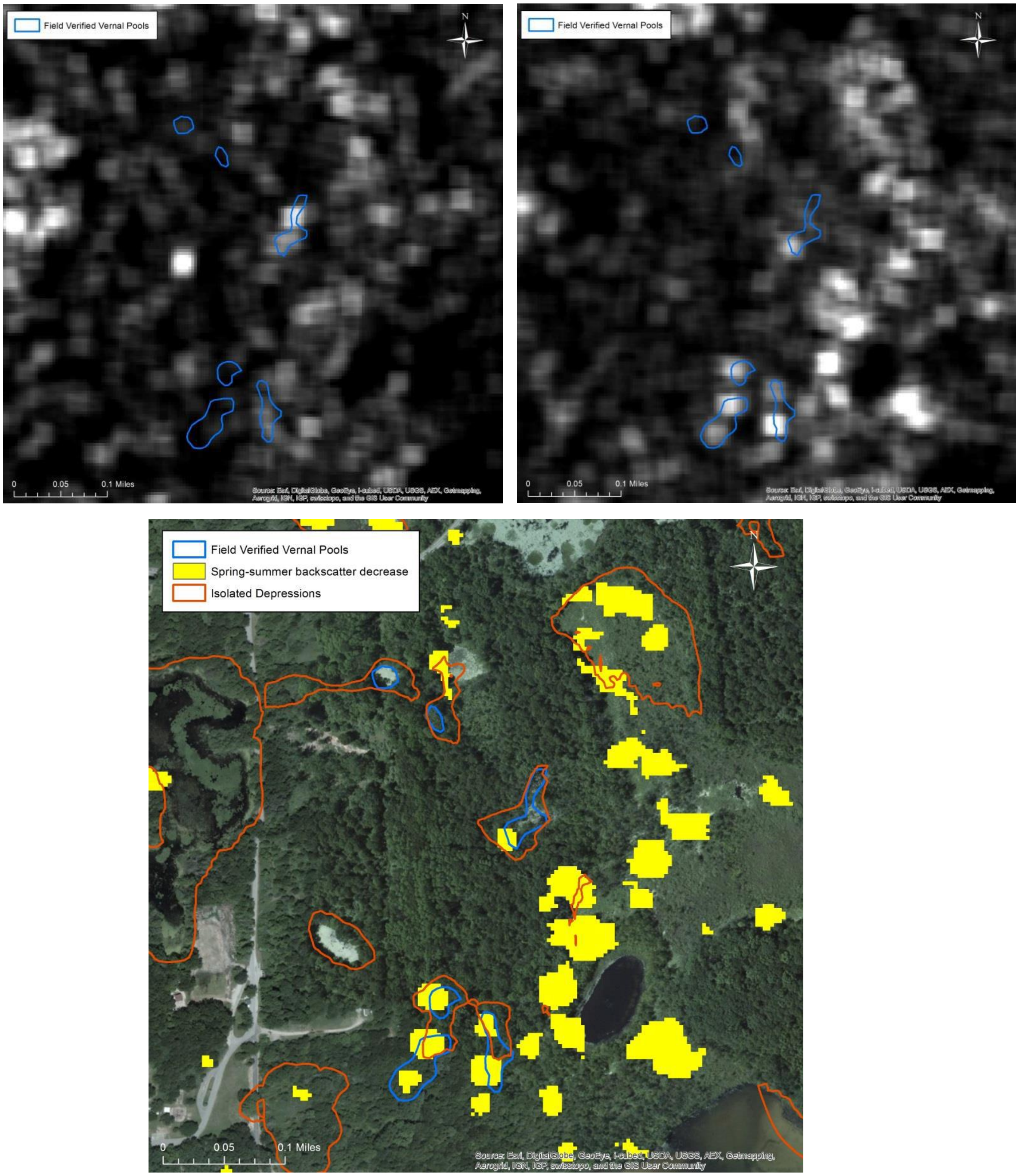


Figure 9. Areas exhibiting high backscatter appear bright in the Radarsat-2 image from April 25 (top left) while appearing darker in the image collected on July 29 (top right). Field verified vernal pools are outlined in blue. The map below the radar images shows the field verified vernal pools overlaid with isolated depressions outlined in orange and areas with significant decreases in detected backscatter between the spring and summer R-2 images in bright yellow.

