Developing an Approach for Identifying, Mapping, and Assessing Vernal Pools in Michigan

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P. O. Box 30458
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Project #10-WL-002

April 2014

Report Number 2014-07

Michigan Natural Features Inventory (MNFI) is a program of Michigan State University Extension in partnership with the Michigan Department of Natural Resources. Michigan Natural Features Inventory is Michigan's natural heritage program, and a member program of NatureServe and the Natural Heritage Network.

The project was supported in part by financial assistance provided by the U.S. Environmental Protection Agency (U.S. EPA) Region 5 through the Michigan Wetlands Protection Program in the Wetlands, Inland Lakes and Streams Unit of the Water Resources Division within the Michigan Department of Environmental Quality (MDEQ). The statements, findings, conclusions, and recommendations provided in this report are those of the Michigan Natural Features Inventory and Michigan State University (MSU) and do not necessarily reflect the views of the DEQ and the U.S. EPA.

Suggested Report Citation:

Lee, Y., P. J. Badra, M. Battaglia, L. L. Bourgeau-Chavez, H. D. Enander, D. A. Hyde, B. J. Klatt, Z. Laubach, M. J. Monfils, M. R. Penskar, K. Scarbrough, and E. H. Schools. 2014. Developing an approach for identifying, mapping, and assessing vernal pools in Michigan. Michigan Natural Features Inventory Report No. 2014-07, Lansing, MI.

[1]Note: Authors noted on cover are affiliated with Michigan Technological Research Institute and not Michigan Natural Features Inventory.

Cover Photographs:

Upper left photo – Spotted Salamander (*Ambystoma maculatum*), Houghton County, MI. Photo by Yu Man Lee, Michigan Natural Features Inventory (MNFI).
Center photo - Vernal pool, Houghton County, MI. Photo by Yu Man Lee, MNFI.
Lower right photo – Fairy shrimp (*Eubranchipus intricatus*). Photo by Vernal Pools Association, http://www.vernalpool.org/bsw/bugs/slides/E_intricatus.htm.

GENERAL INTRODUCTION

Vernal pools (also referred to as ephemeral or seasonal pools) are small, shallow, depressional wetlands that usually contain water for only part of the year. These temporarily-flooded wetlands typically fill with water between late fall and spring from rising groundwater, snowmelt, and/or rainfall. The length of time that surface water is present in these pools varies, but most dry up by late summer or early fall (although some pools do not dry up every year or during particularly wet years). Because they lack permanent water and dry up periodically, vernal pools do not support breeding fish populations.

Despite their small size and temporary nature, vernal pools can be incredibly diverse and productive ecosystems. Vernal pools provide important habitat for many wildlife species. These include invertebrates, frogs, toads, salamanders, snakes, turtles, waterfowl, wetland birds, songbirds, and mammals (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 (Calhoun et al. 2003, Calhoun and deMaynadier 2004). Over 550 animal species have been documented in vernal pools in northeastern America (Colburn 2004). Many animal species use vernal pools as sources of food and water throughout the growing season, as breeding and resting areas, and as stepping stones to disperse to other areas with suitable habitat to complete their life cycle. Vernal pools contribute a tremendous amount of amphibian and invertebrate biomass and, hence, food to other wildlife species in the surrounding ecosystems (Calhoun and deMaynadier 2004). Several rare species in Michigan use vernal pools extensively including the Small-mouthed Salamander (*Ambystoma texanum*, state endangered), Copper-bellied Watersnake (*Nerodia erythrogaster neglecta*, federally threatened and state endangered), Spotted Turtle (*Clemmys guttata*, state threatened) and Blanding's Turtle (*Emydoidea blandingii*, state special concern). As wetlands, vernal pools also contribute and provide other important ecosystem services including nutrient cycling, water storage and infiltration, groundwater recharge, and flood control.

Vernal pools are highly vulnerable to disturbance or destruction, and are being lost across the Midwest and other parts of the country, including Michigan. Because of their small size and seasonal nature, vernal pools can be difficult to identify on the landscape, especially when they are dry, and are often overlooked. Vernal pools receive little or no protection under federal and state wetland regulations because they are small and often isolated from larger and/or permanent waterbodies and wetlands. Many of these small temporary wetlands have been drained or filled due to agricultural, residential, and/or other development. Some pools have been excavated to construct stormwater detention ponds or converted to permanent ponds. Vernal pools also have been impacted by forest management activities. Additionally, these small ecosystems may be impacted by climate change since changes in the hydrologic cycle can cause dramatic shifts in the timing and duration of flooding and number of vernal pools. The loss and fragmentation of vernal pools and wetland complexes can be detrimental to the biodiversity of a region (Gibbs 1993).

Due to recent increased awareness of the importance of vernal pools, there has been growing interest in identifying, studying, and conserving these small but valuable ecosystems in Michigan and other states. Michigan's Wildlife Action Plan has identified ephemeral wetlands as a critical and imperiled habitat in the state (Eagle et al. 2005). 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 (FSC®) forest certification standards also have included protection for vernal pools on forest lands (Michigan Department of Natural Resources and Michigan Department of Environmental Quality 2009, Sustainable Forestry Initiative 2010, Forest Stewardship Council 2010). However, little information is currently available on the status, distribution, and ecology of vernal pools in Michigan.

This project represents the first targeted effort focused on identifying, mapping, assessing, and classifying vernal pools across multiple ecoregions in Michigan. Previous and current research on vernal pools in Michigan have focused on assessing or researching specific questions related to plant or animal species, communities and/or habitat conditions in vernal pools on a local or regional basis, primarily in the southeastern Lower Peninsula and western Upper Peninsula (e.g., Kenk 1949, Wiggins et al. 1980, White Water Associates Inc. 1994 and 1998, Skelly et al. 1999, Higgins and Merritt 2001, Francl 2005, Werner et al. 2007a, Werner et al. 2007b, McCauley et al. 2008, Werner et al. 2009, Hoverman et al. 2011, Greenwald Research Lab pers. comm., Previant pers. comm.). Additionally, some vernal pools in the state have been located and/or mapped again locally or regionally, but this information has not been compiled and/or is not readily available or accessible for assessing the status and distribution of vernal pools statewide. Vernal pools also may have been defined differently among various individuals or entities mapping or researching vernal pools. Information on the status, distribution, and ecology of vernal pools across the state is critical for developing and implementing appropriate conservation efforts for these wetlands.

The goal of this project was to develop an effective and efficient approach for identifying, mapping, and assessing vernal pools and to obtain additional information to enhance our knowledge of vernal pools in Michigan. The purpose of this project also was to develop a framework and foundation for a statewide vernal pools mapping and monitoring program to assess the status, distribution, and ecological values of vernal pools in the future. This project will help Michigan's Wetlands Protection Program build upon and further develop its ability to identify, assess, manage, and protect these wetlands. This project also addresses national priorities developed by the U.S. Environmental Protection Agency's Wetland Program Development Grants. These include the following two national priority areas: 1) Regulation National Priority Area (Enhancing Wetland Protection); and 2) Monitoring and Assessment National Priority Area. This project addresses the Regulation National Priority Area and specifically refining the protection of vulnerable wetlands and aquatic resources, such as geographically isolated wetlands, by developing a methodology and initiating efforts to inventory and evaluate geographically isolated wetlands which would include vernal pools. This project addresses the Monitoring and Assessment National Priority Area and particularly wetland mapping and the need to fill gaps in wetland mapping and data collection. This project will develop an approach and initiate efforts to identify and map vernal pools in Michigan which have not been systematically identified or mapped statewide. This project also will investigate several different methodologies for detecting and map forested vernal pools, and if these approaches are effective, they can help facilitate vernal pool mapping efforts in Michigan and other states. This project also addresses wetland monitoring surveys under the Monitoring and Assessment National Priority Area by conducting surveys to document the status, distribution, and significance of vulnerable wetlands, such as vernal pools, and providing baseline data for monitoring.

To assist with meeting the project goals, this project will address the following objectives and tasks:

- Develop and convene a vernal pools work group to identify vernal pool conservation and management issues/needs in Michigan and help guide development and implementation of this project and efforts to address these needs.
- Consult, compile and synthesize information from states that have developed and implemented vernal pool programs to learn from their experiences and help guide efforts in Michigan.
- Develop a common definition and methodology for identifying vernal pools that will be used for vernal pool identification, mapping, and assessment efforts in Michigan.
- Develop a statewide Geographic Information Systems (GIS) model and data layer to identify and map areas with potential likelihood of occurrence of vernal pools. Create a data layer and database to summarize, track, and monitor the locations of verified vernal pools and physical and biological characteristics identified in the field.
- Conduct a small pilot study to investigate the use of radar for identifying vernal pools in forested areas.
- Conduct air photo interpretation and field visits to verify actual vernal pool occurrences that have been identified by the GIS model and/or use of radar, and collect *in situ* physical and biological data at verified vernal pools in 3-5 pilot areas.
- Develop a pilot volunteer monitoring program for vernal pools.
- Evaluate and compare the effectiveness and efficiency of the GIS model, radar data, air photo interpretation, and field surveys for locating and mapping vernal pools.
- Develop an initial framework or classification scheme and criteria for classifying vernal pools and assessing or ranking their ecological condition or quality based on GIS and field data.
- Develop design and management recommendations for vernal pools and amphibians and reptiles.
- Summarize project activities, results, and major findings in project reports, and disseminate project findings, and products to government agencies and other partners and stakeholders. Update MNFI vernal pools abstract with information from project.

This project was modeled after other states' vernal pool programs but was tailored to Michigan and involved collaboration and coordination among public and private agencies and other partners and stakeholders. The Michigan Natural Features Inventory (MNFI), a program of Michigan State University Extension (MSUE), assisted the Michigan Department of Environmental Quality's (MDEQ) Water Resources Division (WRD) in coordinating and implementing this project. The Michigan Natural Features Inventory was primarily responsible for convening and leading the vernal pools work group, developing methodologies, conducting air photo interpretation and GIS modelling to identify potential vernal pools, conducting field sampling, collecting and analyzing data, overseeing and/or working with contractors and partners, and producing progress and final reports for the project. Additional partners provided assistance on the project. Michigan Tech Research Institute (MTRI), a research center of Michigan Technological University, conducted the pilot radar study. Herpetological Resource and Management (HRM) developed a best management practices manual with design and management recommendations for amphibians and reptiles and vernal pools. The Wildlife, Forest Resources, and Parks and Recreation Divisions of the Michigan Department of Natural Resources (MDNR), The Nature Conservancy, and Michigan Nature Association provided assistance with the vernal pools work group and the pilot volunteer vernal pool monitoring program.

This final report summarizes project activities, results, and findings from the vernal pools project from 2011 - 2014. Each major project component and associated activities and results are summarized in individual chapters. Chapter 1 summarizes activities and accomplishments associated with the Vernal Pools Work Group. Chapter 2 summarizes our efforts to compile information about vernal pool program in other states and what we were able to learn from these other programs. Chapter 3 summarizes our efforts to develop a common vernal pool definition and methodology for identifying vernal pools in Michigan. Chapter 4 summarizes our efforts to identify and map potential vernal pools using aerial photograph interpretation, and to evaluate the effectiveness of this method. Chapter 5 summarizes the activities and results of the pilot study conducted by Michigan Technological Research Institute to investigate the use of radar to map potential vernal pools. Chapter 6 summarizes our efforts to investigate the use of GIS modelling to identify areas with potential likelihood for the presence of vernal pools. Chapter 7 provides an evaluation and comparison of the effectiveness of aerial photograph interpretation, radar, and an isolated wetland analysis conducted by MDEQ for mapping potential vernal pools. Chapter 8 provides a summary of our efforts to develop a pilot volunteer vernal pool mapping and monitoring program. Chapter 9 provides a brief summary of the statewide vernal pools database that we developed as part of this project. Chapter 10 provides a summary of the initial framework and criteria developed for classifying and assessing vernal pools and *in situ* physical and biological data collected in the field. A summary of findings or conclusions and recommendations are provided at the end of the report. Supporting project materials and other project deliverables, including the statewide vernal pools database and spatial data layers or shapefiles from the GIS modelling and radar, are provided in the appendices section of this report or on an attached CD. The statewide vernal pools database is provided on a CD/DVD, and will be made available as an online feature service through Michigan State University. An amphibian and reptile best management practices manual also was developed as part of this project. This document will be submitted separately.

CHAPTER 1: Developing and convening a vernal pools work group in Michigan.

INTRODUCTION

A Vernal Pools Work Group (VPWG) was developed and convened as part of this project. The purpose of this work group was to serve as an advisory group to help identify vernal pool conservation and management issues and needs in Michigan, and guide development and implementation of this project and efforts to address these needs. The Vernal Pools Work Group was asked to address the following issues and tasks at least initially for this project:

1) identify vernal pool conservation and management needs and efforts in Michigan;
2) review vernal pool programs or efforts in other states;
3) help develop a common definition and methodology for identifying and assessing vernal pools in the state;
4) help guide and evaluate project efforts, results, and accomplishments;
5) assist with dissemination of information and results from the project; and
6) help promote and/or facilitate collaboration among vernal pool efforts in the state.

METHODS

The Vernal Pools Work Group was envisioned to include staff from the agencies and organizations directly involved in this project as well as representatives from other public and private agencies and organizations who are currently involved in or who are interested and have potential to become engaged in vernal pool conservation and management in Michigan. The Michigan Natural Features Inventory (MNFI) worked with the MDEQ's Wetlands Program staff in the fall of 2011 to identify representatives from various agencies and organizations to invite to participate in the VPWG. These included representatives from the Michigan Department of Natural Resources' Wildlife Division, Forest Resources Division, Fisheries Division, and Parks and Recreation Division as well as the Michigan Chapter of The Nature Conservancy and the International Joint Commission. A letter and brief summary of the vernal pools project and VPWG were sent to these individuals in November 2011 inviting them to participate in the VPWG. In addition, a representative from the Michigan Nature Association was invited to participate in the VPWG in early 2013. Several additional groups were identified to potentially invite to participate in the VPWG, but we wanted to start off by keeping the size of the VPWG fairly small and manageable for discussions.

MNFI was responsible for organizing and leading the VPWG meetings. The meetings were generally held in the fall, winter, or early spring prior to and after the field season. The meetings generally consisted of MNFI staff providing updates on project design, activities, and preliminary results, and facilitating questions and discussions with the VPWG regarding specific aspects of the project or vernal pools ecology, management and conservation. Meetings were held at the MNFI and MDEQ/MDNR offices in downtown Lansing except for one meeting which was held at the Michigan Environmental Council's office in downtown Lansing. The Vernal Pools Work Group members were able to participate in the meetings remotely if they could not attend in person. Meeting notes and copies of the presentations and other materials were made available to VPWG members after the meetings through e-mail and an internal website set up for the VPWG.

RESULTS

The Vernal Pools Work Group was comprised of representatives from the MNFI project team, MDEQ Wetlands Program, Michigan Tech Research Institute (MTRI), Herpetological Resource and Management (HRM), MDNR Wildlife Division and Forest Resources Division, Michigan Chapter of The Nature Conservancy (TNC), and Michigan Nature Association (MNA) (Appendix 1). Overall, the Vernal Pools Work Group was comprised of 12 core or main members who regularly participated in the meetings from 2011-2014, with an additional 12 members who occasionally participated in the VPWG meetings dependent upon particular topics discussed at the meetings (Appendix 1). Additionally, representatives from the MDNR Fisheries Division and the International Joint Commission initially expressed interest in participating in the VPWG, and participated in the first two meetings of the work group but were not able to participate in subsequent meetings. Representatives from the MDNR Parks and Recreation Division were not able to participate in the VPWG but expressed interest in vernal pools and in getting project updates and being involved in specific discussions that needed input.

The Vernal Pools Work Group had a total of eight meetings from December 2011 to March 2014. The group met on the following dates: 1 December 2011, 17 January 2012, 1 March 2012, 9 April 2012, 8 February 2013, 14 March 2013, 26 February 2014, and 26 March 2014. Participation in the meetings ranged from 9 to 21 members, and included representation from various agencies and organizations, particularly the main partners on the project (i.e., MDEQ, MNFI, MTRI, and HRM). Three additional meetings were held and attended by a subset of the VPWG to address specific issues or components of the project (i.e., mapping of potential vernal pools by the MDEQ using NWI and hydrogeomorphology, study design for field sampling and GIS modelling, and pilot radar study). Vernal Pools Work Group meetings in 2011 and 2012 focused on reviewing and discussing background information on vernal pools and other aspects or components of this project, what other states have done, and study design, approach and methods for the project. Meetings in 2013 and 2014 focused on providing project updates, reviewing and discussing project accomplishments and results related to various components of the project, providing comments and insights to help resolve issues or challenges that arose during the project, and determining if and how vernal pools mapping, monitoring, and conservation efforts could continue in Michigan in the future. Topics that were specifically reviewed and discussed at the Vernal Pools Work Group meetings included the following: 1) what vernal pools are and why they are important; 2) what other states have done to document, assess, and/or protect vernal pools; 3) vernal pool conservation and management issues or needs in Michigan; 4) overview of the vernal pools project; 5) developing a common definition of vernal pools for this project and future vernal pool conservation and management efforts in the state; 6) developing a statewide GIS model and data layer/database of potential and verified vernal pools in the state; 7) investigating the use of radar to identify potential vernal pools in forested areas by conducting a pilot radar study; 8) developing the vernal pools project study design and field sampling approach, including identifying pilot study areas; 9) identifying potential vernal pools in the using air photo interpretation; 10) developing and implementing a volunteer vernal pool mapping and assessment pilot in Michigan; 11) developing an approach for assessing and classifying vernal pools including sampling design and field variables; 12) amphibian and reptile best management practices manual for Michigan; and 13) and plans or ideas for continuing vernal pools work beyond this project.

The Vernal Pools Work Group identified and discussed vernal pool conservation and management needs and efforts in Michigan. In general, vernal pools are currently not very well mapped, tracked, or understood in Michigan. Vernal pools are currently not specifically mapped or tracked in Michigan's Natural Heritage Database, but some may be captured in other forested wetland or palustrine wetland types (e.g., inundated shrub swamp). However, inundated shrub or buttonbush swamps are so common that they are typically not mapped or tracked in the Natural Heritage Database. Vernal pools or vernal ponds are specifically identified and mapped in the MDNR's Integrated Forest Monitoring, Assessment and Prescription (IFMAP) inventory system as an opportunistic field inventory item (OFS), but mapping of vernal pools is optional and may depend on the particular individual doing the stand mapping and delineation. It also may depend on the time of year when the mapping is done (e.g., may miss vernal pools if mapping was done in the summer when pools were dry) and how vernal pools are defined (e.g., only vernal pools in upland forests). Vernal pools also could be captured in or under other forested wetland or non-forested wetland types in IFMAP though (e.g., inundated shrub swamp). Other information sources also could be used to help provide information on locations of vernal pools in the state. For example, information on locations or occurrences of certain amphibian species associated with vernal pools documented in Michigan's Herp Atlas and/or the Natural Heritage Database could be used to provide information on locations of vernal pools or potential vernal pools. The Michigan Natural Features Inventory conducted an earlier project to identify and survey critical non-contiguous wetlands in the state. Results from this project may have some information on distribution or locations of vernal pools, but the project focused mainly on larger wetlands (i.e., >5 acres), and wetlands may not have been individually spatially mapped. The MDEQ also has done some mapping of critical non-contiguous wetlands.

In addition to information on the locations of vernal pools, we need baseline information to better understand vernal pool ecology and distribution in various regions of the state. Some research has been conducted on vernal pools in Michigan, but only in certain targeted study areas and on very specific topics (e.g., amphibian and invertebrate community dynamics and unisexual hybrid salamanders in vernal pools on the E.S. George Reserve in southeast Michigan, bat use of vernal pools, plant and animal species in a small number of vernal pools on commercial forest land in the western Upper Peninsula, bat use of vernal pools in the Ottawa National Forest in the western U.P., and vernal pool distribution and forest ecology in the Pictured Rocks National Lakeshore in central U.P.) (White Water Associates Inc. 1994 and 1998, Skelly et al. 1999, Higgins and Merritt 2001, Francl 2005, Werner et al. 2007a, Werner et al. 2007b, McCauley et al. 2008, Werner et al. 2009, Hoverman et al. 2011, Greenwald Research Lab pers. comm., Previant pers. comm.). For developing a vernal pool classification system, we need to survey and study vernal pools in undisturbed areas such as the Upper Peninsula, but it also was brought up that we also need information on vernal pools in areas where they are most threatened and most in need of protection (e.g., southeast Michigan).

The Vernal Pools Work Group also discussed vernal pools protection in Michigan. There are currently no state legal requirements for protecting vernal pools specifically in Michigan, but there are mechanisms for protecting vernal pools in the state under current state wetland regulations, state management guidelines, and local ordinances. State wetland regulations currently apply to wetlands within 500 feet of a lake or stream, 1,000 feet of a Great Lake, or greater than 5 acres in size. Wetlands that are connected or adjacent to streams and lakes (i.e., within 500 ft) are regulated, but those considered isolated are protected or managed on a case-by-case basis (Lounds pers. comm.). As a result, vernal pools within 500 feet of a lake or stream can get special consideration or can be protected under state wetland regulations. Critical non-contiguous wetlands can get some regulatory protection based on the following four criteria: 1) if it is a rare and imperiled wetland community; 2) if a rare species is present; 3) if it is in a groundwater recharge area; 4) if the wetland provides habitat for special local or regional species which could include species of special concern or Species of Greatest Conservation Need (SGCN) identified by Michigan's Wildife Action Plan (Lounds pers. comm.). But the fourth criteria (i.e., providing habitat for special local or regional species) has not often been invoked (if ever), and is especially difficult to address on private lands (Lounds pers. comm.). There is some legal protection for vernal pools at the local level. For example, the City of Novi has a local wetland ordinance that provides protection for small wetlands if they are identified as "essential" habitat for wildlife species (i.e., significant wildlife habitat) (Mifsud pers. comm.). Under this ordinance, if vernal pools provide habitat for wetland-dependent species, they would be subject to wetland protection and mitigation (Mifsud pers. comm.). However, compiling and providing sufficient evidence to demonstrate vernal pools are essential or significant wildlife habitat can be challenging, particularly evidence that might hold up in court (Mifsud pers. comm.). Use of vernal pools by wetland-dependent species can be highly variable, and multiple years of data are needed (Mifsud pers. comm.). Also, only about 40 communities out of over 1,200 local communities have natural features ordinances, and most of these are in southeast Michigan (Lounds pers. comm.). It was brought up that developing a politically acceptable vernal pool protection strategy could be challenging since they sometimes are not highly valued (e.g., viewed as mosquito breeding grounds). Though not legal protection, the MDNR/MDEQ's Sustainable Soil and Water Quality Practices on Forest Land Guidelines do require protection of vernal pools on state forest lands, and there are audits to see if the guidelines are being followed (Price pers. comm.). These guidelines also can be applied to private lands by commercial and private loggers. These guidelines specify the following: 1) no disturbance to the vernal pool depression; 2) avoid creating deep ruts within 100 ft or at least one tree length of the pool; 3) equipment should only be used when the ground is frozen; and 4) timber harvesting can occur around the pool but must maintain 70% or greater canopy closure. Forest certification standards or programs (e.g., Sustainable Forestry Initiative (SFI®) and Forest Stewardship Council (FSC®) forest certification programs), which are voluntary programs or standards that apply to public and commercial forest lands, also include some protection for vernal pools.

The Vernal Pools Work Group helped guide and evaluated efforts, results and accomplishments related to this project including efforts to develop a common definition and methodology for identifying and assessing vernal pools in the state. Input and feedback from the VPWG regarding specific components of the project are provided in the following pertinent chapters of this report. General comments or needs regarding this project in particular that were discussed included the comment that although this project focuses on identifying and classifying vernal pools, it would be helpful if the project would also consider and continue to keep in mind and revisit how to protect and manage vernal pools as well and how the information collected as part of this project will lead or fit into vernal pool protection or regulation. This was a big reason for the VPWG, and that the Work Group could help provide this perspective and help facilitate this. We also discussed that while this is a statewide project or effort, because we have limited time in the field, this project will focus on several pilot areas and a few main questions as a start.

The Vernal Pools Work Group discussed that this project is a first step in specifically working on or with vernal pools statewide, and that the group should think big to identify future work related to vernal pools. For example, vernal pools seem to provide a good opportunity to engage the public. Future vernal pools work could involve more public involvement, which could result in increased public awareness and support for vernal pools protection (e.g., through local ordinances). It was mentioned that people in watershed groups are often locally active politically, and that we may want to try to get watershed groups involved. Future work also could focus on understanding cumulative impacts on vernal pools at the landscape level since these cumulative impacts on vernal pools could really be detrimental. This work also could help identify which vernal pools are most important to protect or manage. Ohio has looked at cumulative impacts on vernal pools (Lounds pers. comm.). Ohio has lost amphibians from large areas so they are even protecting vernal pools that do not currently support vernal pool fauna in hopes of potentially re-establishing them in the future (Lounds pers. comm.). It also was brought up that vernal pools provide habitat for species in addition to obligate vernal pool species, and that future work could focus on identifying vernal pools that represent "important biological areas," such as vernal pools that provide significant habitat for a high density or abundance of amphibians and not just obligate vernal pool species.

The Vernal Pools Work Group also discussed how the goal of this project is to develop and get a framework in place for determining the best way to implement a vernal pools program in Michigan, and that the next step would be to actually implement the framework and a statewide vernal pools mapping, monitoring, and assessment program. The group spent time during several meetings to discuss potential options and opportunities for the development and implementation of a statewide vernal pools program in the future, including potential structure of and funding for such a program. We discussed potential options for organizations or institutions that could lead, coordinate, and/or house a statewide vernal pools program and database in Michigan, particularly for the long term. Potential options for agencies, organizations or institutions that could help coordinate a volunteer-based statewide vernal pools mapping and monitoring program that were discussed included MNA and Michigan Technological University (there is a faculty member there who has worked with vernal pools and school groups). Potential options for agencies, organizations or institutions that could house the statewide vernal pools database developed and initiated as part of this project include MNFI/Michigan State University, another university, MNA, Michigan Wetlands Association, and HRM as part of or in conjunction with the Michigan Herp Atlas. We also discussed approaches that other states have taken for housing and coordinating the vernal pool program and/or database in their states, which have included government agencies and universities, although some of the programs associated with universities have noted that funding these programs is challenging. We looked at and discussed the vernal pools program in Ohio which is coordinated by the Ohio Vernal Pool Partnership working with Ohio Environmental Protection Agency (i.e., the equivalent of the MDEQ). The Ohio Environmental Council (OEC) leads the program, and 25% of a staff person's position/time at the OEC is to coordinate the Ohio vernal pools program and manage their vernal pools database. The Vernal Pools Work Group thought that this was a good model because of it involved multiple groups partnering with one person with dedicated time to work on the program.

It was also envisioned that the Vernal Pools Work Group would act as liaisons with their respective agencies, organizations, and/or group members, and help share and disseminate information about vernal pools and results of this project. Examples of how Vernal Pools Work Group members have helped disseminate information about vernal pools include a brief article that the MDNR Wildlife Division wrote and published online on their website in 2013 entitled "Wicked big puddles! Learn more about vernal pools" (available at http://www.michigan.gov/dnr/0,4570,7-153-10370_12141-300728--,00.html); an invited presentation on vernal pools and the project to the MNA Board of Trustees at their 2012 annual retreat; and an invited article on vernal pools and the project in the Spring 2013 issue of MNA's magazine (Appendix 2). Additionally, MNFI presented a webinar on the vernal pools project to the Natural Resources Workgroup in the Greening Michigan Institute within Michigan State University Extension in February 2014. MNFI plans to provide additional talks or presentations on the vernal pools project at various meetings and conferences in the near future, including the annual meetings of the Michigan Wetlands Association, Michigan and/or Midwest Partners in Amphibian and Reptile Conservation, and NatureServe and the Natural Heritage Network. We also propose to organize a vernal pools session at the 2015 Annual Meeting of NatureServe and the Natural Heritage Network, which will be held in northern Michigan.

Finally, one of the goals or tasks of the Vernal Pools Work Group was to help promote and/or facilitate collaboration among vernal pool efforts in the state. One of the most significant results that has come out of developing and convening the Vernal Pools Work Group is that the agencies and organizations that have been participating in the VPWG have expressed interest in forming the Michigan Vernal Pool Partnership, a public-private to continue efforts to develop and implement a statewide vernal pools mapping and monitoring program in Michigan. At the last VPWG meeting in March 2014, representatives from the MDEQ, MDNR, MNFI, Michigan Nature Association, Michigan Tech Research Institute, and Herpetological Resource and Management expressed interest in helping to create and participating in the Michigan Vernal Pool Partnership. Steps that have been identified for moving forward with creating the Michigan Vernal Pool Partnership (MVPP) and developing a statewide vernal pools program include the following: 1) identify additional potential partners to invite to participate in the MVPP; 2) identify key or core partners and form an advisory or steering committee for the MVPP; 3) identify a lead for the advisory/steering committee and MVPP; 4) identify the mission, goals, and objectives of the MVPP and a statewide vernal pools program; 5) develop plans and approach for achieving goals and objectives of the MVPP and developing a statewide vernal pools program; 6) organizing a meeting(s) in the near future of the MVPP and the advisory/steering committee; and 7) identifying and securing funding for developing a statewide vernal pools program and supporting the MVPP. The Michigan Nature Association has offered to help lead the Michigan Vernal Pool Partnership and efforts to develop the MVPP including helping to convene an advisory/steering committee, pursuing funding to develop a statewide vernal pools program, and potentially providing funding to support continuing the volunteer vernal pool program in southeast Michigan and launching a new volunteer vernal pool program in northeast Michigan this spring. Michigan Natural Features Inventory has expressed interest in serving as the technical lead for the MVPP and working with MNA to help develop the MVPP. The MDEQ and MNFI will work on identifying and recommending additional partners to invite to participate in the Partnership. We also discussed potential options or venues for organizing a meeting of the MVPP in 2014 or 2015 including the Michigan Wetlands Association's annual meeting in August 2014 and NatureServe's "Biodiversity without Boundaries" conference in April 2015.

Another example of how the Vernal Pools Work Group has helped to promote and facilitate collaboration among vernal pool efforts in Michigan is a new project that MNFI and MTRI will be collaborating on to identify and map vernal pools on state forest lands in the Upper Peninsula. This project is sponsored and funded by the MDNR Forest Resources Division and MNFI, VPWG members, as well as Verso Paper Corporation and the Michigan Forest Products Council. This project will continue efforts to examine and evaluate the use of air photo interpretation, radar, and GIS modelling to identify and map vernal pools. Through the Vernal Pools Work Group and this project, MNFI and the MDEQ also were able to collaborate on an effort to initially evaluate a potential approach for identifying potential vernal pools based on NWI wetlands and hydrogeomorphologic factors and functions.

DISCUSSION

The Vernal Pools Work Group was very engaged and helpful in providing input and feedback that helped guide and improved the vernal pools project. The Vernal Pools Work Group provided invaluable information on current wetland mapping or research efforts, regulations, and other wetland protection measures and gaps in wetland protection that could be or have been applied to vernal pools in Michigan. This information will be very helpful moving forward with vernal pool conservation and management efforts in the future. The Work Group also provided insights into priority information and conservation needs regarding vernal pools and how results from this project could potentially impact vernal pool protection and management in the state. Although we developed the vernal pool definition and sampling design and protocol from a scientific perspective and using the best available science, it also was helpful to consider potential management implications. For example, being able to consistently define and accurately identify vernal pools has important implications for protection and management of vernal pools. As a result, we focused quite a bit of time and effort working on this during the project and during several of the VPWG meetings. Several VPWG members also provided helpful input regarding the sampling design, data analysis, and GIS modelling components.

Based on discussions at several of the VPWG meetings, there are potential options for legally protecting vernal pools at the state level but voluntary measures to protect vernal pools, such as through forest certification or the State's Sustainable Soil and Water Quality Practices on Forest Land guidelines, are likely more promising for providing statewide protection for vernal pools at this time. Voluntary measures or legal protection or at the local level (e.g., local ordinances, voluntary protection by individual landowners and land managers) also is an option for protecting vernal pools at this time. As more information about vernal pools in the state becomes available, efforts to protect and manage vernal pools in the state should be re-examined.

The Vernal Pools Work Group was particularly effective at promoting and facilitating partnerships and collaboration for disseminating information and raising awareness of vernal pools and efforts associated with this project. The Vernal Pools Work Group also was effective at laying the foundation for collaboration on vernal pool conservation efforts in Michigan including efforts to develop and implement a statewide vernal pools mapping and monitoring program in the state. The Michigan Vernal Pools Partnership is similar to the Ohio Vernal Pools Partnership that was developed after a three-year vernal pools project conducted by TNC in Ohio. The Michigan VP Partnership will continue to consult with and learn from vernal pool programs and partnerships in Ohio and other states that have been successful.

CHAPTER 2: Compiling and synthesizing information about vernal pool programs in other states to help guide efforts in Michigan.

INTRODUCTION

Vernal pools are small, shallow, depressional wetlands that usually contain water for only part of the year. These temporarily-flooded wetlands typically fill with water between late fall and spring from rising groundwater, snowmelt, and/or rainfall. Because they lack permanent water and dry up periodically, vernal pools do not support breeding fish populations. Despite their small size and temporary nature, vernal pools can be incredibly diverse and productive ecosystems. Vernal pools provide important habitat for many wildlife species. 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 (Calhoun et al. 2003, Calhoun and deMaynadier 2004). Vernal pools also contribute and provide other important ecosystem services including nutrient cycling, water storage and infiltration, groundwater recharge, and flood control.

Vernal pools are highly vulnerable to disturbance or destruction, and are being lost across the Midwest and other parts of the country, including Michigan. Because of their small size and seasonal nature, vernal pools can be difficult to identify on the landscape, especially when they are dry, and are often overlooked. Vernal pools receive little or no protection under federal and state wetland regulations because they are small and often isolated from larger and/or permanent waterbodies and wetlands.

Due to recent increased awareness of the importance of vernal pools, there has been growing interest in identifying, studying, and conserving these small but valuable ecosystems in Michigan and other states. This project represents the first targeted effort focused on identifying, mapping, assessing, and classifying vernal pools across multiple ecoregions in Michigan. The goal of this project was to develop an effective and efficient approach for identifying, mapping, and assessing vernal pools and to obtain additional information to enhance our knowledge of vernal pools in Michigan. The purpose of this project also was to develop a framework and foundation for developing a statewide vernal pools mapping and monitoring program to assess the status, distribution, and ecological values of vernal pools in the future. This project will help Michigan build upon efforts to identify, assess, and protect these wetlands.

Although Michigan is initiating efforts to map and assess vernal pools, other states in the U.S. have developed and implemented vernal pool mapping, monitoring, and conservation programs or efforts. Understanding what other states or organizations have done and how they have approached vernal pool mapping, assessment, and protection can inform and help guide efforts associated with this project as well as future vernal pool conservation efforts in Michigan. Learning from and building upon what other states have done also can increase efficiency and promote consistency among vernal pool programs. We researched, compiled, and synthesized information about vernal pool programs in other states to inform and guide our efforts to develop an effective and efficient approach to identify, map, and assess vernal pools in Michigan.

METHODS

We researched, compiled, and synthesized information about vernal pool programs and protection measures in other states in 2011 during the first year of the project. We searched online for information about different vernal pool programs, particularly programs in the Northeast and the Midwest/Great Lakes region. We contacted some programs and individuals by e-mail or phone to follow up, ask specific questions, and get copies of reports, materials, and/or additional information about their vernal pool programs. We compiled a variety of information about vernal pool programs in other states, including vernal pool definitions; vernal pool protection measures; efforts to identify and map vernal pools remotely and/or or in the field; efforts to monitor, classify and/or rank vernal pools and the approach and criteria that were used; mapping and monitoring protocols; volunteer vernal pool mapping and monitoring programs; and program administration. A summary of this information was presented and discussed at a Vernal Pools Work Group meeting in December 2011.

