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Natural Resource Stewardship and Science

# Vernal Pool Assessment in Pictured Rocks National Lakeshore in a Dry Year

Natural Resource Technical Report NPS/PIRO/NRTR—2013/766

**ON THE COVER**
Vernal pool in Pictured Rocks National Lakeshore. This pool is an example of a red maple complex.
Photograph by: J. Marr

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## Abstract

Vernal pools are isolated, ephemeral water bodies that are often overlooked on the landscape. Despite their temporary nature, these pools are important to forest communities, providing critical breeding habitat for amphibians and an important food and water source for other taxonomic groups including birds, bats and other terrestrial vertebrates. Sparse information about vernal pools in the upper Midwest, including Pictured Rocks National Lakeshore (PIRO), exists. The objective of this study was to provide quantitative and qualitative evaluation of vernal pool distribution, types, and abiotic and biotic characteristics within PIRO.

We used a combination of remote sensing and field reconnaissance to map and classify vernal pools in PIRO. We located 49 vernal pools in PIRO (0.17 pools/km$^2$) of which 21 were subsampled for quantitative and qualitative characterization during a dry spring. We classified PIRO pools based on physical characteristics that may be applicable at a regional scale. Amphibians were found in 100% of the classic pools and less frequently in the two other physical pool classes.

We created a vegetation classification system specific to PIRO with five community types: three herbaceous communities with open canopies and two forested, closed canopy types with many small, interconnected vernal pools. The majority of the amphibians encountered were in the classic sedge community type, an herbaceous, open canopied type. Based on our analyses, soil carbon may be a simple metric for assessing vernal pool hydroperiods.

We encourage increasing the understanding of vernal pools in PIRO through repeated ground-truthing during wetter years and additional biological monitoring to aid managers in maintaining a population of pools that provide habitat for important flora and fauna.

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# Introduction

Vernal pools are any of a great variety of seasonally flooded ponds located across the U.S., including those that form in the Mediterranean climate of California. This study, however, focuses on "woodland vernal pools" found in northeastern U.S., generally encompassing the extent of the Late-Wisconsin glaciations (Calhoun and deMaynadier 2008). For the purposes of this report the term "vernal pool" describes any fluctuating water body with the following common traits: is relatively small, fills during spring or fall and dries during summer or droughts, lacks fish, and provides breeding habitat for certain species of woodland amphibians and/or characteristic wetland invertebrate species (Colburn 2004, Calhoun and deMaynadier 2008). Vernal pools are also considered "geographically isolated wetlands", and their physical position on the landscape may be described as wetlands surrounded by uplands at the local scale (Tiner 2003).

The temporary quality and geographic isolation of vernal pools caters to certain species with life history strategies that incorporate aquatic and terrestrial requirements (Williams 1996). For instance, vernal pools are home to hundreds of multi-cellular species, including several rare taxa that are adapted to the fluctuating water levels of vernal pools or relocation to the surrounding upland habitat (Batzer et al. 2004, Colburn 2004). The fluctuating dry and wet conditions also structure vegetation by eliminating many plant species that are not adapted to seasonal anaerobic conditions. Vernal pools are especially important because they provide breeding habitat for fish-intolerant amphibian species, such as mole salamanders (Ambystomatidae) and wood frog (*Lithobates sylvaticus*) (Zedler 2003).

However, geographic isolation is also what inhibits the protection of vernal pools. Because of their classification as isolated wetlands, vernal pools have lost federal protection from the Clean Water Act (Downing et al. 2003), leaving few laws to protect vernal pools (Preisser et al. 2000). Vernal pools are threatened directly and indirectly by a variety of human activities. Development is considered one of the primary causes of vernal pool loss in the U.S. (Mahoney and Klemens 2008). Indirect impacts on vernal pools include invasive species, climate change, habitat fragmentation, groundwater extraction, and water contamination.

The loss of federal protection makes parks and other conservation areas critical for protection of vernal pools. However, there is sparse information on vernal pools for many areas of the country, including Pictured Rocks National Lakeshore (PIRO). A few studies, which have included vernal pool habitat in PIRO, indicate that some pools support fish-intolerant species of fairy shrimp (*Eubranchipus*) and amphibians (Casper 2005) and may be used by large mammals such as black bears (*Ursus americanus*) (DeBruyn 1997). The first step in conservation of vernal pools is locating and describing them on the landscape. Therefore, the objectives of this study were to provide a quantitative and qualitative evaluation of vernal pool distribution, types, and characteristics within Pictured Rocks National Lakeshore.