DISCUSSION

Aerial Photograph Interpretation

We were able to identify and map a large number of potential vernal pools (i.e., 1,332) from aerial photo interpretation across the two study areas within the Baraga and Crystal Falls State Forest Areas in the western Upper Peninsula. We were able to exceed our goal of reviewing and mapping potential vernal pools across at least 15,000 acres of state forest lands by reviewing approximately 115,000 to 120,000 acres of state forest lands within the selected study areas. This was accomplished over approximately a one-week (5-7-day) period. Additionally, this project in conjunction with MNFI's previous project has resulted in almost 1,500 potential vernal pools identified and mapped within the Baraga and Crystal Falls State Forest Areas in the western Upper Peninsula. The 1,332 potential vernal pools that were mapped from aerial photos for this project nearly quadrupled the number of potential vernal pools that had been mapped in the statewide vernal pool database in the western Upper Peninsula, bringing the total number of potential vernal pools mapped from 461 to 1793.

The amount of area that can be reviewed and mapped for potential vernal pools (and ability to accurately identify and map potential vernal pools from aerial imagery) will depend on the amount 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. For this project and MNFI's earlier vernal pool project, statewide 1998 color infrared (CIR) aerial photo imagery was used to map potential vernal pools. Obtaining more recent, high-resolution CIR aerial photos of the state taken in the spring during leaf-off conditions would increase the effectiveness and efficiency of aerial photo interpretation for mapping vernal pools. More recent statewide CIR aerial imagery are available but they were not taken during leaf-off conditions, and could not be used to identify potential vernal pools. However, we were able to find and use more recent, high resolution, leaf-off natural color aerial imagery of the study areas, which proved to be very helpful and even more effective at indicating potential vernal pools than the CIR aerial imagery in some cases. The C-CAP 2006 land cover data layer also was helpful for verifying upland forest and palustrine forest and wetland areas. But despite the availability of leaf-off CIR and high resolution and leaf-off natural color aerial imagery, some vernal pools found in the field could still not be seen on the aerial photo imagery. This may have been due to the small size and/or shallow nature of the vernal pools, and/or timing of the photos and when the vernal pools were wet or dry.

The accuracy rate and commission and omission error rate estimates we obtained for mapping vernal pools from aerial photo interpretation for this project were moderate to low. They were surprisingly very similar with accuracy and error rates obtained during MNFI's earlier vernal pool project and previous vernal pool mapping effort in the western Upper Peninsula. Our overall accuracy rate for correctly identifying vernal pools from aerial photo interpretation for this project was 58% (i.e., based on both verified and potential/likely vernal pools identified in the field, 48% if only including the verified pools). Our commission error rate was 42% and potential or pseudo-omission error was about 25% (Table 11). Our accuracy rate for mapping vernal pools using aerial photo interpretation in the western Upper Peninsula study area for MNFI's previous vernal pools project, which was just to the south of our study area in the Baraga State Forest Area, was 47% for individual vernal pools (for verified and likely vernal pools) and 60% for randomly selected sample test cells, with a commission error rate of 40% and omission error rate of 25% for sampled test cells (Table 11) (Lee et al. 2014).