We were particularly interested in obtaining additional information about vernal pool programs in states surrounding Michigan and in the Great Lakes. We also were particularly interested in learning more about other states' volunteer vernal pool mapping and monitoring programs and their experiences with training volunteers, resource materials that they have developed, and data quality control. To help address these two needs, we attended a volunteer vernal pool training workshop in Ohio in the spring of 2012 that was co-sponsored by Toledo Metroparks and the Ohio Environmental Council, who coordinates Ohio's vernal pools volunteer mapping and monitoring program. We were able to experience the training workshop, identify and obtain resource materials for volunteers, and talk to the Ohio vernal pool program coordinator and one of the volunteer coordinators who were great resources for information. We also had phone discussions with a researcher in Maine (Dr. Aram Calhoun) who has been studying and working with vernal pools, volunteers, and local units of government to help map, monitor, and protect vernal pools in Maine for over 10 years. We also had a conference call with an ecologist from the Wisconsin Natural Heritage Program who has been conducting vernal pools mapping and research in Wisconsin, similar to the work we conducted for this project. We shared information about our respective projects and discussed issues related to defining, classifying, ranking, and mapping vernal pools and database issues.

RESULTS

We identified 37 vernal pool programs, research projects, and/or initiatives in 13 different states outside of Michigan (Table 2.1). It is important to note that this is not necessarily an exhaustive or complete list of vernal pool programs or projects, and additional vernal pool programs and/or projects may have been conducted in other states that were not documented by our efforts. Most of the vernal pool programs/projects have been conducted in 10 states in the northeastern U.S. (i.e., Maine, Vermont, New Hampshire, Massachusetts, Connecticut, Rhode Island, New Jersey, New York, Maryland, and Pennsylvania) (Table 2.1). Vernal pool programs or projects also have been implemented in Virginia and in the Midwest in Ohio and Wisconsin (Table 2.1). Fourteen of the programs in 10 different states are statewide programs, while 21 are local or regional programs within 10 different states.

All 13 states are interested in and have included efforts to document vernal pools in the field, primarily through the use of trained volunteers. Some of these states have had formal programs or targeted efforts to document vernal pools in the field, such as the volunteer vernal pool mapping and monitoring programs in Wisconsin, Ohio, and Maine. But other states that don't have formal vernal mapping and monitoring programs still have developed educational materials and/or a protocol, and have encouraged people to document and submit information about the location and condition of vernal pools to a state agency (e.g., New Hampshire) or other coordinating agency or organization.

Approximately 15 vernal pool programs/projects in 10 different states have incorporated mapping of vernal pools either locally, regionally, within a watershed, or statewide (Table 2.1). Eight of these states have included efforts to identify and map potential vernal pools remotely, through aerial photo interpretation (i.e., programs in 8 states), GIS modelling (to a very limited degree for the most part) (5 states), and the use of LiDar as part of a small project in Ohio. Eleven states map actual or verified vernal pools (Table 2.1).

Some states also have implemented efforts to monitor, classify, and assess or rank the quality of, vernal pools. Approximately seven programs in 5 different states (Connecticut, Maryland, Virginia, Vermont, Ohio, and New York) have conducted monitoring for vernal pools, mostly at local levels (Table 2.1). Only 6 states/projects classify vernal pools (i.e., New York, Pennsylvania, Vermont, Wisconsin, and Rhode Island) (Table 2.1). Fifteen programs in 9 states (Massachusetts, Maine, New Jersey, New York, Pennsylvania, Rhode Island, Ohio, Vermont, and Virginia) have included efforts to assess or rank the ecological value of vernal pools (Table 2.1).

The vernal pool programs or projects have been administered by different types of organizations. About 14 of the programs/projects have been administered by state government agencies, including 4 programs that were administered by state natural heritage programs. The remaining programs/projects have been administered primarily by natural resource- or conservation-related groups or organizations including The Nature Conservancy, Audobon Chapters, nature centers, local conservation districts, land trusts, and universities. A small number of programs/projects have been administered by groups that focus primarily on vernal pools, such as the Ohio Vernal Pool Partnership, Southeast Wisconsin Ephemeral Pond Monitoring Network, Virginia Vernal Pool Society, and the Cape Ann Vernal Pool Team.

Six states provide specific legal protection for vernal pools (i.e., Maine, Massachusetts, Vermont, New Hampshire, Connecticut, and New Jersey) (Table 2.1). Three additional states (i.e., Ohio, Rhode Island, Pennsylvania, Wisconsin, and Virginia) could provide legal protection for vernal pools under other state wildlife habitat or wetland regulations, but it is unclear if vernal pools would be adequately protected under these regulations. Seven of these states protect vernal pools for their wildlife habitat values. As a result, most vernal pool regulations require collecting data to demonstrate a vernal pool represents significant wildlife habitat in order for it to be protected. This is often requires documenting the presence and/or abundance of vernal pool indicator species; vernal pool obligate and/or facultative species; rare, threatened and endangered species; and/or special features within the wetland that functions as important wildlife habitat.

Table 2.1. Overview of vernal pool (VP) programs and related efforts in the following states: Maine (ME), Vermont (VT), New Hampshire (NH), Massachusetts (MA), Connecticut (CT), Rhode Island (RI), New Jersey (NJ), Maryland (MD), New York (NY), Pennsylvania (PA), Ohio (OH), Wisconsin (WI), and Virginia (VA).

	ME	VT	NH	MA	CT	RI	NJ	MD	NY	PA	OH	WI	VA
Legal protection for vernal pools	X	X[1]	X	X	X	X[1]	X	X		X[1]		X[1]	X[1]
Year vernal pool regulation / protection enacted	2007 (1995)[2]	1990	2008 (1969)[3]	1987	1995	1994	2001	1989		1980?		2001?	
Mapping of potential and/or actual vernal pools (state/local level)	X (PVP)	X (PVP)	X (PVP)	X (PVP)	X	X (PVP)	X (PVP)	X	X (PVP)	X	X	X (PVP)	X
Active surveys for vernal pools – statewide[4]	X	X	X	X?			X			X	X		X
Year statewide surveys started	~2005	2009	2004	2001			2000	2007		2004	2005	2006	?
Active surveys for vernal pools – local/watershed[4]	X	X	X	X	X	X	X	X	X	X	X		
Year local/ watershed-based surveys started	2008	~2006?	2010	1990	2005	2003	?	2007	2007	?	?		
Vernal pool monitoring		X			X			X	X		X		X
Vernal pool classification		X				X			X	X		X	
Vernal pool quality assessment/ranking	X	X		X		X	X		X	X	X		X

[1] Vernal pools protected as "wetlands significant for wildlife" in VT; as a "special aquatic site" in RI; as general wetlands in PA, WI, VA.
[2]Vernal pools eligible for protection in 1995 but only significant vernal pools could be protected, and it took until 2007 to finally define significant vernal pools that would be protected and how.
[3]Vernal pools included in general wetland protection starting in 1969 but explicit protection and permitting added in 2008.
[4]Concerted, coordinated effort to conduct field surveys/visits to vernal pools, with or without prior mapping, usually using trained volunteers.

The following information was compiled from other states and summarized to inform and guide our project's efforts, particularly regarding how to define vernal pools:

Physical Attributes:

- Size - Often described as "small." A few programs give a range - 10 sq ft to a few acres in NJ; usually larger than a bedroom and smaller than an acre in Wisconsin; less than 0.5 acre in NY; less than 1 sq meter to < 1 acre in Maryland. Maine specifically includes pools in spruce-fir forests which are up to 2 acres.
- Origin - Natural or "man"-made. Maine, New Hampshire, and Vermont specify natural (or created for mitigation purposes); in the case of Maine and New Hampshire, these are legal definitions. Other programs specifically include artificial pools.
- Permanence - Sometimes specified as "temporary," but usually addressed more specifically in hydroperiod. Some mention that they may not draw down completely in particularly wet years or that they may not draw down completely in most years, but become so shallow that fish cannot survive.
- Hydrology - Isolated; confined depression; no permanent inflow or outflow or permanently flowing inlet or outlet; ponded.
- Hydroperiod- Filled in the spring (sometimes also in fall; one specifies that they fill after ice melt); dry out by late summer; sometimes a two month minimum is specified. New Jersey specifies two continuous months between March and September of a normal rainfall year.
- Hydrology and hydroperiod are the core characteristics used in pretty much every definition.

Fishlessness:

- In a sense, this is at the base of all other definitions. It is frequently mentioned and used as proof of the temporary nature of the pool and sometimes as proof that indicator species could breed there. Sometimes fish can occur if they are just there temporarily (e.g. flooding from a nearby river), in which case there is no "viable" or "permanent" population. In Maine and Wisconsin, the predatory nature of the fish is specified (i.e. minnows can occur in vernal pools). Sometimes pool can be not temporary, as long as there are no fish (i.e., Queen's project in RI).

Biological Attributes:

- Obligate/Indicator Species - Frequently, specific species are listed (e.g., *Ambystomatid* salamanders, Wood Frogs, fairy shrimp). Some require breeding evidence (for amphibians), not just mere presence. Maine requires a specific number of egg masses for a pool to be considered "significant". New Hampshire lists a specific species of fingernail clam.
- Facultative Species - Rarely, this can be used as a stand-alone criterion, if there is evidence of breeding; consist of amphibians, reptiles, and invertebrates.

- Threatened/Endangered Species - In Maine, documented presence of threatened and endangered species turns a vernal pool into a significant vernal pool, which has specific legal protections.
- Vegetation - Seldom mentioned. Not used as a defining characteristic. Some mention hydric plants as an indication of a vernal pool, but not a requirement. Community/habitat classification-based descriptions (such as in Wisconsin) might include a list of plants expected to be associated with vernal pools. A Vermont definition that limits itself to forested areas mentions that vegetation is usually sparse or absent. The legal definition in Maryland includes sparse vegetation as a criterion. There are a few that mentions special concern plants which can be found in vernal pools. Pennsylvania mapped as *potential* vernal pool occurrences of two particular plant species: *Glyceria acutiflora* & *Scirpus insistricinus*. (One is found in Michigan.)
- Most states use a combination of physical and biological attributes to define vernal pool or significant vernal pool to meet legal criteria for protection. For example, a vernal pool has a confined, ephemeral hydrology + the presence of at least one indicator species. In these cases, sometimes fishlessness is used as proof that the physical requirements have been met; in other definitions, fishlessness is used to prove that the biological requirements have been met. (The Queen's River project in Rhode Island essentially used fishlessness to meet both criteria.) This dual physical/biological definition begs the question: what if a pool meets the physical criteria, but not the biological criteria, or vice versa? What do you call this type of habitat? Do you track it? The Wood-Pawcatuck study in Rhode Island came up with a classification scheme to deal with this problem. A program in New York (Upper Susquehanna Coalition) essentially used only the presence of indicator species. In New Jersey, there is a dual definition, BUT if you don't find the vernal pool species, it can still be certified as a vernal pool, as long as you provide supplemental (and somewhat burdensome) documentation of its physical attributes.
- Many programs have discovered that wood frogs and mole salamanders do not confine their breeding activity to traditionally-defined forested vernal pools. A study in Rhode Island started with a definition of vernal pools which relied primarily on the presence/breeding activity of indicator species and fishlessness. They were attempting to ground-truth some 678 features, and by the time they were done, they had changed the definition to a confined, ephemeral basin + presence/breeding evidence of indicator species. Almost 50% of the features which were not confined, ephemeral basins had breeding populations of indicator species (compared to ~87% of those that were confined and ephemeral). Maine's training materials make a point of mentioning that salamanders can't read and just because there are eggs in a body of water does not mean that body of water is necessarily a vernal pool. Pennsylvania was also finding breeding activity pretty much everywhere, especially wood frogs.

Habitat/Vegetation:

- Definitions derived from Natural Heritage Programs generally limit themselves to forested habitats. Some scientific studies seeking to classify, assess, rank, or describe vernal pools will limit themselves to forested landscapes, and possibly also undisturbed or less disturbed landscapes. Most of the statewide or local mapping programs whose main goal is to find the pools do not limit themselves in this way. New York is an exception: the Hudson River Valley initiative calls them woodland pools to emphasize the importance of forest for the adults. They do not really consider pools in open areas as part of their definition, but they do point out during training sessions that these areas can also serve as breeding habitat for mole salamanders. Many times the goals of the program inform their decisions on which pools to map. For example, Ohio was using a very broad definition and wished to capture areas where vernal pools may have existed historically, so they included pools in agricultural settings, depending on what species were utilizing it. On the other hand, VT usually did not include these pools because they have not found indicator species in them. They also did not include pools inside mapped wetlands because these were already protected as part of the wetland.

Legal Definitions:

Some states have specific legal definitions of vernal pools which depend on a combination of both physical and biological characteristics. The determination of whether or not a pool is protected (i.e., significant, certified, or documented) is usually the presence of breeding obligate/indicator species (or fairy shrimp), so a field visit in the spring is necessary. Some specify that a pool must be natural; none specify the habitat (forested, open, et cetera). All are primarily focused on the wildlife in the pool.

- Maine - significant (not all vernal pools are significant)
- Massachusetts - certified (if a pool has been visited and meets the definition, it is a certified vernal pool; otherwise it is not a vernal pool)
- New Jersey - certified
- New Hampshire – documented

Other states have different approaches:

- Rhode Island - Regulates “special aquatic sites” capable of supporting and providing habitat for aquatic life forms
- Maryland - Non-Tidal Wetland Protection Act gives a definition of vernal pools, which, among other things, specifies that they “provide habitat for amphibian species.” The state law is designed to be mostly implemented at the local level.
- Connecticut - The state includes “vernal or intermittent” bodies of water in its definition of “watercourses”, but neither ‘vernal’ nor ‘vernal pool’ is defined in the statute. The specific implementation of the regulation is done at the local level.
- Vermont - provides protection as wetlands that functionally provide significant habitat for wildlife. Has proposed to administratively reclassify as class II wetlands, which would provide greater protection.
- Wisconsin - may be protected under broad definition of wetlands

The actual protection afforded to vernal pools can vary. Often it is only the vernal pool itself that is protected. A few states provide for a buffer around the vernal pool, usually in the range of 30 to 183 meters (100 to 600 feet).

DISCUSSION

Our efforts to compile and synthesize information and learn from vernal pool programs, projects and/or efforts in other states provided some very interesting and helpful insights and guidance. It was surprising and encouraging to learn that a number of states and programs have been actively mapping, monitoring, assessing, and/or protecting vernal pools. Interest in vernal pools and efforts to map, monitor, and assess them appear to be growing in recent years as evidenced by the number of states that have initiated statewide and/or local vernal pool mapping programs since 2001 (Table 2.1). It also was interesting to find out that almost 60% of the vernal pool programs have not been administered by state government agencies, although they are often involved as a partner in the programs. Many of the vernal pool projects appear to have been funded by the U.S. EPA, which clearly has helped facilitate development of vernal pool programs in a number of states. However, some vernal pool programs, particularly those administered by universities, have found it challenging to continue to sustain the program over time due to lack of funding. Approaches that other states have taken and challenges they have addressed will be important to keep in mind for developing a statewide vernal pool mapping and monitoring program in Michigan, which should include a plan for funding and sustaining the program over time. It also was interesting to note that only two states in the Midwest/Great Lakes besides Michigan (i.e., Wisconsin and Ohio) appear to have vernal pool mapping and monitoring programs. Hopefully, this will change in the future.

Information on how other states and programs have defined vernal pools helped us develop the definition of vernal pools that we used for this project. Information from other states provided insight into several issues or challenges that the MNFI project team and the Vernal Pools Work Group had to address regarding the vernal pool definition. For example, most wetland communities in the state are defined at least in part by the vegetation in the wetland. However, other states have generally not used vegetation to define vernal pools because vegetation can be absent/sparse in some vernal pools, and because vernal pools are generally characterized by the surrounding vegetation, which can be highly variable since vernal pools occur throughout the state in all or many forest types. It also was interesting that the presence of certain indicator animal species has been included in some vernal pool definitions, particularly for legal definitions, since most wetlands, natural communities or habitats have not been defined by the animals that use them. Vernal pool definitions also appear to vary to some degree among states and/or vernal pool programs, but certain core elements, such as hydrology, hydroperiod, and fishlessness, appear to be present across all the definitions. This is important to keep in mind when sharing or comparing data between states or programs.

It was beneficial to obtain information on how other states have provided protection for vernal pools in terms of regulations. Vernal pools have primarily been protected for their wildlife habitat values (e.g., presence and/or abundance of certain vernal pool indicator species). Critical non-contiguous wetlands in Michigan can get some protection if the wetland provides habitat for threatened and endangered species and/or special local or regional species which could include species of special concern or SGCN identified by Michigan's Wildife Action Plan (Lounds pers. comm.). This could apply to vernal pools in some cases, but this criteria has rarely been invoked (Lounds pers. comm). This also emphasizes the need for documenting and getting a better understanding of vernal pool indicator species and other animals that inhabit vernal pools.

CHAPTER 3: Developing a common definition and methodology for identifying vernal pools in Michigan.

INTRODUCTION

Due to recent increased awareness of the importance of vernal pools, there has been growing interest in identifying, studying, and conserving these small but valuable ecosystems in Michigan. However, little information is currently available regarding the status, distribution, and ecology of vernal pools in Michigan. This project represents the first targeted effort focused on identifying, mapping, assessing, and classifying vernal pools across multiple ecoregions in Michigan. The goal of this project was to develop an effective and efficient approach for identifying, mapping, and assessing vernal pools and to obtain additional information to enhance our knowledge of vernal pools in Michigan. The purpose of this project also was to develop a framework and foundation for developing a statewide vernal pools mapping and monitoring program to assess the status, distribution, and ecological values of vernal pools in the future. This project will help Michigan's Wetlands Protection Program build upon and further develop its ability to identify, assess, manage, and protect these wetlands.

One of the first objectives of this project was to develop a common definition and methodology for identifying vernal pools in Michigan. Vernal pools have been defined differently among states, programs, projects, and individuals, although certain core elements have been consistent across definitions. In some states, vernal pools have been defined based on physical and biological attributes such as the presence of vernal pool indicator species. For example, in Maine, vernal pools are defined as naturally occurring, seasonal bodies of water, free of predatory fish populations, that provide breeding habitat for one or more of Maine's four vernal pool indicator species- spotted and blue-spotted salamanders, wood frogs, and fairy shrimp (Morgan and Calhoun 2012). Similarly, in New Hampshire, a vernal pool is a temporary body of water which provides essential breeding habitat for certain amphibians, such as wood frogs and spotted salamanders, and invertebrates, such as fairy shrimp (New Hampshire Fish and Game Department 2004). In New Jersey, vernal pools are confined wetland depressions, either natural or man-made, that hold water for at least two consecutive months from March through September, are devoid of breeding fish populations, and features at least one obligate or two facultative amphibian or reptile species (New Jersey Division of Wildlife 2014). However, some states define vernal pools based solely on physical attributes. In Ohio, for the Ohio Vernal Pool Monitoring Program, 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). In Wisconsin, ephemeral ponds (or vernal pools) are depressions with impeded drainage (usually in forest landscapes), that hold water for a period of time following snowmelt and spring rains but typically dry out by mid-summer (Wisconsin DNR 2014). We found that vernal pools were defined differently even among MNFI's project team and the VPWG at the start of this project. Vernal pool sampling and monitoring methodologies also have differed among programs and states. To ensure that vernal pools were defined consistently for this project and for future vernal pool mapping and conservation efforts in the state, we developed a common definition of vernal pools. We also developed a common methodology for identifying, mapping, and monitoring vernal pools for this project and use in the future.

METHODS

To develop a common definition and methodology for identifying and mapping vernal pools in Michigan, we researched and compiled information on how other states and vernal pool programs or projects defined vernal pools (Appendix 4). We consulted the literature and other references on vernal pools (e.g., Coburn 2004, Calhoun and deMaynadier 2008). We also talked to several vernal pool program coordinators in other states (i.e., Ohio and Maine), and researchers who have studied vernal pools in Michigan or other states (i.e., Pennsylvania, Wisconsin). The project team compiled, reviewed, and discussed the information from other states, vernal pool programs/projects, and researchers. We discussed our current natural community classification system (Kost et al. 2007), and how vernal pools would fit within this framework and other natural community designations in the state. For the methodology, we examined our current methods for collecting information about natural communities.

Based on the information we compiled and our discussions, we developed a draft vernal pool definition and methodology. The draft definition and methodology were discussed among the MNFI project team, and also were presented to and discussed with the Vernal Pools Work Group during several meetings in late 2011 and in early 2012 and 2013 prior to the field season in each of those years. The draft definition and methodology were revised after these discussions. We revisited the draft definition and methodology after our field seasons in 2012 and 2013 and data analysis in early 2014. The vernal pool definition was revised again based on study results and discussions in early 2014, and recommendations for improving the methodology were developed. The final vernal pool definition and methodology that we developed are presented in this report.

RESULTS

Vernal Pool Definition

The following is the final common definition or description of vernal pools that was developed 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 sparse cover of persistent emergent plants. Substrates are comprised of hydric soils and often covered by leaf litter. Vernal pools are important for wildlife because they provide essential habitat for many animals, including amphibian and invertebrate species that depend on them for part or all of their life cycle.

Table 3.1. Required attributes for vernal pools.

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.

Regarding the definition of vernal pools, it is important to note that we defined vernal pools as natural features within natural communities and not distinct natural communities for this project and in general at this time. It also is important to note that vernal pools can be defined or identified based on their ecological function (e.g,, providing habitat for vernal pool indicator species) in addition to their physical characteristics.

Vernal Pool Methodology for Identifying Vernal Pools

We developed a methodology for identifying vernal pools in the field based on the vernal pool definition we developed and methodologies developed and utilized by other vernal pool programs or projects in other states. We also investigated approaches or methods for identifying vernal pools or potential vernal pools using remote sensing and GIS modelling. These methods are discussed in Chapters 4, 5 and 6 of this report. We tried to develop a field methodology that was effective for collecting the information needed to document a vernal pool but also efficient and relatively easy to understand and implement in the field. This methodology was developed primarily for use by vernal pool volunteers but can also be used by land managers, researchers, and other professionals. This methodology is primarily targeted for identifying or verifying vernal pools, but can be modified or tailored to collect additional or specific information to address other project goals or objectives or research questions. Appendix 3 provides a detailed description of the methodology.

The following is the methodology we developed for identifying vernal pools in the field:

1) If possible, obtain training prior to identifying vernal pools in the field. Training is required for volunteers. Obtain and review training materials.

2) Identify or select a potential vernal pool (PVP) or multiple potential vernal pools to ground-truth and survey in the field. Note that each potential vernal pool has been assigned a unique identification number (Pool ID #). Use this Pool ID # on your data form and photo-documentation. Other or additional vernal pools that have not previously mapped or identified also can be surveyed in the field. Assign a temporary, unique pool ID # to any new or additional pools, and a permanent Pool ID # will be assigned later.

3) Obtain air photos, topographic maps, and other appropriate maps to locate potential vernal pool(s) in the field.

4) Conduct field surveys to ground-truth and map potential vernal pools (PVPs) and collect data on their physical and biological characteristics.

    - Conduct at least 3 field visits to the vernal pool(s) within a given year. Vernal pools can potentially be identified with just two visits (i.e., spring and late summer/fall), but conducting three visits is more reliable and provides more information.

        - Visit 1 - Early spring (generally mid-late March – mid-April in southern Michigan, early/mid-April – early/mid-May in northern Michigan) - The first visit should be conducted soon after ice melt when the vernal pools are filled with surface water and just after the peak of wood frog breeding to document wood frog egg masses. Other obligate vernal pool indicator species such as fairy shrimp, and spotted salamander and blue-spotted salamander adults, spermatophores, and/or egg masses also can be observed if present. The timing of peak wood frog activity will vary across the state and will differ from pool to pool depending on geographic location, weather, tree cover/exposure to sunlight, and pool depth. Wood frogs typically begin calling in mid-late March in the southern Lower Peninsula, early to mid-April in the northern Lower Peninsula, and mid-late April in the Upper Peninsula, but these dates can shift earlier or later depending on the weather. Amphibian emergence from hibernation occurs after the first warm spring rains or substantial snowmelt, and migration to breeding pools usually occurs on a warm rainy or misty evening(s) (40-50^{o}F).

        - Visit 2 – Mid-spring (generally early/mid-April – mid-May in S. MI, mid-late April – late May in N. MI) – The second visit should be conducted roughly 2-3 weeks after the first visit to document and do a final count of blue-spotted and spotted salamander egg masses. Fairy shrimp may still be present in some pools, and wood frog tadpoles may be observed during this visit. This is also when biodiversity is generally at its highest in the vernal pools, so a number of other animal species, including rare species such as the Blanding’s turtle, may be observed during this visit.

    - Visit 3 – Late summer/early fall (late July – September) – The third visit is to document the vernal pool drying or drawing down. Some pools may contain water for longer periods of time and dry up later in the year or only in some years. If the vernal pool still contains quite a bit of water during this visit, an additional visit should be conducted later in the summer or early fall and/or in subsequent years, if possible, to document and confirm pool drying. Most pools seem to dry by September.

- Because of potential year-to-year variations in pool size, duration, water levels, and use by indicator species and other animal species, multiple years (e.g., 2-3 years) of field surveys and data for a given pool would be ideal. Additional visits to the pool within a year also can provide useful information. Adding a visit in late June/early July to see if the pool still has water and survey for indicator species and other animal species can provide information about pool hydroperiod or duration and biodiversity within the pool.

- Vernal pools also can be documented in the field in late summer, fall, and/or winter when they are dry. The following physical and/or biological characteristics can be used to indicate seasonal flooding at a dry vernal pool. However, the pool or depression should be revisited in the spring to verify flooding and confirm vernal pool status.
    - Physical characteristics: 1) stained leaves in a depression; 2) water stains or siltation marks on surrounding tree trunks or vegetation; 3) trees with buttressed trunks or stilt trunks; 4) wetland plants or sphagnum moss growing in a dry depression; 5) wetland or hydric soils.
    - Biological characteristics: 1) cases of caddisfly larvae; 2) adults, juveniles, or shells of either freshwater/fingernail clams or amphibious, air-breathing snails; 3) shed skins or exuvia of dragonfly or damselfly larvae on vegetation along the edge of a dry depression

- Potential vernal pools (PVPs) that are ground-truthed or verified and new or additional vernal pools encountered in the field should be located and mapped using a GPS (Global Positioning System) unit, when possible. Otherwise, please mark the location of the vernal pool on a Google Map (accessed online), paper topographic map, and/or air photo.

- Some PVPs may turn out to be tree shadows or different types of wetlands other than vernal pools. Potential vernal pools that turn out to not be vernal pools should still be documented, and the data should still be submitted.

5) Complete a vernal pools field form during each survey visit to the vernal pool (Appendix 4). If a rare species is observed, a MNFI Special Species Form should be completed.

6) Photo document vernal pools and associated indicator species and any rare species observed at pools. Photos should be taken of the entire vernal pool from outside the pool and the surrounding habitat from all four cardinal directions, if possible, during each survey visit. Photos should clearly labelled a using standard file naming convention (see Appendix 3 for more details and examples).

DISCUSSION

Developing a common vernal pool definition proved to be more challenging than originally anticipated. This was due to several reasons including different definitions of vernal pools among project team members initially; different definitions among other states and vernal pool programs; lack of baseline on data on vernal pools in Michigan; implications for vernal pools protection and classification; and challenging and highly variable nature of wetlands and vernal pools in particular. We encountered and discussed a number of issues related to the definition, which included the following:

- *Vernal pools as natural features and not natural communities* - Because vernal pools are often so small and are generally characterized by the surrounding natural community or landscape, we decided to define vernal pools as natural features and not distinct natural communities at this time, although some vernal pools can be designated or classified as a natural community (e.g., inundated shrub/buttonbush swamp).

- *Vernal pools occurring in forested landscapes and naturally occurring* – We recognized that vernal pools can occur in areas that are not forested, and that man-made pools also can provide vernal pool functions, but we decided to limit our definition to vernal pools in forested landscapes and naturally occurring pools for this project.

- *Pool size* – We had a quite a bit of discussion about pool size and whether we should set a minimum or maximum pool size, and what would those limits be. Concerns were raised about including very small pools (e.g., <5-10 m^2), very large pools, and implications for management or protection. We decided to not include a minimum or maximum pool size at this time because we thought that the other required vernal pool attributes (e.g., typical pool hydroperiod of at least two months in most years, drying or drawing down in most years) would naturally "set" minimum and maximum pool sizes.

- *Geomorphology* – We initially defined vernal pools as confined or isolated basin depressions. However, after encountering some features in the field that were connected to or part of larger wetland complexes and looked like vernal pools and/or provided vernal pool functions (e.g., breeding habitat for vernal pool indicator species), we decided to revisit this, and modified the definition to include vernal pools that are connected to or part of other/larger wetland complexes as long as the those wetlands were also isolated and not continuously connected to permanent water bodies. We also thought that vernal pools that are connected to or part of other wetland complexes could potentially be classified as a separate type of vernal pool. This needs further research and investigation though.

- *Hydrology* – We included a typical minimum hydroperiod of two months in most years in the vernal pool definition to distinguish vernal pools from pools that just fill up with rainwater and only last for several days or weeks. A two-month minimum hydroperiod is needed for vernal pool indicator species to complete development of their young and successfully reproduce, and for biological communities typical of vernal pools to establish (Colburn 2004). Other vernal pool programs (e.g., New Jersey) and references (e.g., Colburn 2004) also have included a two-month minimum hydroperiod in their definition of a vernal pool. Although we included this as a required attribute, it may be difficult to directly document this in the field. Field indicators (e.g., presence of wetland vegetation and/or hydric soils) will likely need to be used to indicate pool hydroperiod.

- *Vegetation* – Most states do not include vegetation characteristics in their vernal pool definitions. We included vegetation in the vernal pool description and initially included it in the list of the vernal pool required attributes, but we decided to remove vegetation from the required attributes, because vegetation in and around the vernal pools is so variable. We also felt the other attributes are more important for defining vernal pools. However, we need to make sure that not all wetlands end up being called vernal pools.

- *Indicator species* – The presence or evidence of vernal pool indicator species breeding is not required for designating a vernal pool, but if they are documented, this would indicate the presence of a vernal pool. We did not require the presence of vernal pool indicator species because these species do not occur in all vernal pools and may not be present or breed in a pool every year. Vernal pools also provide habitat for a number of other species, and provide other important ecological functions. Also, some states have found that Wood Frogs breed in a number of other wetland types other than vernal pools, and have removed presence of indicator species from their vernal pool definitions (e.g, Pennsylvania). Other species also may be appropriate indicator species. This should be revisited in the future, and additional research is needed.

Finally, it is important to note that the vernal pool definition and methodology developed as part of this project should be considered a working definition and methodology, and should be revisited as we obtain more information and increase our knowledge and understanding of vernal pools. Additional research is needed to address issues discussed earlier (e.g., pool size, connection to other wetlands, minimum hydroperiod, presence of certain indicator species, and vegetation characteristics). It also should be pointed out that vernal pools could potentially be defined differently for management or protection (e.g., vernal pools that provide habitat for indicator species could be designated "significant" vernal pool or only vernal pools that are completely isolated from other wetlands could be recognized for protection). However, maintaining a clear and consistent definition of vernal pools that can be applied across the state would be ideal.

CHAPTER 4: Evaluating the effectiveness and efficiency of aerial photo interpretation and field surveys for locating and mapping vernal pools in forested areas in Michigan.

INTRODUCTION

Vernal pools are small, temporary bodies of water that form in shallow depressions primarily in forested areas throughout Michigan. They 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 connected to or part of larger wetland complexes. They also lack permanent connections to other water bodies, but can be temporarily connected to permanent water in some cases. The periodic drying of vernal pools prevents fish from establishing permanent 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 wildlife species. These include invertebrates, frogs, toads, salamanders, snakes, turtles, waterfowl, wetland birds, songbirds, and mammals (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 (Calhoun et al. 2003, Calhoun and deMaynadier 2004). Over 550 animal species have been documented in vernal pools in northeastern America (Colburn 2004). Vernal pools also provide food, water and/or habitat for a number of other animal species, including several endangered, threatened or rare species in Michigan. As wetlands, vernal pools contribute other important ecosystem services including nutrient cycling, water storage and infiltration, groundwater recharge, and flood control.

Vernal pools are highly vulnerable to disturbance or destruction, and are being lost across the Midwest and other parts of the country, including Michigan. Because of their small size and seasonal nature, vernal pools can be difficult to identify on the landscape, especially when they are dry, and are often overlooked. Vernal pools receive little or no protection under federal and state wetland regulations because they are small and often isolated from larger and/or permanent waterbodies and wetlands. Many of these small temporary wetlands have been drained or filled due to agricultural, residential, and/or other development. Some pools have been excavated to construct stormwater detention ponds or converted to permanent ponds. Vernal pools also have been impacted by forest management activities. Additionally, these small ecosystems may be impacted by climate change since changes in the hydrologic cycle can cause dramatic shifts in the timing and duration of flooding and number of vernal pools.

Due to recent increased awareness of the importance of vernal pools, there has been growing interest in identifying, studying, and conserving these small but valuable ecosystems in Michigan and other states. Michigan's Wildlife Action Plan has identified ephemeral wetlands as a critical and imperiled habitat in the state (Eagle et al. 2005). 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 also have included protection for vernal pools on forest lands (Michigan Department of Natural Resources and Michigan Department of Environmental Quality 2009, Sustainable Forestry Initiative 2010, Forest Stewardship Council 2010). However, 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 conservation efforts for these wetlands.

One of the goals of this project was to develop an effective and efficient approach for identifying and mapping vernal pools in the state. Some research and management efforts have identified and mapped vernal pools in the state but these efforts have focused primarily on several small, targeted or localized study areas (e.g., E. S. George Reserve in southeast Michigan, Pictured Rocks Natural Lakeshore in the central Upper Peninsula). Vernal pools also have been documented opportunistically as part of other natural features or natural resource inventories (e.g., MDNR's Integrated Forest Monitoring, Assessment and Prescription (IFMAP) inventory of state lands), or included in other wetland inventory efforts (e.g., NWI). But vernal pools have not been systematically inventoried and mapped throughout the state. Additionally, because of their small size, temporary nature, and tendency to occur in forested ecosystems, vernal pools can be challenging to locate with conventional survey and mapping techniques. Only several states (e.g., Massachusetts, Maine, New Hampshire, New Jersey, Rhode Island, and Vermont) have explicitly mapped potential vernal pool locations, primarily based on aerial photo interpretation (Burne 2001, Colburn 2004, Lathrop et al. 2005, Calhoun and deMaynadier 2008). Currently, the most common way to inventory and map vernal pools is through aerial photograph interpretation (Tiner 1990, Stone 1992, Brooks et al. 1998, Burne 2001, Lathrop et al. 2005, Burne and Lathrop 2008). Some states, such as New Jersey, have combined air photo interpretation with a GIS model to try to increase efficiency in identifying potential vernal pools. While aerial photo interpretation and field surveys can be fairly accurate or effective in identifying and mapping vernal pools, these approaches also are very time- and labor-intensive and expensive (Colburn 2004). Additionally, the accuracy rate of aerial photograph interpretation varies depending on landscape characteristics, surrounding forest cover, pool type and size, timing of the photos, photograph scale, and interpreter experience (Brooks et al. 1998, Burne 2001, Calhoun et al. 2003, Colburn 2004, Lathrop et al. 2005, Burne and Lathrop 2008).

Developing an effective and efficient approach for identifying, mapping, and assessing vernal pools is essential for conservation of these wetlands. Identifying an effective and efficient approach (or approaches) for mapping vernal pools in forested would allow us to better assess and monitor the distribution of vernal pools in the state. This information also would allow us to assess where vernal pools might be at greater risk or where they might be more common within the state, which would have important implications for vernal pool conservation and management efforts. This project investigated and evaluated several different methodologies for detecting and mapping vernal pools in forested landscapes, including air photo interpretation, GIS modelling, radar, and field surveys. New technologies, such as radar, may be able to enhance our ability to accurately locate and map vernal pools, particularly in forested landscapes. Additionally, the MDEQ Wetlands Program has been performing landscape-level assessment work which has involved mapping all watercourses based on aerial photographs and classifying all wetlands using NWI, landscape or topographic position, hydrological isolation, wetland function, and several other habitat indicators. The MDEQ is interested in trying to identify and map vernal pools using this approach. We conducted a preliminary evaluation of the effectiveness of this method for identifying potential vernal pools as well. This chapter summarizes efforts to identify and map vernal pools through aerial photograph interpretation and field sampling that were conducted as part of this project. This chapter also presents an accuracy assessment of the use of aerial photograph interpretation for mapping vernal pools. Efforts to identify and map vernal pools or areas with potential likelihood for presence of vernal pools using radar and GIS modelling are summarized and discussed in Chapters 5 and 6. An evaluation of the effectiveness and efficiency of these different methods for identifying and mapping potential vernal pools or areas with potential likelihood for presence of of vernal pools is presented in Chapter 7.