## Study Area

Pictured Rocks National Lakeshore (PIRO) is located in the north-central Upper Peninsula of Michigan, along the southern shore of Lake Superior. The dominant forest types are northern hardwoods, upland conifers, and conifer swamps; peatlands are also significantly represented in the area (Albert 1995). From 2005 through 2010, average January and February maximum and minimum temperatures were 25.7 and 13.5 °F (-3.5 and -10.3 °C), and average July and August maximum and minimum temperatures were 73.6 and 56.6 F (23.1 and 13.7 °C). Average annual precipitation for 2005-2009 was 36 in (904 mm) with approximately 43% of that falling as snow.

PIRO is comprised of two zones with differing management priorities totaling 29,637 ha (73,235 ac): the shoreline zone (13,731 ha; 33,929 ac) that is owned in fee by the National Park Service (NPS) with preservation as a priority, and the inland buffer zone (IBZ; 15,907 ha; 39,306 ac) that allows economic utilization of renewable natural resources such as timber production. The IBZ consists largely of lands owned by a commercial timber corporation (45%), State of Michigan (35%), and private citizens (15%). Slightly less than 5% of the IBZ is owned by NPS.

# Methods

## Vernal Pool Identification and Distribution

Aerial photography was the initial tool to identify potential vernal pools at PIRO. Dr. Charles Olson of Michigan Technological Research Institute (MTRI) used color, leaf-off, aerial photographs taken in May 2004 at 1:12,000 scale. Photographs were georeferenced for use in this project. Dr. Olson defined water features of interest in a broad sense and identified all locations where they existed. In general water features were defined as water, ice, or snow not hydrologically connected to a river, wetland, or lake; specific water feature types described from aerial photographs are provided in Appendix A. Using ArcMap 9.3 (ESRI 2009), a polygon shapefile was created of each potential vernal pool's perimeter, with a polygon centroid used to subsequently locate water features with a GPS unit. Springtime imagery provided a clear view of the ground and increased the likelihood that pools will be flooded and visible under the hardwoods.

Between January and July of 2009 MTRI identified 204 water features of interest within PIRO. Ground-truthing was conducted at 162 of the 204 possible vernal pools during summer 2009 to confirm locations of water features, verify which water features were actually vernal pools, and provide a physical classification system for the verified vernal pools. The other 42 water features of interest that were not visited were deemed very unlikely to be vernal pools based on previous visitation to similar water features of interest identified by MTRI. These false positives were usually the result of snow or ice accumulation along the lakeshore (e.g., Appendix A, Types 11-15) or adjacent to two-track roads (Appendix A, Types 16 and 21).

Using the broad category of water features for identifying potential vernal pools decreased the error of omission, and specific features most likely to be associated with vernal pools were determined by field reconnaissance. Of the 11 water features used to narrow the search for vernal pools from aerial photographs (Appendix A), 10 had at least one vernal pool. Water features #31 (standing water without apparent inflow or outflow) and #41 (isolated wet areas with tree overstory) accounted for 78% (38 of 49) of the identifications of all pools.

Of the 162 probable vernal pool sites, 49 of them (30%) were verified as vernal pools during field reconnaissance in the summer of 2009 (Figure 1). Based upon guidelines by Colburn (2004) and Calhoun and deMaynadier (2008), several criteria were used to distinguish if a water feature was a vernal pool rather than a permanent body of water: surface area, water depth, lack of predatory fish, no visible connection to a permanent body of water or wetland, delineation of perimeter, and evidence of drying and flooding. The perimeters of vernal pools commonly exhibited slight topographical rises or 'banks' (<1 m). Additionally, during visits in the late summer of 2009 and 2010, dry vernal pool basins were lined with hardwood leaves that appeared 'shellacked' from the presence of water earlier in the year.