The accuracy rates for vernal pool mapping in the western Upper Peninsula (UP) for both this project and MNFI's previous vernal pool project are lower than the accuracy rates that were obtained for similar vernal pool mapping efforts in the northeast and southeast Lower Peninsula based on results from MNFI's earlier project (Table 11) (Lee et al. 2014). The study areas in the western UP for this project and MNFI's previous vernal pool project are located in bedrock-controlled physiographic regions, where the bedrock is closer to the surface in many areas. As a result, many of the vernal pools we have encountered in the western UP tend to be very small and shallow. Vernal pools in the western UP may be shallower and smaller than the vernal pools in the northeast and southeast Lower Peninsula, which may make vernal pools in the western UP more difficult to identify from aerial photos. Additionally, many of the vernal pools we have identified in the field in the western UP are predominantly open/sparsely vegetated pools typically with a few trees growing within the basin and trees along the immediate edge of the pool, or forested vernal pools with a number of trees growing in the pool basin or depression. In general, the "open" vernal pools in the western UP generally seem more forested and smaller and shallower than the "classic" open vernal pools found in other parts of the state, particularly in southern Michigan (see Figure 10 below). The more forested nature of the vernal pools in the western UP, in combination with their small size and shallow depth, may make them more difficult to identify from aerial photos in the western UP. More extensive forested cover across the landscape and greater amounts of coniferous vegetation in general in the western UP also likely contributed to lower accuracy and higher error rates for mapping vernal pools in the UP compared to other parts of the state. Additional efforts to identify and map vernal pools using aerial photos should be conducted to further investigate this, and improve our ability to identify vernal pools using aerial photo interpretation in the UP.

Vernal pool mapping accuracy rates for the western UP also are lower, and error rates are higher, than those reported for vernal pool mapping efforts in other states (e.g., in MA - Burne 2001 and NJ – Lathrop et al. 2005) (Table 11). Differences in accuracy and error rates between our study and those of 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. Other factors mentioned earlier regarding the small, shallow, and forested nature of the vernal pools in the western UP also may have contributed to lower vernal pool mapping accuracy rates in the western UP compared to other studies.

Figure 10. Examples of open vernal photos (top left and right) and forested vernal pools (middle left and right) found during this study on state forest lands in the western Upper Peninsula, and examples of open vernal pools (bottom left and right) found in southeast Michigan.

Table 11. 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 that these are general comparisons and not direct comparisons since study designs and methods varied among projects.

State and Study/Authors	Accuracy Rate (True Positives)	Accuracy Rate (True Negatives)	Commission Error (False Positives)	Omission Error (False Negatives)
MI – W. Upper Peninsula (Lee 2014, Current Study)	58%[1]	-	42%[2]	(~25%)[3]
MI – W. Upper Peninsula (Lee et al. 2014 – individual pools/test cells)	47%[1] / 60%[4]	- / 75%[5]	- / 40%[6]	- / 25%[7]
MI – NE Lower Peninsula (Lee et al. 2014 – individual pools/test cells)	84%[1] / 85%[4]	- / 97%[5]	- / 15%[6]	- / 3%[7]
MI – SE Lower Peninsula (Lee et al. 2014 – individual pools/test cells)	77%[1] / 73%[4]	- / 88%[5]	- / 27%[6]	- / 12%[7]
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 and potential/likely vernal pools compared to the total number of potential vernal pools identified from aerial photo interpretation and surveyed in the field.
[2]Commission error (false positives) was calculated based on the individual vernal pools that were verified to not be vernal pools in the field (i.e., other wetland type or dry/no water present) compared to the number of potential vernal pools identified from aerial photo interpretation.
[3]This omission error was estimated based on the number of individual vernal pools and potential/likely vernal pools verified in the field and not mapped during aerial photo interpretation compared to the total number of verified and likely vernal pools identified in the field.
[4]Accuracy rate (true positives) was calculated based on the number of test cells with vernal pools identified 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 with vernal pools not identified in the field compared to the number of test cells surveyed that contained did not contain potential vernal pools identified from aerial photo interpretation.
[6]Commission error (false positives) was calculated based on the number of test cells that did not contain vernal pools/possible vernal pools identified from/during field sampling compared to the number of test cells that contained vernal pools identified from aerial photo interpretation.
[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.

Several factors likely contributed to commission error 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, and likely contributed to commission error. Also, since we mapped potential vernal pools (PVPs) based primarily on color-infrared photos taken in the spring when pools were assumed to be wet, there was no definitive way for determining that mapped PVPs were seasonally, semi-permanently flooded wetlands, or permanently flooded waterbodies or wetlands without field verification. In general, we were conservative, and erred on the side of being inclusive in our mapping of potential vernal pools which likely contributed to higher commission error in our study. Burne (2001) also reported similar sources of 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.