METHODS

Study Areas

To identify and select study areas for this project, we examined and considered several different factors. We first examined areas in the state where vernal pools occur in forested settings and are likely more abundant. 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). Secondly, we decided to focus the study areas on public lands to minimize issues related to landowner contact or access to sites. Thirdly, for developing the vernal pool classification framework, we needed to study vernal pools in relatively undisturbed areas in different parts of the state (i.e., Southern Lower Peninsula, Northern Lower Peninsula, and Upper Peninsula). We also wanted to examine and compare the effectiveness of the different methods for mapping vernal pools in different parts of the state to see if their effectiveness varies regionally. However, we decided to focus on several ecoregions and to not include study areas in certain parts of the state for this particular project (e.g., the Maumee Lake Plain (Sub-subsection VI.1.1) in southeast Lower Peninsula and the Niagaran Escarpment and Lake Plain (Subsection VIII.1) in the eastern Upper Peninsula) because the landscapes in these areas are so different and potentially the vernal pools in these areas also might be different from those in other parts of the state. We also had to consider and were limited to areas of the state that had the radar data and aerial photographs that we needed for identifying potential vernal pools (i.e., available radar data for spring and summer/flooded and not flooded conditions; high resolution, color-infrared leaf-off aerial photo imagery).

To help identify potential study areas, we also performed a GIS-based hotspot analysis on isolated forested wetlands to look for concentrations of hydrologically isolated wetlands in forested settings. This analysis helped identify areas in the state with potential likelihood or greater potential for encountering vernal pools. We first started with all National Wetland Inventory palustrine wetlands except excavated wetlands. We then selected forested wetlands in that at least 75% of a 100-meter buffer was forested, and wetlands that were at least 5 meters from a stream or a lake. Wetlands that were immediately adjacent or connected to wetlands that were adjacent or connected to a stream or lake were removed from the analysis. This analysis resulted in the identification of 115,358 isolated forested wetlands. These wetlands ranged in size from < 0.001 acre – 857 acres, with a vast majority of them < 2.5 acres in size. We used ArcGIS version 10.1 software (Environmental Systems Research Institute (ESRI), Redlands, California) to perform a hotspot analysis on these isolated forested wetlands using ~1 square mile hexagons. Results of the hotspot analysis of isolated forested wetlands are provided in Appendices 5 and 6.

We identified a number of potential study areas based on the ecological regions where vernal pools are likely more abundant, the isolated forested wetlands hotspot analysis, MNFI staff expertise and knowledge of the areas, and other considerations discussed earlier. We decided to select and focus on three study areas for the project. One study area was located in the southern Lower Peninsula (SLP) in the Waterloo and Pinckney State Recreation Areas in Washtenaw and Livingston counties and the Proud Lake and Highland State Recreation Areas in Oakland County (Figure 4.1). This study area was located within the Jackson Interlobate ecological region (Sub-subsection (VI.1.3) (Albert 1995) and Southeastern Interlobate Core physiographic region (Schaetzl et al. 2009) (Table 4.1). A second study area was located in the northern Lower Peninsula (NLP) in the Atlanta State Forest and the Huron National Forest in Montmorency, Oscoda, and Alcona counties (Figure 4.1). This study area was located within the Vanderbilt Moraine ecoregion (Sub-subsection VII.2.3) and the Grayling Outwash Plain ecoregion (Sub-subsection VII.2.2) (Albert 1995) and the Northern Lower Peninsula Tunneled Uplands physiographic region (Schaetzl et al. 2009) (Table 4.1). The third study area was located in the western Upper Peninsula (UP) in the Ottawa National Forest and Crystal Falls State Forest in Houghton, Baraga, and Iron counties (Figure 4.1). This study area was located in the Winegar Moraine (Sub-subsection IX.3.2) and Brule and Paint River (Sub-subsection IX.3.1) ecoregions (Albert 1995) and Sturgeon Incised Terrain physiographic region (Schaetzl et. al 2009) (Table 4.1). Albert (1995) and Schaetzl et al. (2009) provide detailed information about the characteristics of these ecoregions and physiographic regions.

Identifying and Mapping Vernal Pools through Aerial Photo Interpretation

Aerial photograph interpretation was used to identify and map potential vernal pools (PVPs) in all three study areas. For the study area in the southern Lower Peninsula, color-infrared and/or natural color aerial photo imagery from the spring of 1998, summer of 2005, and spring and summer of 2010 were available for the state and for Washtenaw, Livingston, and Oakland counties. For the study areas in the northern Lower Peninsula and western Upper Peninsula, only statewide color infrared aerial imagery from the spring of 1998 and natural color aerial imagery from the summer of 2005 and 2010 were available. Using ESRI ArcGIS software, we visually examined these available aerial imagery as well as additional aerial imagery from the MDNR and other sources (where available) and topographic maps on a computer screen at a map scale of 1:5000 to detect potential wetland areas and potential vernal pools in the study areas. 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. Topographic maps were examined to verify whether depressions or low slopes that existed would be favorable for development of hydrologically isolated wetlands and whether inlets/outlets were present. The statewide mosaic in leaf-on, natural color (NAIP 2010) helped determine whether the potential vernal pool (PVP) was forested, non-forested emergent vegetation, or non-forested shrub-dominated. Partner, 1998 CIR imagery, DNR State Park, NAIP 2005/2010 all helped in interpretation of PVPs that were likely dominated by floating aquatic vegetation (*Lemna* spp., *Nuphar* spp., *Nymphaea* spp.) based on color and texture signatures.

Table 4.1. Summary of study areas selected for aerial photo interpretation and field sampling.

Region	**Study Area / Managed Area**	**County(ies)**	**Subsection/ Sub-Subsection Number**	**Ecological Region - Subsection / Sub-Subsection**	**Physiographic Region**	**Landforms**
SLP	Waterloo and Pinckney State Recreation Areas	Washtenaw, Livingston	VI.1.3	Washtenaw - Jackson Interlobate	Southeastern Interlobate - Southeastern Interlobate Core	Ice-Contact Outwash Sand and Gravel; Glacial Outwash Sand and Gravel and Post-Glacial Alluvium
SLP	Highland State Recreation Area	Oakland	VI.1.3	Washtenaw - Jackson Interlobate	Southeastern Interlobate - Southeastern Interlobate Core	End Moraines of Coarse-Textured Till; Glacial Outwash Sand and Gravel and Post-Glacial Alluvium
SLP	Proud Lake State Recreation Area	Oakland	VI.1.3	Washtenaw - Jackson Interlobate	Southeastern Interlobate - Southeastern Interlobate Core	Glacial Outwash Sand and Gravel and Post-Glacial Alluvium; End Moraines of Coarse-Textured Till
NLP	Huron National Forest	Alcona, Oscoda	VII.2.3, VII.2.2	Highplains - Vanderbilt Moraines, Highplains - Grayling Outwash Plain	Northern Lower Peninsula High Hills - Northern Lower Peninsula Tunneled Uplands	End Moraines of Coarse-Textured Till
NLP	Atlanta State Forest	Montmorency	VII.2.3	Highplains - Vanderbilt Moraines	Northern Lower Peninsula High Hills - Northern Lower Peninsula Tunneled Uplands	Coarse-Textured Glacial Till
UP	Ottawa National Forest	Baraga, Houghton, Iron	IX.3.2, IX.3.1	Upper Wisconsin/ Michigan Moraines - Winegar Moraine	Superior Bedrock Uplands - Sturgeon Incised Terrain	End Moraines of Coarse-Textured Till; Coarse-Textured Glacial Till
UP	Crystal Falls State Forest	Baraga, Iron	IX.3.2, IX.3.1	Upper Wisconsin/ Michigan Moraines - Winegar Moraine	Superior Bedrock Uplands - Sturgeon Incised Terrain	End Moraines of Coarse-Textured Till; Coarse-Textured Glacial Till

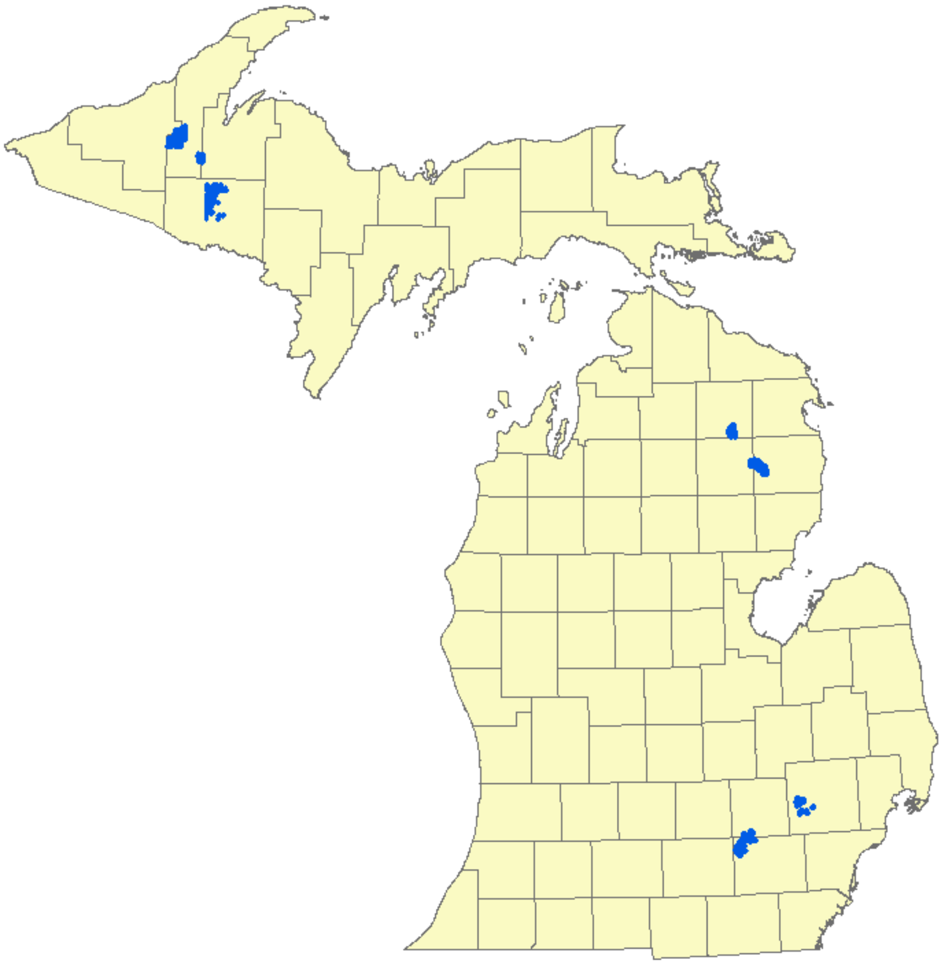


Figure 4.1. Map showing general locations of the three study areas in the southern/southeastern Lower Peninsula (SLP), northern/northeastern Lower Peninsula (NLP), and western Upper Peninsula (UP) of Michigan.

Only isolated forested vernal pools or those that supported floating aquatic or submergent vegetation were mapped as potential vernal pools (PVPs). Wetlands that appeared to be dominated by shrubs or emergent vegetation (i.e., > 50% cover) were not mapped as PVPs, although we later revised the vernal pool definition to include shrub-dominated wetlands (>50% cover) as vernal pools. Larger isolated wetlands were designated as PVPs based on the likelihood of stable hydrologic input and potential to experience a significant draw-down in water levels during most years. In the northeastern U.S., including Michigan, most vernal pools are less than 1 ha/ 2.5 ac in size (Calhoun and de Maynadier 2008), and the vast majority is less than 0.4 ha/1.0 ac in size. The upper size range of vernal pools is limited because they tend to acquire the vegetation of particular natural community types (e.g., wet prairie or southern hardwood swamp) as their size increases and therefore are not considered vernal pools by most definitions (Thomas et al. 2010). 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 all three study areas to provide consistency in interpretation across the study areas.

Identifying and Mapping Vernal Pools through Field Sampling

Field sampling was conducted in all three study areas in 2012 and 2013 to identify, map, and assess vernal pools on the ground. Field sampling to identify and map vernal pools was primarily conducted in 2012 in all three study areas. Additional targeted sampling was conducted in 2013 to verify or confirm some of the sampling results from 2012 and to identify and map additional vernal pools. These efforts also were conducted to validate vernal pool mapping results from aerial photograph interpretation and other remote sensing and modelling methods that were conducted as part of this project. This information was used to evaluate the effectiveness and efficiency of these different methods for identifying and mapping vernal pools. Field sampling results from 2012 also were used to identify potential study sites for efforts in 2013 to characterize and assess vernal pools on the ground. Additionally, vernal pools identified and mapped in the field in 2012 and 2013 were used to develop and evaluate GIS models to identify and map areas with potential likelihood for presence of vernal pools (see Chapter 6).

We used a stratified random sampling design for the field surveys to identify and map vernal pools. A sampling grid of 1-ha (2.5 ac) test cells was applied to each study area (Figure 4.2). Within each study area, test cells were randomly ordered for field sampling starting from 1 through the last test cell in the study area. We surveyed test cells that contained potential vernal pools (PVPs) identified and mapped from aerial photo interpretation as well as test cells that did not contain any PVPs. We surveyed the entire area within sampled test cells. This sampling design allowed us to estimate accuracy rates and error rates associated with commission (i.e., false positives) and omission (i.e., false negatives) within each study area and

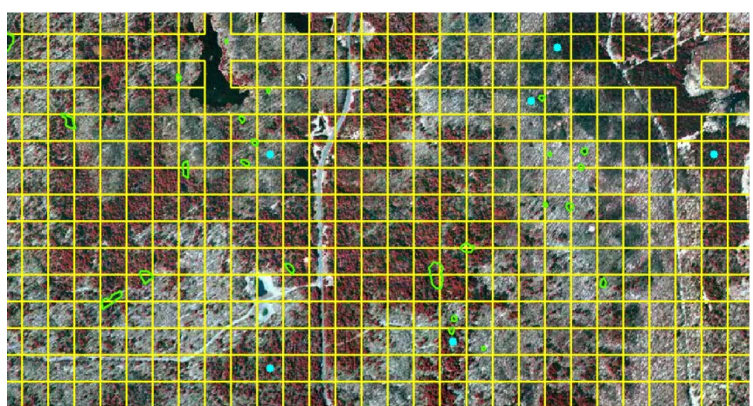


Figure 4.2. Example of sampling grid comprised of 1-ha (2.5-ac) test cells that was applied to each study area for field sampling.

across study areas. The first 150 randomly ordered test cells in each study area were selected or targeted for sampling in 2012. Because such a small number of these test cells contained PVPs mapped from aerial photo interpretation, we identified additional test cells with PVPs to sample within each study area, and randomly ordered them for sampling. The first 40 of these randomly ordered test cells with PVPs were targeted for sampling in 2012. This was done to increase the number of test cells surveyed with PVPs to better estimate commission error. We also sampled a small number of test cells that contained PVPs identified only from the MDEQ's isolated depressional wetland analysis to add to the accuracy assessment and evaluation of this method.

We conducted field sampling to identify and map vernal pools during two different time periods in 2012. We conducted field sampling in the spring and early summer of 2012 (i.e., early season sampling) in each study area to identify vernal pools when they are typically filled with water. Early season sampling was conducted from 4 May to 14 June 2012 overall, with early season sampling conducted in the study area in the SLP from 4 May to 18 May, in the NLP from 23 May to 6 June, and in the UP from 10 June to 14 June. We sampled test cells in each study area following the randomly assigned order starting with test cell ordered 1. The goal during the early season sampling was to survey the test cells randomly ordered 1 through 50, or as many of these test cells as possible, within each study area. Additional test cells in each study area were surveyed during the early season as time permitted.

We also conducted field sampling during late summer and fall of 2012 (i.e., late season sampling). Late season sampling was conducted from 14 August to 2 November 2012 overall, with late season sampling conducted in the study area in the SLP from 14 August to 2 November, in the NLP from 21 August to 12 October, and in the UP from 18 September to 20 October. Late season sampling consisted of surveying additional test cells to identify and map vernal pools and revisiting test cells that contained vernal pools identified during the early season sampling to verify that the pools dry or draw down significantly and are temporarily flooded or semi-permanent and not permanently flooded. The goal during the late season sampling was to revisit all test cells that had vernal pools identified during the early season sampling, and to survey additional test cells ordered 51 through 150, or as many of these test cells as possible and as time and funding permitted. Late season sampling also included sampling additional test cells with PVPs to better estimate commission error. We attempted to survey at least 25-30 of the first 40 additional test cells with PVPs that were randomly ordered for sampling. Late season sampling also included sampling a small number of test cells in the study area in the SLP that contained potential vernal pools identified from MDEQ's isolated depressional wetland analysis but not from MNFI's aerial photo interpretation.

In 2013, surveys focused on revisiting some of the test cells and/or vernal pools that were initially sampled during the early and/or late seasons in 2012 and needed additional verification or needed to be mapped. For example, these included vernal pools or potential vernal pools that were found during late season surveys in 2012 and were dry. Surveys in 2013 also included surveying and mapping additional vernal pools to collect additional information and identify additional study sites for accuracy assessment, ecological characterization, and GIS modelling efforts in 2013.

A total of 402 test cells were sampled across all three study areas in 2012 (Table 4.3). These consisted of 125 test cells sampled in the study area in the SLP, 168 test cells sampled in the study area in the NLP, and 109 test cells sampled in the study area in the UP (Table 4.3). A total of 149 test cells were surveyed during the early season in 2012 (Table 4.3). An additional 253 test cells were surveyed during the late season in 2012, of which 92 were additional test cells with PVPs selected for sampling to better estimate commission error (including 5 test cells in the study area in the SLP that contained PVPs identified only from MDEQ's isolated wetland analysis) (Table 4.3). Twenty-six of the test cells (i.e., 12 in the SLP, 5 in the NLP, and 9 in the UP) were surveyed initially during the early season in 2012 and revisited during the late season in 2012 to confirm pool drying and verify test cell sampling results.

Table 4.3. Summary of randomly ordered test cells that were sampled during the early and late seasons in 2012 to identify and map vernal pools on the ground in the study areas in the southern Lowe Peninsula (SLP), northern Lower Peninsula (NLP), and western Upper Peninsula (UP).

Study Area	Number of Test Cells Sampled - Early Season[1]	Number of Test Cells Sampled - Late Season[1]	Number of Additional Test Cells with PVPs Sampled – Late Season[2]	Total Number of Test Cells Sampled in 2012[3]
SLP	44	50	31	**125**
NLP	57	76	35	**168**
UP	48	35	26	**109**
Total	149	161	92	**402**

[1]These test cells were selected from the first 150 randomly ordered test cells within each study area.
[2]These test cells were selected from first 40 additional test cells with PVPs that were identified and randomly ordered for sampling to better estimate commission error within each study area. These test cells were surveyed in addition to the test cells that were selected from the first 150 randomly ordered test cells within each study area.
[3]These included test cells/vernal pools that were revisited in 2013 for verification and/or mapping.

Field sampling to identify and map vernal pools on the ground primarily consisted of two observers or surveyors systematically walking a series of transects or passes through each 1-ha test cell selected for sampling to identify and locate vernal pools within the test cell. Observers used GPS units (i.e., Ashtech units and/or IPAQ GPS units) to navigate to the sample test cell. Once at or in the test cell, observers divided up the test cell into halves or thirds, and walked parallel to each other through the test cell from one end of the test cell to the other end, making one or two passes through the test cell depending on visibility (e.g., vegetation type and density, slope, etc.) and ability to see vernal pools within the test cell. Surveyors either walked north to south or east to west (or vice versa) through the test cell. One or both observers had a GPS unit with the test cell grid, aerial photographic imagery, and other relevant maps for each study area so that observers could see the boundaries of the test cells during field surveys. Mapped potential vernal pools were confirmed and additional new or unmapped vernal pools were identified and located within the sample test cells.

We created a geodatabase using ESRI ArcGIS software to record and organize data from the field sampling. Data were primarily recorded in the field on a handheld GPS or PDA device (i.e., Ashtech GPS unit or IPAQ GPS unit). Data collected for each test cell surveyed included survey date, surveyor initials, and vernal pool presence based on the five categories described in Table 4.4 and the vernal pool definition developed as part of this project (see Chapter 3). Each sample test cell was assigned only one of the five categories. If a test cell contained at least one confirmed or possible vernal pool, the test cell was assigned the 'H2O-VP" or "H2O-VP?"category, even if the test cell also contained other waterbodies or wetlands that were not vernal pools.

Vernal pools identified in the field were mapped in the field, 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. Dry vernal pools identified during late season surveys in 2012 were revisited and mapped in 2013 when the pools were filled with water when possible. Additional vernal pools or potential vernal pools that were encountered during field sampling outside of selected test cells also were recorded and mapped, when possible. Vernal pools identified in the field were photographed for documentation and verification.

Table 4.4. Categories used to designate vernal pool presence in test cells sampled within each study area in 2012.

Vernal Pool Category	Category Definition/Description
H2O-VP	Water/wetland was present in the test cell, and the wetland was a vernal pool. [Note: Before the "Dry-VP" category was available, this category was used during late season surveys to designate test cells that contained vernal pools that were dry (i.e., no water present but obvious/discrete basin and evidence that water had been present). Just noted pool was dry in the notes.]
H2O-VP?	Water/wetland was present in the test cell, and the wetland may be a vernal pool (not 100% sure/need to revisit and/or further discussion/consideration). [Note: During the late season survey, we also used this category to designate test cells that contained areas/wetlands that looked like they might be vernal pools but were dry. Noted potential dry vernal pool in the notes.]
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.
Dry-VP	This category/designation was added for late season sampling in the UP. This was for vernal pools that were dry (i.e., completely dry). If the pool still had some water, the "H2O-VP" category was used.

Accuracy Assessment

To evaluate the effectiveness of aerial photograph interpretation for identifying and mapping vernal pools, we conducted an accuracy assessment of this method by comparing vernal pool mapping results from the aerial photograph interpretation to field sampling results of the test cells from 2012 and 2013. As part of the accuracy assessment, we wanted to quantify the accuracy rate of aerial photo interpretation for mapping vernal pools (i.e., true positives) and areas without vernal pools (i.e., true negatives), as well as error rates associated with omission (i.e., pools observed in the field but were not mapped from aerial photography, also known as false negatives), and commission (i.e., pools mapped from aerial photography that were not vernal pools, also known as false positives). 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 (see Chapter 3); and (2) features that were not waterbodies or wetlands (e.g., dry land). Field sampling of test cells conducted by MNFI was the primary method used to assess the accuracy of aerial photo interpretation as well as other methods for identifying and mapping vernal pools or areas with suitable habitat and potential likelihood for presence of vernal pools. Accuracy, commission, and omission error rates were determined by comparing the test cells that contained vernal pools/PVPs identified from aerial photo interpretation and test cells that did not contain vernal pools/PVPs identified from aerial photography with test cells in which vernal pools were identified in the field (i.e., test cells categorized as H2O-VP, H2O-VP?, or Dry-VP) and those in which vernal pools were not identified in the field (i.e., test cells categorized as H2O-NVP or H2O-None) in 2012 and 2013 (Table 4.5).

Table 4.5. Summary of test cell comparisons that were used to determine accuracy rates and commission and omission error rates associated with mapping vernal pools (VPs) from aerial photograph interpretation.

	Surveyed Test Cells with VPs[2] (H2O-VP, H2O-VP?, Dry-VP)	Surveyed Test Cells without VPs[2] (H2O-NVP, H2O-None)
Surveyed Test Cells with PVPs[1]	Accuracy / True Positives	Commission / False Positives
Surveyed Test Cells without PVPs[1]	Omission / False Negatives	Accuracy / True Negatives

[1]PVPs – Potential vernal pools identified from aerial photograph interpretation.
[2]VPs – Vernal pools identified from field sampling.

RESULTS

Aerial Photo Interpretation

A total of 1,342 vernal pools or potential vernal pools were identified and mapped across the three study areas from aerial photograph interpretation. Of these, 510 potential vernal pools were mapped in the study area in the SLP, 379 were mapped in the study area in the NLP, and 453 were mapped in the study area in the UP. A total of 136 vernal pools or potential vernal pools were identified and mapped from aerial photo interpretation in the test cells that were sampled in 2012 and 2013. Of these, 47 potential vernal pools were identified and mapped in the sampled test cells in the SLP study area, 57 were mapped in sampled test cells in the NLP study area, and 32 were mapped in sampled test cells in the UP study area.

Of the 402 test cells that were sampled in 2012 and 2013, 110 (27%) of the test cells contained potential vernal pools identified and mapped from aerial photo interpretation, and the remaining 292 (73%) test cells did not contain potential vernal pools mapped from aerial photo interpretation (Table 4.6). The numbers and percentages of test cells that were surveyed in each study area that contained potential vernal pools identified from aerial photo interpretation were fairly similar across the three study areas. They ranged from 40 (32%) of 125 test cells sampled in the SLP study area to 40 (24%) of 168 test cells sampled in the NLP study area and 30 (28%) of the 109 test cells sampled in the UP study area. The numbers of test cells that were surveyed that did not contain potential vernal pools identified from aerial photo interpretation varied somewhat among the three study areas, but the percentages of sampled test cells that did not contain potential vernal pools identified from aerial photo interpretation were fairly similar across the study areas. The numbers and percentages of sampled test cells that did not contain potential vernal pools identified from aerial photo interpretation ranged from 85 (68%) of 125 sampled test cells in the SLP study area to 128 (76%) of 168 sampled test cells in the NLP study area and 79 (72%) of 109 sampled test cells in the UP study area.

Field Sampling

A total of 155 vernal pools were identified in the test cells that were sampled across the three study areas in 2012 and 2013. Of the total number of vernal pools, 51 vernal pools were identified during field sampling in the SLP study area, 57 in the NLP study area, and 47 in the UP study area. Of the 155 vernal pools identified in the sampled test cells in the field, 99 of the pools had been identified and mapped from aerial photo interpretation, and 56 of the pools had not been mapped and were new or additional pools encountered in the field. Of the 99 vernal pools mapped in the field, 36 were located in test cells in the SLP study area, 48 were located in the NLP study area, and 15 were located in the UP study area. We also identified over 60 additional vernal pools in the field outside of the sampled test cells across the three study areas.

Vernal pools were identified in the field in 115 (28%) of the 402 test cells that were sampled across the three study areas in 2012 and 2013 (Table 4.6). Vernal pools were identified in similar numbers and percentages of sampled test cells across the study areas. Vernal pools were found in the field in 39 (31%) of 125 sampled test cells in the SLP study area, 38 (23%) of 168 sampled test cells in the NLP study area, and 38 (35%) of 109 sampled test cells in the UP study area (Table 4.6).

Accuracy Assessment

The accuracy rates for identifying and mapping vernal pools from aerial photograph interpretation based on vernal pools and test cells sampled in 2012 and 2013 were fairly high overall across the three study areas (Table 4.6). Of the 136 potential vernal pools identified and mapped from aerial photo interpretation in test cells sampled across all three study areas, 99 of them were verified as vernal pools in the field. This resulted in an overall accuracy rate of 73%. The accuracy rate for aerial photo interpretation correctly identifying and mapping vernal pools was highest in the NLP study area, with 48 (84%) of the 57 vernal pools mapped from aerial photo interpretation verified as vernal pools in the field. In the SLP study area, the accuracy rate was similar, with 36 (77%) of the 47 vernal pools mapped from aerial photos verified as actual vernal pools in the field. The accuracy rate for identifying and mapping vernal pools from aerial photo interpretation was lowest in the UP study area, with only 15 (47%) of 32 potential vernal pools mapped from aerial photos verified as vernal pools in the field.

The accuracy rate for aerial photo interpretation correctly identifying test cells with vernal pools in the field was 74% overall, and the accuracy rate for correctly identifying test cells that did not contain vernal pools in the field was 88% overall (Table 4.6). The accuracy rates did vary somewhat regionally across the three study areas though. The accuracy rates for aerial photo interpretation for identifying and mapping vernal pools in sampled test cells were highest in the NLP study area. Aerial photo interpretation was able to correctly identify and map vernal pools in 85% of the sampled test cells that contained vernal pools in the field, and correctly identify the absence of vernal pools in 97% of the sampled test cells that did not contain vernal pools in the field in the NLP study area (Table 4.6). The accuracy rates for aerial photo interpretation were slightly lower but still fairly high in the SLP study area, with aerial photo interpretation correctly identifying vernal pools in 73% of the sampled test cells that contained vernal pools in the field and correctly identifying the absence of vernal pools in 88% of the sampled test cells that did not contain vernal pools in the field (Table 4.6). The accuracy rate for correctly identifying and mapping vernal pools in sampled test cells was lowest in the UP study area (i.e., 60%), although the accuracy rate for correctly identifying the absence of vernal pools in sampled test cells was fairly high (i.e., 75%) (Table 4.6).

Commission and omission error rates for identifying and mapping vernal pools from aerial photograph interpretation were fairly low overall across the three study areas and within each of the study areas. The overall commission error rate for identifying and mapping vernal pools from aerial photo interpretation was 26% across the three study areas, indicating vernal pools were not present in 26% of the sampled test cells in which we had mapped vernal pools from aerial photographs (i.e., false positives) (Table 4.6). Commission error ranged from 15% in the NLP study area to 27% in the SLP study area and 40% in the UP study area (Table 4.6). The overall omission error rate for identifying and mapping vernal pools from aerial photo interpretation was 12% across the study areas, indicating vernal pools were not mapped from aerial photo interpretation in 12% of the sampled test cells that actually contained vernal pools in the field (i.e., false negatives) (Table 4.6). Omission error ranged from only 3% in the NLP study area and 12% in the SLP study area to 25% in the UP study area (Table 4.6).

Table 4.6. Accuracy assessment of aerial photograph interpretation for identifying and mapping vernal pools in the study areas in southeast Lower Peninsula (SLP), northeast Lower Peninsula (NLP), and western Upper Peninsula (UP) based on test cells that were sampled in 2012 and 2013.

Study Area	Number of Test Cells with PVPs[2]	Number of Test Cells with VPs/VP?[3] in the Field	Accuracy Rate[4] (True Positives)	Number of Test Cells with No VPs/VP?[2] in the Field	Commission Error[5] (False Positives)
SLP (n=125)[1]	40	29	73%	11	27%
NLP (n=168)[1]	40	34	85%	6	15%
UP (n=109)[1]	30	18	60%	12	40%
Overall/Total	110	81	74%	29	26%
Study Area	**Number of Test Cells without PVPs[1]**	**Number of Test Cells with VPs/VP?[2] in the Field**	**Omission Error[6] (False Negatives)**	**Number of Test Cells with No VPs/VP?[2] in the Field**	**Accuracy Rate[7] (True Negatives)**
SLP (n=125)[1]	85	10	12%	75	88%
NLP (n=168)[1]	128	4	3%	124	97%
UP (n=109)[1]	79	20	25%	59`	75%
Overall/Total	292	34	12%	258	88%

[1]Sample size in terms of the total number of test cells surveyed in each study area.
[2]PVPs = Potential vernal pools identified from aerial photograph interpretation.
[3]VPs/VP? = Vernal pools / possible vernal pools identified from field sampling.
[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 (e.g., 29/40 or 73% accuracy rate for the SLP study area).
[5]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 (e.g., 11/40 or 27% commission error rate for the SLP study area).
[6]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 (e.g., 10/85 or 12% omission error rate for the SLP study area).
[7]Accuracy rate (true negatives) was calculated based on the number of test cells that did not contain 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 (e.g., 75/85 or 88% accuracy rate for the SLP study area).

DISCUSSION

Overall, aerial photograph interpretation was fairly effective for identifying and mapping vernal pools across the three study areas, and particularly within the SLP and NLP study areas. The overall accuracy rate for identifying and mapping vernal pools from aerial photo interpretation across the three study areas was 73% for correctly identifying and mapping individual vernal pools, 74% for correctly identifying and mapping vernal pools in sampled test cells, and 88% for correctly identifying the absence of vernal pools in sampled test cells. Commission error was low to moderate, and higher than omission error, ranging from 15% in the NLP study area to 40% in the UP study area and 26% overall. Omission error rates were fairly low except in the UP study area, ranging from 3% in the NLP study area and 12% in the SLP study area and across the three study areas to 25% in the UP.

Our overall accuracy rate and accuracy rates for individual study areas for identifying and mapping vernal pools from aerial photo interpretation were generally little lower than accuracy rates reported from vernal pool mapping efforts in other states that have utilized aerial photo interpretation to identify and map vernal pools. Our commission error rates also were generally higher than those reported in other states. For example, several vernal pool mapping efforts using aerial photos in Massachusetts reported accuracy rates of over 80 - 90% and commission errors of less than 3-5% (Burne 2001). A statewide vernal pool mapping effort in New Jersey that included mapping vernal pools from aerial photographs and field sampling reported an accuracy rate of 88% and a commission error rate of 12% for identifying and mapping individual vernal pools (Lathrop et al. 2005). The vernal pool mapping effort in New Jersey also systematically surveyed 60 1-ha test plots to estimate omission error, which was about 30%. This effort is similar to our field sampling design, and their omission error was generally much higher than our omission error rates. Differences in accuracy and commission and omission 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 photos used, timing of the aerial photos, and photointerpreter experience.

Our commission error rates were fairly high compared to other studies, and higher than our omission rates. Casting of shade by canopy trees can appear very similar to wetlands, and likely contributed to commission error. Also, since we only had and utilized color-infrared photos for spring when pools were wet and not during the summer when pools were dry, there was no definitive way for remotely ensuring that mapped PVPs were temporarily-inundated or semi-permanently flooded wetlands. 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. Additionally, because we were viewing aerial photos on the computer screen and not using stereoscopes which would allow us to see the topographic variations in the terrain better, this may have contributed to our commission error.

Several factors likely contributed to our omission error. As reported in other studies, very small pools are generally difficult to identify and map, and can not be identified and mapped with great reliability using aerial photos. Burne (2001) found that pools smaller than 15 – 18 m (50-60 ft) in diameter could not be reliably identified from aerial photos at a scale of 1:12,000, and pools between 18 and 38 m (60 and 125 ft) in diameter were easily confused with tree shadows and some types of man-made features. Burne (2001) found that pools at least 30 m (100 ft) 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 40 m (131 ft) or areas less than 120 m^2 (0.03 ac) are difficult to reliably identify and map with aerial photos, but pools with perimeters greater than approximately 50 m and areas greater than approximately 200m2 (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, and can contribute to omission error (Burne 2001). Both these factors contributed to our omission error, particularly in the study area in the UP where we had more coniferous trees and vegetation than in the study areas in the SLP and NLP. We also changed our definition of vernal pools slightly after aerial photo interpretation was completed to include pools that had >50% shrubs in the basin. This also may have contributed to omission error since we tried to not include pools that appeared to have >50% shrub cover during aerial photo interpretation.

Aerial photo interpretation was fairly effective at identifying and mapping vernal pools in the study areas in the SLP and NLP, but was not very effective in the study area in the UP. We are not entirely sure why this was the case. More extensive forested cover across the landscape and greater amounts of coniferous vegetation in general in the study area in the UP likely made it more difficult to detect vernal pools on aerial photos and likely contributed to lower accuracy and higher commission and omission error for identifying and mapping vernal pools in the UP. Additional efforts to identify and map vernal pools using aerial photos should be conducted to further investigate this, and to see if we can improve our ability to identify vernal pools using aerial photo interpretation in the UP.

The numbers of sampled test cells that contained vernal pools in the field were very low compared to the number of test cells that were surveyed within and across the three study areas, with vernal pools found in only 115 (28%) of the 402 test cells sampled. This suggests that vernal pools may not be very common or may not occur very frequently or in high densities across the landscape, although they can be fairly abundant or dense in some areas (i.e., locally common in some areas). Results from the small isolated wetland hotspot analysis we conducted to identify potential study areas also seem to suggest vernal pools may be more common or abundant in some areas or parts of the state than others. More research and monitoring are needed to determine the distribution and abundance of vernal pools within the study areas and across the state. We also found that approximately 25% of the potential vernal pools that were mapped from our aerial photo interpretation was not mapped in NWI.