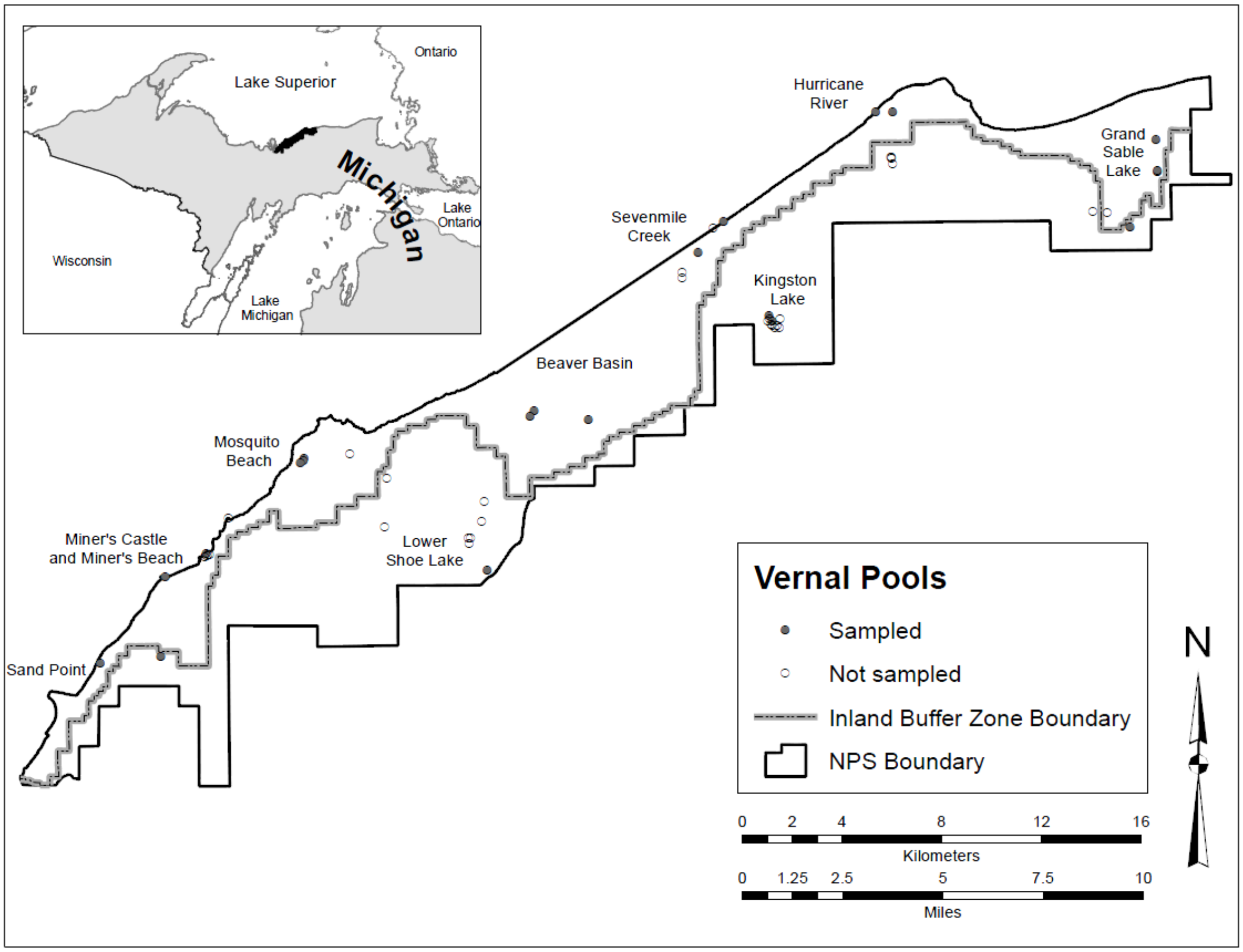


**Figure 1.** Map of 49 Vernal Pools at PIRO verified by field reconnaissance. The shaded circles represent 21 vernal pools that were subsampled for more detailed data collection.

To help organize vernal pool sampling, the 49 confirmed vernal pools were then classified into four types based on general physical characteristics: classic, complex, dune and swale, and kettle/kame (Table 1). This initial physical classification simplified pool types based on easily perceived characteristics such as size, shape, surrounding landscape, etc. Of the 49 confirmed vernal pools, classic pools (n= 14) and complex pools (n= 20) were the most common vernal pool types. Twenty-six vernal pools were found in the shoreline zone, and 23 were found in the IBZ.

## Data Collection

We randomly selected 21 vernal pools (population size = 49), stratified by the four physical classes of vernal pools, for more specific quantitative and qualitative data. Pools were selected in proportion to their presence in each physical class. Of the 21 subsampled vernal pools, 16 were in the shoreline zone and five were in the IBZ. We sampled vernal pools for water chemistry, soil carbon and nitrogen, vegetation, aquatic macroinvertebrates, and amphibians during spring and summer of 2010 (Table 2).