A number of factors likely contributed to our 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 ac (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 ac (200 m^2 / 0.02 ha) in size (assuming a roughly circular shape) can be reliably mapped at 1:5000 scale. Photo interpretation of vernal pools in areas dominated by coniferous vegetation also 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 and vernal pool type may impact the effectiveness of mapping potential vernal pools from aerial photos. Different physiographic regions within the state are characterized by different landforms, soils, hydrology, and vegetation, which can impact vernal pool abundance and distribution on the landscape and impact the ability to see vernal pools in aerial photos and, hence, mapping accuracy and error rates. The two physiographic regions included in this project are quite similar to each other, which may have contributed to only a small difference in vernal pool mapping accuracy between the two study areas and regions. In contrast, one of the study areas for MNFI's previous vernal pool project was located in the northeast Lower Peninsula in a much drier physiographic region and landscape than the western UP. Vernal pools may have been easier to detect in aerial photos in that type of physiographic region, which could have contributed to much higher vernal pool mapping accuracy rates for that study area (Table 10).

Open and forested vernal pools comprised higher percentages of the potential vernal pools that were surveyed and verified as vernal pools in the field compared to the percentages of marsh and shrubby pools. While it may be easier to detect open pools from aerial photos, the higher percentage of open and forested vernal pools is more likely because these types of vernal pools are more common than the marsh and shrubby pools, particularly in the western UP. MNFI's previous vernal pool project and other studies also have reported open and forested vernal pools being more common than marsh and/or shrubby pools (Colburn 2004, Lee et al. 2014). However, it may be challenging to identify and distinguish marsh and shrubby vernal pools from permanently flooded emergent and shrubby wetlands from aerial photos. Additional investigation into the abundance and distribution of different vernal pool types in the western UP and across the state and how vernal pool type and distribution might impact vernal pool mapping is warranted.

Radar

Although the spring and summer C-Band SAR data were able to detect seasonal differences in flooding and vernal pools in the Pinckney Recreation Area in southeast Michigan, it was not able to detect sufficient variability to detect vernal pools in the western UP study area. At the time of the western UP spring image collection, there was standing water in the vernal pools, but the leaves had fully flushed, which may be limiting the ability of the SAR beam to reach the ground. The pools in western UP were also much smaller than in Pinckney. This then leads to questions about the dry (summer) SAR collections, and if leaves limit the penetration capability, then the methodology of differencing of spring and summer data would be of question. Leaf flush had just begun when the Pinckney spring image was collected, which may explain why it was possible to detect vernal pools there but not in the other study areas. Because of its shorter wavelength, C-band SAR is not able to penetrate canopy cover as well as L-band. Further investigation into the forest structural differences between these vernal pool locations is needed before conclusions may be drawn, but early spring collections before leaf-flush appear to be ideal for detection of inundation and critical for detecting vernal pools in a forested landscape.

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 over 100 vernal pools on state forest lands in the western UP. Field validation is especially warranted given the moderate to low accuracy and error rates for mapping vernal pools from aerial photos in the western UP that were estimated for this project and MNFI's previous vernal pool project. For example, with a 25% omission error rate for the study areas in the western UP, this means that field surveys could reveal as many as 25% more pools on the landscape than identified from aerial photographs alone.

Field sampling for this project reconfirmed the importance of the timing of field surveys for verifying vernal pools, identifying vernal pool type, and documenting the presence of vernal pool indicator species. Field survey results from this year also further suggest that multiple survey visits within a year and/or across multiple years are important and, in some cases, necessary. Vernal pool hydrology can be very difficult to predict, and can vary within a year and from one year to the next. For example, many of the vernal pools we surveyed during the early season in early July were dry or almost dry. We had expected most of the pools to still contain water in early July given the amount of snowfall in late winter and early spring and the late spring we had in 2014. Also, vernal pools were still wet in early July during MNFI's previous vernal pool project. In fact, several of the vernal pools that we surveyed in July 2013 that were full or partially full were dry or mostly dry when we visited them in July 2014. We had planned to survey for vernal pool indicator species such as Blue-spotted Salamander and Spotted Salamander larvae during the early season surveys, but were unable to survey for them in many of the pools because they were dry. Interestingly, a number of the pools that were dry in July had some water in them during the late season survey in early October.