This study represents the first targeted and extensive effort to use aerial photo interpretation and field sampling to systematically identify and map vernal pools in Michigan. This study also represents the first time the use of aerial photo interpretation for identifying and mapping vernal pools remotely have been systematically evaluated in Michigan, and one of only several efforts that have rigorously evaluated the effectiveness of aerial photo interpretation for mapping vernal pools in the country (e.g., Burne 2001, Lathrop et al. 2005). Our study is also one of only a few studies that have utilized a probabilistic sampling design, and have determined and provided commission and omission error rates (Calhoun et al. 2003, Lathrop et al. 2005, Van Meter et al. 2008). If an effective probabilistic sampling design and method for documenting and mapping vernal pools can be developed, including knowledge of its accuracy and commission and omission error rates, a sampling program could be implemented that identifies and locates a subset of vernal pools from which an unbiased estimate of the total amount of vernal pool habitat could be obtained (Van Meter et al. 2008). This sample also could be used to monitor and make inferences about the status of associated target species (e.g., Wood Frogs and mole salamanders) (Van Meter et al. 2008).

Results from this study suggest that developing an effective vernal pool mapping and sampling program would be possible, and that aerial photo interpretation is an effective method for mapping vernal pools in the state, at least potentially for parts of the state such as the SLP and NLP. However, we would need to improve and further evaluate the capability of this method before it could be used to document and map vernal pools reliably in certain parts of the state, such as the western UP, eastern UP, and lakeplain ecoregions. Additionally, while aerial photo interpretation can be very effective at identifying and mapping vernal pools in some areas, this method can be very time-consuming and expensive (Colburn 2004). The effectiveness of this method also is sensitive to a number of factors which were described earlier. Developing or utilizing a different and more efficient method or combining aerial photo interpretation with another method (e.g., radar and/or GIS modelling) that could help make it more efficient and reduce the time needed to map potential vernal pools while maintaining high accuracy should be considered. Obtaining recent, high-resolution CIR aerial photos of the state taken in the spring during leaf-off conditions also would increase the effectiveness and efficiency of aerial photo interpretation for mapping vernal pools. While documenting and mapping vernal pools from aerial photo interpretation can be time intensive and costly, this method (or another effective remote sensing or modelling method) is still more cost-effective and efficient for identifying and mapping vernal pools than just field sampling alone.

Finally, while field sampling (or ground-truthing) can be time intensive and expensive, it is essential for validating the presence of vernal pools as well as associated indicator and/or other targeted species (Brown and Jung 2005). Field validation is especially warranted given some of the omission and commission error rates that were documented during this study. For example, we documented a 25% omission error rate in the UP study area which means that field sampling could reveal as many as 25% more pools than identified from aerial photographs alone. Options for improving the efficiency and effectiveness of field validation efforts should be considered and further investigated. One option may be to prioritize areas or focus on particular areas for field validation (e.g., areas where commission and/or omission error are particularly high or higher than other areas). If the objective is to validate or confirm presence of a vernal pool, a tiered or step-wise approach using field indicators could be developed to try to reduce time and resources needed for field validation. For example, potential vernal pools could be surveyed early in the spring after snowmelt to look for evidence of breeding vernal pool obligate or indicator species such as fairy shrimp and adults, larvae, and/or egg masses of *Ambystomatid* salamanders (esp. Spotted Salamander/Blue-spotted Salamander) and Wood Frogs. If these species are observed in the pool, a second visit to document pool drying is not needed to verify presence of a vernal pool. If these species are not observed during the first visit, a second visit to document pool drying/significant drawdown would be needed to verify the feature is a vernal pool. Other field indicators could be developed to verify a vernal pool when it is wet or dry, such as the presence of certain obligate or facultative wetland plant species in the pool basin, presence of fingernail clams in a dry pool basin, presence of a certain amount or depth (e.g., 2-3 cm) of organic soil/muck in the top layer of the pool’s substrate in a dry pool basin, and/or some combination of field indicators. Field sampling from this project also provided insights into the best times to survey for vernal pools and look for some of these field indicators. Additional work is needed to identify the most efficient and reliable field indicators and methodology for validating vernal pools, and to clarify if different indicators or methods are needed for different parts of the state and/or different types of vernal pools (e.g., whether fairy shrimp is found in vernal pools throughout the state and in all pool types).

CHAPTER 5: Investigating the use of radar for identifying vernal pools in forested areas in Michigan.

INTRODUCTION

The detection and mapping of vernal pools is hindered by forest canopy cover, making the utility of optical imagery alone limited. An improved remote sensing method was sought that would be applicable to map the entire state of Michigan; one which would be efficient, cost-effective and have high accuracy. Towards this end, satellite-based radar data were evaluated to determine if the 10 m resolution Japanese ALOS PALSAR FBS (fine beam single) imagery (circa 2006-2011) could be used to effectively detect potential vernal pools. Using the definition criteria of a vernal pool (that they are flooded in the spring and dry in the summer), two seasons of radar imagery were sought which would capture these hydrological differences.

Radar sensors (synthetic aperture radar – SAR) are low frequency active systems, providing their own energy source and allowing collection of data regardless of cloud cover or daylight. Their low frequency also allows for penetration of a canopy cover to detect the presence of standing water. Characteristic enhanced (bright) radar signatures are observed, with high energy reflected from the forests in the flooded condition due to a "double-bounce effect" (Figure 5.1). Here the incoming energy bounces from the tree trunks to the smooth, high dielectric water surface and back to the sensor, with less energy absorbed than from a non-flooded forest. In the dry state, the reflected signatures are typically moderate, with a gray appearance in the image.

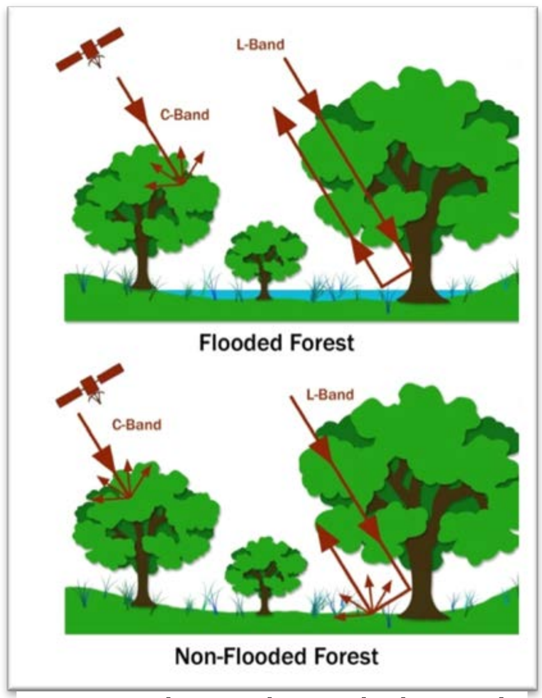


Figure 5.1. Schematic showing the theoretical scattering of L-band (~24 cm wavelength) SAR from flooded versus non-flooded forests.

Using this temporal set of signatures characteristic of vernal pools, a method was developed to find areas of "potential vernal pools." Once such a method was developed, maps for each region of study were created and work was focused on verifying these maps. The second step of this project was to use the 10 m L-band PALSAR data in combination with LiDAR data and Digital Elevation Model (DEM) data to improve mapping capability. While the PALSAR alone may be used to blindly determine areas of potential vernal pools, in this second step, known vernal pools were used to train a classifier to map, with greater accuracy and lower commission error, potential vernal pools. This second step focused on Pinckney State Recreation Area for development, and the approach was then applied to the northern Lower Peninsula study area.

METHODS

Pilot Study Areas

The study areas for the pilot radar study included the Pinckney and Proud Lake State Recreation Areas in the southern Lower Peninsula (SLP), northern Lower Peninsula (NLP), and western Upper Peninsula (UP) (Figure 5.2).

SAR approach to detect potential vernal pools without training data

Using the methods shown in the box below, preliminary maps of potential SAR-derived vernal pools were created for image pairs (Table 5.1) for each of the study areas (Figure 5.2) in 2013. An example of the process is shown with a subset of a PALSAR scene in Figure 3. The final map presents a probability map of the potential of finding a vernal pond near the locations identified in the map. Comparison of these maps to field data and air photo delineated vernal pools was conducted by MNFI, and a subset of the positive vernal pools field points are shown in Figure 3 as bright green dots. Probability maps for each of the pilot study areas were delivered to MNFI in 2013. These maps provide a guide for where to conduct field work and/or where to use leaf off air photos to delineate vernal ponds. In the next section, SAR is integrated with LiDAR and DEM data to improve delineation of vernal ponds from remote sensing.

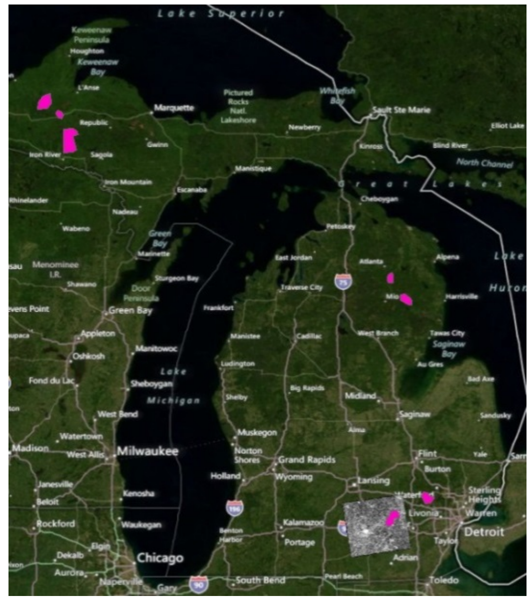


Figure 5.2. Map of pilot study areas with potential vernal pools (pink). The gray square image in the lower part of the map is a PALSAR image over Pinckney Recreational area.

SAR Methodology:

- A spring/summer image pair of PALSAR is used for detection of potential vernal pools:

  - The summer scene is subtracted from the Spring scene and areas of high return are extracted and assigned a value of 1.

  - A neighborhood Focal Sum is calculated in a 5 x 5 pixel moving window (6.5 m pixel spacing = 1056 m^2 ~ 0.1 ha).

- The resulting raster layer gives a probability of how likely an area is to contain a vernal pool (red is higher probability, green lowest in Figure 5.3).

- Subtracting the two dates in this method is important because it highlights those areas that were wet (bright) in the spring, and dry (darker) in the summer.

Table 5.1. List of PALSAR 10-m resolution L-HH images all processed, orthorectified and preliminary maps created for vernal pools.

Image ID	Mode	Incident Angle	Image Date	Study Area	image date notes
ALPSRP223340890	FBS	34.3	4/4/2010	NLP	need to mosaic 2 images
ALPSRP223340880	FBS	34.3	4/4/2010	NLP	need to mosaic 2 images
ALPSRP223050910	FBS	34.3	4/4/2010	UP	need to mosaic 2 images
ALPSRP223050920	FBS	34.3	4/4/2010	UP	need to mosaic 2 images
ALPSRP029480880	FBS	41.5	8/14/2006	NLP	
ALPSRP018540880	FBS	41.5	5/31/2006	NLP	
ALPSRP024960910	FBS	34.3	3/25/2007	UP	need to mosaic 2 images
ALPSRP024960920	FBS	34.3	3/25/2007	UP	need to mosaic 2 images
ALPSRP062010910	FBS	41.5	7/14/2006	UP	need to mosaic 2 images
ALPSRP062010920	FBS	41.5	7/14/2006	UP	need to mosaic 2 images
ALPSRP223340840	FBS	34.3	4/4/2010	Proud Lake	
ALPSRP018540840	FBS	41.5	5/31/2006	Proud Lake	to capture Highland SRA
ALPSRP029480840	FBS	41.5	8/14/2006	Proud Lake	
ALPSRP018540830	FBS	41.5	5/31/06	Pinckney Rec Area	
ALPSRP027730830	FBS	41.5	8/2/06	Pinckney Rec Area	

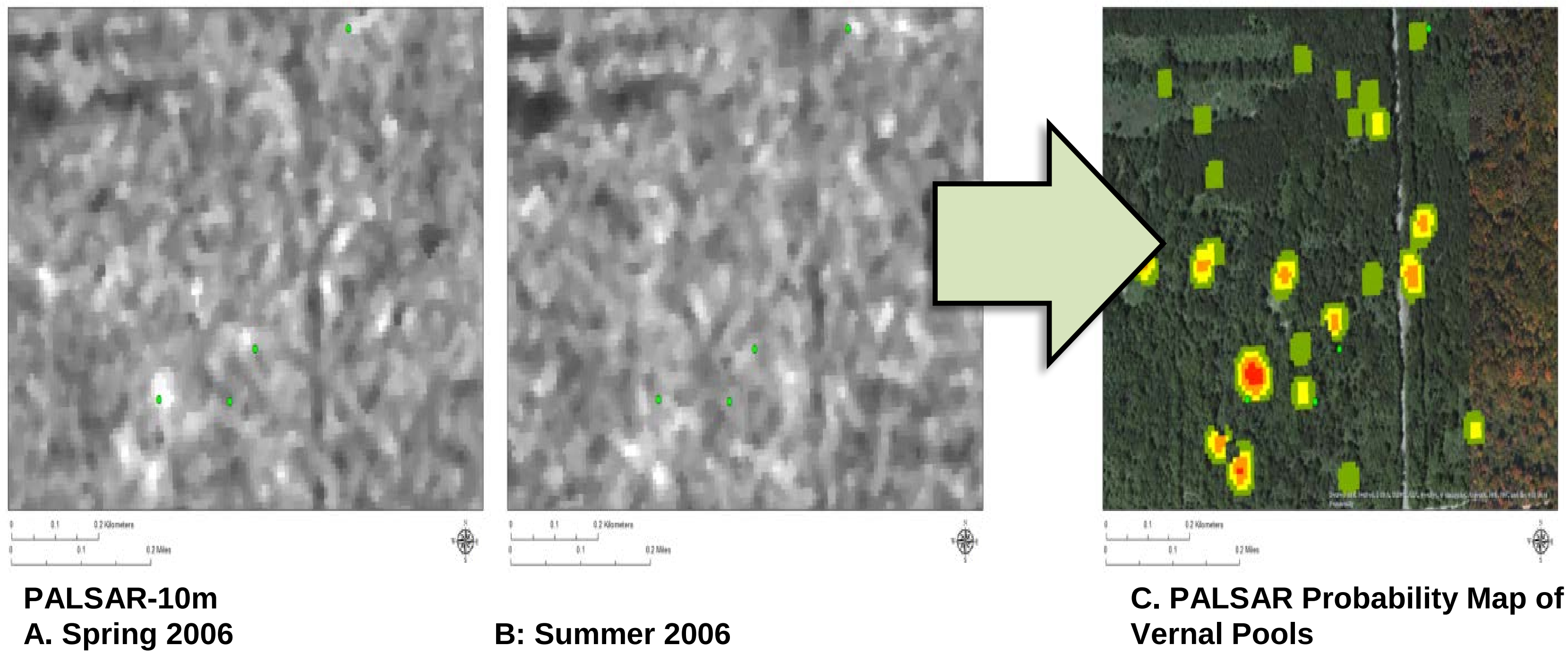
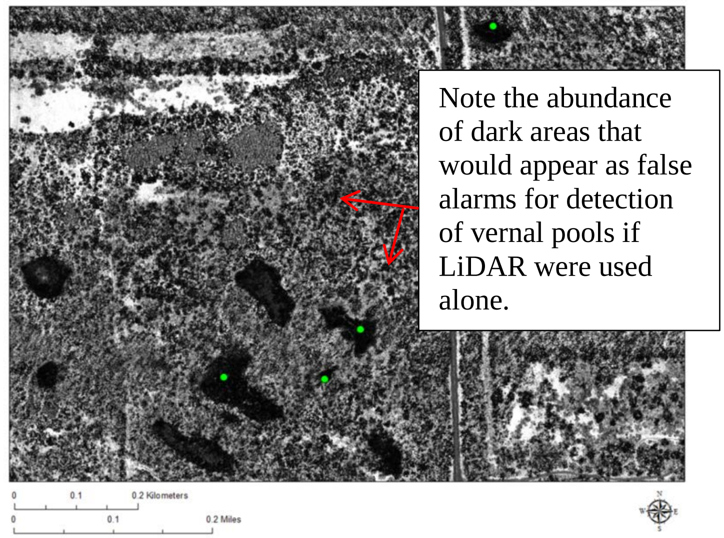


Figure 5.3. A) PALSAR spring and B) Summer image subsets within the Pinckney Recreation Area used to create a C) PALSAR probability map of vernal pools. Green points in the images are MNFI positive identification of water locations. The PALSAR probability map (C) is overlaid on an aerial image with red/yellow/green spots showing probability of potential vernal pools. Red areas have highest probability of being a vernal pool.

Research with Radar and LiDAR Data

Radar data for the Pinckney Recreation area served as the area for initial algorithm and method development for the detection of vernal pools using SAR, as well as the region for further evaluation of a high resolution LiDAR dataset obtained from SEMCOG (2.5 m resolution 2009 data), and the 10 m DEM USGS database.

LiDAR intensity data are useful for finding wet areas due to the tendency of the sensor signal to be absorbed by water. Because of this, wet areas in an intensity image will usually appear darker than the surrounding image (Figure 5.4). Intensity data are particularly useful for locating wet areas beneath vegetation canopies in leaf off condition which cannot be readily observed with traditional optical imagery.



Spring 2009 LiDAR Intensity-60cm

Figure 5.4. 2.5 m resolution Spring 2009 LiDAR intensity image of a subregion of Pinckney Recreation Area, MI.

Combining SAR with LiDAR

A Random Forests (Breiman 2001) classifier was evaluated for mapping vernal pools with the SAR, LiDAR, and 10 m DEM datasets combined. This was applied to the Pinckney State Recreation Area data. Due to time and budget constraints, the Random Forests method was not applied to the Proud Lake pilot area. Since LiDAR data are not available for the entire state, the utility of the LiDAR DEM in comparison to the statewide 10 m USGS DEM was analyzed.

The maps are assessed for accuracy using producer's and user's accuracy. User's accuracy is a measure of how accurately a classification performed in the field (errors of commission = 100 - user's accuracy) while producer's accuracy is a measure of how accurately the analyst classified the image data (errors of omission = 100 - producer's accuracy) (Congalton and Green, 1999).

Possible Input Layers included in Random Forests:

-2006 Spring/Summer PALSAR images

-2006 Change detection PALSAR product

-2009 Spring LiDAR Intensity image

-2009 LiDAR DEM derived product

-2009 LiDAR TWI derived product

- USGS 10 m DEM

- USGS 10 m Isolated Depressions derived product

- USGS 10 m TPI derived product

Development of SAR Change Detection

As described earlier in the project overview, SAR is useful in detecting flooded forests because of the double-bounce scattering effect. Since vernal pools are wet in the spring and dry in the summer, the associated SAR data are able to highlight these seasonal variations. To develop a useful change product, a spring and summer SAR scene were selected and processed so each pixel represents the intensity of the beam returning to the radar sensor. Using a tool in PCI Geomatica, areas of high seasonal change were isolated and the resulting change data products were used as an input layer to the Random Forests Classifier.

Development of Isolated Depressions Maps

A method to create a map of isolated depressions was developed by "filling" areas in the DEM using ArcGIS that have no flow outlet. The depression-less DEM was then subtracted from the raw DEM, with the resulting dataset showing isolated depressions. These depressions are, in theory, independent of local surface-water hydrology. These were then used as an input layer to the Random Forests Classifier.

Development of the TPI

The Topographic Position Index (TPI) is a measurement of a point's elevational position relative to the area immediately surrounding it (Weiss 2001). To calculate TPI, each cell in a DEM is compared to the average value of cells in its surrounding neighborhood. In the resulting dataset, negative values indicate the cell is relatively lower in elevation than the area around it, while positive values indicate the cell is relatively higher in elevation. TPI is highly dependent on input parameters such as the shape and size of the neighborhood. For this project, a circular neighborhood with a 10 cell radius was used.

RESULTS

LiDAR and 10 m DEM vs. SAR and 10 m DEM

Running the Random Forests classifier with the LiDAR intensity and Isolated Depressions and TPI alone (Figure 5.5, left image and table below) had poor results, with 39% Producer's accuracy (62% omission error) and 86% User's accuracy (14% commission error). However, for the same area, using the PALSAR spring and summer images, the PALSAR change map, the 10 m TPI and Isolated Depressions (Figure 5.5, right and table below) had much better results; Producer's accuracy 91% (9% omission error) and 94% User's accuracy (6% commission error).

Random Forest Result with LiDAR and DEM Alone | **Random Forest Result with SAR and DEM Alone**

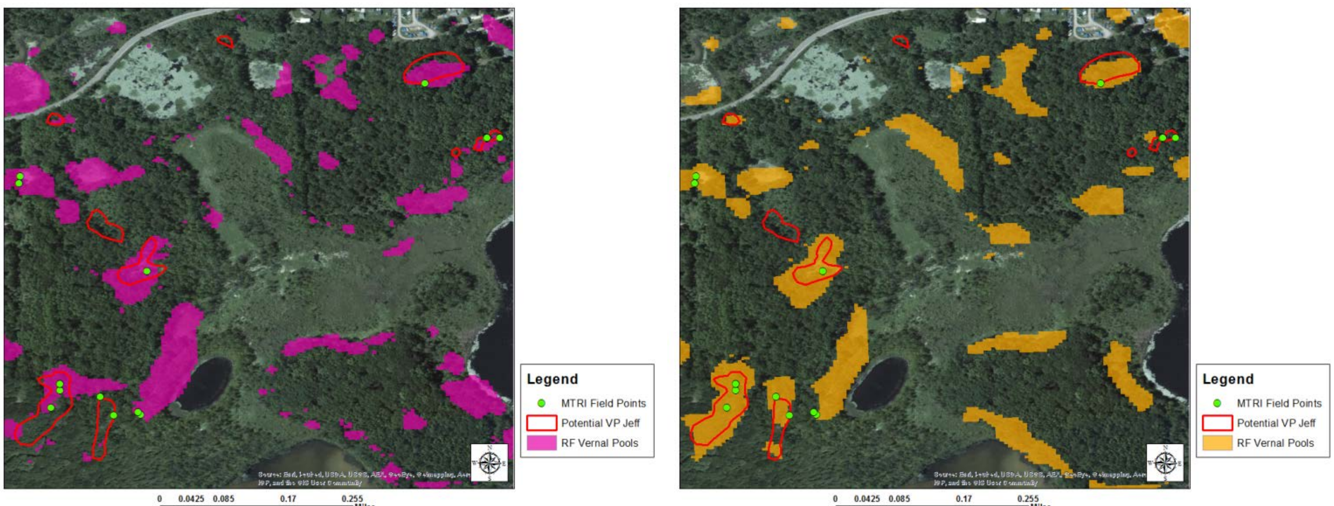


Figure 5.5. Comparison of the LiDAR and DEM potential vernal pool map (left) to SAR and DEM-generated potential vernal pool map (right). Red outlines show potential pools from airphotos, and green dots are field verified locations of vernal pools. Although many of the areas are similar between the 2 products, notice the missed areas in the southwest corner of the LiDAR-DEM product (left image) which are captured in the SAR-DEM product (right image).

Random Forest Result with LiDAR and DEM Alone

Classified	Ground Truthed Values				
	Other	Vernal Pool	Sum	Commission Error	User Accuracy
Other	198	120	318	38%	62%
Vernal Pool	12	75	87	14%	86%
Sum	210	195	405		
Omission Error	6%	62%			
Producer Accuracy	94%	39%			

Total Accuracy= 67%

Random Forest Result with SAR and DEM Alone

Classified	Ground Truthed Values				
	Other	Vernal Pool	Sum	Commission Error	User Accuracy
Other	202	19	221	9%	91%
Vernal Pool	11	182	193	6%	94%
Sum	213	201	414		
Omission Error	5%	10%			
Producer Accuracy	95%	91%			

Total Accuracy= 93%

DISCUSSION

Although the LiDAR intensity image alone appears to have high accuracy, it produces many false alarms, and when combined with the DEM product misses some verified vernal pools (Figure 5.5 left). However, it provides boundary information when combined with SAR. While SAR alone provided a tool to narrow down the regions field visited or interpreted with aerial imagery or other data sources, it did not provide delineation of vernal pool boundaries (Figure 5.6 left). Combining SAR with either of the two DEM (LiDAR based or USGS DEM) datasets complemented each other to produce an improved mapping capability (Figure 5.6 right shows the PALSAR & 10 m DEM result).

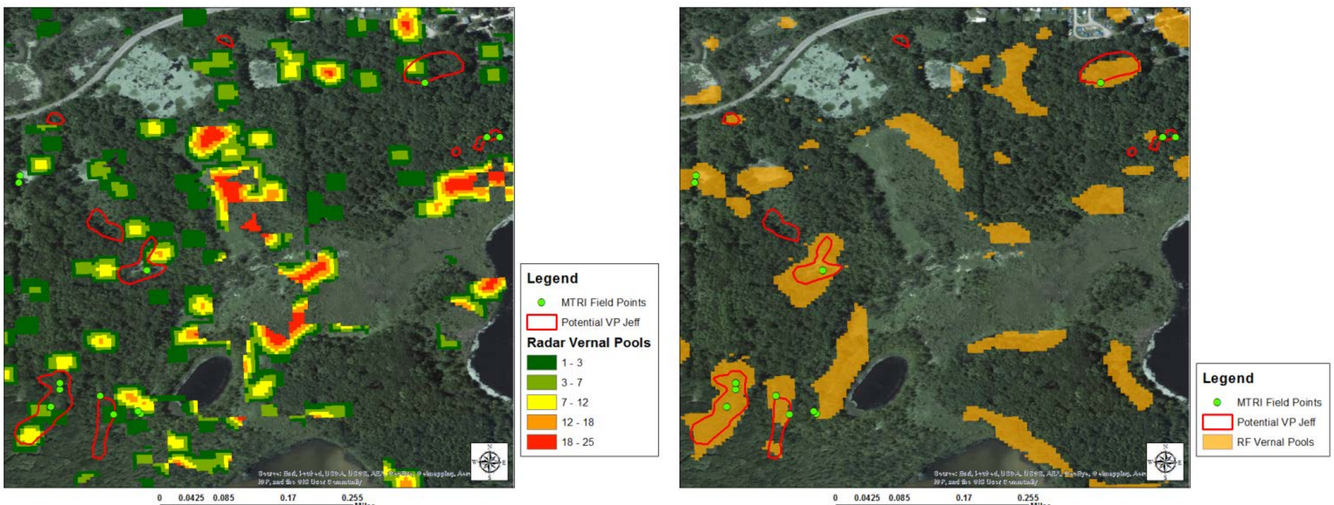


Figure 5.6. SAR-derived Potential vernal pool map (left). MTRI field points with positive identification of water are shown as green dots, and red/yellow/green areas represent potential vernal pools from PALSAR. Red areas have higher probability than yellow/green areas of being vernal pools. The SAR-10 m DEM map is shown at right for comparison. The intersection of the DEM with the PALSAR appears to reduce commission error and define boundaries of vernal pools.

Application of SAR & 10 m DEM Methodology to Northern LP Study Site

The approach of using SAR and the derived 10m DEM products had the best results for the Pinckney Recreation Area pilot study region. Using this approach, an analysis was conducted on the northern Lower Peninsula pilot study area to determine suitability and transferability of the approach to another study site with different vegetation, topography and climate. The results are shown in Figure 5.7, with the blue polygons showing potential vernal pools and the accuracy assessment in the table below it. Field visits were conducted by MNFI and are shown as green dots for the positively identified vernal pool (Figure 5.7).

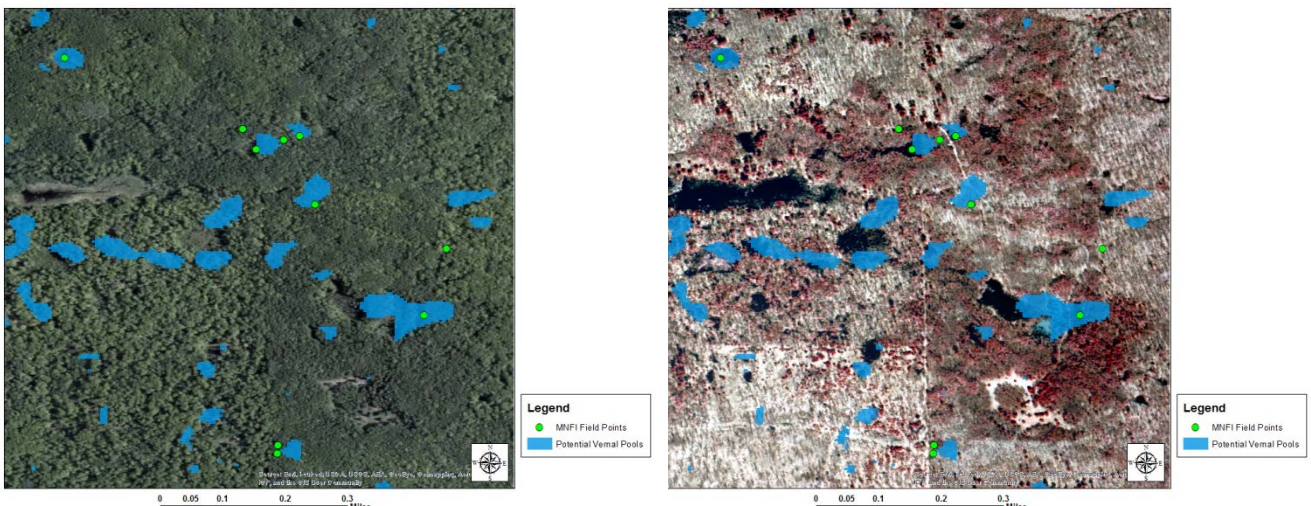


Figure 5.7. SAR potential vernal pool map of Upper LP study area with leaf-on background image (left) and leaf-off April 1998 spring background image (right). Accuracy assessment is below.

Random Forest Result with SAR and 10 m DEM

Classified	Ground Truthed Values				
	Other	Vernal Pool	Sum	Commission Error	User Accuracy
Other	216	35	251	14%	86%
Vernal Pool	3	172	175	2%	98%
Sum	219	207	426		
Omission Error	1%	17%			
Producer Accuracy	99%	83%			

Total Accuracy= 91%

Testing of SAR & 10 m DEM Methodology to UP Pilot Study Site

While the SAR and 10 m DEM method proved to be successful in the Pinckney and upper Lower Peninsula pilot study areas, we were unable to provide a map product for the Upper Peninsula pilot study area primarily due to data availability and time. The timing of the SAR data collection is critical for detection of the inundation condition versus the "dry" condition. The available SAR data for the Upper Peninsula site appear to be less than ideal. Due to its more northerly location, spring onset may be later than the April image date selected for this pilot analysis. While SAR change detection between April and July may be suitable for lower latitudes or even for some years in the UP, it does not appear to be operative for this area for the years evaluated. With timely SAR data collected after snowmelt and during vernal pool inundation, the approach developed for the other two sites should prove useful for vernal pool detection throughout the Great Lakes region.

CHAPTER 6: Development of a GIS model and data layer to identify and map areas with potential likelihood of vernal pool occurrence in forested areas in Michigan.

INTRODUCTION

Species distribution modeling or the statistical modeling of species or habitat distribution is a common approach in ecological research and conservation planning. Documented locations of a species or community of interest are related to environmental information in a model to predict habitat suitability across a landscape. Models trained on presence-only data are frequently used, and since 2006 the MaxEnt software package (Phillips et al. 2006) has been one of the most popular tools with over 1000 published applications (Merow et al. 2013).

MaxEnt is a maximum entropy machine learning approach that compares known locations to random background points of a set of environmental predictors to derive a spatial explicit prediction of relative habitat suitability. This is accomplished by minimizing the relative entropy between two probability densities, one estimated from presence data and one from the background. Different levels of complexity are used, depending on the amount of data available. Elith et al. (2006) found MaxEnt equivalent or superior to other predictive modeling approaches.

METHODS

Study Area

We produced vernal pools distribution models for three physiographic regions in which our samples occurred in the southern Lower Peninsula (SLP), the northern Lower Peninsula (NLP) and the Upper Peninsula (UP) (Figure 6.1). Physiographic regions are areas delineated relatively uniform with respect to key physical attributes. We had originally proposed developing a statewide vernal pool distribution model but decided it would be more appropriate to develop regional models given the limited extent of our data.

The site in the SLP occurred within the Southeastern Interlobate Core (Schaetzl et al. 2009). Schaetzl et al. (2009) describe the region as a high relief, very hummocky region of many lakes and isolated, sandy and gravelly kames. It is underlain by thick drift, especially in the north. The slopes are short, steep, and complex. This area is a classic interlobate region, formed between Saginaw and Huron-Erie lobes during the last or Wisconsin stage of glaciation. Hydrologically the drainage pattern is deranged, with many kettles, swamps and lakes, and many wetlands, but often not interconnected.

The NLP sampling area fell within a large physiographic region named Northern Lower Peninsula Tunneled Uplands, so named because valleys are probably subglacial tunnel channels (Blewett 1995). According to Schaetzl et al. (2009), "this region is a high relief area of large, broad, generally flat-floored valleys between uplands formed in thick, sandy drift. Upland areas are steep-sided, gullied and/or hummocky. Well drained and somewhat excessively drained, sandy soils on uplands. Soils in valleys are usually Histosols or poorly drained sands. Most soils formed in till or outwash parent materials. Several groundwater-fed streams originate and flow through the region. Valleys contain wetlands of various size."

The sample sites in the UP occurred within the Sturgeon Incised Terrain, part of a high elevation, largely bedrock-controlled landscape that has been modified by glacial scour and deposition, with areas of high hills and low mountains formed on bedrock (Schaetzl et al. 2009). It is an upland, moderate-high relief landscape with many dendritically incised stream channels and valleys emanating from it; many are deep and/or steep-sided and most drain to Lake Superior. There are few lakes, and heavy snow is received during the winter. Well-drained and drier soils occur on uplands and on valley sides. Soils are sandy loam and similar coarse textures. Tills and glaciofluvial sediments form the parent materials in a thick drift.

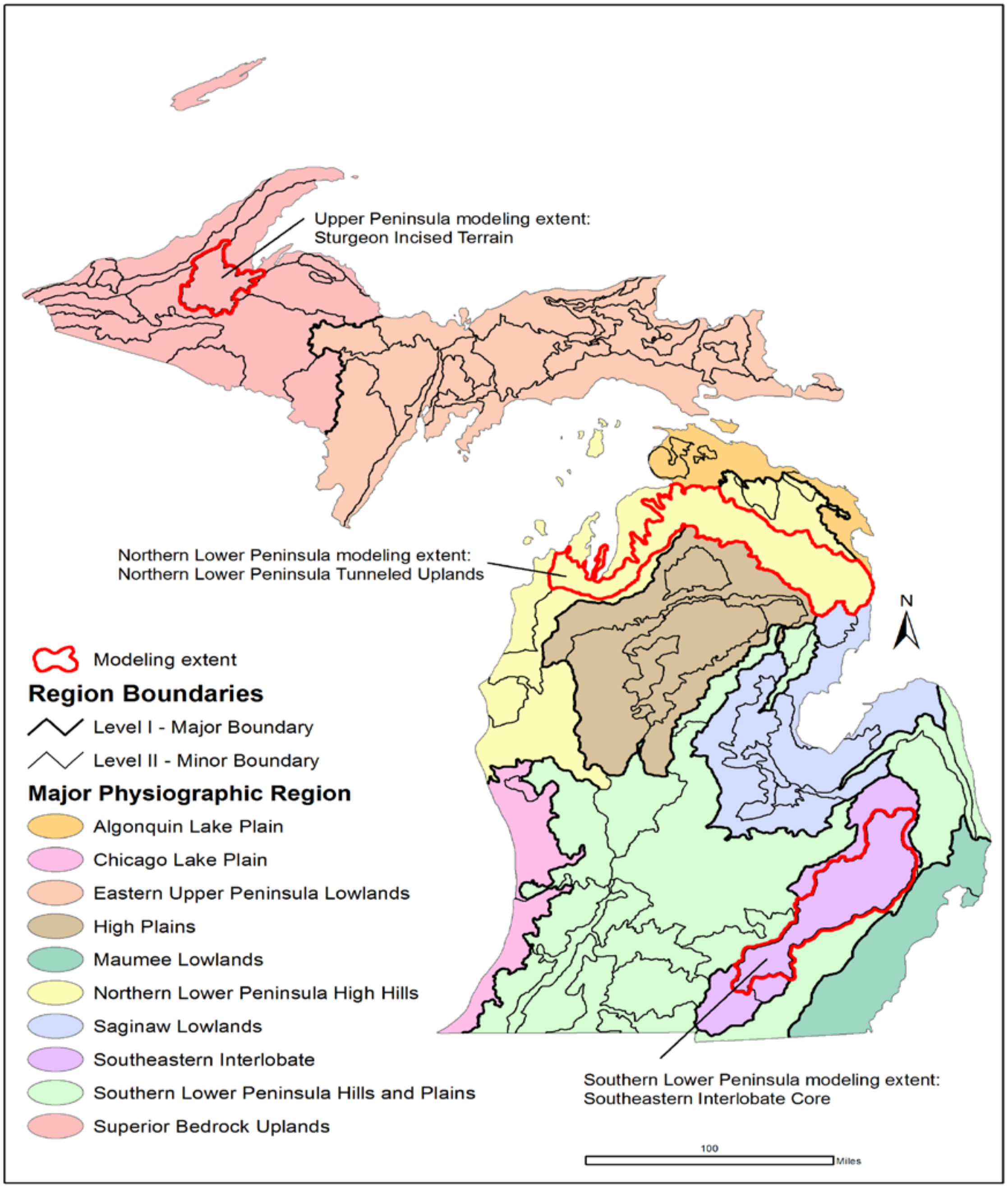


Figure 6.1. The modeling extents of the three sites were physiographic region boundaries (Schaetzl et. al 2009).