**Table 1.** Definitions of the types of vernal pools at PIRO based on physical characteristics.

1) **Classic**: a single and isolated vernal pool within a forest, usually upland. No connection to streams, lakes, wetland areas, or other vernal pools within 100m.
   a. Have a definable boundary that is either a change in topography, vegetation composition, or both. May have an open or closed canopy.
   b. Found within lowland areas (mixed conifer types of hemlock, maple, beech) with soils having high soil moisture content.

2) **Complex**: very intricate classification because several vernal pool water features may exist. Vernal pools are numerous and in close proximity to each other, some less than 1m apart.
   a. Occur typically in flat woods, but may be seen within beaches or terraces. A nearby river, stream, lake, wetland, human management, or beaver activity may lead to soil and drainage conditions that influence vernal pools. Vernal pools are formed within the deeper depressions, including pit and mound (cradle/knoll) topography.
   b. Usually have mucky soils with moss hummocks. Abundance of coarse woody debris from multi-tree species. Understory may have *Iris versicolor*, lily pads, and other wetland obligates.
   c. Do not have a definable boundary, either through changes in topography or species composition.

3) **Dune and swale**: located along the shores of Lake Superior, but concentrated between Hurricane Beach and Beaver Lake. Shrub-forms dominate and typically dry by mid-June. May be a catchment or where surrounding dunes impedes subsurface flow. Linear in form.
   a. Sand Point marsh area.
   b. Inland shore of Beaver Lake.
   c. Ridges and eskers produce vernal pools by shedding snowmelt and rainwater quickly from slopes, thus ponding at ridge/esker base.

4) **Kettle/kame**: originated as glacial features and occur on the sandy outwash plain in the Kingston Lake area.
   a. Quite open with no canopy closure from surrounding jack, red, and/or white pine.
   b. Slopes of the shorelines occurring in 2009-2010 vary from quite steep to shallow.

**Note:** These categories are from field observations and photo interpretations and do not have any quantified data to support them.

**Table 2.** Twenty-one vernal pools chosen for more detailed data collection.

| Site name[1] | Date sampled | Pool # | Standing water, saturated, or dry | Vernal pool physical classification |
|---|---|---|---|---|
| Miners Castle road | 5/18/10 | [2]445 | standing water | complex |
| Miners Castle | 5/18/10 | 394 | saturated | complex |
| North of Sand Point | 5/19/10 | 444 | saturated | complex |
| Miners Beach | 5/19/10 | [3]347 | dry | complex |
| Lower Shoe Lake | 5/19/10 | [1]415 | dry | classic |
| Beaver basin | 5/20/10 | 290 | saturated | classic |
| Beaver basin | 5/20/10 | 280 | standing water | classic |
| Beaver basin | 5/20/10 | 281 | dry | classic |
| Kingston Lake | 5/21/10 | [2]265 | dry | kettle/kame |
| Kingston Lake | 5/21/10 | [2]199 | standing water | kettle/kame |
| Grand Sable Lake | 5/25/10 | 152 | dry | complex |
| Grand Sable Lake | 5/25/10 | 153 | dry | complex |

**Table 2.** Twenty-one vernal pools chosen for more detailed data collection (continued).

| | | | | |
|---|---|---|---|---|
| Grand Sable Lake | 5/25/10 | 147 | saturated | complex |
| Hurricane River | 5/26/10 | 125 | saturated | dune and swale |
| Hurricane River | 5/26/10 | 122 | saturated | dune and swale |
| Sevenmile Creek | 5/27/10 | 165 | saturated | classic |
| Sevenmile Creek | 5/27/10 | 161 | saturated | classic |
| Grand Sable Lake | 5/27/10 | [2]181 | standing water | complex |
| Mosquito Beach | 6/08/10 | [3]304 | dry | classic |
| Mosquito Beach | 6/15/10 | [3]305 | dry | classic |
| Mosquito Beach | 7/07/10 | [3]312 | standing water | complex |

[1]Site name indicates the general location of each vernal pool relative to features at PIRO.
[2]Indicates pools located in IBZ as opposed to shoreline zone.
[3]Pools #347, #304, #305, and #312 were not sampled for macroinvertebrates or amphibians.