The atypical pattern in water levels and lack of water in many of the pools made it challenging to verify, classify, and/or map the extent of some of the vernal pools in the field. We were not able to document standing water in some of the pools because they were dry during both the early season and late season surveys. We used other indicators or evidence of regular flooding and water storage to verify vernal pools in some cases. During the late season surveys in 2014, we were not able to document drying in some of the vernal pools or potential vernal pools. This made it difficult to verify whether some of the potential vernal pools were vernal pools that typically would dry annually, semi-permanent vernal pools, or permanent wetlands.

Classifying vernal pools based on vegetation also can be challenging in some cases. Some vernal pool types can look very different depending on their landscape setting or time of year. For example, as mentioned earlier, open pools in the western UP can look different from the typical "classic" open pools in the southern Lower Peninsula (Figure 10). Vernal pools also can look different depending on time of year. For example, some marsh pools can look like open or sparsely vegetated pools in the early spring and/or fall and have very dense vegetation during the summer when the pool is dry (Colburn 2014). As a result, timing of surveys is important, and multiple visits during different times of the year are ideal for classifying vernal pools.

Vernal pool indicator species were documented in only a small number of pools that were surveyed (i.e., 8 (6%) of the 134 pools). This was somewhat surprising since Wood Frogs and Blue-spotted and/or Spotted salamander larvae were found in almost all the pools surveyed in the western UP in July 2013 during MNFI's previous vernal pool project (Lee et al. 2014). This may have been due to drier conditions in July 2014 compared to 2013. Additionally, because the focus of this project was on mapping vernal pools, we attempted to visit as many potential vernal pools as we could during our field surveys, and did not conduct systematic or intensive surveys for vernal pool indicator species. As a result, we may have missed documenting them in some of the pools. Interestingly, vernal pool indicator species also were documented in only a small percentage of the pools that were surveyed in the southeast and northeast Lower Peninsula during MNFI's previous vernal pool project (Lee et al. 2014). Similarly, vernal pool indicator species were found in only 22% of vernal pools surveyed in New Jersey (Lathrop et al. 2005). Vernal pool-dependent amphibians and fairy shrimp also are not found in a given vernal pool every year (Colburn 2004). Additional research to assess and determine the status and distribution of vernal pool indicator species and factors that contribute to their occurrence and abundance is warranted to help inform vernal pool management and protection.

Management Considerations

Information on the status and locations of potential and field verified vernal pools compiled as a result of this project will help state forest managers plan and implement forest management activities in or around vernal pools within the Baraga and Crystal Falls State Forest study areas. Given the accuracy that have been obtained for mapping vernal pools from aerial photo interpretation in the western UP, we recommend potential vernal pools be surveyed prior to or as part of forest planning activities to verify if these are actual vernal pools on the ground. The vernal pool survey protocol and field form (Appendix 2) that were used for this project could be utilized to verify vernal pools in the field. Vernal pool locations and data that have been documented as part of this and other projects in the future have been or will be compiled in the statewide vernal pool database, which is currently housed and managed by MNFI. This information could be integrated into the state forest inventory database. 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. Data on the presence of indicator species also can be used to help plan and adjust vernal pool management and protection.

Vernal pools are not evenly distributed across Michigan (Thomas et al. 2010), and they are not located everywhere in the state. Results from this project and MNFI's previous vernal pool project seem to support these assertions. 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 southeast and northeast 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. Results from a small isolated wetland hotspot analysis that was conducted for MNFI's previous vernal pool project also seem to suggest vernal pools may be more common in some parts of the state than others.