Training/test samples

The known presence and absence locations were collected as described in Chapter 4 of this report, and were screened to remove any points <= 100 meters from any other point. The resulting presence samples numbered 116 for the SLP, 58 for the NLP and 72 for the UP. The potential vernal pool sites that were field confirmed as not being vernal pools and thus available as a severe test of absence included 141, 9, and 17 locations respectively for the SLP, NLP, and UP.

Environmental data

Potential environmental predictors were identified from literature review and expert knowledge of vernal pools. Then available GIS data were located and compiled. Based on perceived importance and state-wide availability (with one exception), 27 environmental predictors were identified or derived from available spatial data (Table 6.1) in five broad classes of geology, groundwater, topography, soils, and land cover.

Geology

Wetland formation and abundance can be related to the glacial geology of a landscape (Palik et al. 2003), although this will vary geographically (Tiner 2003). Surficial geology (Farrand and Bell, 1982a, 1982b) and glacial landsystem (Lusch et al. 2005) classifications were available for the state although the scales were relatively coarse. A landform classification based on glaciation history, soils, geology, and landscapes had been completed for the upper and northern Lower Peninsula (NRCS 2006).

Groundwater

Vernal pools are most abundant where water tables are high. Several useful datasets were available from the Groundwater Inventory and Mapping Project by Lusch et al. (2005) including estimated annual groundwater recharge, estimated transmissivity of glacial deposits, depth to water table and first water elevation, drift thickness, and bedrock surface elevation. These are state-wide datasets that incorporated oil, gas, and water well logs (over 270,000 points for the bedrock surface and drift thickness layers).

Lusch et al. (2005) describe the calculation of the estimated annual groundwater recharge layer from USGS stream flow gages and base flow yield. Watershed characteristics describing geology, land cover, and general climate were also included in the model to identify characteristics that might be useful in predicting the value for the residual. Each of these predictive variables were calculated for each Public Land Survey section, and the data used to predict a residual, then the residual added to the base recharge prediction for the region.

The first water dataset was interpolated using ordinary kriging of data points from surface hydrography, wet soils, and wetlands, and the quality of the source data can vary by county. The water table depth dataset was produced by subtracting the first water dataset from the digital elevation model (Lusch et al. 2005).

Topography
Elevation was available for the state at both the 10 meter and the 30 meter resolution. Initially we thought the 10 meter resolution data might be more effective at modeling small entities like vernal pools - in Michigan the vast majority are less than 0.4 hectare (1 acre) in size (Calhoun and deMaynadier 2008) - but it became clear that the limitations of hardware and software would not allow a model to run based on 10 meter data at the selected geographic extents.

Slope, local relief (the difference in elevation for all points in a set neighborhood radius), Topographic Position Index (continuous and 6-class) (Weiss 2001), Bolstad concavity-convexity index (CCI) (Bolstad et al. 1998), the McNabb terrain shape index (McNabb 1989), the compound topographic index (CTI) (Moore et al. 1993), and surface curvature (or the slope of the slope), were each derived from the 30 m elevation layer.

Indexes describing the shape of the surface of the earth (CCI, CTI, curvature) may separate the inherent concave vernal pool depressional areas by their geometry. Areas of high slope and/or high local relief should not be as likely to have vernal pools.

The Topographic Position Index (TPI) is simply the difference between the cell elevation value and the average elevation of the cells in the neighborhood surrounding it. If it's significantly lower than the surrounding neighborhood then it's likely to be at or near the bottom of a valley. High values could suggest at or near the top of a ridge. Values near zero could either mean a flat area or a mid-slope area. Using the TPI at different scales plus a slope layer allows the classification of the landscape into landform categories (Weiss 2001). We used tools from Jenness Enterprises (2013) to create a continuous and a 6-class TPI layer, with a neighborhood size determined by sensitivity analysis (described in methods).

Soils
The NRCS Soil Survey Geographic (SSURGO) database was available for all 83 counties in Michigan and merged into a statewide vector file before converting to a 30 m raster grid. We created separate layers for parent material class, upper solum texture, parent material texture, and lower horizon texture modifier ("gravelly", "cobbly", etc.) allowing for the selection of soils with a significant amount of coarse fragments in their parent materials. 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).

The soils were also coded to their Natural Soil Drainage Index (Schaetzl et al. 2009) which is a continuous value measuring the long-term wetness of soils. Finally layers were produced representing the amount of clay in both the surface horizon and in the entire soil depth, since substrates of vernal pools often consist of mineral soils underlain by an impermeable layer such as clay (Thomas et al. 2010), unless the vernal pools are strongly connected to the water table (Calhoun and deMaynadier 2008) when there will tend to be more coarse fragments.

Landcover
The most recent landcover dataset available was the C-CAP 2006 (NOAA 2008) Anderson Level I and II dataset. Vernal pools are described as completely or partially surrounded by forests, woodlands or savannas (Colburn 2004). Both the land classification itself as a categorical variable, and a derived layer of the percent of forested landcover or water in a 300 m^2 neighborhood (local positive landcover) were used in the modeling process.

Table 6.1. Environmental variables available for modeling.

Name	Scale/resolution	Source
Surficial geology	1:500,000	Farrand and Bell (1982a, 1982b)
Estimated groundwater recharge	PLSS section	RS&GIS, Michigan State University (Lusch et al. 2005).
Glacial landsystems	1:250,000	RS&GIS, Michigan State University (Lusch et al. 2005).
Glacial deposits - estimated transmissivity	1000 m raster	RS&GIS, Michigan State University (Lusch et al. 2005).
Depth to water table	30 m raster	RS&GIS, Michigan State University (Lusch et al. 2005).
First water table elevation	30 m raster	RS&GIS, Michigan State University (Lusch et al. 2005).
Drift thickness	500 m raster	RS&GIS, Michigan State University (Lusch et al. 2005).
Bedrock surface elevation	500 m raster	RS&GIS, Michigan State University (Lusch et al. 2005).
Elevation	10 m & 30 m raster	USGS (2009a, 2009b)
Local elevation difference[a]	30 m raster	Derived from 30m Digital Elevation
Slope (degrees)	30 m raster	Derived from 30m Digital Elevation
Topographic position index (continuous)	30 m raster	Derived from 30m Digital Elevation and Weiss (2001), Jenness (2013)
Topographic position (6 classes)	30 m raster	Derived from 30m Digital Elevation and Weiss (2001), Jenness (2013)
Bolstad concavity-convexity index	30 m raster	Derived from 30m Digital Elevation and Bolstad et al. (1998)
Compound topographic index (CTI)	30 m raster	Derived from 30m Digital Elevation and Moore et al. (1993)
McNab terrain shape index	30 m raster	Derived from 30m Digital Elevation and McNab 1989.
Surface curvature	30 m raster	Derived from 30m Digital Elevation and ArcMap Spatial Analyst Curvature tool
UP and NLP Landform map	est 1:250,000	NRCS 2006, http://www.mi.nrcs.usda.gov/soils.html
Soil series parent material	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/
Natural Soil Drainage Index[b]	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/ and Schaetzl et al. (2009)
Clay in all horizons	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/
Clay in uppermost mineral horizon	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/
Texture of uppermost mineral horizon	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/
Texture of parent material	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/
Parent material graveliness	1:15,840	SSURGO Soils data, http://datagateway.nrcs.usda.gov/
Anderson Level I and II cover types (2006)	30 m raster	NOAA (2008)
Local positive landcover[c]	30 m raster	Derived from CCAP 2006 land cover

[a]For all points within a 300 m^2 radius

[b]Ordinal ranking of natural soil wetness classes, 0-99.

[c]Percent forest or water in a 300 m^2 neighborhood.

Model Methods

Our objective was two-fold: 1) to investigate the environmental drivers of vernal pool distribution in the landscape, and 2) estimate the relative suitability of habitat for vernal pool presence in the modeling extent. With objective one, we hoped to increase understanding of the linkage between landscape environmental gradients within the five general classes described above and the presence of vernal pools. Under objective two, we hoped to refine or augment our ability to locate and map new vernal pools on the landscape.

When determining the appropriate neighborhood size for a neighborhood environmental variable one can either choose based on known theory or generate a sensitivity analysis by creating the variable at various neighborhood scales and measuring the response of the model gain. The scale at which the response peaks would likely be the best variable to use in the modeling. The latter method was used to determine the neighborhood size for the TPI, local relief, and positive land cover variables (see example in Figure 6.2).

The correlation of the environmental variables was investigated and those that were highly correlated were first run individually in the model. From each group of correlated variables only the one with the highest response was retained to use in the modeling exercise. While Maxent is known to be somewhat robust to multicollinearity, the interactions of correlated variables can confuse the variable response curves and interfere with our understanding of objective one. Additionally parsimonious models are favored by the Akaike Information Criterion (AIC), a criterion we will use for model selection (see below).

Distribution models for each site were generated using MaxEnt (Version 3.3.3) and all variables, with the caveat that for correlated variables only the most responsive variable was used. To obtain a solution, MaxEnt maximizes the gain function, a penalized maximum likelihood function. Exponentiating the gain of the model gives the likelihood ratio of an average presence location to an average background location, so finding the maximum gives the model that can best differentiate presence points from the background. Individual variable jackknife plots are available to illustrate the gain (positive or negative) that each variable is contributing to the model. Our process was to iteratively remove the least-contributing variable and re-run the model until two variables remain.

Model Evaluation

Penalizing for model complexity is an internal function of Maxent, as is regularization, a process that attempts to prevent over-fitting. Area under the receiver-operator curve (AUC) is the most common metric of model evaluation for Maxent models. AUC provides a single measure of model performance, independent of any threshold choice. The receiver-operator curve (ROC) is obtained by plotting sensitivity (% correct positive) on the y axis and 1–specificity (% correct negative) on the x axis for all possible thresholds. In the case of presence-only models where we have no negative data, AUC is interpreted as the probability that a randomly chosen presence location is ranked higher than a randomly chosen background point. An AUC of 1.0 is perfection, and an AUC of 0.5 indicates a random prediction (Phillips et al. 2006).

We report maximum training AUC, which is often reported in the literature as an estimate of model quality but is generally expected to favor models with more parameters (Warren and Seifert 2011). We also report maximum test AUC, which is thought not to suffer from the same overfitting problems that could occur in AUC_{TRAIN}. If a model is overfit to training data, the fit of independent test data should not necessarily improve (Warren and Seifert 2011). We used ENMTools Version 1.4.3 (Warren et al. 2010) to report the Akaike information criterion with a correction for finite sample sizes (AICc). AIC is a measure of the relative quality of a model for a given set of data and AICc has a greater penalty for extra parameters and is strongly recommended by Burnham and Anderson (2002). Given a set of candidate models for the data, the preferred model is the one with the minimum AICc value.

We also report the number of model parameters. The number of environmental variables in the model is not the same as the number of model parameters, because MaxEnt can model linear, quadratic, product, threshold, and hinge features, as well as categorical features. Hinge features are similar to threshold features, except a linear function is used instead of a step function.

Model gain is calculated by MaxEnt for each model starting from 0 and rising to an asymptote. Gain is a measure related to deviance, a measure of goodness of fit, such that the average likelihood of the presence samples is the natural log of the gain (e^{gain}) times higher than that of a random background pixel.

The continuous output of the MaxEnt model can be interpreted as increasing suitability, and a threshold value may be selected to convert the continuous values to a binary. The threshold can be chosen based a number of methods including user-specified omission rate. We evaluated the trade-off between choosing a lower threshold (less area predicted suitable) and choosing a higher threshold that would have a low omission rate. Since our second objective was to try to identify suitable areas for finding new vernal pools, we chose to err on the side of commission, or possibly predicting excess suitable habitat, rather than under-predicting and missing some vernal pools. We chose to use a threshold where test omission = 0%.

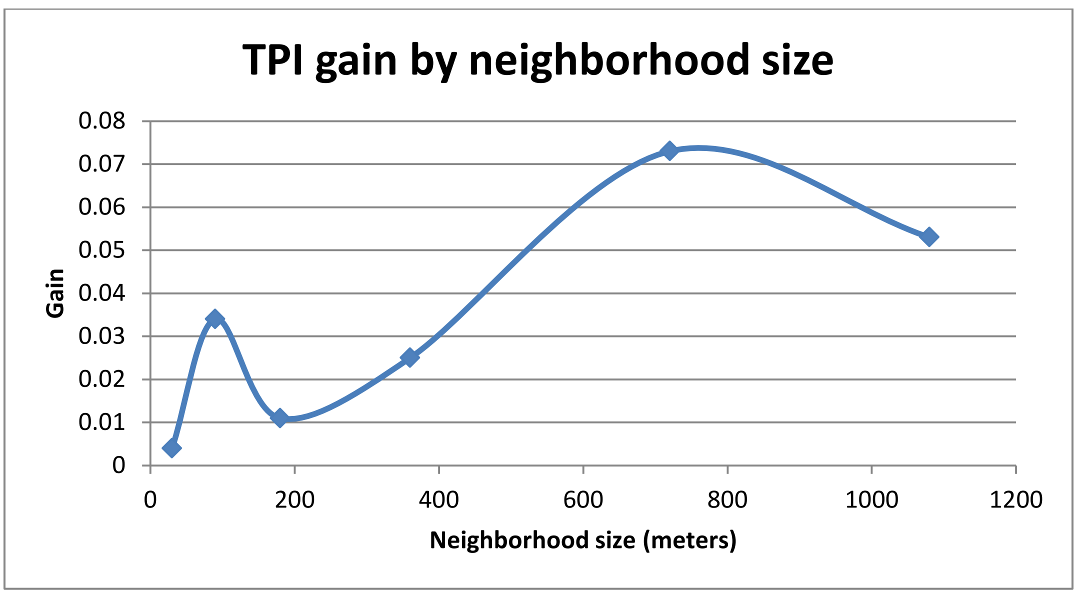


Figure 6.2. Sensitivity analysis to determine optimum neighborhood size for topographic position index indicates 720 meters (24 cells).

RESULTS

The best models for each of the study areas and their respective environmental variable contributions are reported in Table 6.2. Variable permutation importance is also reported as a second measure of variable significance, because the variable importance is only heuristically defined and depends on the path the algorithm takes to get to the solution. This second measure depends only on the final Maxent model, not the path used to obtain it. The contribution for each variable is determined by randomly permuting the values of that variable among the training points (both presence and background) and measuring the resulting decrease in AUC_{Train}. A large decrease indicates that the model depends seriously on that variable. These values are normalized to provide percentages (Phillips et al. 2006).

Figures 6.3 – 6.5 show the variable response curves for the important variables in the SLP, NLP and UP models respectively. Where there are categorical variables, the higher responding classes are labeled. Ground water recharge, depth to first water table, and surficial geology occur in all three sites' final models. Drift thickness and positive land cover occur in both the Lower Peninsula sites' model results.

The model evaluation metrics for each site are listed in Table 6.3. The NLP model had the highest gain at 2.978 followed closely by the SLP at 2.884. Both models have high AUC values of 0.99 and 0.98 respectively, where 1.0 is equal to perfection and 0.5 is a random prediction. The UP model is not as noteworthy, with a gain of 1.632 and an AUC of 0.94. We had to resort to an environmental layer that was not available state-wide, the landform classification, to produce even those results.

DISCUSSION

Based on the AUC and model gain values, the GIS models in the SLP and NLP appeared to perform very well in meeting the two objectives of the modelling effort: 1) to investigate the environmental drivers of vernal pool distribution in the landscape, and 2) estimate the relative suitability of habitat for vernal pool presence in the modeling extent. Groundwater recharge, depth to first water table, surficial geology, drift thickness, and positive land cover may be important environmental drivers of vernal pool distribution across the state given their contribution to the GIS models in two or all three of the study areas. These environmental drivers could be used to help identify areas that may be particularly suitable for vernal pool presence (or restoration). These environmental drivers should be included and further examined in future efforts to model and predict habitat suitability and potential distribution of vernal pools in other parts of the state and statewide.

It is interesting to note that the GIS model for the NLP study area performed the best followed by the model for the SLP study area, and that the model for the UP study area performed the worst of the three models. This was similar to the accuracy assessment results for the aerial photo interpretation, in which the aerial photo interpretation performed the best (i.e., highest accuracy rates and lowest error rates) in the NLP study area followed by the SLP study area, and the aerial photo interpretation performed the worst in the UP study area. Clearly, additional work is needed to develop a more effective approach for identifying and mapping potential vernal pools or areas with potential likelihood for presence of vernal pools in the Upper Peninsula.

These results suggest that GIS or statistical modelling can be used to effectively predict areas suitable for vernal pools presence at least within the modeling extent. These models should be further tested within the modeling extent. Additional models also should be developed and tested for other parts of the state and/or statewide to further evaluate the effectiveness of this method for mapping vernal pools or areas suitable for vernal pools in Michigan. However, given the level of resolution for some available data and limited computing capability, the GIS models are predicting suitable areas for vernal pools at a very coarse scale (i.e., 30-m resolution). We could use GIS modelling as an initial first step to identify large areas or landscapes that are suitable for vernal pools presence and follow up with more focused or targeted methods that allow for mapping potential vernal pools at a finer scale (e.g., air photo interpretation and/or radar). Reif et al. (2009) found that combining GIS analysis and remote sensing increased producer and user accuracies for mapping isolated wetlands by 10% or greater, with an almost 20% increase in producer accuracy for mapping small, isolated wetlands (i.e., as small as 0.5 ac/ 0.20 ha). Aerial photo interpretation can be an effective method for identifying and mapping vernal pools, but it can also be difficult, time-consuming, and costly, especially if applied to large areas or statewide. GIS modelling could be used to help identify and focus aerial photo interpretation on geographic areas that may be more suitable for vernal pools presence, increasing the effectiveness and efficiency of both methods for identifying and mapping vernal pools in the state.

Table 6.2. Final models for each study area and the variables that contributed to each model.

Southern Lower Peninsula			Northern Lower Peninsula			Upper Peninsula		
Variable	**Percent contribution**	**Permutation importance**	**Variable**	**Percent contribution**	**Permutation importance**	**Variable**	**Percent contribution**	**Permutation importance**
Positive Landcover ($1km^2$)	39.7	41.4	Surficial geology	29.3	23.3	NRCS Landforms	54.9	23.9
Ground water recharge	32.6	33.0	Soil subtexture	23.1	4.5	Surficial Geology	20.5	7.4
Elevation (30m)	7.7	9.6	Positive landcover ($1\ km^2$)	17.4	13.9	Depth to first water table	11.0	23.5
Drift thickness	7.0	1.9	Ground water recharge	13.7	26.6	Ground water recharge	5.9	34.4
Surficial geology	5.9	1.7	Drift thickness	8.7	27.1	Parent material	4.6	9.2
Depth to first water table	3.6	3.2	Depth to first water table	7.9	4.6	Topographic position index (6 class)	3.1	1.6
Topographic position index	2.2	3.5						
Clay in all horizons	1.3	5.7						

Table 6.3. Model evaluation metrics for all sites.

Site	Variables	Gain	e^{Gain}	AUC_{Train}	AUC_{Test}	Parameters	Log Likelihood	AICc	$Omission_{Test}$	$Omission_{Train}$	FPA[1]	Commission
SLP	8	2.884	17.9	0.984	0.989	42	-1380	2893	0%	3.4%	7.73%	78.7%
NLP	6	2.978	19.6	0.991	0.992	23	-519	1142	0%	4.00%	4.30%	52.9%
UP	6	1.632	5.1	0.941	0.939	22	-688	1451	0%	9.50%	14.80%	55.6%

[1] Fractional predicted area

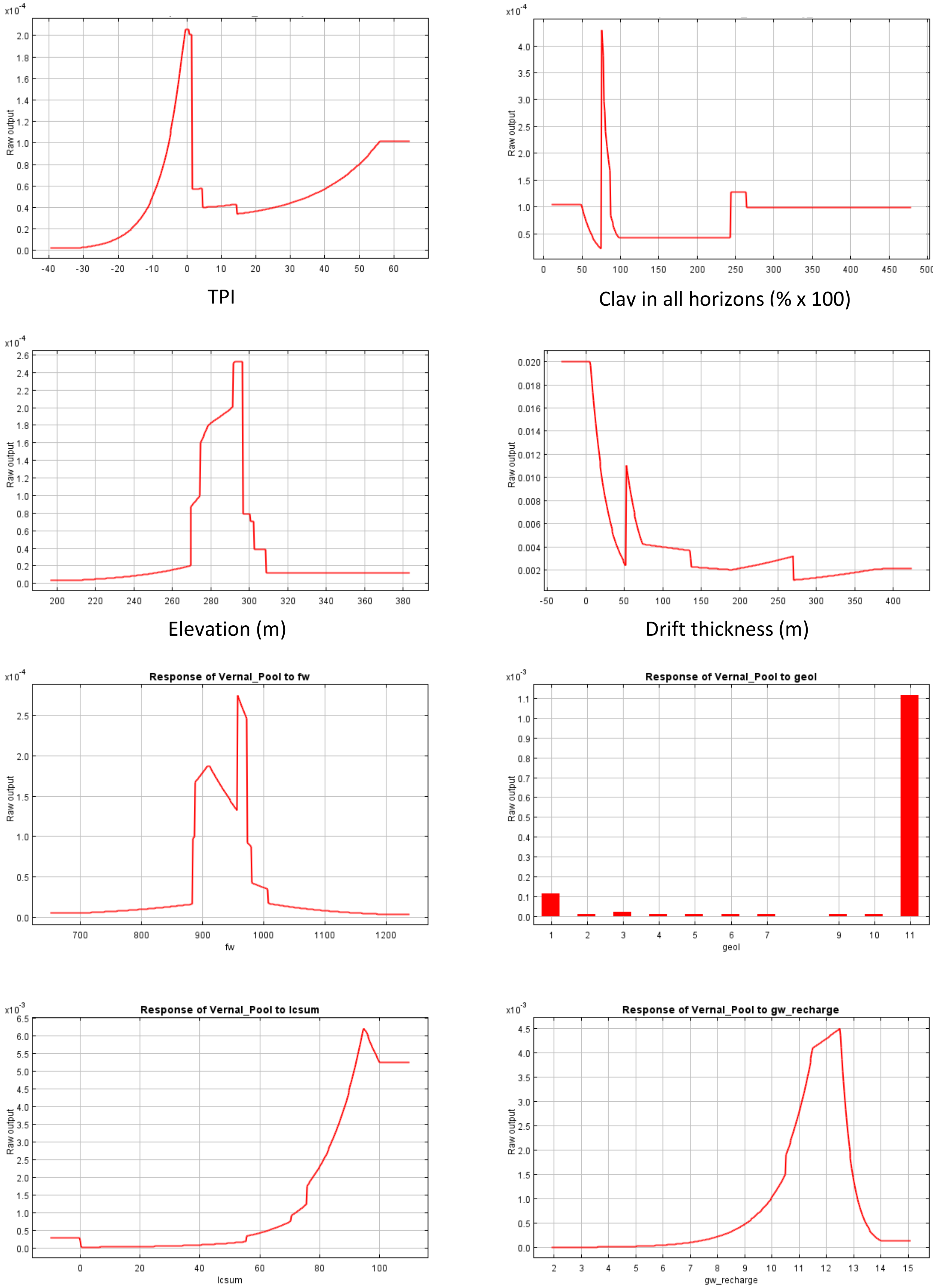


Figure 6.3. Variable response curves for the southern Lower Peninsula model.

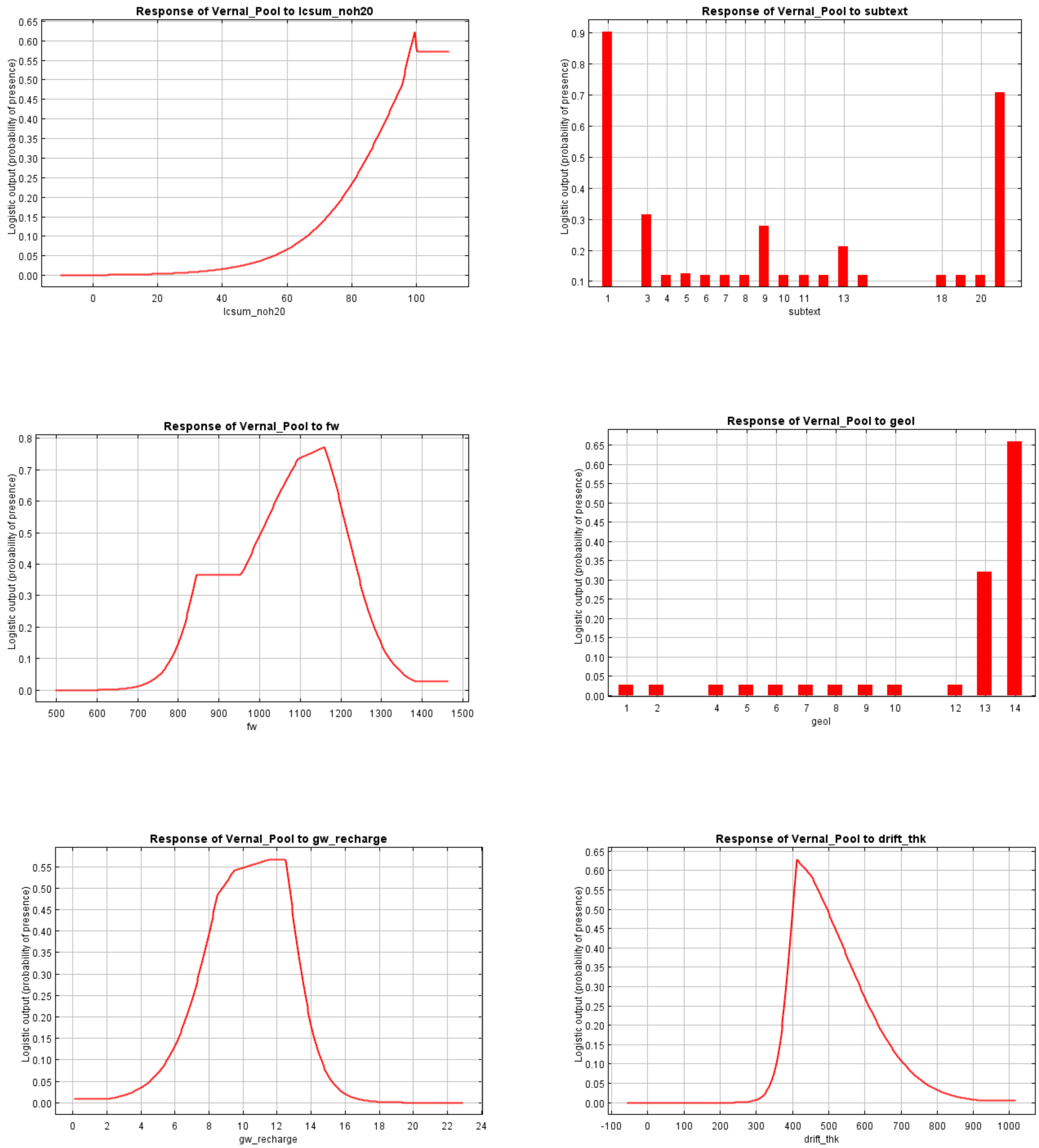


Figure 6.4. Variable response curves for the northern Lower Peninsula model.

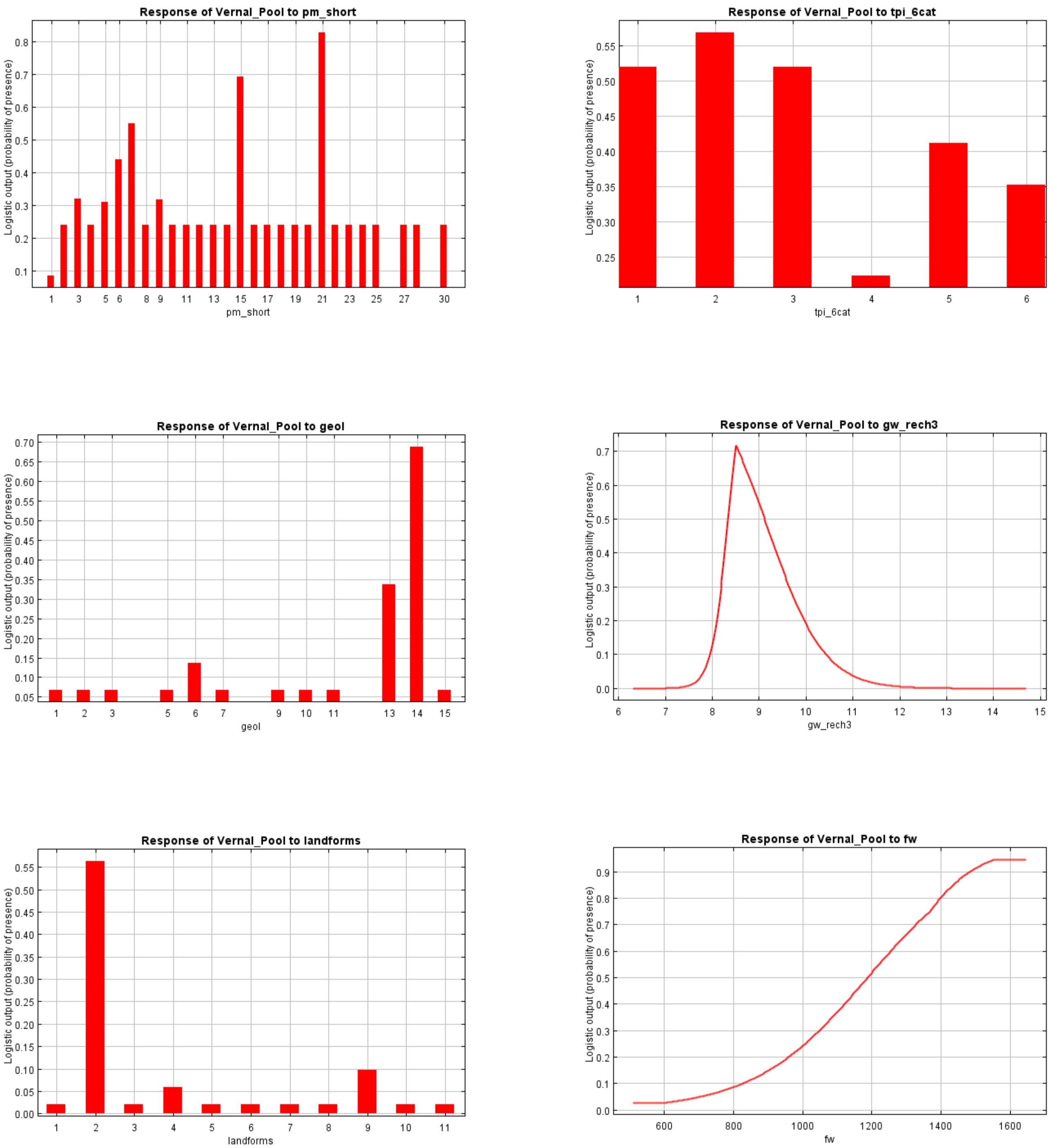


Figure 6.5. Upper Peninsula model variable response curves.

CHAPTER 7: Evaluating and comparing the effectiveness and efficiency of using aerial photo interpretation, radar, GIS modelling, and field surveys for locating and mapping vernal pools in forested areas in Michigan.

INTRODUCTION

One of the goals of this project was to develop an effective and efficient approach for identifying and mapping vernal pools in the state. Because of their small size, temporary nature, and tendency to occur in forested ecosystems, vernal pools can be challenging to locate with conventional survey and mapping techniques. Currently, the most common way to inventory and map vernal pools is aerial photograph interpretation (Tiner 1990, Stone 1992, Brooks et al. 1998, Burne 2001, Lathrop et al. 2005, Burne and Lathrop 2008). Only several states (e.g., Massachusetts, Maine, New Hampshire, New Jersey, Rhode Island, and Vermont) have explicitly mapped potential vernal pool locations, primarily based on aerial photo interpretation (Burne 2001, Colburn 2004, Lathrop et al. 2005, Calhoun and deMaynadier 2008). Some states, such as Massachusetts and New Jersey, have combined air photo interpretation with a GIS model to try to increase efficiency in identifying potential vernal pools. While aerial photo interpretation and field surveys can be fairly accurate or effective in identifying and mapping vernal pools, these approaches also are very time- and labor-intensive and expensive (Colburn 2004). Additionally, the accuracy rate of aerial photograph interpretation varies depending on landscape characteristics, surrounding forest cover, pool type and size, timing of the photos, photograph scale, and interpreter experience (Brooks et al. 1998, Burne 2001, Calhoun et al. 2003, Colburn 2004, Lathrop et al. 2005, Burne and Lathrop 2008).

Developing an effective and efficient approach for identifying, mapping, and assessing vernal pools is essential for conservation of these wetlands. Identifying an effective and efficient approach (or approaches) for mapping vernal pools in forested would allow us to better assess and monitor the distribution of vernal pools in the state. This information also would allow us to assess where vernal pools might be at greater risk or where they might be more common within the state, which would have important implications for vernal pool conservation and management efforts. This project investigated and evaluated several different methodologies for detecting and mapping vernal pools in forested landscapes, including air photo interpretation, GIS modelling, radar, and field surveys. New technologies, such as radar, may be able to enhance our ability to accurately locate and map vernal pools, particularly in forested landscapes. Additionally, the MDEQ Wetlands Program has been performing landscape-level assessment work which has involved mapping all watercourses based on aerial photographs and classifying all wetlands using NWI, landscape or topographic position, hydrological isolation, wetland function, and several other habitat indicators. The MDEQ is interested in trying to identify and map vernal pools using this approach. We conducted a preliminary evaluation of the effectiveness of this method for identifying potential vernal pools as well. This chapter presents an evaluation and comparison of the effectiveness and efficiency of these different methods for identifying and mapping potential vernal pools or areas with potential likelihood for presence of vernal pools to help identify an effective and efficient approach for mapping vernal pools in the state. Based on this evaluation, recommendations are provided for an effective approach/ approaches for documenting and mapping vernal pools in Michigan.

METHODS

The specific methods that were used to identify and map vernal pools or areas with potential likelihood for presence of vernal pools using aerial photograph interpretation, radar, and GIS modelling were described in detail in Chapters 4, 5, and 6, respectively. The MDEQ's isolated wetland analysis basically consisted of identifying depressional wetlands, using NWI wetlands, that are hydrologically isolated, generally 2.5 acres or smaller, and have other characteristics of vernal pools. Since NWI is based on aerial photograph interpretation, this method basically represents a combination of aerial photo interpretation and GIS modelling.

The study areas for the various methods overlapped but differed in extent or scale. The aerial photograph interpretation conducted by MNFI focused on the three study areas for this project that were listed and described in Chapter 4. The MDEQ's isolated wetland analysis was part of a larger wetland or landscape analysis that was conducted in the Portage Creek Watershed which overlapped with this project's study area in the Waterloo-Pinckney State Recreation Area. As a result, the study area for the MDEQ's isolated wetland analysis for purposes of this project basically consisted of an area within the Waterloo-Pinckney State Recreation Area that is part of or overlaps with the Portage Creek Watershed. The pilot radar study was able to identify potential vernal pools within the study areas in the southern Lower Peninsula (SLP) and northern Lower Peninsula (NLP) (see Chapters 4 and 5) and also outside the study areas within the extent of the radar images or scenes. The GIS modelling utilized vernal pools data from the aerial photo interpretation from all three study areas to develop models predicting suitable areas for presence of vernal pools across the physiographic regions or portions of the physiographic regions in which the three study areas are located (see Chapter 6).