### *Water and soil data collection*

Specific conductivity and pH of water were measured in standing water using a YSI 63 handheld pH meter (Yellow Springs, OH). If standing water was not present, soil pH was determined from the mean of nine soil pH readings (Kelway soil pH meter; Wycoff, NJ) taken within the dried pool area. A soil auger was used to collect the top 20 cm of soil from the center or wettest part of the vernal pool. The soil sample was sealed in a plastic bag, transported out of the field, and frozen until analysis for carbon (C) and nitrogen (N) concentrations. In the lab, soil samples were dried at 60 °C, sieved (2mm opening) to remove rocks and large organic debris, finely ground with a ball mill (SPEX 8000M; Metuchen, NJ), and weighed into tins for C and N elemental analysis (Fisons NA 1500; Milan, Italy).

### *Hydroperiod data*

Similar to work by Brooks and Hayashi (2002), we developed a relative hydroperiod index based on the presence or absence of standing water during periodic visits over two field seasons (2009/2010). We assigned a hydric value at each visit: “0” if dry, “0.5” if saturated, or “1” if standing water was present. The mean hydric value of each pool was calculated by adding the hydric values from all visits and dividing by the number of visits.

### *Vegetation data collection*

Vegetation data were collected from all subsampled pools (n=21) during June and July 2010. Vegetation composition within each homogenous vegetation stand was analyzed using the relevé method to acquire a complete species list from each stand (Mueller-Dombois and Ellenberg, 1974). Relevé data were analyzed within each homogenous vegetation stand within the vernal pool boundaries, and the identity and cover class of each vascular plant species was estimated. Cover class was later converted to percent cover (PC) using a scale of 1 (0-1 PC), 2 (1-5 PC), 3 (5-25 PC), 4 (25-50 PC), 5 (50-75 PC), and 6 (75-100 PC). Each plot was then marked using a handheld geographic positioning system (GPS) unit. Taxonomy of the USDA Plant Database was followed (USDA, NRCS 2011).

Vegetation was classified using agglomerative cluster analysis with Sørensen distance measure and flexible beta linkages method with $\beta = -0.25$, using PC-ORD 5.0 (McCune and Mefford, 2006). Indicator species analysis was used to prune the dendrogram and optimize the number of clusters (Chimner et al. 2010). We averaged *p*-values across all species for each cluster level using Monte Carlo Analysis. The cluster level with the lowest average *p*-value was used as the optimal level.

#### *Macroinvertebrate data collection*

Macroinvertebrates were sampled only in the four pools with standing water during the May 2010 sampling dates (Table 1). Two dip net samples (mesh size = 500µm) in each vernal pool, one in the middle of the pool and one along the edge, were collected. In ponds with little standing water only one sample was collected. Organisms from the substrate and the water column were targeted. Both samples were pooled and preserved in the field with 95% ethanol (Batzer et al. 2004). Invertebrates were separated from detritus by hand in the lab and identified to the taxonomic level of family (Merritt and Cummins 1996, Hilsenhoff 1995). Relative abundances of macroinvertebrate taxa were calculated per pond sample. When two samples were collected in larger ponds, the total number of each taxa captured was divided by two to express the mean relative abundance of each taxa per sample.

#### *Amphibian data collection*

Amphibians were sampled at 17 vernal pools that were visited during the May 2010 sampling dates (Table 1) using area-based visual encounter surveys (Harding 1997, Dodd 2009). We chose a 25 m transect around the perimeter of each vernal pool in an area where the density of woody debris was highest. Two surveyors walked side by side along the length of the transect surveying a swath 5 m in width (total area = 125 $m^2$). Within the survey area all woody debris was turned over and the number and species of amphibians present were recorded. Woody debris was returned to its original position. Other amphibians encountered during data collection at each vernal pool were recorded separately.

Cover boards were placed at three vernal pool sites (pools #415, #445, and #147) (Appendix B). Sites were chosen based on ease of access so monitoring could occur frequently and inexpensively. Four cover boards were placed in pairs at each site. The paired boards were placed 1 m apart and within 5 m of the edge of the vernal pools (Appendix C).

### Vernal Pool Area Calculations

Vernal pool areas were estimated during the 2010 field season. Vernal pool perimeters were defined by a micro-topography break (i.e., bank) or by an abrupt shift in the herbaceous layer (e.g., presence/absence of *Osmunda* sp). We assumed that this perimeter defined the maximum water surface area covered by the vernal pool. Three methods were used to determine the areas of the vernal pools, depending a balance of feasibility and accuracy.