Not only do vernal pools only occur in certain places, they are typically very small, and as a result, they generally comprise such a small total area and percentage of forested landscapes. We had estimated based on other studies and analysis of small isolated wetlands in the state that vernal pools are typically less than 0.5 ac or smaller in the state. The results from this project certainly supported this, with verified vernal pools ranging in size from less than 0.001 ac to about 4 ac (<0.0001 ha - 2 ha), and mean vernal pool area ranging from 0.11 ac (0.04 ha) in the Crystal Falls study area to 0.35 ac (0.14 ha) in the Baraga study area. Additionally, the 78 vernal pools that were verified in the Crystal Falls study area comprised a total of only 8.5 ac (3.5 ha), and the 34 verified vernal pools in the Baraga study area comprised a total of only 12 ac (4.8 ha), for a grand total of about 21 ac (~8 ha) for all 112 verified vernal pools. We may have underestimated the size or area of vernal pools for this project since we did not map all verified vernal pools in the field, and since many of the pools were dry during the surveys which made it challenging to accurately determine and map the extent of the pools. However, even if we doubled the area, this would result in only about 40 ac (~16 ha) for over 100 vernal pools. Even for the nearly 1,500 total potential vernal pools that had been mapped, the total acreage was about 256 acres (~104 ha), which represented approximately 0.2% of the study area (based on an estimate of about 115,000 -120,000 acres of the study area reviewed for potential vernal pools).

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 that have adapted to their unique conditions. 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 (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 amphibians that occur in and around vernal pools. Additional information on forest management best practices or guidelines for vernal pools is provided in Colburn (204) and Calhoun and deMaynadier (2008).

Vernal pools are highly variable (Colburn 2004). Each 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 (Thomas et al. 2010). Because all these factors tend to vary across the landscape, each vernal pool is unique (Thomas et al. 2010). Large vernal pools with longer hydroperiods tend to have greater within-pool species diversity than small pools with shorter hydroperiods, but some small pools have high invertebrate species diversity, and different species likely occur in different pools across a landscape (Colburn 2004). Protecting a diversity of large and small vernal pools in an area, and particularly areas with clusters of vernal pools, would likely maximize protection of biodiversity within these pools (Colburn 2004).

It is important to keep in mind that Wood Frogs, Blue-spotted Salamanders, Spotted Salamanders, and other amphibians that breed in vernal pools spend most of the year in the surrounding forests, and some species migrate quite a distance from their breeding pools (Colburn 2004). As a result, managing a larger buffer of upland habitat (e.g., up to 400 ft/ 122 m) for vernal pool-breeding amphibians has been proposed in some forest management guidelines (Calhoun and deMaynadier 2008). Michigan's Sustainable Soil and Water Quality Practices on Forest Land recommend no disturbance to the pool depression and a managed buffer of 100 feet around the pool (MDNR and MDEQ 2009). Given how small vernal pools are and how they may be distributed across the landscape, how would managing a larger buffer around vernal pools impact forest management activities in an area?

While mapping potential vernal pools using aerial photo interpretation can be time consuming and has been only moderately accurate in the western UP, aerial photo interpretation is currently still the most effective method we have for identifying and mapping vernal pools remotely. The use of radar to identify and map potential vernal pools appears promising, at least in southeast Michigan, but additional work is still needed to demonstrate the effectiveness of this method for mapping vernal pools in other parts of the state. We are interested in working with MTRI 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.). However, this method requires appropriate spring and summer radar data, which are still limited at this time. Aerial imagery needed to map potential vernal pools is already available for the entire state. 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). This project added a significant number of potential vernal pools identified and mapped from aerial photos in the statewide vernal pool database in the western UP. While not all of these represent actual vernal pools on the ground, having this information has allowed us to conduct targeted field surveys in the western UP which have resulted in identifying a total of 173 active vernal pools on the ground to date, of which 112 were documented during this study. Accuracy rates for mapping vernal pools from aerial imagery also may increase over time as higher resolution and more recent imagery become available, and as photo interpreters become more experienced at identifying and mapping vernal pools from aerial imagery. Combining aerial photo interpretation with another method (e.g., radar and/or GIS modelling) could help make it more efficient for mapping potential vernal pools across the state. The use of new technology such as drones or UAVs (unmanned aerial vehicles) to map potential vernal pools in the field also should be investigated.