We evaluated and compared the effectiveness of the aerial photo interpretation and radar by examining and comparing the accuracy and error rates each method reported as part of its own accuracy assessment or evaluation. We also evaluated and compared the effectiveness of these two methods using the test cell approach that was used to assess the aerial photo interpretation. We also utilized this approach to assess and compare the accuracy and effectiveness of the MDEQ's isolated wetland analysis for identifying and mapping potential vernal pools. To assess the accuracy of the radar and MDEQ's isolated wetland analysis using the test cell approach, we examined each test cell that was sampled in the SLP and NLP study areas (only for the radar study) and whether it contained potential vernal pools identified from the radar study and/or MDEQ's isolated wetland analysis. We examined and compared the presence, location, and shape/extent of the potential vernal pools identified from the radar study and/or MDEQ's wetland analysis with the potential vernal pools documented (or not documented) in the field and from the aerial photo interpretation. We then performed the same accuracy assessment that we conducted for the aerial photo interpretation (see Chapter 4) by comparing the field data or results from the sampled test cells and the potential vernal pools identified in the test cells from radar and/or MDEQ's wetland analysis. This allowed us to estimate and compare accuracy rates and commission and omission error rates across the three methods. Because the GIS model output is at a much coarser scale and doesn't specifically map individual potential vernal pools, we did not include the GIS model results in the test cell accuracy assessment.

RESULTS

Accuracy Assessments Based on Test Cells Sampled in 2012 and 2013

Aerial Photograph Interpretation

Detailed results of the accuracy assessment for aerial photograph interpretation are provided in the results section of Chapter 4 and Table 4.6. Accuracy assessment results for aerial photo interpretation for the study area in the SLP and the NLP also are provided in Tables 7.2 and 7.3.

Radar

A total of 268 sampled test cells in the SLP and NLP study areas (i.e., 100 test cells in the SLP, 168 test cells in the NLP) were included in the accuracy assessment of radar for identifying and mapping vernal pools. A total of 159 (59%) of the 268 test cells that were sampled in the SLP and NLP study areas in 2012 and 2013 contained at least one potential vernal pool identified from radar (Table 7.1). These were comprised of 65 (65%) of 100 sampled test cells included in the analysis for the SLP study area, and 94 (56%) of 168 test cells sampled in the NLP study area. Potential vernal pools identified from radar data were not available for the UP study area.

Based on the test cells that were sampled in 2012 and 2013, the accuracy rates for identifying and mapping vernal pools from radar data were mixed within and across the study areas in the SLP and the NLP (Table 7.1). The accuracy rate for radar correctly identifying test cells with vernal pools in the field (i.e., true positives) was fairly low at 34% overall across the SLP and NLP study areas. However, the accuracy rate for correctly identifying test cells that did not contain vernal pools in the field (i.e., true negatives) was much higher at 81% overall across the two study areas (Table 7.1). The accuracy rates also did vary somewhat regionally between the two study areas. The accuracy rates for radar were higher in the SLP study area than in the NLP study area. These results indicate that radar was able to correctly identify and map vernal pools in 49% of the sampled test cells that contained vernal pools in the field, but radar was able to correctly identify the absence of vernal pools in 86% of the sampled test cells that did not contain vernal pools in the field in the SLP study area (Table 7.1). The accuracy rates for radar were lower in the NLP study area, with radar correctly identifying vernal pools in 23% of the sampled test cells that contained vernal pools in the field, but it was able to correctly identify the absence of vernal pools in 78% of the sampled test cells that did not contain vernal pools in the field (Table 7.1).

The commission error rates (i.e., false positives) for identifying and mapping vernal pools from radar were fairly high, but the omission error rates (i.e., false negatives) were low (Table 7.1). The overall commission error rate for identifying and mapping vernal pools using radar data was 66% across the SLP and NLP study areas, indicating vernal pools were not present in 66% of the sampled test cells in which vernal pools had been mapped from the radar data (i.e., false positives) (Table 7.1). Commission error ranged from 51% in the SLP study area to 77% in the NLP study area (Table 7.1). The overall omission error rate for identifying and mapping vernal pools from radar was 19% across the two study areas, indicating vernal pools were not mapped from radar in 19% of the sampled test cells that actually contained vernal pools in the field (i.e., false negatives) (Table 7.1). Omission error ranged from only 14% in the SLP study area and 22% in the NLP study area (Table 7.1).

Table 7.1. Assessing the accuracy of radar for identifying and mapping vernal pools based on data from field surveys conducted in 2012 and 2013 of randomly ordered test cells in the SLP and NLP study areas.

Test Cells with PVPs[2]	**Test Cells that contained VPs/ possible VPs[3] in the field (i.e., H2O-VP, H2O-VP?)**	**Accuracy Rate[4] (True Positives)**	**Test cells that did not contain VPs/ potential VPs in the field (i.e., H2O-NVP, H2O-None)**	**Commission Error[5] (False Positives)**
SLP (n = 65)[1]	32	49%	33	51%
NLP (n = 94)[1]	22	23%	72	77%
UP**	-	-	-	-
Overall (n = 159)	54	34%	105	66%
Test Cells without PVPs[2]	**Test cells that contained VPs/ potential VPs[3] in the field (i.e., H2O-VP, H2O-VP?)**	**Omission Error[6] (False Negatives)**	**Test cells that did not contain VPs/ potential VPs in the field (i.e., H2O-NVP, H2O-None)**	**Accuracy Rate[7] (True Negatives)**
SLP (n = 35)[1]	5	14%	30	86%
NLP (n = 74)[1]	16	22%	58	78%
UP**	-	-	-	-
Overall (n = 109)	21	19%	88	81%

[1]Sample size in terms of the total number of test cells surveyed in each study area with PVPs identified from radar or did not have PVPs.
[2]PVPs = Potential vernal pools identified from radar.
[3]VPs/VP? = Vernal pools / possible vernal pools identified from field sampling.
[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 radar (e.g., 32/65 or 49% accuracy rate for the SLP study area).
[5]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 (e.g., 33/65 or 51% commission error rate for the SLP study area).
[6]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 (e.g., 5/35 or 14% omission error rate for the SLP study area).
[7]Accuracy rate (true negatives) was calculated based on the number of test cells that did not contain 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 (e.g., 30/35 or 86% accuracy rate for the SLP study area).

MDEQ's Isolated Wetland Analysis

The accuracy assessment for the MDEQ's isolated wetland analysis was only conducted for the SLP study area because this is the only study area that overlapped with the MDEQ's original study area for the analysis, and this is the only study area for which we had data from MDEQ's analysis. A total of 100 test cells that were sampled in the SLP study area in 2012 and 2013 were included in the accuracy assessment for this method. Only 22 (22%) of these test cells contained at least one potential vernal pool identified from MDEQ's isolated wetland analysis (Table 7.2).

Based on the test cells that were sampled and included in this accuracy assessment, the accuracy rates for identifying and mapping vernal pools using MDEQ's isolated wetland analysis were low to moderate (Table 7.2). The accuracy rate for the MDEQ's isolated wetland analysis was 45% for correctly identifying the presence of vernal pools in test cells in the field, and 65% for correctly identifying the absence of vernal pools in test cells in the field (Table 7.2). Additionally, the commission and omission error rates for identifying and mapping vernal pools using MDEQ's isolated wetland analysis were fairly high (Table 7.2). The commission error rate for the MDEQ's isolated wetland analysis was 55%, indicating vernal pools were not found in the field in 55% of the test cells in which the isolated wetland analysis had identified and mapped potential vernal pools (Table 7.2). The omission error rate was 35%, indicating vernal pools were present in the field in 35% of the sampled test cells in which the isolated wetland analysis had not identified and mapped a vernal pool (Table 7.2).

Comparison of Remote Sensing Methods

In the study area in the southern Lower Peninsula, aerial photograph interpretation had the highest accuracy rates and the lowest error rates compared to the accuracy and error rates for radar and MDEQ's isolated wetland analysis (Table 7.2). The accuracy rate for aerial photo interpretation for correctly identifying the presence of vernal pools in the SLP was 73% compared to 49% for radar and 45% for the MDEQ's isolated wetland analysis (Table 7.2). The accuracy rate for aerial photo interpretation for correctly identifying the absence of vernal pools was 85%, which was similar to the accuracy rate for radar which was 86%, and much higher than the accuracy rate for the MDEQ's isolated wetland analysis (65%) (Table 7.2). The commission error rate was much lower for aerial photo interpretation than that for radar and the isolated wetland analysis, with 27% commission error rate for aerial photo interpretation compared to 51% and 55% for radar and DEQ's isolated wetland analysis, respectively (Table 7.2). Omission error also was low for aerial photo interpretation at 15%, which was comparable to the omission error rate for radar which was 14% but much lower than the 35% omission error rate for the isolated wetland analysis (Table 7.2).

In the study area in the NLP, aerial photo interpretation had significantly higher accuracy rates and much lower error rates than did radar (Table 7.3). Accuracy rates for aerial photo interpretation in the NLP study area were 85% for correctly identifying the presence of vernal pools and 97% for correctly identifying the absence of vernal pools compared to 23% and 78%, respectively, for radar (Table 7.3). Commission and omission error rates also were significantly lower for aerial photo interpretation than for radar (Table 7.3).

Table 7.2. Results of the accuracy assessments for aerial photo interpretation, radar, and MDEQ's isolated wetland analysis for the study area in the southern Lower Peninsula (SLP).

SLP				
Test cells with PVPs	**Test cells that contained VPs/ potential VPs in the field (i.e., H2O-VP, H2O-VP?)**	**Accuracy Rate (True Positives)**	**Test cells that did not contain VPs/ potential VPs in the field (i.e., H2O-NVP, H2O-None)**	**Commission Error (False Positives)**
Air Photo (n = 40)	29	73%	11	27%
Radar (n = 65)	32	49%	33	51%
DEQ (n = 22)	10	45%	12	55%
Test cells without PVPs	**Test cells that contained VPs/ potential VPs in the field (i.e., H2O-VP, H2O-VP?)**	**Omission Error (False Negatives)**	**Test cells that did not contain VPs/ potential VPs in the field (i.e., H2O-NVP, H2O-None)**	**Accuracy Rate (True Negatives)**
Air Photo (n = 60)	9	15%	51	85%
Radar (n = 35)	5	14%	30	86%
DEQ (n = 78)	27	35%	51	65%

Table 7.3. Results of the accuracy assessments for aerial photo interpretation and radar for the study area in the northern Lower Peninsula (NLP).

NLP				
Test cells with PVPs	**Test cells that contained VPs/ potential VPs in the field (i.e., H2O-VP, H2O-VP?)**	**Accuracy Rate (True Positives)**	**Test cells that did not contain VPs/ potential VPs in the field (i.e., H2O-NVP, H2O-None)**	**Commission Error (False Positives)**
Air Photo (n = 40)	34	85%	6	15%
Radar (n = 94)	22	23%	72	77%
Test cells without PVPs	**Test cells that contained VPs/ potential VPs in the field (i.e., H2O-VP, H2O-VP?)**	**Omission Error (False Negatives)**	**Test cells that did not contain VPs/ potential VPs in the field (i.e., H2O-NVP, H2O-None)**	**Accuracy Rate (True Negatives)**
Air Photo (n = 128)	4	3%	124	97%
Radar (n = 74)	16	22%	58	78%

DISCUSSION

Aerial photograph interpretation had the highest accuracy rates and lowest commission and omission error rates compared to radar and MDEQ's isolated wetland analysis, and performed better at identifying and mapping vernal pools in the SLP and/or NLP than these methods. In general, both the radar and isolated wetlands analysis had very high/much higher commission (i.e., false positive) error rates compared to the aerial photo interpretation. These methods also had much higher commission error than omission error, although the omission error for the isolated wetlands analysis in the SLP was fairly high (i.e., 35%). The radar data might not have performed that well because of limited training data, particularly for the NLP study area.

Although the radar did not perform as well as aerial photo interpretation for this initial project, the use of radar for mapping vernal pools/potential vernal pools should be further investigated. This method should be further investigated given the efficiency of this method for mapping vernal pools/potential vernal pools compared to aerial photo interpretation. Now that the approach and methodology for using radar to identify and map vernal pools has been developed and initially tested, it could potentially only take hours to map potential vernal pools using radar compared to probably days or weeks for aerial photo interpretation to map potential vernal pools across a similar sized area, assuming the radar data or imagery is available and has been georeferenced and ready for analysis. Although we were not able to test the radar in the UP study area, radar may be more effective than aerial photo interpretation in the UP or parts of the UP because radar may be able to better detect the presence of water or inundation below the tree canopy in areas that are dominated by or have greater densities of coniferous vegetation. We may be able to further investigate this as part of a new vernal pools project in the western UP this summer. Because the radar seems to have high commission error but fairly low omission error, it may be possible to combine the use of radar with aerial photo interpretation to improve the effectiveness and efficiency of both methods for mapping vernal pools. Additionally, although radar commission error was high, there were still instances where the radar did not detect vernal pools on the ground but the aerial photo interpretation did. Combining radar with the GIS modelling results also may be effective and should be examined. However, SAR/PALSAR radar data/imagery is currently not available for the entire state. So using radar to map potential vernal pools may not be an option for certain parts of the state or for mapping vernal pools statewide.

MDEQ's isolated wetland analysis also could be further investigated. Reif et al. (2009) suggest that combining remote sensing with GIS analyses can be particularly effective for mapping isolated wetlands. Combining the GIS/Maxent model results or incorporating some of the environmental drivers that were important contributors to the GIS models into the isolated wetland analysis could be considered and investigated. Vernal pool locations and data from this project could be incorporated into the isolated wetlands analysis to refine the model.

Given the results of the accuracy assessments, evaluation of the different methods, and available resources at this time (e.g., available radar data), we recommend the following general approach or options for mapping potential vernal pools in the state at this time:

1) If possible, start by developing a GIS model using available data and information from GIS models that have been developed or use existing GIS models that have been

developed to identify areas with potential likelihood for the presence of vernal pools at a landscape regional scale (e.g., physiographic region). Develop statewide GIS model or prioritize areas for modelling (e.g., areas that may be hotspots for vernal pools based on hotspot analysis – see Chapter 4 and Appendices 5 and 6).

2) In addition to or instead of a GIS model, use radar to map potential vernal pools in a geographic area. The use of radar to map potential vernal pools should continue to be developed and tested in different parts of the state where required radar imagery is available.

3) Conduct targeted aerial photo interpretation in areas identified by GIS model as having potential likelihood or greater likelihood for presence of vernal pools AND/OR conduct targeted aerial photo interpretation of potential vernal pools identified by radar. Aerial photo interpretation appears to be very effective at identifying and mapping vernal pools at least in parts of the state (e.g., SLP and NLP), but can be very time-intensive. Combining aerial photo interpretation with GIS modelling and/or radar to target or focus aerial photo interpretation efforts could increase the efficiency of this method and could be particularly effective at mapping vernal pools across large geographic areas or statewide. If GIS modelling and /or radar become more effective over time, these methods could be used instead of aerial photo interpretation, or could reduce the need/scope for aerial photo interpretation.

4) Continue to investigate other methods for combining GIS analysis and remote sensing such as the MDEQ's isolated wetland analysis or combining the GIS models with radar.

5) Conduct field surveys of potential vernal pools using methodology that was developed for this project to verify or validate vernal pools on the ground, and collect additional information about them. Use field validation results to refine remote sensing methods.

While we were not able to identify a single effective and efficient method for identifying and mapping vernal pools remotely, we were able to identify an approach (i.e., aerial photo interpretation) that does appear to be effective for mapping vernal pools in Michigan at this time, at least in certain parts of the state. We also were able to demonstrate that radar and GIS modelling can be used to map potential vernal pools or areas with potential likelihood for presence of vernal pools. Although these methods need further investigation and refinement, they provide options for potentially increasing the efficiency of aerial photo interpretation and developing a more efficient and effective method for mapping vernal pools statewide in the future (e.g., by combining multiple methods/approaches). Reif et al. (2009) suggest that the smaller isolated wetlands, the more sophisticated the level of expertise, the higher the cost, and the more necessary to do a full-scale analysis. This certainly seems to be the case with mapping vernal pools. However, obtaining reliable information on the locations and distribution of vernal pools is critical for managing and protecting these important wetlands. Also, having this information in advance (e.g., during the planning stage) can help inform and guide development of appropriate management prescriptions and strategies and facilitate effective (and potentially more efficient) management and conservation efforts.

CHAPTER 8: Developing a pilot volunteer vernal pool mapping and monitoring program in Michigan

INTRODUCTION

The goal of developing a volunteer vernal pool mapping and monitoring program is to engage and train citizen scientists to gather field information to help identify, assess, and monitor vernal pools in Michigan. We initiated a pilot volunteer program as part of this project to better assess what is required to support a volunteer vernal pool mapping and monitoring program, to evaluate the quality of the data that volunteers collect and submit, and to develop the capability and evaluate the feasibility of developing such a program in Michigan. It was hoped that the data collected from the volunteers would contribute to a better understanding of the location, distribution, abundance and ecology of these unique wetland habitats and aid in their conservation and management. Oscarson and Calhoun (2007) suggest that the use of citizen-scientists to collect data on natural resources is gaining credibility, and many communities now consider this to be a valuable tool. They illustrate through case studies in four New England towns that vernal pool conservation initiatives can be developed in local communities using the skills of trained citizen-scientists to collect accurate data. Communities are then better able to incorporate pool conservation strategies into the local planning and regulatory processes. Additionally, at least 11 states in the Northeast and Great Lakes and at least one Canadian province have had volunteer vernal pool mapping and/or monitoring programs or efforts (see Table 2.1).

METHODS

Development of a Volunteer Vernal Pool Protocol, Training Workshop, and Materials

We initiated this component of the project by conducting research on volunteer vernal pool programs established in other states, and spoke with staff members from some of the programs about their experiences regarding the volunteer vernal pool programs in their respective states. They provided valuable input and stressed the importance of developing field forms and accompanying training materials that are easy to understand so that non-scientists could successfully collect the required data. We reviewed the vernal pool mapping and/or monitoring protocols that were developed and utilized by volunteer programs in other states. We identified information about vernal pools that we wanted to collect and thought would be feasible for volunteers to collect. We also attended a vernal pool training workshop sponsored by the Ohio Environmental Council in spring of 2012.

After reviewing other volunteer vernal pool programs and our information needs, we developed a volunteer vernal pool mapping and monitoring protocol during the winter and spring of 2012. The volunteer vernal pool mapping and monitoring protocol basically consisted of conducting at least three field visits to the pool within a given year (i.e., early spring soon after ice melt from mid-March to mid-April, mid-spring about 2-3 weeks later from mid-April to mid-late May, and late summer from late July to August/September when pools might be dry), and recording information about the physical characteristics, water temperature, water level, maximum water depth, soils, vegetative cover/structure, cover objects, disturbance, and presence of vernal pool indicator species and other animal species within the pool and vegetation and disturbance around the pool (see Appendix 3 for more information). Photo documenting the vernal pool as well as indicator species, rare species, and other species of interest that they reported also was part of the protocol. We asked the volunteers to select and survey a potential vernal pool that had been mapped in our study areas for the pilot program, and to monitor the same pool over multiple years (i.e., at least 2-3 years) if possible. We required volunteers to attend a vernal pool training workshop prior to initiating monitoring, and we strongly encouraged them to work with at least one other adult for safety reasons. We asked the volunteers to submit their completed data forms, photos, maps, and volunteer time log in the fall (by mid-September/October) either by sending them in the mail, through e-mail, and uploading them into a folder on Dropbox (www.dropbox.com).

We developed and provided or made available a number of training materials and resources to provide support and assistance to the volunteers. We developed a field form and an accompanying training manual describing the procedures for collecting data in the field (Appendix 4). We incorporated input from the 2012 volunteers and made minor edits to the field form and training manual in 2013 to eliminate any terms that might cause confusion and to further clarify the instructions. We utilized many of the resources the Ohio Vernal Pool Partnership had developed and adapted them for use in Michigan.

We determined that the vernal pool training workshops in 2012 and 2013 should consist of an indoor presentation followed by field visits to vernal pools with instruction and practice collecting data in the field. We created a PowerPoint presentation for the trainings which provided an overview of the key characteristics and ecology of vernal pools, and the plants and animals typically associated with these vernal pools with a special emphasis on vernal pool obligate species (see attached materials). In addition, the presentation included information on the significance of vernal pools, their current status and threats and the interest by MDEQ and MNDR in gaining more information on the status, distribution and ecology of vernal pools in MI so they can better protect and manage them. We also reviewed the vernal pool survey protocol, instructions on how to complete the field form, safety precautions, and how to prevent the spread of invasive plants and wildlife disease when moving between vernal pools, including disinfecting boots and equipment with a bleach solution prior to and after sampling in the pool. In 2013, we also had a guest speaker, Paul Anderson, at the training workshop who shared information about his research related to Blue-Spotted Salamanders and vernal pools. We provided maps of potential vernal pools at the training workshops and asked volunteers to form teams and identify the pool(s) that they would like to monitor. We visited the workshop location prior to the workshops to identify vernal pools nearby that would be easily accessible for a large group of people and developed a plan for conducting the field portion of the trainings. We decided that we would limit the number of training participants to thirty people so that we could more effectively provide supervision and training and to limit our impact to the vernal pools. We incorporated feedback from the volunteers in 2012 to revise and improve the training in 2013.

Volunteer Recruitment and Training

In 2012 and 2013, we decided to launch the pilot volunteer program in our study area in southeast Michigan which consisted of the Waterloo-Pinckney, Highland, and Proud Lake State Recreation Areas. We collaborated with the DNR State Parks Stewardship Program and asked volunteers to register as volunteers with that program since they were equipped to address liability issues and keep track of volunteer hours to use as match for other projects taking place in state parks and recreation areas. In addition, working on state land did not require the extensive work that would have been required to identify and contact private landowners to secure permission to conduct surveys on their land. We provided each volunteer with a letter stating that they were participating in the Volunteer Vernal Pool Program, and contacted park managers prior to project initiation to inform them that volunteers would be visiting and collecting data on vernal pools in their area.

We promoted the volunteer vernal pool program and training workshops in southeast Michigan with the help of partners who were active in conservation efforts in southeast Michigan. The DNR State Parks Stewardship Program, Huron River Watershed Council, the Stewardship Network and the MSUE Conservation Stewards Program shared information about the Volunteer Vernal Pool Program and volunteer training through their online newsletters, email blasts, and presentations at their meetings. In 2013, volunteers from 2012 were invited to participate in the training workshop as a refresher training.

In 2013, we decided to launch a pilot volunteer vernal pool mapping and monitoring program in our study area in northeast Michigan. We scheduled and promoted a training workshop in Atlanta, MI with the assistance of the Montmorency County Conservation Club, Huron Pines, Au Sable River Watershed Council, the Upper Black River Council, and the local DNR biologist. Unfortunately, due to a late spring, we had to cancel and reschedule the workshop.

Volunteer Logistics, Support, Data Collection and Analysis
Immediately following the training workshops, we developed and mailed site packets to the volunteers. These packets contained 1) topographic maps; 2) aerial photos (CIR and regular - overview and zoomed in to pool); 3) the vernal pool training manual; and 4) field forms. We encouraged volunteers to contact us if they had any questions or if they needed to be assigned another pool. We developed a vernal pool website where resources and materials could be easily accessed by volunteers. Examples of these included the training presentation, disinfection procedure to use when visiting pools, MNFI Special Species Form for recording rare species, a form to track their hours, and the vernal pool field form and training manual.

In the fall of 2012 and 2013, after the volunteers had made their final pool visit, we contacted them and reminded them to submit their data to us. Volunteers were provided a link to a folder in "Dropbox" (www.dropbox.com) where they could upload their forms and photos. They also could send in their data through email or mail in in a hard copy of their forms and photos. All of the data were summarized in an Excel spreadsheet, and each team's data and photos were reviewed for quality control. We compared the photos of the pools with the data forms for each of their three site visits and determined whether the pool was either 1) a vernal pool; 2) not a vernal pool; or 3) a potential vernal pool which requires more data to make a final determination.

Volunteer Program Evaluation
We know that successful volunteer programs are those in which participants feel that their efforts are valued and appreciated, and that the data they collect contributes to project goals. We developed a short survey for distribution at the workshop to solicit feedback on both the indoor and field portions of the training in 2012 and 2013 so that we could incorporate this input into

future events and assist us with assessing the effectiveness of our training. In 2012, we planned a volunteer appreciation luncheon in the fall to share the results of the data they collected, express our appreciation, and invite their feedback on the volunteer program. In 2013, we planned a volunteer appreciation meeting but it was canceled due to poor weather. Instead, we compiled a presentation summarizing their data and sent them a pdf of this document along with a thank you note through email. We also asked them to complete a survey through a link to "Survey Monkey" to provide their input on the training and volunteer program.

RESULTS

Volunteer Recruitment and Training

In 2012, we conducted a training workshop on Saturday, April 14, from 9:00 am to 12:30 pm at the Eddy Discovery Center, located near Chelsea in the Waterloo Recreation Area in Washtenaw County. Thirty people registered and attended the training workshop. Twelve people expressed interest in the training workshop after registration was full (i.e., 30 participants), and were put on a waiting list to be contacted for future trainings. In 2013, we conducted the training workshop on Saturday, April 13, from 10:00 am to 2:30 pm at the Proud Lake Recreation Area, located near the town of Milford in Oakland County. We had originally scheduled the training for March 16th but rescheduled the workshop for March 30th and then again delayed it until April 13th due to the late arrival of spring and unsuitable conditions for monitoring vernal pools. Thirty six people attended the training, although 7 of these were experienced volunteers from the previous year. Six people were put on a list to be contacted for future trainings as they were unable to attend the rescheduled date.

For the outdoor field training, we split the volunteers into two groups, and demonstrated how to collect data, take and label photographs of the pool, and fill out the field form. We instructed volunteers on how to document the location of the pool, describe the type of vernal pool and surrounding habitat, record physical characteristics of the pool, document threats, and collect data on animal indicator species. In 2012, we were not able to find and show the volunteers amphibian egg masses, fairy shrimp, or other indicator species during the outdoor field training due to early spring and warm weather conditions and/or absence of indicator species. In 2013, we were able to spend time identifying amphibian egg masses and invertebrates and view many of the invertebrates in the pools under a microscope. In addition, we visited wetlands that were not vernal pools, discussed the differences, and reviewed the key characteristics of vernal pools.

In spring 2013, we were not able to recruit enough volunteers to launch a pilot volunteer program in northeast Michigan. However, we met with several conservation groups and potential partners in northern Michigan in December 2013 to discuss the idea of developing a volunteer vernal pool program in the northern Lower Peninsula. Representatives from Huron Pines, Montmorency County Conservation Club, Montmorency County Conservation District, Tip of the Mitt Watershed Council, Headwaters Land Conservancy, Grand Traverse Land Conservancy, and Leelanau Land Conservancy participated in the meeting. All the groups expressed interest in helping to launch a volunteer vernal pool program in northern Michigan.

We have initiated efforts to launch a volunteer vernal pool mapping and monitoring program in northeast Michigan. We decided to initiate efforts in northeast Michigan because several groups were interested and ready to collaborate to implement the program, and some potential vernal pools have already been identified on state and federal lands in northeast Michigan through this project and by the MDNR for volunteers to select, verify, and/or monitor. In February 2014, Huron Pines, Montmorency County Conservation Club (MCCC), Montmorency County Conservation District (MCCD), and Headwaters Land Conservancy in collaboration with MNFI organized a presentation about vernal pools and the vernal pool mapping and monitoring program in Atlanta. Over 40 people attended the presentation, and many of the attendees expressed interest in participating in the volunteer vernal pool mapping and monitoring program. Based on the interest at the presentation and by the local partners, we decided to move forward with launching a volunteer vernal pool mapping and monitoring program in northeast Michigan. A volunteer vernal pool training workshop is planned for May 2014. Huron Pines has offered to help coordinate the volunteer vernal pools program in northeast Michigan, and the MCCC, MCCD, Headwaters Land Conservancy, and MDNR staff in the Pigeon River Country State Forest and Atlanta Field Office are sponsoring and/or providing assistance with the training workshop and/or vernal pools program.

Volunteer Logistics, Support, Data Collection and Analysis

In 2012, a total of 14 teams (30 people) monitored 32 potential vernal pools (PVPs) two to three times in the spring and summer, logging a total of 180 hours. Pools were monitored in all four of the study areas in southeast Michigan including Pinckney Recreation Area, Proud Lake Recreation Area, Highland Recreation Area and Waterloo State Recreation Area. Overall, data quality was fairly high. Data forms were complete, maps were clear, and photos were clearly labeled. Some volunteers used “Dropbox” to submit data while others mailed in their data. Of the 32 PVPs visited, 16 were confirmed to be vernal pools, 9 were confirmed to not be vernal pools, and 7 PVPs had insufficient data to confirm whether they were vernal pools or not. A list of the animals documented by volunteers during 2012 field visits can be found in Appendix 7.

In 2013, a total of 19 teams (37 people) monitored 48 potential vernal pools (PVPs) two to three times in the spring and summer, logging over 200 hours. Of the 37 volunteers in 2013, 14 (38%) were returning volunteers who had participated in the volunteer vernal pools program in 2012, and 23 (62%) were new volunteers. Pools were again monitored in all four of the recreation areas in southeast Michigan. Fifteen (31%) of the 48 vernal pools monitored in 2013 were also monitored in 2012. Data quality was good for the most part. Seventy-five percent of volunteers submitted complete data forms with clearly labeled maps and photos. Some participants encountered challenges with presenting and submitting their data. Of the 48 PVPs visited, 30 were confirmed to be vernal pools, 7 were confirmed to not be vernal pools, and 9 PVPs had insufficient data to confirm either way. A table of the animals documented by volunteers during 2013 visits can be found in Appendix 8.

Volunteer Program Evaluation

In 2012 and 2013, volunteers who attended the training workshops provided feedback on the workshop and training materials. Volunteers shared that they learned about the ecological importance of vernal pools, the existence of obligate species and how to identify invertebrates, salamander eggs and larvae and how to record their findings. Most respondents felt confident that they could correctly assess a vernal pool and found the indoor session to be easy to understand, although a few expressed that it was too long and contained too much information.

All respondents expressed that the outdoor session was very beneficial, and some mentioned that it was a good experience to visit a vernal pool as well as a permanent wetland to discuss the differences. The most common responses when asked what they found to be most helpful included: 1) the outdoor portion – actually going through the process and having one-on-one time with naturalists; 2) indoor session and hands-on approach; and 3) understanding the protocol. The topics that some would have liked more detail on included species identification and identifying animals in the field. Finally, many commented that they appreciated having instructors with various expertise and enjoyed being able to ask them questions.

In the fall of 2012, we hosted a volunteer appreciation luncheon on November 10th at the Eddy Discovery Center. We gave a presentation summarizing the data they collected, and invited their feedback regarding the volunteer program. Volunteers shared that for the most part the procedures and data form were easy to understand. Some were confused by some of the ecological terms used to describe habitat. We revised the training manual and field form in 2013 to address this issue. A few individuals expressed that they had difficulty locating their vernal pools in the field. In 2013, our volunteer appreciation gathering was canceled due to poor weather conditions. All of the volunteers were sent a thank you note and a summary of results from the volunteer monitoring.

2013 Volunteer Survey Results (Survey Monkey)
Twenty two (59%) of 37 volunteers responded to our survey which included eight questions.

- 100% felt adequately trained to monitor vernal pools and felt that the procedures were easy to follow.
- 95% would participate in future training events.
- 85% want to continue to monitor vernal pools.
- 55% would be willing to mentor/train others.
    - Some suggested setting up a local network of support.
- A few individuals wanted more support to help find vernal pools in the field.

The following table summarizes responses to Question #2 regarding additional training:

MNFI Vernal Pool Project Evaluation

Is there additional training that would be helpful to you in monitoring vernal pools?		
Answer Options	Response Percent	Response Count
How to use GPS to navigate and record data	47.4%	9
How to create and label maps and upload data	31.6%	6
How to take better photographs in the field	26.3%	5
How to identify invertebrates	36.8%	7
How to identify amphibians and reptiles	36.8%	7
How to identify natural communities	26.3%	5
Field-based training to look at different types of vernal pools and wetlands	42.1%	8
Other (please specify)		5
	answered question	19
	skipped question	3

DISCUSSION

Lessons learned and recommendations

Overall, we are extremely pleased with the results of the pilot volunteer program. There was a great deal of interest and enthusiasm for the project from a wide variety of people including families with young children, college students, working adults, and retired individuals. The volunteer program increased awareness and understanding of vernal pools among the program participants and partners. The program also provided an opportunity for citizens to become engaged in research and conservation of vernal pools and biodiversity/natural resources. Some participants had previous experience with natural resource-related projects (e.g. invasive plant removal, wild seed collection), while this was the first time some volunteers had worked on a natural resource project. Volunteers visited and monitored a total of 65 potential vernal pools, including 15 pools that were monitored during both years, and contributed valuable data about these pools to the project. It would have required many hours of paid staff time to visit this many pools to collect the same amount of data. We were also pleased that a number of the volunteers (38%) participated in the vernal pool program in 2012 and 2013, and our data return rate was pretty high compared to data return rates other volunteer programs (e.g., volunteer herp monitoring programs) have reported (i.e., <10% - 25%) (Lee 2012). Based on our experiences with the volunteer program in 2012 and 2013, feedback from the volunteers, and other resources on volunteer management, we have identified the following challenges and opportunities that could be addressed for future volunteer vernal pool monitoring efforts.

Timing of training

It was challenging to time the spring training workshops due to the unpredictability of weather and very difficult to predict when vernal pools will thaw and obligate species such as fairy shrimp, salamanders and wood frogs will become active. This may become more apparent with monitoring over time. However, with this issue in mind, it may be best to schedule and publicize both an early date and a later date for the spring training and then communicate with registered volunteers when we have determined the best time to conduct the training.

Additional training

Many volunteers communicated that they would be interested in participating in refresher workshops or training on specific topics such as navigation and use of GPS, photography tips, labeling maps and photographs using a computer software program, and identification of invertebrates, amphibians, reptiles and ecological communities. Future trainings should include some resources and time to cover these topics and other particular challenges and difficulties that volunteers face. Additional training materials/resources (e.g., keys to help identify frog and salamander eggs and/or larvae/tadpoles and invertebrates commonly encountered in vernal pools), especially materials that can be taken into the field for reference, also would be helpful. Development of a training plan for volunteers also would be beneficial.

After reviewing the volunteer data from 2012 and 2013, we have identified the following variables or parts of the volunteer survey protocol and data form that should be revised or clarified, and emphasized during future volunteer trainings.

General

- Revise the protocol and data form to clarify when certain data should be collected (e.g., tree canopy cover during late spring or summer visit) and which data only need to be collected once (e.g., pool size) during the field season to streamline and simplify data collection

- Check data between visits to be sure it makes sense. (e.g. > 50% shrubs visit 1 but <50% visits 2, 3)
- Revise percent cover categories/ranges and other data fields to match data fields and categories/ranges in the statewide vernal pool database

Photos

- Make sure photos are taken from the same vantage point for all three visits
- Make sure that the label isn't the focal point of the photo but rather the pool
- Photo document plants and animals recorded on the data form, esp. indicator species
- Also include references used to help identify plants and animals
- Remind volunteers to use photo labeling conventions
- Organize photos from same pool together

Substrate

- Volunteers often did not fill in substrate on the data forms or indicated some confusion or uncertainty with this field. Based on field data collected by MNFI in 2013, this field could include fewer options that volunteers can reliably identify.
- Emphasize during training that substrate should be recorded when pool is dry

Pool location

- Indicate distance from a landmark so others can find the pool in future years

Water level

- Provide additional training on how to record this field

Volunteer data collection and analysis

We learned that it is important to allocate adequate time to collect, organize, and enter the volunteer data into the statewide database. It also requires time to organize and carefully review the field forms and photographs to verify the status of the potential vernal pool and other data collected for quality control. This should take less time though as volunteers become more experienced. Also, more experienced volunteers or local volunteer coordinators could help with training volunteers and data quality control in the future. Prysby and Super (2007) recommend considering including several levels of participation for volunteers. Differing roles allow participants with different levels of ability and commitment to get involved with the program, can give experienced volunteers more responsibility over time, and can help retain volunteers.