The first method was used for 11 vernal pools and required establishing a center point of each pool, determined by the intersection of the lines describing the greatest length and greatest width. Distance was measured to the nearest 0.01 m from the center point to the pool’s perimeter at cardinal and sub-cardinal directions using a Suunto Kb-14 Compass (Vantaa, Finland) and Haglöf Vertex III Hypsometer (Laangsele, Sweden). This provided eight triangles with two known sides and the known angle between (45°). Area for each triangle was determined using the equation of side-angle-side:

$$A = \frac{1}{2} ab (\sin C)$$

These eight areas were combined to estimate the total area of the vernal pool, resulting in an octagon. This method provided the greatest accuracy relative to the two following methods. However, limitations were experienced when measuring narrow, linear vernal pools, those with high amounts of vegetation that impacted line of sight, and vernal pools that had standing water (>1 meter) that prevented occupation of the vernal pool center.

The second method was employed for seven vernal pools and involved using a DeLorme PN-30 GPS (WAAS enabled) (Yarmouth, ME) with tracking function activated. This function recorded a waypoint every second, while an observer walked the perimeter of the vernal pool. This series of waypoints was later converted into a polygon within ArcMap 9.3 (Redlands, CA) to determine the area. This method was used for vernal pools that exhibited irregular perimeters or had dense vegetation that prevented direct line of sight to use a compass and hypsometer. Individual GPS waypoint readings were commonly ± 3-7 m. Estimates of area were influenced by GPS multipath signals (e.g., atmospheric conditions, canopy, terrain), satellite availability, satellite geometry, and distance traveled between waypoint recordings.

The third method was employed for three vernal pools and required MTRI to delineate the perimeter of these vernal pools using 2004 leaf-off imagery. This method was used for pools that were too difficult to distinguish from surrounding vegetation due to drought or linearity (i.e., <2 m across), both of which made using methods number one and two unreliable. The aerial photography taken in May 2004 provided a starker contrast of the boundary than could be identified in the field reconnaissance. The pool perimeter was digitized within ArcGIS 9.3, creating a polygon to determine the area. Overall, this method was least preferable due to the combined error of imagery (e.g., clarity, photographic scale, resolution) and the observer's interpretation of a vernal pool's perimeter under dense canopy with remote imagery.

# Results

## Hydrologic and Soil Characteristics

Many of the pools that were visited in 2010 for water chemistry and amphibian and macroinvertebrate sampling were dry due to the warm and dry conditions of the spring 2010 and several winters of lower than average snowfall. 2010 was the warmest and driest spring (March, April and May) on record (1912–2010 NCDC data for Munising). The average daily temperature for March-May was 6.9 °C, a full 3 °C warmer than average. Total precipitation for March-May was 6.35 cm, which is only one-third of the long-term average of 18.33 cm. March of 2010 was the driest on record with less than 1 cm of precipitation, with April and May the 10$^{th}$ driest on record with ca. 3 cm per month of precipitation.

The pH of standing water averaged 5.0 with a range of 3.9-6.3, while soil pH for the pools that were dry at the time of measurement averaged 5.9 with a range of 5.0-6.5 (Table 3). Specific conductance of the water of pools with standing water, averaged 49.3 µS/cm with a range of 22.7-83.3 µS/cm (Table 3). Soil C and N averaged 13.5 % C and 0.7 % N, and ranged between 0.5 to 46.1 % C and <0.1 to 2.3 % N, respectively (Table 3). Soil N data correlated well with soil C.

**Table 3.** Water chemistry and soil characteristics of 21 subsampled vernal pools.

| Pool # | Soil pH | Water pH | Specific conductivity (µS/cm) | Soil C (%) | Soil N (%) |
|---|---|---|---|---|---|
| 122 | 6.5 | | | 28.7 | 1.3 |
| 125 | 5.2 | | | 1.3 | 0.1 |
| 147 | 6.2 | | | 8.3 | 0.6 |
| 152 | 5.8 | | | 4.2 | 0.2 |
| 153 | 5.8 | | | 4.8 | 0.2 |
| 161 | 5.9 | | | 38.5 | 1.9 |
| 165 | 5.8 | | | 13.9 | 0.8 |
| 181 | 6.0 | 4.9 | 51.7 | 28.0 | 1.5 |
| 199 | | 6.3 | 83.3 | 5.9 | 0.4 |
| 265 | 6.3 | | | 3.8 | 0.2 |
| 280 | 5.3 | 4.9 | 39.6 | 23.3 | 1.5 |
| 281 | 5.6 | | | 33.1 | 2.0 |
| 290 | 5.9 | | | 46.2 | 2.2 |
| 304 | 6.3 | | | 0.5 | 0.0 |
| 305 | 6.1 | | | 0.7 | 0.1 |
| 312 | 5.0 | | | 29.8 | 1.5 |
| 347 | 6.3 | | | 2.7 | 0.2 |
| 394 | 6.0 | | | 14.7 | 1.1 |
| 415 | 6.0 | | | 0.7 | 0.1 |
| 444 | 6.3 | | | 2.9 | 0.2 |
| 445 | | 3.9 | 22.7 | 3.8 | 0.2 |