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APPENDICES

Appendix 1. Informational handout on vernal pool types, their definitions, and photos of examples.

<u>VERNAL POOL TYPES</u>:

1) **Open Pool –** "Classic" vernal pool, rooted/live trees, shrubs and/or non-woody herbaceous or persistent emergent plants covering <10% of the ground within pool basin

2) **Sparsely Vegetated Pool –** Rooted/live trees, shrubs, and/or non-woody herbaceous or persistent emergent plants covering 10% to < 30% of the ground within pool basin

3) **Shrubby Pool –** Pool dominated by shrubs – Vegetation covers $\geq$ 30% of the ground with shrubs comprising $\geq$ 30% of the uppermost vegetation layer within pool basin.

4) **Forested Pool –** Pool dominated by trees - Vegetation covers ≥ 30% of the ground with rooted/live trees comprising ≥ 30% of the uppermost vegetation layer in pool basin. For example, forested swamp pool, pool within larger forested swamp, floodplain pool.

5) **Marsh Pool –** Pool dominated by non-woody herbaceous or persistent emergent plants – Non-woody herbaceous and/or persistent emergent plants comprise 30 – 50% of the uppermost vegetation layer in pool basin. Trees and shrubs may be present but < 30% cover.

Appendix 2. Vernal Pool Survey and Monitoring Data Form.

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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%

Tree canopy over pool basin (when leaves are fully out): ☐ 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

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) ☐ $\leq$ 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 3. MNFI Abstract on Vernal Pools.

Vernal Pool

Michael A. Kost

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

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).

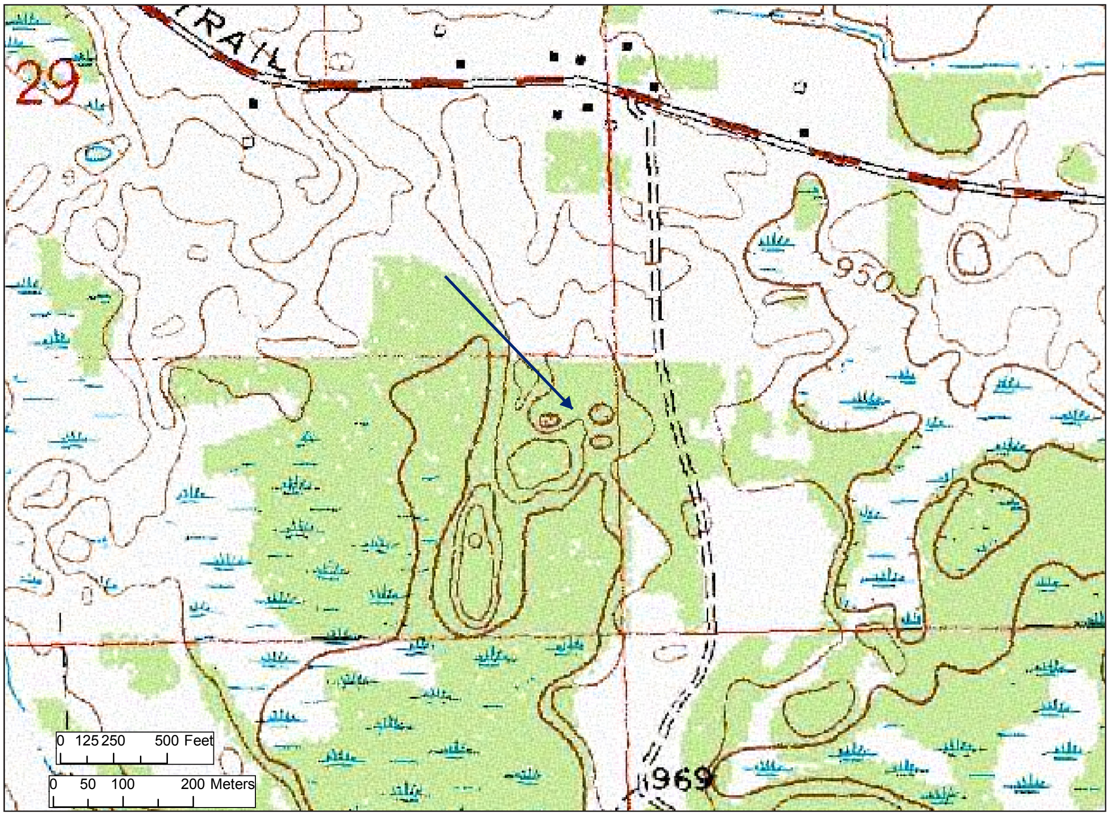
To distinguish vernal pools from briefly puddled upland depressions, true ponds, flowing waterbodies, and a variety of open wetland types, their definition can be further narrowed to sites that meet the following criteria:

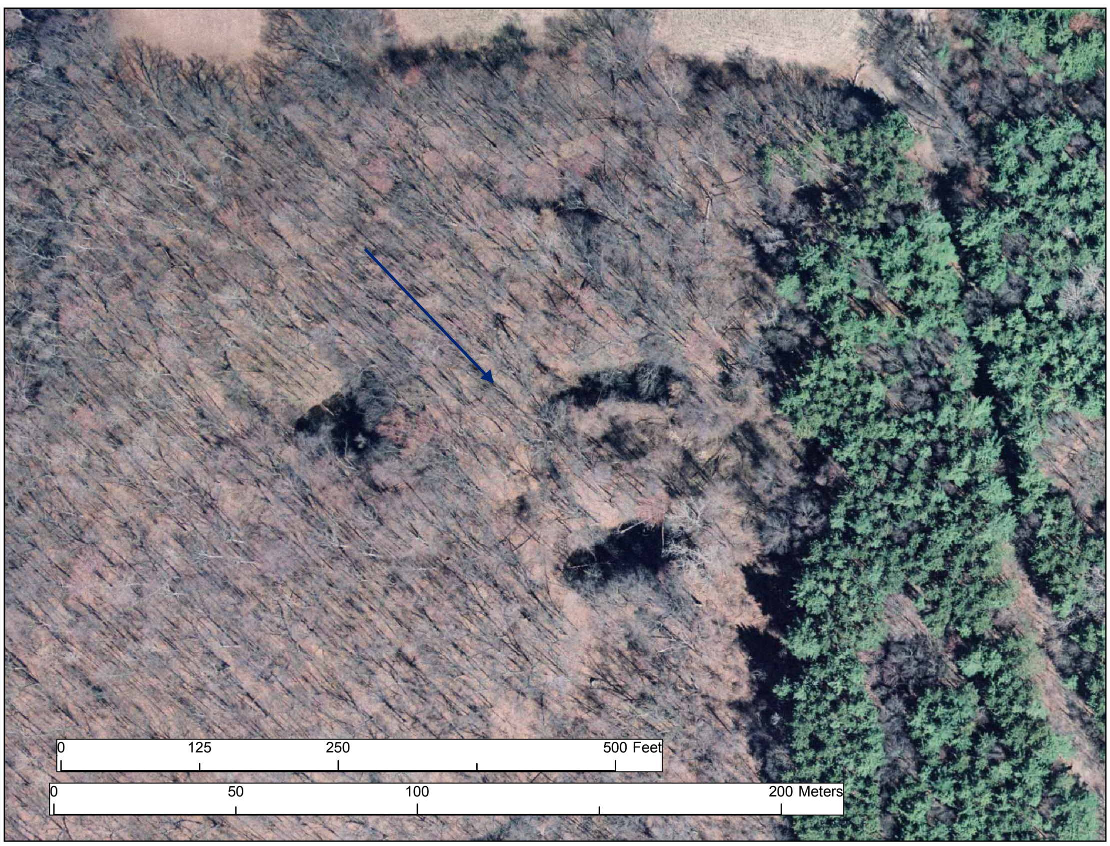
- flooded long enough and frequently enough, *and* dried out long enough and frequently enough to harbor flora and/or fauna that have specialized adaptations or life cycles for coping with both inundation and water drawdown. Notably, permanent fish populations do not occur in vernal pools because they 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

Steve A. Thomas

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.

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

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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).

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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