Volunteer project leaders in other states also have learned that if you can make data submission fun through contests or competition between volunteer teams, it improves timely submission of quality data. Perhaps it might be an incentive to show a map indicating where we had updated vernal pool information (e.g., highlighting new pools as they are confirmed) so volunteers could see the impact of contributing their team's data. Other incentives for returning data, especially negative data, could be provided, and the importance of returning all data, including negative data, could be stressed in the future. It may be a good idea to designate one person in each group of volunteers to be the main contact and person responsible for compiling and submitting the group's data forms and photographs. It also may be helpful to provide a checklist of items that need to be submitted at the end of the season such as volunteer hours, data forms, and photographs. Providing an online data entry system whereby volunteers and/or local volunteer coordinators could enter the data themselves would help facilitate easy submission of data and ability to easily access and share data online. Having volunteers enter their own data also would help them realize what they might have done wrong or didn't fill out in the field.

Need for ongoing volunteer support and volunteer recruitment and retention
We learned that it would be beneficial to have someone available to provide assistance and regular communication with volunteers during the field season. We did provide as much support as we could but resources for ongoing communication and support were limited. It would be ideal to have more contact with volunteers during the field season to keep them invested in the project and encourage them to submit their data promptly. Reporting results to volunteers and acknowledging their contributions to the project and how their data will be used and will fit into the overall program goals in a timely manner is important for volunteer retention. Having local or regional groups serve as volunteer coordinators to organize and work with volunteers could help with volunteer recruitment and retention, provide ongoing assistance to and communication with volunteers during and after the field season, enhance data submission, and help build a sense of community and a support network among the volunteers. Local or regional volunteer coordinators could work in collaboration with a statewide vernal pools program coordinator. Additional time and resources should be devoted to developing and updating the vernal pool website and potentially developing a Facebook page and utilizing other social media. Establishing a newsletter, either online or hard copy, a listserv, and/or a chat room could help provide regular updates and facilitate communication with volunteers, partners, and stakeholders including researchers and managers who use the data (Prysby and Super 2007).

Some volunteers lack access to or familiarity with technology such as GPS units, smartphones, and/or computer software for creating maps, viewing and labeling photos, and sharing files such as Dropbox. It would be prudent to have at least one member of each group have access to a GPS unit or similar device**.** It may be a good idea to purchase several inexpensive GPS units that could be loaned out to volunteers to use when first navigating to their pools until they become familiar with the route. Some volunteers had difficulty accessing vernal pools due to briars, dead and downed trees, etc. In the future, volunteers could be assigned to different pools, or alternative routes to pools or other options should be explored. Ensuring volunteers have the equipment they need and can access sample sites is critical volunteer retention as inability to find or access study sites is a common reason for volunteer attrition (Prysby and Super 2007).

Next Steps
It is very encouraging that 85% of our volunteers in southeast Michigan are interested in continuing to monitor vernal pools and that strong interest has been communicated by several groups and individuals in northeast Michigan. We would like to maintain the momentum and interest that the project has generated and maintain the project while initiating efforts in other areas of the state, such as our efforts in northeast Michigan this year. Hopefully, our efforts towards the establishment of a public/private partnership to develop a statewide vernal pool mapping and monitoring program will be successful. We have already seen some success from this effort as the Michigan Nature Association has agreed to provide a small amount of funding to support the volunteer vernal pools program in 2014 while we look for additional funding to further develop and implement the program. Developing a volunteer recruitment and retention plan as well as a sustainability and funding plan for a vernal pools monitoring program, including clearly defining the goals and sampling design of the program, also is critical.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Michigan Department of Environmental Quality (MDEQ) through a wetland program development grant from the U.S. Environmental Protection Agency. Michigan Natural Features Inventory provided match/in-kind support for this grant. There are a number of individuals who provided guidance, assistance, and support for this project. We would like to thank Amy Lounds, Anne Garwood (Hokanson), and Chad Fizzell with the MDEQ Wetlands Program for providing administrative oversight, guidance and assistance with this project and for participating in the Vernal Pools Work Group (VPWG). The MDEQ Wetlands Program also provided the isolated wetland analysis that we were able to evaluate as part of this project. We greatly appreciate all the other members of the Vernal Pools Work Group – Amy Derosier and Lori Sargent with the MDNR Wildlife Division, Amy Clark Eagle with the MDNR Forest Resources Division, Chris May with the Michigan Chapter of The Nature Conservancy, Garret Johnson with Michigan Nature Association (MNA), David Mifsud with Herpetological Resource and Management, and Laura Bourgeau-Chavez with Michigan Technological Research Institute (MTRI) and other members of the project team at MTRI including Kirk Scarborough, Michael Battaglia, Sarah Endres, and Zach Laubach. We also would like to thank Tom Goniea with the MDNR Fisheries Division and David Dempsey with the International Joint Commission for participating in the VPWG. We also are extremely grateful to MNFI staff members who were also part of the vernal pools project team and/or who provided technical assistance including Mike Kost, Josh Cohen, Phyllis Higman, Jo Latimore, and Suzan Campbell. We also had several seasonal staff who provided invaluable assistance in the field including John Fody, Becky Norris, and Joann Jeplawy. We also would like to acknowledge MNFI's administrative staff, Nancy Toben and Sue Ridge, and staff in the Contracts and Grants Office for their assistance with this project.

A number of partners also provided assistance with this project without whom we would not have been able to complete this project. We are very grateful to Laurel Melvtiz and MDNR Parks Stewardship Program for providing invaluable assistance with the pilot volunteer vernal pool program in southeast Michigan. We would like to thank Huron Pines for their help trying to launch a pilot volunteer program in northeast Lower Peninsula, and the various groups that met with us and have expressed interest in collaborating with us to implement a volunteer vernal pools program in northern Michigan in the future. We would like to acknowledge Huron Pines, Montmorency County Conservation Club, Montmorency County Conservation District, Headwaters Land Conservancy, and MNA for collaborating with us to initiate a volunteer vernal pools program in northern Michigan. We would like to thank the Waterloo, Pinckney, Highland and Proud Lake State Recreation Areas, Huron National Forest, Au Sable State Forest, Ottawa National Forest, Crystal Falls State Forest, and their staff for letting us conduct the project on their lands and for their assistance with this project. We also would like to especially acknowledge the staff at the Eddy Geology Center and Proud Lake SRA for letting us use their facilities and for their assistance with the volunteer training workshops. We would like to thank Theresa Yoder and her students at the University of Michigan-Flint for their assistance with identifying and mapping vernal pools. Last but not least, we would like to thank all the volunteers who have participated in the vernal pool mapping and monitoring program and have helped verify and collect information about vernal pools in the field. We greatly all your time, efforts, enthusiasm and interest in vernal pools and their conservation!!

REFERENCES

Blewett, W.L. 1990. The glacial geomorphology of the Port Huron complex in northwestern southern Michigan. PhD Dissertation, Department of Geography, Michigan State University. 191 pp.

Bolstad, P.V., Swank, W., Vose, J. 1998. Predicting southern Appalachian overstory vegetation with digital terrain data. *Landscape Ecology*. Vol. 13, 271-283.

Breiman, L. 2001. Random Forests. Machine Learning 45: 5-32.

Burnham, K.P. and Anderson, D.R. 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach (2nd ed.), Springer-Verlag.

Calhoun, A. J. and P. G. de Maynadier. 2008. Science and Conservation of Vernal Pools in Northeastern North America. CRC Press, New York, NY. 363 pp.

Colburn, E.A. 2004. Vernal Pools: Natural History and Conservation. The McDonald and Woodward Publishing Company, Granville, OH. 426 pp.

Congalton, R.G., Green, K., 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. Lewis Publications, Boca Raton, Florida, p. 137.

Damon B. Oscarson, D.B and A.J.K. Calhoun, Developing pool conservation plans at the local level using citizen-scientists. Wetlands, Vol. 27, No. 1, March 2007, pp.

Dunn, O. J. 1964. Multiple contrasts using rank sums. Technometrics 6:241–252.

Elith, et al. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography*. Vol 29(2): 129-151.

Elith, J., Phillips, S.J., Hastie, T., Dudik, M., Chee, Y.E., and Yates, C.J. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*. 17:43-57.

Elliott, A. C., and L. S. Hynan. 2011. A SAS® macro implementation of a multiple comparison post hoc test for a Kruskal–Wallis analysis. Computer Methods and Programs in Biomedicine 102:75–80.

Elliott, A. C., and W. A. Woodward. 2010. SAS essentials: a guide to mastering SAS for research. John Wiley and Sons, San Francisco, California, USA.

Environmental Laboratory. (1987). "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Farrand, W. R. and Bell, D. L. 1982a. Quaternary Geology of Northern Michigan. 1:500,000 scale. Lansing, MI: Department of Natural Resources, Geological Survey Division.

Farrand, W. R. and Bell, D. L. 1982b. Quaternary Geology of Southern Michigan. 1:500,000 scale. Lansing, MI: Department of Natural Resources, Geological Survey Division.

Godwin, K. S., J. P. Shallenberger, D. J. Leopold, and B. L. Bedford. 2002. Linking landscape properties to local hydrogeologic gradients and plant species occurrence in minerotrophic fens of New York State, USA: A hydrogeologic setting (HGS) framework. *Wetlands.* 22:722–737.

Holland, R.F. and S.K. Jain. 1981. Insular biogeography of vernal pools in the Central Valley of California. The American Naturalist 117: 24-37.

Jenness Enterprises. 2013. Land Facet Corridor Designer for ArcGis 10 v. 1.2.884. Available from http://www.jennessent.com/arcgis/land_facets.htm. Accessed 2/11/2014

Herman, K. D., L. A. Masters, M. R. Penskar, A. A. Reznicek, G. S. Wilhelm, and W. W. Brodowicz. 2001. Floristic quality assessment with wetland categories and computer application programs for the State of Michigan, Revised, 2nd Edition. Michigan Department of Natural Resources, Wildlife Division, Natural Heritage Program. *Lansing, MI. 21 pp. + Appendices.*

Kost, M. A., D. A. Albert, J. G. Cohen, B. S. Slaughter, R. K. Schillo, C. R. Weber, and K. A. Chapman. 2007. Natural Communities of Michigan: Classification and Description. Report to the Michigan Department of Natural Resources Wildlife Division and Forest, Mineral and Fire Management Division. Report Number 2007-21, Version 1.2, Last Updated: July 9, 2010, Lansing, Michigan. 321 pp.

Lee, Y. 2012. Developing a Conceptual Framework of Recommendations for Monitoring Amphibians and Reptiles Using Non-Calling Surveys and Volunteers. Final Report to the Michigan Department of Natural Resources. Michigan Natural Features Inventory Report No. 2012-11, Lansing, Michigan. 24 pp. + appendices.

Leppo, B., E. Zimmerman, S. Ray, G. Podniesinski, and M. Furedi. 2009. Pennsylvania Statewide Seasonal Pool Ecosystem Classification: description, mapping, and classification of seasonal pools, their associated plant and animal communities, and the surrounding landscape. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, USA.

Lusch, D. P., Reeves, H., and Miller, S. 2005. Technical Report, Groundwater Inventory and Mapping Project. Lansing, MI: Water Bureau, Michigan Department of Environmental Quality, 248 pp. [http://gwmap.rsgis.msu.edu/Technical_Report.pdf].

McCune, B., and J. B. Grace. 2002. Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon, USA.

McNab, H.W. 1989. Terrain shape index: quantifying effect of minor landforms on tree height. *Forest Science*. 35(1): 91-104.

Merow, C., Smith, M.J. and Silander Jr., J.A.. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. *Ecography*. 36:001-012.

Michigan Department of Natural Resources (Michigan DNR) and Michigan Department of Environmental Quality (Michigan DEQ). 2009. Sustainable Soil and Water Quality Practices on Forest Land. Revised Feb. 24, 2009. Lansing, MI. 79 pp.

Mielke, P. W. Jr. 1984. Meteorological applications of permutation techniques based on distance functions. Pages 813–830 *in* P. R. Krishnaiah, and P. K. Sen, editors. Handbook of statistics. Volume 4. Elsevier Science Publishers, Amsterdam, The Netherlands.

Mitsch, W. J. and J.G. Gosselink. 2000. *Wetlands*, 3rd ed.. John Wiley and Sons, New York.

Moore, ID., Gessler, P.E., Nielsen, G.A., and Petersen, G.A. 1993. Terrain attributes: estimation methods and scale effects. In Modeling Change in Environmental Systems, edited by A.J. Jakeman, M.B. Beck and M. McAleer (London: Wiley), pp. 189 – 214.

Morgan, D.E., and A.J.K. Calhoun. 2012. The Maine Municipal Guide to Mapping and Conserving Vernal Pools. University of Maine, Sustainability Solutions Initiative, Orono, ME.

National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center (2008) C-CAP zone 41 2006-Era Land Cover. Time period of content 2005–2006 [http://www.csc.noaa.gov/digitalcoast/data/ccapregional/].

Natural Resources Conservation Service. 2006. Landforms Report for Michigan Upper Peninsula. *Draft.* [http://www.mi.nrcs.usda.gov/soils.html]

Palik, B. J., R. Buech, and L. Egeland. 2003. Using an ecological land hierarchy to predict seasonal-wetland abundance in upland forests. *Ecological Applications* 13:1153–1163.

Phillips, S.J., Anderson, R.P., Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*. 109:231-259.

Prysby, M. and P. Super. 2007. *Director's Guide to Best Practices Programming – Citizen Science*. Association of Nature Center Administrators. Logan, Utah. 53 pp.

Schaetzl, R. J., Krist F. J., Jr., Stanley, K. E., and Hupy, C. M. (2009) The Natural Soil Drainage Index: An ordinal estimate of long-term, soil wetness. *Physical Geography*, Vol. 30:383-409.

Thomas, S. A., Y. Lee, M. A. Kost, and D. A. Albert, 2010. Abstract for vernal pool. Michigan Natural Features Inventory, Lansing, MI. 24 pp.

Tiner, R. W. 2003. Estimated extent of geographically isolated wetlands in selected areas of the United States. *Wetlands* 23:636–652.

United States Department of Agriculture, Natural Resources Conservation Service. 2010. *Field Indicators of Hydric Soils in the United States, Version 7.0.* L.M. Vasilas, G.W. Hurt, and C.V. Noble (eds.). USDA, NRCS, in cooperation with the National Technical Committee for Hydric Soils.

United States Geological Survey 2009a. Digital Elevation Model (DEM) for Michigan from the National Elevation Dataset. 10 m raster dataset, [http://ned.usgs.gov/]

United States Geological Survey 2009b. Digital Elevation Model (DEM) for Michigan from the National Elevation Dataset. 30 m raster dataset, [http://ned.usgs.gov/]

Vermont Wetlands Bioassessment Program. 2003. An evaluation of the chemical, physical, and biological characteristics of seasonal pools and northern white cedar swamps. Final report, Vermont Department of Environmental Conservation and Vermont Department of Fish and Wildlife, Montpelier, USA.

Warren, D.L., Glor, R.E., and Turelli, M. 2010. ENMTools: a toolbox for comparative studies of environmental niche models. *Ecography*. 607-611. (Version 1.4.3)

Warren, D.L. and Seifert, S.N. 2011. Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria. *Ecological Applications*. 21(2):335-342.

Weiss, A. 2001. Topographic Position and Landforms Analysis. Poster presentation, ESRI User Conference, San Diego, CA. Available, by permission from the author, at http://www.jennessent.com/arcview/TPI_Weiss_poster.htm

APPENDICES

Appendix 1. Vernal Pools Work Group members.

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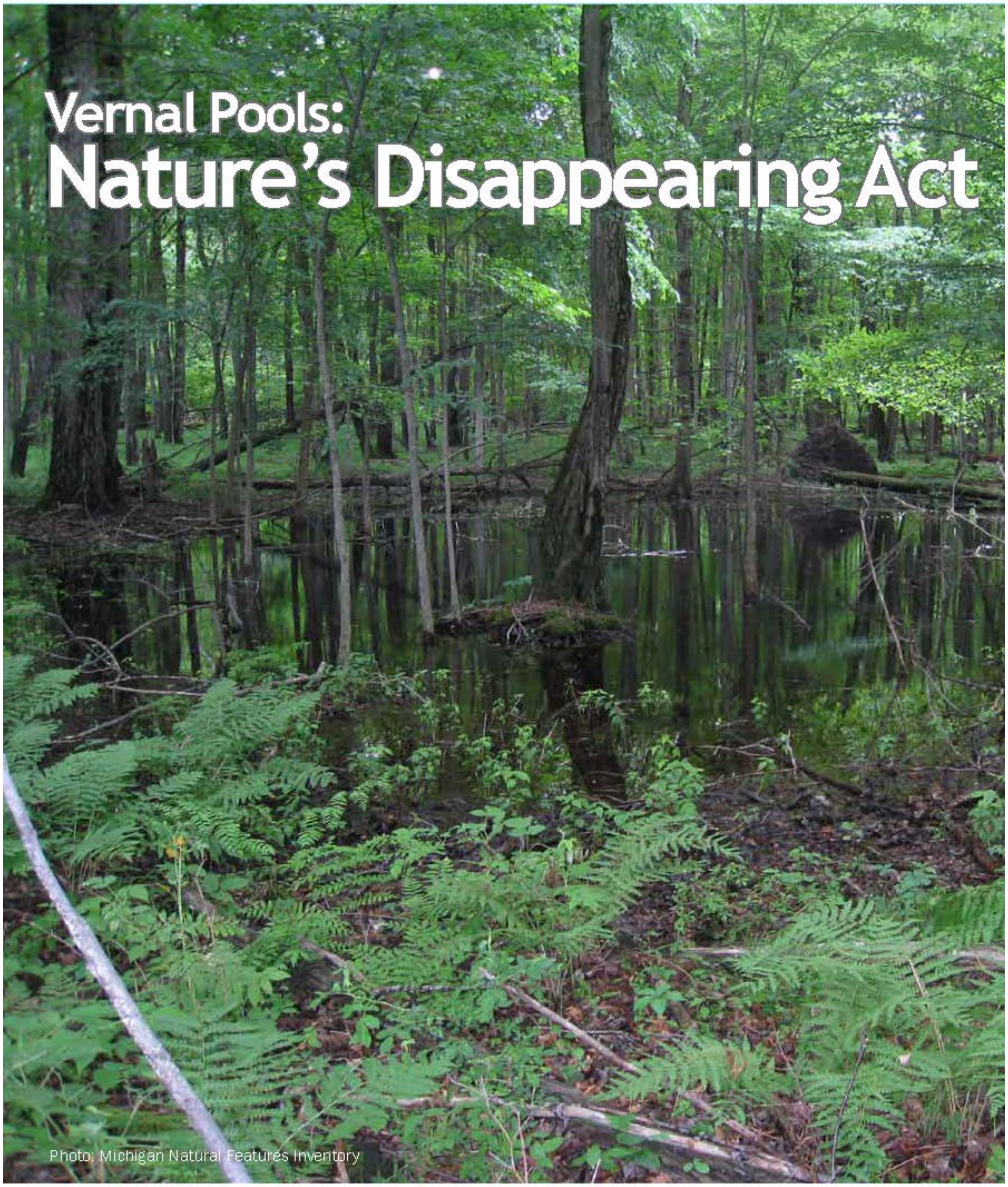
Appendix 2. Article on Vernal Pools in MNA Magazine Spring 2012 Issue.



Appendix 2. Continued.

▲ Jewelweed at an MNA sanctuary. *Photo from MNA archives*

By Yu Man Lee, Conservation Scientist
Michigan Natural Features Inventory

If you have spent time exploring Michigan's forests in the spring, you may have come across shallow pools of water scattered throughout the landscape.

Only within the last decade or two have we started to understand and fully appreciate the significance of these small, temporary wetlands known as vernal pools. However, vernal pools continue to disappear from Michigan's landscape and face a number of threats including land use changes and associated impacts, and lack of understanding and awareness of these important ecosystems.

▲ A dry vernal pool. *Photo courtesy of Michigan Natural Features Inventory*

Vernal pools ("vernal" means spring) are filled with water in the spring and "disappear" by late summer. These wetlands provide special and unique habitats for plants and animals, including some species that are especially adapted for life in vernal pools. These pools provide safe haven from predators for some species, such as wood frogs and spotted salamanders that come to vernal pools early in the spring to breed and lay their eggs.

But it's a race against time every year for their larvae or tadpoles as they have to fully develop and transform into adults before the pools dry up.

Vernal pools, also called seasonal or ephemeral pools, are small, shallow depressions that usually contain water for only part of the year. These temporary wetlands typically fill with water between late fall and spring from rising groundwater, snowmelt, and rainfall.

The length of time that surface water is present in these pools varies, but most dry up by late summer or early fall (although some pools do not dry up every year or during particularly wet years). Because they lack a permanent water source and dry up periodically, vernal pools do not support breeding fish populations.

Vernal pools occur throughout Michigan, and can be highly variable. They vary in size and depth, with most pools less than one-half acre and less than four feet deep. Vernal pools are primarily found in forested areas. They may be isolated and surrounded by dry upland forest, or located within or adjacent to other wetlands such as forested swamps and river floodplains.

Vernal pools also can occur in open areas, including prairies, old fields, marshes, and bogs. The vegetation within vernal pools can vary greatly. Some vernal pools may have few to no plants growing in them, while other pools may be dominated by trees, shrubs, or grasses. In some pools, annual plants may become established after the water levels recede.

More than 550 animal species have been documented in vernal pools in northeastern America.

Despite their small size and temporary nature, vernal pools can be incredibly diverse and productive ecosystems. Vernal pools provide important habitat for many wildlife species. These include invertebrates, frogs, toads, salamanders, snakes, turtles, waterfowl, wetland birds, songbirds, and mammals. Over 550 animal species have been documented in vernal pools in northeastern America.

Many animal species use vernal pools as sources of food and water throughout the growing season, as breeding and resting areas, and as stepping stones to disperse to other areas with suitable habitat to complete their life cycle. Several rare species in Michigan use vernal pools extensively including the smallmouth salamander (state endangered), copperbelly watersnake (federally threatened, state endangered), spotted turtle (state threatened) and Blanding's turtle (state special concern).

The abundance of invertebrates in vernal pools is especially impressive. Hundreds if not thousands of frogs and salamanders migrate to and breed in some vernal pools in the spring. In some New England forests, the biomass or combined weight of vernal pool-breeding amphibians has been greater than the biomass of all the small mammals and breeding birds combined on a per area basis.

Invertebrates comprise the majority of the animal species and biomass in vernal pools, with aquatic insects representing one of the largest groups. These include caddisflies, water beetles, damselflies, dragonflies, mayflies, mosquitoes, and other kinds of aquatic insects. Other invertebrates including tiny crustaceans, fingernail clams, snails, flatworms, water mites, and springtails also occur in vernal pools.

Amphibians and invertebrates are important parts of the energy cycle and food chain in vernal pools and the surrounding forest ecosystems. They consume and help break down leaf litter, detritus, and other decomposing matter. They serve as predators on smaller animals, and as parasites on larger animals. They also provide an important food source for other invertebrates, amphibians, and wildlife species throughout the spring and summer.

▲ A wood frog at an MNA sanctuary. *Photo by Susan B. Miller*

Ideal Breeding Habitat

Many of the animal species that live in vernal pools have developed special life history strategies for dealing with the highly variable and seasonal nature of these wetlands. Several amphibian and invertebrate species actually require or are highly dependent on vernal pools for part or all of their life cycle. These vernal pool indicator species include the wood frog, spotted salamander, blue-spotted salamander, and fairy shrimp. Vernal pools provide ideal breeding habitat for these species.

The dry period in vernal pools reduces or eliminates populations of predators or dominant competitors such as fish, which cannot survive drought, and bullfrogs, which usually take more than a year to develop from tadpole to adult. Wood frog, spotted salamander, and blue-spotted salamander egg masses and tadpoles or larvae also are more vulnerable to fish predation because they lack the chemical or physical defenses to predation possessed by species that regularly breed in permanent pools with fish populations.

Even though these species may breed in other wetlands, successful

► It's one of nature's rarely witnessed rituals. Each spring, spotted salamanders leave their nesting grounds and seek nearby vernal pools, which serve as breeding ponds. Adults stay in the vernal pool for only a few days, and the female leaves behind eggs that cling to underwater plants. Some salamanders live for decades, and have been known to return to the same vernal pool each year. *Photo courtesy of Michigan Natural Features Inventory*

Appendix 2. Continued.

▲ A vernal pool. *Photo courtesy of Michigan Natural Features Inventory*

production of juveniles is much higher in vernal pools than in wetlands with permanent populations of fish or other predators such as bullfrogs and green frogs.

Some species spend their entire lives in a single vernal pool. Fairy shrimp are crustaceans (0.6 to 1.5 inches long) that are restricted to fish-free, temporary waters. Their eggs may require drying, flooding, and freezing to successfully hatch, and can survive in the sediment for several years.

The plants found in and around vernal pools are similar to those found in the surrounding landscape, but also contain species adapted to wetter conditions. Common trees and shrubs of vernal pools in Michigan include red maple, yellow birch, American elm, white pine, hemlock, northern white-cedar, willow, buttonbush, speckled alder, winterberry, and dogwood.

Common herbaceous or non-woody plant species include duckweed, sphagnum moss, jewelweed, marsh marigold, skunk cabbage, blue-joint grass, rushes, and sedges. Several rare plants are associated with vernal pools in Michigan, including Shumard's oak (state special concern), raven's-foot sedge (state endangered), squarrose sedge (special concern), and false hop sedge (state threatened).

Vernal pools receive little or no protection under federal and state wetland regulations.

As wetlands, vernal pools also provide other important functions. Vernal pools contribute to groundwater recharge and flood control by acting as natural sponges and capturing, storing, and slowly releasing water over a long period of time. They also help improve water quality by acting as sediment traps or sinks. Vernal pools are fascinating environments, and provide excellent opportunities for viewing and learning about wetlands, plants, and animals.

Highly Vulnerable to Disturbance

Vernal pools are highly vulnerable to disturbance or destruction. Because of their small size and seasonal nature, vernal pools can be difficult to identify on the landscape, especially when they are dry, and are often overlooked. Unfortunately, vernal pools receive little or no protection under federal and state wetland regulations because they are small and often isolated from larger and/or permanent waterbodies and wetlands.

Vernal pools face a number of threats due to land use changes. Many vernal pools have been drained or filled and extensive loss of forests have occurred in some areas due to residential, commercial, and/or agricultural development. Some pools have been excavated to create stormwater detention ponds, or converted to permanent ponds.

Appendix 2. Continued.

Vernal pools also may be vulnerable to climate change due to potential for increased temperatures and evaporation, drier conditions, and hydrological changes. Additionally, limited information is available on the status, distribution, and ecology of vernal pools across the state in Michigan.

Conserving Vernal Pools

Due to recent increased awareness of the importance of vernal pools, there has been growing interest in identifying, studying, and conserving these small but valuable ecosystems in Michigan and other states.

The Michigan Department of Environmental Quality (MDEQ) and the Michigan Natural Features Inventory (MNFI), a program of Michigan State University Extension, have been collaborating to develop and initiate efforts to identify, map, and assess vernal pools in Michigan using remote sensing, GIS modeling, and field sampling by MNFI staff and volunteers.

Funding for this project has been provided by the MDEQ with funds from the U. S. Environmental Protection Agency. Additional partners include the Michigan Nature Association, Michigan Department of Natural Resources, Herpetological Resource and Management, Michigan Technological University, The Nature Conservancy, Huron River Watershed Council, and Huron Pines.

This partnership will enhance our understanding of vernal pools in Michigan, which will help develop and implement appropriate and effective conservation strategies for vernal pools and associated plants and animals. This information will help provide the foundation for developing and implementing a statewide program to inventory, monitor, and protect vernal pools in Michigan in the future.

>>For More Information

Please contact Yu Man Lee, conservation scientist with the Michigan Natural Features Inventory at leeyum@msu.edu for more information or visit MNFI's website at mnfi.anr.msu.edu.

Vernal Pools Abstract
Michigan Natural Features Inventory
Available at mnfi.anr.msu.edu

Vernal Pools: Natural History and Conservation
Elizabeth A. Colburn
McDonald and Woodward Publishing Company

▲ A blue-spotted salamander. *Photo courtesy of Michigan Natural Features Inventory*

▲ A baby spotted turtle. *Photo by Amanda Orban*

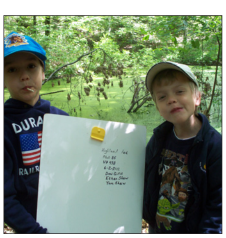
▲ Marsh marigold at an MNA sanctuary. *Photo by Arlene Johnson*

Appendix 3. Volunteer Vernal Pool Training Manual 2014

MICHIGAN STATE UNIVERSITY | Extension

Volunteer Training Manual

Michigan Vernal Pool Mapping and Monitoring Project



MICHIGAN NATURAL FEATURES INVENTORY

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DEQ

Vernal Pools

What is a vernal pool?

Vernal pools, also called seasonal or ephemeral pools, are small, shallow depressions that usually contain water for only part of the year. These temporary wetlands typically fill with water between late fall and spring from rising groundwater, snowmelt, and rainfall. The length of time that surface water is present in these pools varies, but most dry up by late summer or early fall (although some pools do not dry up every year or during particularly wet years). Vernal pools occur in confined basins or depressions, and have no permanent inlets or outlets or continuous surface water connections to permanent water bodies. Because they lack a permanent water source and dry up periodically, vernal pools do not support breeding fish populations.

Vernal pools are primarily found in forested areas, and occur throughout Michigan. They can be highly variable. They vary in size and depth, with most pools less than one-half acre and less than four feet deep. Vernal pools may be isolated and surrounded by dry upland forest, or located within or adjacent to other wetlands such as forested swamps and river floodplains. Vernal pools also can occur in open areas, including prairies, old fields, marshes, and bogs. The vegetation within vernal pools can vary greatly. Some vernal pools may have little to no plants growing in them, while other pools may contain trees, shrubs, and/or grasses. In some pools, annual plants may become established after the pool dries up.

Why are vernal pools important?

Despite their small size and temporary nature, vernal pools can be incredibly diverse and productive ecosystems. Vernal pools provide important habitat for many wildlife species. These include invertebrates, frogs, toads, salamanders, snakes, turtles, waterfowl, wetland birds, songbirds, and mammals. Over 550 animal species have been documented in vernal pools in northeastern America (Colburn 2004). Many animal species use vernal pools as sources of food and water throughout the growing season, as breeding and resting areas, and as stepping stones to disperse to other areas with suitable habitat to complete their life cycle (Gibbs 1993, Semlitsch and Bodie 1998, Gibbs 2000, Mitchell et al. 2008). Several rare species in Michigan use vernal pools extensively including the Smallmouth Salamander (state endangered), Copperbelly Watersnake (federally threatened, state endangered), Spotted Turtle (state threatened) and Blanding's turtle (state special concern). The large number and biomass (combined weight) of amphibians and invertebrates that live in vernal pools and the surrounding forest ecosystems provide an important food source for other animals throughout the spring and summer.

Many of the animal species that live in vernal pools have developed specialized life history strategies for dealing with the highly variable and seasonal nature of these wetlands. Several amphibian and invertebrate species actually require or are highly dependent on vernal pools for part or all of their life cycle, and are considered obligate vernal pool indicator species. These include the Wood Frog, Spotted Salamander, and Blue-spotted Salamander, and invertebrates such as fairy shrimp, clam shrimp, and several freshwater snails and dragonflies. The egg masses and young of Wood Frogs and Spotted and Blue-spotted Salamanders do not have toxic compounds, or the mechanical or physiological barriers to predation that characterize egg masses of many aquatic amphibians that regularly breed in permanent pools with fish populations (Brodie 1987). As a result, even though these species may breed in other wetlands, successful production of juveniles may be much higher in vernal pools than in other wetlands with permanent populations of fish or other predators such as bullfrogs and green frogs. Fairy shrimp occur only in waters that are free of fish populations, and spend their entire lives in a single vernal pool. Their eggs may require drying, flooding, and freezing to successfully hatch, and can survive in the sediment for several years. Thus, vernal pools provide critical habitat for these indicator species.

As wetlands, vernal pools also provide other important functions. Vernal pools contribute to groundwater recharge or storage and flood control by acting as natural sponges and capturing, storing, and slowly releasing water over a long period of time. They also help improve water quality by acting as sediment traps or sinks. However, because of their small size and isolated and temporary nature, vernal pools often receive little or no protection under federal and state regulations. They also can be difficult to identify on the landscape, especially when they are dry, and are highly vulnerable to disturbance or destruction.

Smallmouth salamander (*Ambystoma texanum*)

Project Overview

Due to recent increased awareness of the ecological significance of vernal pools, there has been growing interest in identifying, monitoring, and protecting these small but valuable ecosystems. In order to further understand and adequately protect these critical habitats, it is essential to know where they occur. However, due to their small size and seasonal nature, vernal pools can be difficult to identify and map, and have not been well-documented by the National Wetland Inventory (NWI) or other traditional wetland mapping efforts. Little information is currently available on the status, distribution, and ecology of vernal pools across the state in Michigan. The Michigan Natural Features Inventory (MNFI), a program of Michigan State University Extension, in collaboration with the Michigan Department of Environmental Quality (MDEQ), conducted a three-year project to develop and initiate efforts to identify, map, and assess vernal pools in Michigan using remote mapping techniques and field sampling. Funding for this project was provided by the U.S. Environmental Protection Agency and the MDEQ. Additional partners on this project include the Michigan Department of Natural Resources (MDNR), Herpetological Resource and Management, Michigan Technological University, and Michigan Nature Association. The goal of this project was to enhance our understanding of vernal pools in Michigan and provide a framework for assessing their status, distribution, and ecological values across the landscape. The project is continuing efforts to identify, map and monitor vernal pools, and to develop and implement a statewide vernal pools mapping and monitoring program. These efforts will inform and aid in the development and implementation of appropriate conservation strategies for vernal pools and associated plants and animals in Michigan.

Project Goals and Objectives

The project's overall goals are to:

1. Develop an effective and efficient approach for identifying, mapping, and assessing vernal pools in Michigan to aid in conservation of these ecosystems.
2. Initiate efforts to identify, map, and assess vernal pools.
3. Raise awareness about the value of vernal pools and help build support for statewide conservation of these systems.

The primary objectives are:

1. Identify and map the location of potential vernal pools in forested landscapes in three pilot study areas in Michigan using remote mapping techniques including aerial photo interpretation, radar, and GIS (Geographic Information Systems) modeling.
2. Evaluate and compare the effectiveness and efficiency of the remote mapping techniques for locating and mapping potential vernal pools by conducting field sampling and developing a pilot volunteer program to verify the presence and location of vernal pools in the field and collect physical and biological data on them.
3. Develop a GIS layer of both potential and verified vernal pools, and a database consisting of biological and physical attributes of all verified pools to track vernal pools in the state.

Protocol for Surveying, Mapping, and Assessing Vernal Pools

1) Attend a volunteer vernal pool training workshop. Obtain and review training materials.

2) Identify or select a potential vernal pool (PVP) or multiple potential vernal pools to ground-truth and survey in the field. Note that each potential vernal pool has been assigned a unique identification number (Pool ID #). Use this Pool ID # on your data form and photo documentation.

3) Obtain air photos, topographic maps, and other appropriate maps to locate potential vernal pool(s) in the field.

4) Obtain landowner permission to visit the property, if necessary. Notify the landowner or land manager of site visit in advance.

5) Find a partner to work with. For safety reasons, we request that volunteers work in pairs with one person collecting data in the pool while the other person completes the data form.

6) Conduct field surveys to ground-truth and map potential vernal pools (PVPs) and collect data on their physical and biological characteristics.

- Please conduct at least 3 field visits to the vernal pool(s) within a given year. You are welcome to make additional visits to the pools if you would like.

Visit 1—Early spring
(generally mid-late March – mid-April in southern Michigan, early/mid-April – late April/early May in northern Michigan)

The first visit should be conducted soon after ice melt when the vernal pools are filled with surface water and just after the peak of Wood Frog breeding to document Wood Frog egg masses. Other obligate vernal pool indicator species such as fairy shrimp, and Spotted Salamander and Blue-spotted Salamander adults, spermatophores, and/or egg masses also can be observed if present. The timing of peak Wood Frog activity will vary across the state and will differ from pool to pool depending on geographic location, weather, tree cover/exposure to sunlight, and pool depth. Wood Frogs typically begin calling in mid-late March in the Southern Lower Peninsula, early to mid-April in the Northern Lower Peninsula, and mid-late April in the Upper Peninsula, but these dates can shift earlier or later depending on the weather. Amphibian emergence from hibernation occurs after the first warm spring rains or substantial snowmelt, and migration to breeding pools usually occurs on a warm rainy or misty evening(s) (40-50^{o}F).