Soil C was correlated with relative hydroperiod index (Figure 2). Pools that had standing water or had areas that were saturated most of the time we visited them, had greater soil carbon; whereas pools that tended to be dry when visited had lower soil carbon.

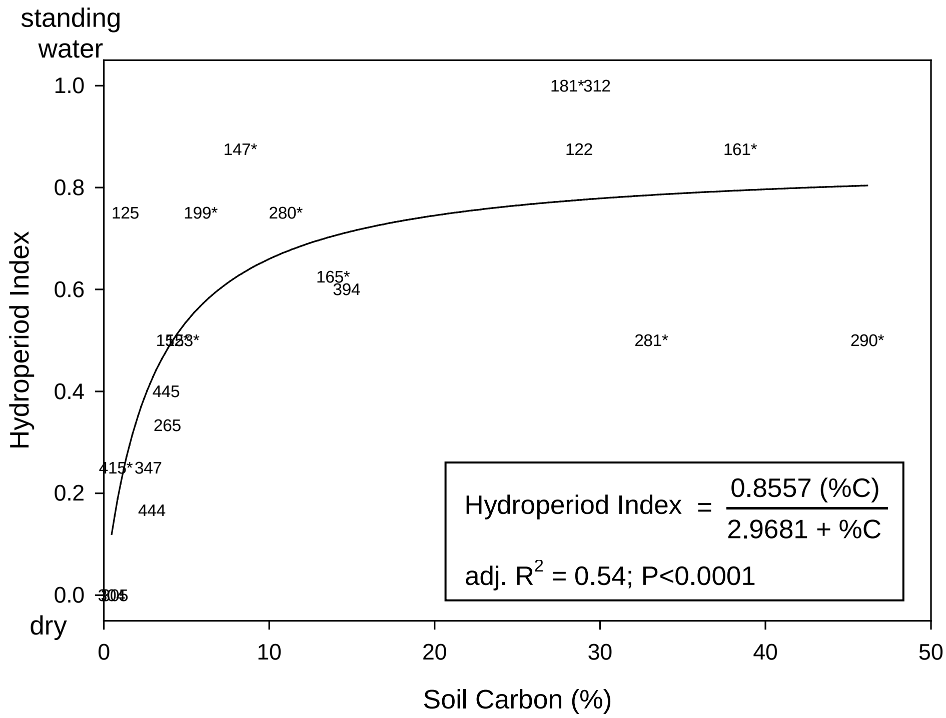


**Figure 2.** Soil carbon of vernal pools predicted by the relative hydroperiod index (see methods for description of calculation). The pools with an asterisk indicate the presence of amphibians observed either during or outside of the survey.

## Vegetation Classification

We identified 115 vascular plant species at the 21 pools that were subsampled. Vegetation composition varied greatly with wetness of the site, microtopographic features, and canopy openness. Cluster analysis grouped the vegetation into five distinct community types (Table 4, Appendix D), that resulted in an information retention of about 25%, with an overall percent chaining of 6.09%.

Species richness for vascular plants varied between 21 and 59 per community type (Table 4). The two forested communities (red maple complex and sugar maple complex) had the highest species richness (Table 4). Increased species richness in forested communities could be due to the greater number of microtopography features. The forested communities, especially red maple complex, had vegetation growing on downed logs in the pools. The logs tended to be covered with brown moss, with many seedlings and saplings of trees (*Acer rubrum, Betula alleghaniensis, Thuja occidentalis,* and *Tsuga canadensis)* and many vascular plants, including *Carex brunnescens, Maianthemum canadense,* and *Mitchella repens*. The forested vernal pools also had elevated hummocks or mounds in them, which created drier areas for plants to grow. Moist hummocks mostly occurred in the red maple communities and included the following species: *Acer rubrum* seedlings, *Calamagrostis canadensis, Coptis trifolia, Thelypteris phegopteris, Oxalis acetosella, Trientalis borealis* and *Vaccinium myrtilloides, w*hereas drier hummocks within the sugar maple communities consisted of *Carex arctata, Cinna latifolia, Clintonia borealis, Dryopteris intermedia, Fagus grandifolia*, and *Veronica* sp.