Wood frog egg mass

Simon Pierre Barrette, Wikimedia Commons

Fairy shrimp

Christian Fischer, Wikimedia Commons

Wod frog tadpole

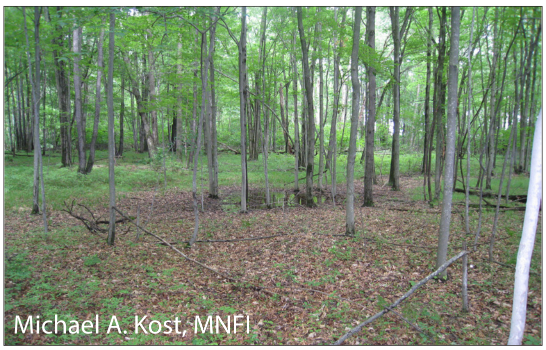
Brian Gratwicke, Wikimedia Commons

Visit 2 —Mid-spring

(early/mid-April – mid-May in S. MI, mid-late April – late May in N. MI)

The second visit should be conducted roughly 2-3 weeks after the first visit to document and do a final count of Blue-spotted and Spotted Salamander egg masses. Fairy shrimp may still be present in some pools, and Wood Frog tadpoles may be observed during this visit. This is also when biodiversity is generally at its highest in the vernal pools, so a number of other animal species, including rare species such as the Blanding's Turtle, may be observed during this visit.

Dried up vernal pool



Michael A. Kost, MNFI

Visit 3 —Late summer/early fall

(late July - September)

The third visit is to document the vernal pool drying up. Some pools may contain water for longer periods of time and dry up later in the year or only in some years. If the vernal pool still contains quite a bit of water during this visit, an additional visit should be conducted later in the summer or early fall (i.e., late August or September) and/or in subsequent years, if possible, to document and confirm pool drying.

- Because of potential year-to-year variations in pool size, duration, water levels, and use by indicator species and other animal species, multiple years (e.g., 2-3 years) of field surveys and data for a given pool would be ideal. Additional visits within a year also would provide more information about the hydrology and plants and animals in the pools.
- To accurately assess the physical characteristics of a vernal pool and get an accurate count or estimate of indicator species in the pool, one person in each survey team will need to walk around within the pool. If the pool has a soft mucky bottom or has a lot of sedimentation, extra care should be taken to avoid stirring up sediments or stepping on egg masses.
- Potential vernal pools (PVPs) that are ground-truthed or verified in the field will be documented, mapped, and surveyed. Any new vernal pools encountered in the field that were not initially mapped as potential vernal pools also should be documented, mapped, and surveyed if possible. We strongly suggest using a GPS (Global Positioning System) unit to mark the exact location of your vernal pool(s) as this makes map making and information sharing much easier. Please set your GPS unit to NAD83 datum. If possible, please save your GPS waypoints and tracks on your unit. Otherwise, please mark the location of your vernal pool or survey site on a Google Map (accessed online), paper topographic map, and/or air photo.
- Some PVPs may turn out to be tree shadows or different types of wetlands other than vernal pools. This information is just as important as confirmed vernal pools!!

Please document, map, and report back on all PVPs you visit, even the ones that aren't vernal pools after all!

7) Complete a Volunteer Vernal Pool Monitoring Form during each survey visit to the vernal pool. See the attached data form and detailed instructions for filling out the form. If a rare species is observed, please also complete and submit a MNFI Special Species Form.

8) Photo document vernal pool(s) and associated indicator species and any rare species observed at pools. **Photo documentation of indicator species and rare species is required.**

Indicator Species

Wood frog

Spotted Salamander

Blue spotted Salamander

Fingernail clams

Fairy shrimp

- Please take photos of the entire vernal pool and the surrounding habitat from outside the pool in all four cardinal directions (5 photos total), if possible, during each survey visit so that we can see the entire pool and all the vegetation and habitat conditions within and around the pool. Please make sure to take photos from the same locations during each visit. To keep track of all your vernal pool pictures, we recommend "labeling" your photos in the field by including a small chalkboard, whiteboard, or sheet of paper in the photo with the following information:

  1) the pool's ID # or name;

  2) the site or property name;

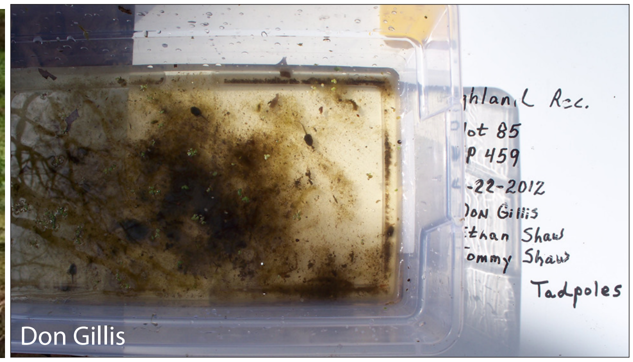
  3) the survey date including the year;

  4) your name; and

  5) what the picture documents (e.g., habitat looking south from pool, wood frog eggs). See examples on the next page.

Field photo label examples

Julie Cassidy



Don Gillis

- Please create a file folder to organize and store photos for each vernal pool on your computer, and label the file folder using the following scheme: Pool ID #, observer's last name, the year, and name of site/study area – e.g., MNFI1-228_Lee_2014_SLP-Waterloo.
- Please label the image/photo files of the vernal pool, indicator species, and other species using the following file name format:
  Pool ID #_subject of photo_visit #
  Examples:
  MNFI1-228_Wood frog egg mass_Visit 1.jpg
  MNFI1-228_Habitat looking north from pool_Visit 2.jpg

9) If you observe any wetland violations or other violations in the field, please report them to the Michigan Department of Environmental Quality, Michigan Department of Natural Resources, or other appropriate resource management or law enforcement agency. Please contact 911 for any emergencies in the field.

10) Designate a team leader to compile all data forms, maps, photos, GPS files (waypoints and tracks), and volunteer time log after all field surveys have been completed. Save all photo images and GPS files on your computer and/or onto a CD or DVD.

11) Have team leader send in your completed data forms, maps, photos or CD/DVD, and volunteer time log by mail to the following address, or upload the forms, maps, photos, and volunteer time log to a specified file location (e.g., Dropbox) by September 30:

    Michigan Natural Features Inventory
    c/o Michigan Vernal Pools Project
    P. O. Box 13036
    Lansing, MI 48901-3036

12) If you have any questions, please contact:

    Daria Hyde (hydeda@msu.edu, 517-284-6189) or

    Yu Man Lee (leeyum@msu.edu, 517-284-6201)

    with the Michigan Natural Features Inventory.

    You can also access vernal pool information, resource materials, and the monitoring form through our vernal pool website at **http://mnfi.anr.msu.edu/vernalpools/**. You will need to enter the username "Volunteer" and password "vpool" to access the website.

Instructions—Volunteer Vernal Pool Monitoring Form

The goals of the field sampling are to 1) determine whether or not a remotely mapped "potential" vernal pool is indeed a vernal pool, 2) identify and map additional vernal pools encountered in the field that were not remotely mapped, and 3) collect biological and physical data about vernal pools in Michigan. This information will be used to develop and implement an effective approach for mapping, assessing, and classifying vernal pools in Michigan. It is important to note that this protocol and form may be revised in the future. Please make sure you are using the latest versions. Fields that are highlighted in gray on the form only need to be filled out during the first visit of each year that the pool is monitored unless the information needs to be revised or updated during subsequent visits.

1. Observer and Property Information

1a) Observer Information

Visit # - Please check the appropriate visit number for each survey visit to the pool.

Name(s) - Write the first and last names of all surveyors for that visit (and on each visit).

Date - Please indicate month, date, and year (mm/dd/yyyy) of the survey visit.

Time - Please write in the time you started the survey (from) and the time you ended the survey (to), noting AM or PM for both.

1b) Property Information

Ownership – Please check whether the vernal pool you are visiting is located on publicly owned land or privately-owned land.

Site name – Please write in the name of the site in which the pool is located if it has a formally designated name (e.g., Waterloo State Recreation Area). If the site is privately owned and/or does not have a designated name, please write in a specific name for the site based on local geographic landmark(s) (e.g., Mill Lake Southeast) or ownership (e.g., Chelsea Hunt Club).

Plot # - Please indicate the pre-assigned identification # for the sample plot/test cell in which the vernal pools is located, if applicable and available.

Landowner/Manager - Please write in the name, address, city, state, and zip code for the owner or manager of the site/property in which the vernal pool is located (e.g., Michigan DNR and address of park headquarters or local office; or John Smith and property address).

2) Vernal Pool Location Information

2a) Vernal Pool Location

Was pool mapped as a Potential Vernal Pool (PVP)? – Please indicate whether the pool you are visiting or surveying was mapped as a potential vernal pool (PVP).

Pool ID # - If the pool you are visiting or surveying was mapped as a potential vernal pool (PVP), please write in the pre-assigned unique identification number (Pool ID #) of the PVP. If the pool was not mapped as a PVP, please leave this blank.

New VP ID # - If you encounter a vernal pool (VP) in the field that was not remotely mapped as a potential vernal pool (PVP), please document and map it as well. You will need to assign the new vernal pool a unique identification (ID) number and write the ID # you assigned to the pool in this space.

To assign unique ID numbers to new pools encountered in the field, please add letters in alphabetical order to the ID # of the closest mapped potential vernal pool. For example, if new vernal pool is located closest to MNFI1-228, please assign it a temporary Pool ID # of MNFI1-228A. If there are three new pools found closest to MNFI1-228, please assign the three new pools Pool ID #'s of MNFI1-228A, -228B, and -228C.

Please make sure to locate each new vernal pool found in the field with a GPS point, if possible and indicate each new pool on maps and/or air photos with assigned Pool ID #'s.

County – Please indicate the county in which the vernal pool or survey site is located.

Township/Range/Section/1/4 Info - Please write in the township (T), range (R), section (S), and quarter section for the location of the vernal pool found or site surveyed (e.g., T2S R4E Sec. 25 SE1/4). The following link provides additional information about the township, range, section mapping system:

http://nationalatlas.gov/articles/boundaries/a_plss.html.

You can find the township, range, and section for your vernal pool location on a topographic map, county map, and online. The following is a link to one website that provides township, range, and section information for specific locations:

http://www.earthpoint.us/Townships.aspx.

Method for locating pool – Please indicate the method(s) used for locating and mapping the vernal pool or survey site in the field by checking whether you used a GPS unit, a topo or topographic map, Google Earth, and/or an air photo. Please check all that apply.

Latitude/Longitude – Please write in the latitude and longitude coordinates for the location of the vernal pool or site surveyed in the field. Please enter coordinates in the decimal degree format. Most GPS units will default to this format. If your GPS unit is showing UTM or some other coordinates, you can change the display, typically in the settings menu. UTM coordinates will be two numbers like decimal degrees but will not have a decimal point or a "º" symbol after them.

Latitude and longitude in the non-decimal degree will show degrees (º), minutes ("), and seconds (') symbols. Your coordinate reading format should match that shown in the example on the field form:

Latitude: 44.764322 Longitude: -72.654222.

If you do not have a GPS unit, you can also get latitude and longitude coordinates for a specific location online. Here is a link to a website where you can find the latitude and longitude coordinates for a specific location using Google Maps - **http://itouchmap.com/latlong.html**. Also, many smartphones have GPS capabilities and can take GPS points or provide coordinates using an application. Please remember to record the latitude and longitude for where you visited/surveyed even if the potential vernal pool turns out to not be a vernal pool.

Verification Latitude/Longitude – If you are using a GPS unit, for verification of the GPS unit's accuracy and vernal pool location, please take a GPS point at the nearest crossroad intersection. Please record the names of the crossroads and the latitude and longitude coordinates for the crossroad intersection. If you are not using a GPS unit, you can leave this blank.

2b) Brief Site Directions to Pool

Please provide brief written directions for how to locate and get to the pool in the field. Please include the following: 1) description of a logical starting point; 2) distances from the starting point and other landmarks along the way to the pool; 3) 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 ½ mi. The pool is the first pool on your left, just behind a low stone wall."

3. Vernal Pool Field Verification Information

3a) Pool Type

Open Pool – Check this box for the "classic" vernal pool

- Less than 10% of the pool basin (when filled with water) is covered with vegetation (live trees, shrubs and/or non-woody herbaceous or persistent emergent plants).

Sparsely Vegetated Pool – Check this box if:

- Between 10% and 30% of the pool basin (when filled with water) is comprised of vegetation (live trees, shrubs and/or non-woody herbaceous or persistent emergent plants) .

Forested Pool – Check this box if:

- More than 30% of the pool basin (when filled with water) is comprised of vegetation (live trees, shrubs or and/or non-woody herbaceous or persistent emergent plants)

AND

- Rooted/live trees comprise 30% or greater of the uppermost vegetation layer within the pool

Shrubby Pool – Check this box if:

- More than 30% of the pool basin (when filled with water) is comprised of vegetation (trees, shrubs or and/or non-woody herbaceous or emergent plants)

AND

- Shrubs comprise 30% or greater of the uppermost vegetation layer within the pool.
- If trees are present they comprise less than 30% of the uppermost vegetation layer within the pool basin.

Marshy Pool – Check this box if:

- Herbaceous and/or emergent vegetation comprise between 30-50% of the uppermost vegetation layer within the pool basin when the pool is filled with water.

- If trees and shrubs present they cover less than 30% of the uppermost vegetation layer within the pool basin.
- If tree and/or shrubs cover less than 30% and emergent plants comprise over 50% of the pool basin, the wetland will be classified as an emergent wetland and **NOT** a vernal pool for purposes of this project.

Other – Check this box if the vernal pool does not fit one of the other pool types. Please provide description of the pool in space provided, particularly how pool differs from other pool types.

3b) Presence of Inlet or Outlet

Is this pool connected to or part of another water feature? – Check "No, pool is isolated" if there is no evidence of any channelized water above ground entering or exiting the pool or any above ground connection to another wetland or water body. Check "Yes" if the pool has evidence of channelized water entering or exiting the pool or a surface water connection to another wetland or water body, or if the pool is part of another wetland (e.g., pool within a forested swamp or connected to a bog or marsh). If yes, please check ALL the different types of wetlands or water bodies to which the pool is connected.

If an inlet/outlet is present, indicate type – Check "permanent" if there is channelized water continuously or permanently running into or out of the pool. These sites are typically not vernal pools. Check "temporary" if there is evidence of channelized water entering or exiting the pool, but it doesn't appear to run continuously or be permanent. Many vernal pools, for example, have an outlet that functions if the water level in the pool reaches a certain level. Check "do not know" if unsure whether the channelized water running into or out of the pool is permanent or temporary.

3c) Surrounding Habitat

Check the box/boxes that best describe the surrounding forest or habitat that occurs within 100 feet of the vernal pool. If multiple types of forest or habitats occur within 100 feet of the pool, you can check multiple boxes. Please check **ALL** that apply.

Upland Deciduous Forest – Check this box if the forest surrounding the pool occurs in the uplands (i.e., high ground or elevated land) where drainage is sufficient so that the soils do not become saturated (soil moisture ranges from dry to moist), and the forest primarily consists of or is dominated by deciduous or hardwood trees. Trees often found in upland deciduous or hardwood forests include black oak, white oak, red oak, hickories, cherries, beech, aspen, and sugar maple.

Upland Coniferous Forest – Check this box if the forest surrounding the pool occurs in the uplands where drainage is sufficient so that the soils do not become saturated, and the forest primarily consists of or is dominated by coniferous or evergreen trees. Trees often found in upland coniferous forests include jack pine, red pine, white pine, white spruce, balsam fir, hemlock, and cedar.

Upland Mixed Forest - Check this box if the forest surrounding the pool occurs in the uplands where drainage is sufficient so that the soils do not become saturated, and the forest consists of a mix of or dominated by both deciduous/hardwood and coniferous/evergreen trees.

Lowland Deciduous Forest - Check this box if the forest surrounding the pool occurs in the lowlands (i.e., low ground, usually level landor depression) where drainage is poor so that the soils are wet or saturated, or standing water is present, and the forest primarily consists of or is dominated by deciduous or hardwood trees. Trees often found in lowland deciduous or hardwood forests include black ash, green ash, silver maple, red maple, basswood, sycamore, cottonwood, American elm, swamp white oak, pin oak, and yellow birch.

Lowland Coniferous Forest - Check this box if the forest surrounding the pool occurs in the lowlands where drainage is poor so that the soils are wet or saturated, or standing water is present, and the forest primarily consists of or is dominated by coniferous or evergreen trees. Trees often found in lowland coniferous forests include tamarack, northern white cedar, black spruce, white spruce, hemlock, balsam fir, and white pine.

Lowland Mixed Forest – Check this box if the forest surrounding the pool occurs in the lowlands where drainage is poor so that the soils are wet or saturated, or standing water is present, and the forest consists of a mix of deciduous/hardwood and coniferous/evergreen trees.

Floodplain – Check this box if the pool occurs in a floodplain along or near a stream/river.

Emergent Wetland – Check this box if the surrounding habitat within 100 ft of the pool contains open or emergent wetlands (e.g., marsh, wet meadow, wet prairie, bog).

Grassland or Open – Check this box if the surrounding habitat within 100 ft of the pool contains grassland or open habitats in upland settings (e.g., old field, prairie).

Disturbances - Check the box/boxes that best describe any disturbances in the surrounding habitat within 100 feet of the vernal pool. Please check **ALL** that apply.

4) Pool Characteristics

4a) Approximate Maximum Pool Depth

This is an approximate depth at the deepest part of the pool (typically the center). Feel free to use a stick or other measuring device if you would like, or estimate from the pool edge if you cannot wade into the deepest part. Please check the appropriate box, and only **ONE** box.

4b) Water Level at Time of Survey

This is an estimate of the percent of the entire pool basin that is filled with water (i.e., combination of water level and percent of basin filled with water relative to high water mark). In order to estimate this and 4d, examine the edges of the pool for signs of high water. Signs include water-stained leaves, sediment deposits on the leaf litter, water marks or moss on tree trunks, and mucky/squishy soil. Please check appropriate box, and only **ONE** box. If water level varies across the basin, please average for entire basin and provide explanation.

4c) Water Temperature

Take three water temperature readings along the length of the pool (two at either end and one in or close to the center of the pool). Record the average of the three water temperature readings. If the pool is dry or too shallow, leave this blank.

4d) Approximate Size of Pool

Record the width and length of the pool when it is completely full or at maximum capacity at its widest and longest points. You can measure the width and length of the pool using a measuring tape or rangefinder, or by pacing. If you have a GPS unit and can record tracks, you can walk along and GPS the perimeter of the pool, which can be used to calculate the area of the pool. Please check how the pool dimensions were determined – either by pacing, measuring, or using GPS. To obtain these measurements when the pool is not completely full, examine the pool basin for evidence of high water (see 4b), and take measurements at the high water mark. We need the approximate width and length of the pool to estimate pool area. While the length of the pool perimeter is useful information, it does not provide enough information to estimate pool area.

4e) Substrate

Please check the type(s) of substrate or soil in the pool basin. It will be easiest to determine this when the pool is dry. To determine the soil texture (defined below), take a small sample of soil (below the leaf litter if present, 1-2 inches deep if possible), add some water, and rub it between your fingers to feel the soil texture. Please check **ALL** that apply.

Leaf Litter – Check this box if leaf litter is present on the ground in the pool basin.

Muck-Peat – Check this box if the substrate contains muck and/or peat. Muck is an organic soil consisting of highly decomposed materials (i.e., altered beyond recognition/can't see any plant fibers or material). Muck has a "greasy" feel. Peat is an organic soil consisting of materials that are only slightly or partially decomposed (i.e., plant residues are recognizable/can see plant fibers). Both are very dark or black in color, especially muck. To determine if muck and/or peat is present, first remove loose leaves, needles, bark, and other easily identified plant remains.

Sand-Gravel – Check this box if substrate primarily contains sand and/or gravel (coarse-grained). Soil feels very gritty, and would not remain in a ball when wet and squeezed.

Silt-Clay – Check this box if substrate primarily contains silt and/or clay (fine-grained sediments). Soil does not feel gritty or feels smooth and/or sticky. Soil sample when wet is able to be squeezed into forming a strong ribbon (>2 inches long).

Loam – Check this box if soil is made up of sand, silt, and clay in relatively even concentrations. Soil feels a little gritty and a little sticky. Soil sample when wet is able to be squeezed into forming a weak or medium ribbon (<2 inches long).

Bedrock – Check this box if the substrate in the pool basin contains exposed rock on the surface.

Unknown – Check this box if you are not sure of the substrate type.

Other – Check this box and indicate other substrate types not listed here.

4f) Vegetation in Pool

Check if trees (> 4 inches in diameter) are present within the pool basin or only along the edge of the pool. If trees are present within the pool basin, please count or estimate the number of trees within the pool basin. Also indicate if live and/or dead trees/snags are present in the pool.

Estimate and check box for percent cover or percent of pool that is occupied by the different types of vegetation – i.e., floating/submergent vegetation (e.g., duckweed), emergent vegetation (plants that are rooted in soil, grow in water, and extend above the surface – e.g., grasses, sedges, reeds, bulrushes, cattails), shrubs, and tree canopy over the pool basin. Some vegetation is only present or most visible in the spring when the pool is wet or has water (i.e., floating/submergent vegetation, emergent vegetation), while some vegetation is most visible later in the summer (e.g., shrubs and tree canopy). Please estimate different types of vegetation when they are most visible (e.g., tree canopy when leaves are fully out). Also, vegetation in the pools can change within a year when the pool is wet and when the pool is dry. Please note significant changes in vegetation within and between years.

4g) Pool Disturbance

Check **ALL** forms of disturbance that have affected the pool.

4h) Cover

Check any and **ALL** materials in the pool that can provide egg attachment sites and cover for adults, larvae, and/or eggs of indicator species and other amphibians and invertebrates.

5) Indicator Species and Additional Species

Table

Species observed – Identify vernal pool indicator species using the pool. Presence of other amphibian and invertebrate species and other wildlife species also should be recorded in this column below the indicator species listed.

Adults – Please enter the approximate number of adults observed for the amphibian indicator species and other vertebrate species present in the pool. For invertebrates such as fairy shrimp and fingernail clams, counting individuals is not necessary. Indicating presence of these species with an "X" in this column is sufficient.

Tadpoles/Larvae – Mark an "X" in this column to indicate the presence of tadpoles or larvae of each amphibian species present.

Egg Masses – Please enter the number of egg masses (not individual eggs) of each species present in the pool. Use the check boxes to indicate if the number of egg masses was based on an actual count or an estimate. If you observe spermatophores, you may be a little early and will need to return to the pool a little later to observe egg masses.

Photo? – Please take a photograph documenting the presence of each indicator species and other species in the pool (egg masses, tadpoles/larvae, metamorphs, and/or adults). Put a check if a photo was taken of a particular species. Please label photos using naming conventions provided earlier. Photo-documentation of indicator species is required.

Notes/Photo ID# - Use this column to enter any comments on the species present and/or the photo numbers on your camera. Photos will be renamed later using the recommended protocol.

Were any of the following observed? – Please check whether any fish were observed in the pool and their estimated lengths in terms of less than or equal to 3 inches long and greater than 3 inchyes long. Note: Fish of multiple sizes/lengths could be observed in a pool.

Please also record if bullfrog tadpoles and/or adults, green frog tadpoles and/or adults, and other wildlife species were observed in the pool.

6) Comments

Please record here any additional information, comments, problems or issues regarding about the survey, the vernal pool, the data collected, and/or the plant and animal species observed in the pool or in the surrounding habitat.

7) Draw Diagram of Pool

Please draw general diagram or sketch of the vernal pool showing the shape of the vernal pool, any landmarks in or around the pool basin, area surveyed for indicator species if entire pool was not surveyed, locations of indicator species or other wildlife species observed, locations of any rare species observed, and other interesting things to note. Please indicate North in the diagram by including a north arrow.

References

Brodie, E. D., Jr. 1987. Antipredator mechanisms of larval anurans: Protection of palatable individuals. Herpetologica 43: 369-373.

Calhoun, A. J. K and P. G. deMaynadier. 2008. Science and Conservation of Vernal Pools in Northeastern North America. CRC Press, Boca Raton, FL. 363 pp.

Colburn, E. A. 2004. Vernal Pools Natural History and Conservation. The McDonald & Woodward Publishing Company, Blacksburg, VA. 426 pp.

Gibbs, J. P. 1993. Importance of small wetlands for the persistence of local populations of wetland associated animals. Wetlands 13: 25-31.

Gibbs, J. P. 2000. Wetland loss and biodiversity conservation. Conservation Biology 14: 314-317.

Mitchell, J. C., P.W. C. Paton, and C. J. Raithel. 2008. The importance of vernal pools to reptiles, birds, and mammals. Pages 169-192 In: Calhoun, A. J. K. and P. G. deMaynadier (eds). Science and Conservation of Vernal Pools in Northeastern North America. CRC Press, Boca Raton, FL.

Morgan, D. E. and A. J. K. Calhoun. 2011. The Maine Municipal Guide to Mapping and Conserving Vernal Pools. University of Maine, Sustainability Solutions Initiative, Orono, ME.

Semlitsch, R. D. and J. R. Bodie. 1998. Are small, isolated wetlands expendable? Conservation Biology 12: 1129-1133.

Thomas, S.A., Y. Lee, M. A. Kost, & D. A. Albert. 2010. Abstract for vernal pool. Michigan Natural Features Inventory, Lansing, MI. 24 pp.

Vermont Studies for Ecostudies and Arrowwood Environmental. 2009. Vermont Vernal Pool Mapping Project Volunteer Training Manual. Norwich, VT. 14 pp.

Appendix 4. Vernal Pools Field Form 2014.

Michigan Natural Features Inventory

MICHIGAN STATE UNIVERSITY EXTENSION

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) ☐ ≤ 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)**:**

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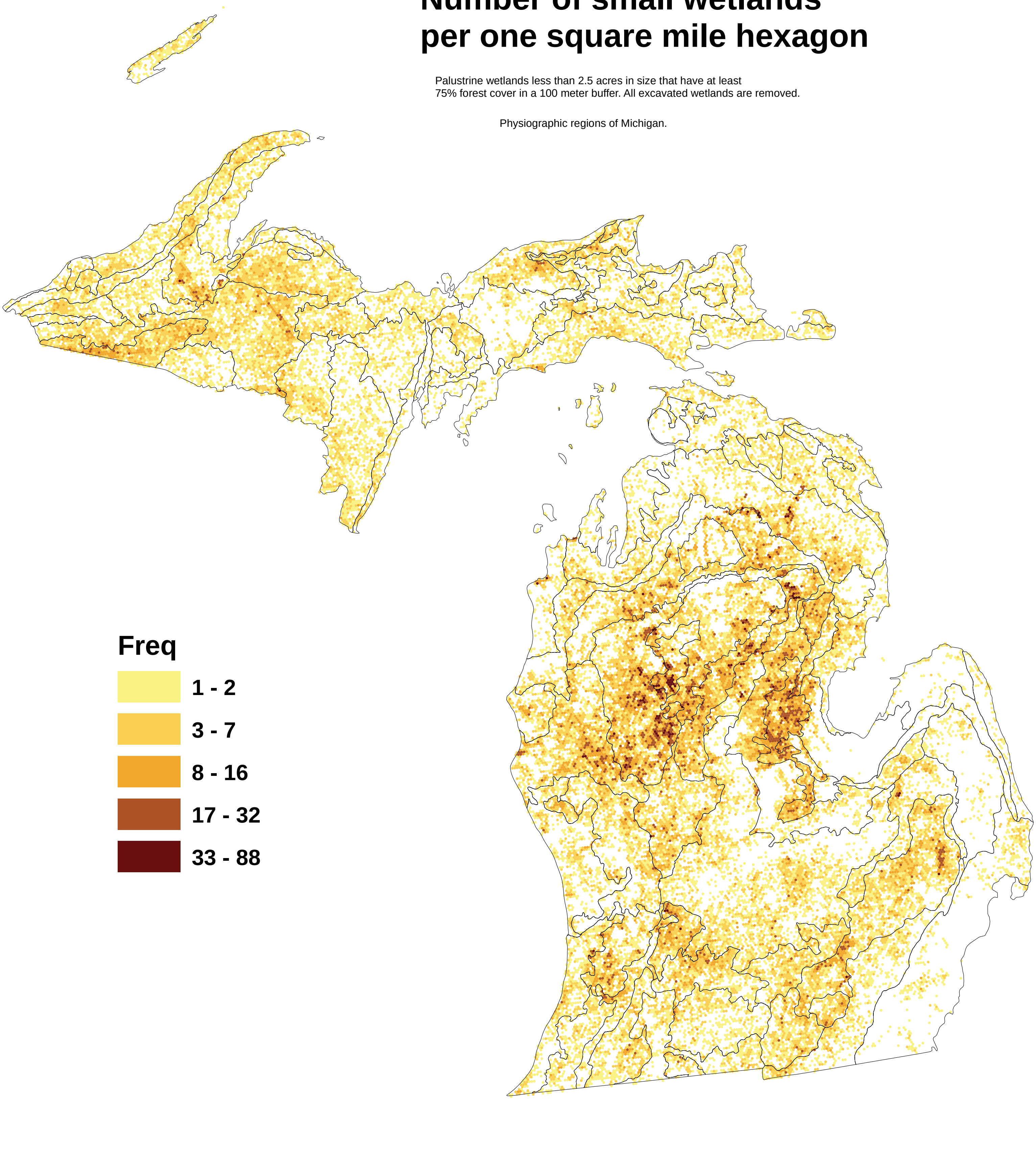
Appendix 5. Map showing Number of Isolated Wetlands by Physiographic Region

Number of small wetlands per one square mile hexagon

Palustrine wetlands less than 2.5 acres in size that have at least
75% forest cover in a 100 meter buffer. All excavated wetlands are removed.

Physiographic regions of Michigan.

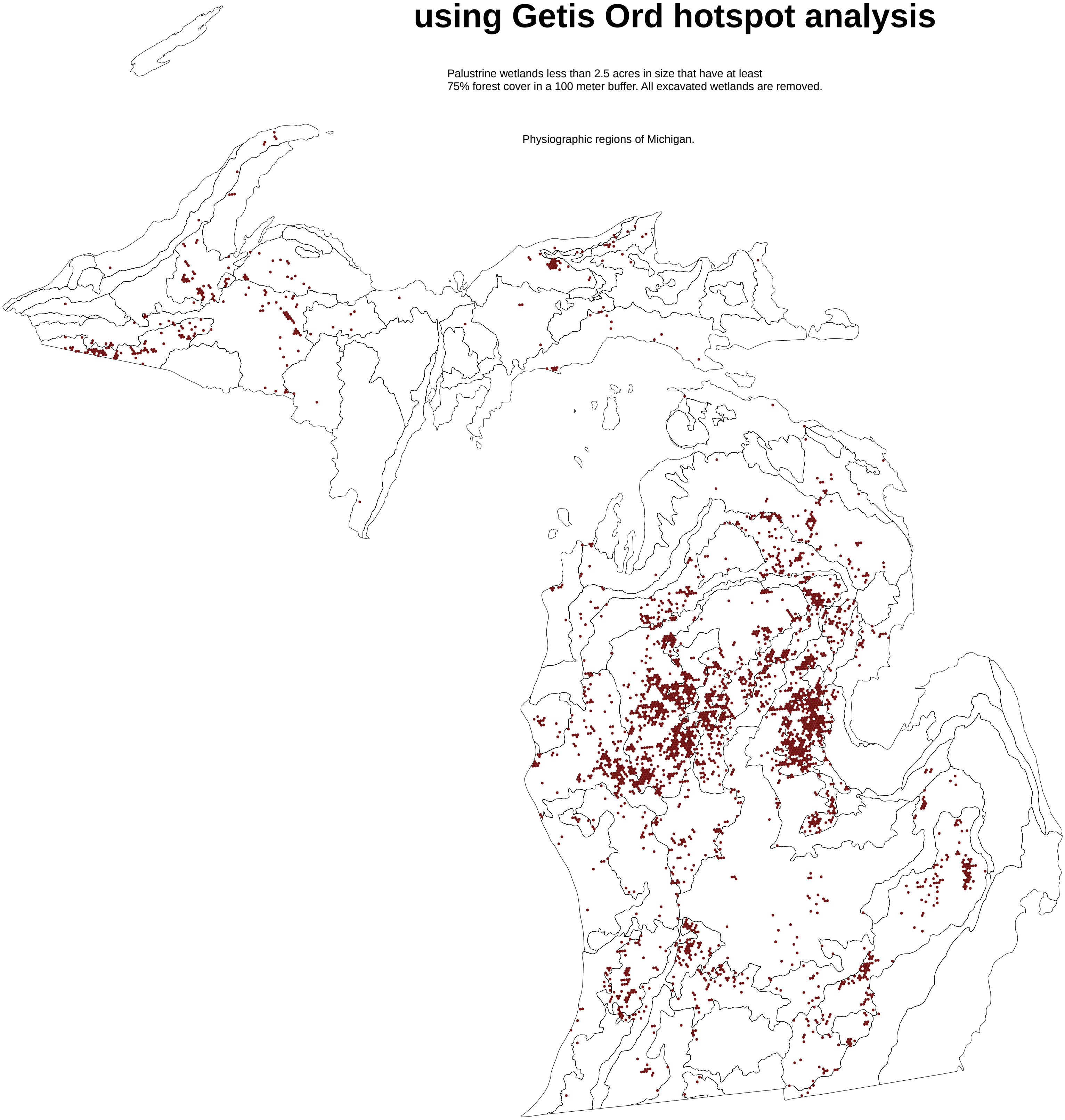


Appendix 6. Map showing Results of Isolated Wetland Hotspot Analysis by Physiographic Region.

Small wetland statistical hotspots using Getis Ord hotspot analysis

Palustrine wetlands less than 2.5 acres in size that have at least
75% forest cover in a 100 meter buffer. All excavated wetlands are removed.

Physiographic regions of Michigan.



Appendix 7. Summary of animals documented in vernal pools by volunteers in 2012.

2012- Vernal Pool Project **<u>Amphibians Documented</u>** ➢ Bullfrog ➢ Green frog ➢ Salamander larvae ➢ Spring peeper ➢ Spotted salamander ➢ Wood frog (Numerous!) **<u>Reptiles Documented</u>** ➢ Garter snake ➢ Northern watersnake ➢ Ribbon snake (dead) **<u>Fish Documented</u>** ➢ < 1 inch (several)	**<u>Invertebrates Documented</u>** ➢ Aquatic sowbug ➢ Aquatic worms ➢ Backswimmer ➢ Bloodworm ➢ Caddisfly case ➢ Clam shrimp ➢ Cyclops ➢ Damselfly Fingernail Clams ➢ Daphnia with eggs sacs ➢ Dragonfly ➢ Fairy shrimp ➢ Flatworm ➢ Mayfly ➢ Midge larvae ➢ Mosquito ➢ Ostracod ➢ Scud (sideswimmer) ➢ Spiral snails ➢ Thread worm ➢ Water beetles ➢ Water boatman ➢ Water bug ➢ Water fleas ➢ Water mite ➢ Water striders ➢ Water tiger larvae

Appendix 8. Summary of animals documented in vernal pools by volunteers in 2013.

2013: Vernal Pool Project

Amphibians Documented

- Blue spotted salamander (hybrid)
- Bullfrog
- Chorus frog
- Green frog
- Salamander larvae
- Spotted salamander
- Wood frog (Numerous!)

Reptiles Documented

- Garter snake
- Blanding’s turtle

Fish Documented

- < 1 inch (several)

Birds Documented

- Black-capped chickadee
- Canada geese
- Common yellowthroat
- Mallards
- Red-winged blackbird
- Tree swallow
- Turkey vulture
- Wild turkey
- Wood ducks

Invertebrates Documented

- Aquatic sowbug
- Aquatic worms
- Backswimmer
- Blackfly larvae
- Bloodworm
- Caddisfly
- Clam shrimp
- Cocopods/cyclops
- Crayfish
- Damselfly larvae
- Daphnia
- Deerfly/Horsefly larvae
- Dobson fly
- Dragonfly
- Fairy shrimp
- Flatworm
- Fingernail clams
- Green darner
- Gyralus snail
- Leech
- Midge larvae
- Millipide
- Mosquito larvae
- Ostracod
- Phantom midge
- Predacious diving beetle
- Rams Horn snails
- Scud (sideswimmer)
- Spiral snails
- Springtails
- Thread worm
- Water beetles/whirligig beetles
- Water boatman
- Water bug
- Water fleas
- Water striders
- Wolf spider