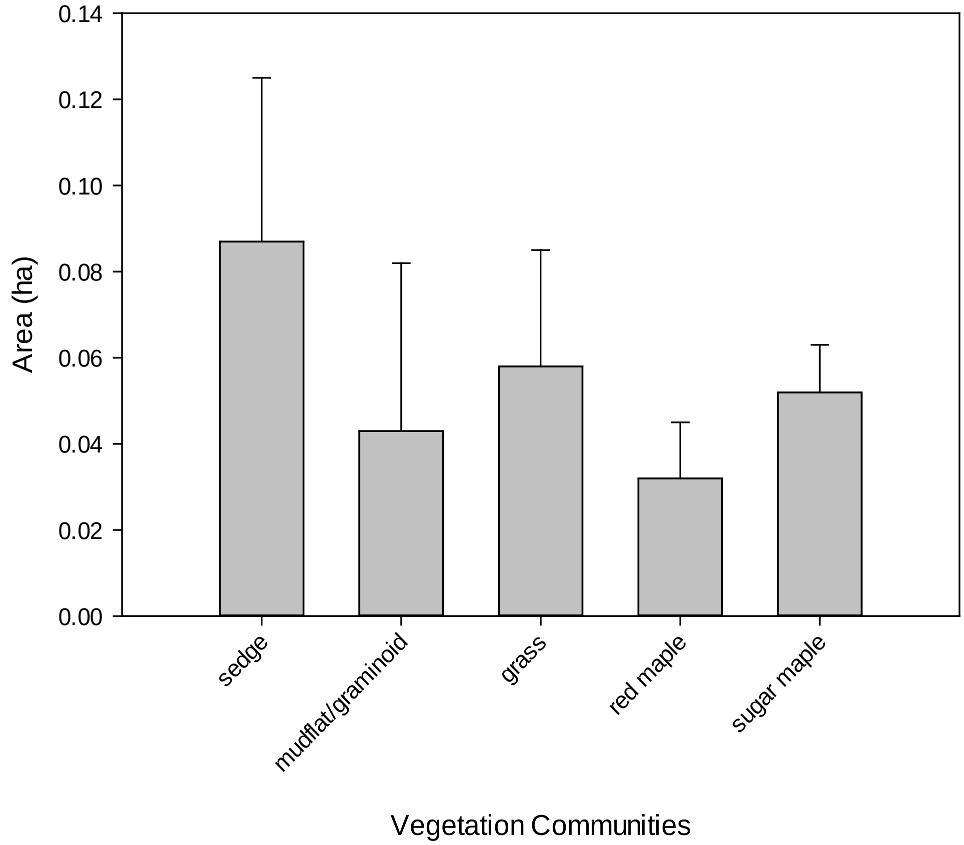


**Figure 3.** Average vernal pool area in hectares (error bars are 1 standard error) by vegetation community.

**Table 4.** Vegetation communities with indicator species, number of pools in each community (n), and species richness.

| Vegetation Community | n | Species richness |
|---|---|---|
| sedge *(Carex retrorsa/Onoclea sensibilis)* | 5 | 35 |
| mudflat/graminoids *(Juncus effusus/Scirpus cyperinus)* | 2 | 21 |
| grass *(Calamagrostis canadensis/Carex vesicaria)* | 3 | 38 |
| red maple *(Acer rubrum/Carex brunnescens)* | 8 | 59 |
| sugar maple (*Acer saccharum/Matteuccia struthiopteris)* | 4 | 54 |

The non-forested communities were dominated by several species of sedges, grasses, and forbs (Table 5). Unlike vegetation in the forested communities that appeared more structured by microtopography, the vegetation in the non-forested classic pools tended to have vegetation in bands. The middle of the pools usually had the deepest water and might have contained aquatic plants if wet enough (e.g., *Potamogeton* spp.*)*. In the shallower water surrounding the aquatics, there were typically bands of emergent plants (e.g., *Carex* spp.) and an outer ring that included drier grasses and forbs. However, this pattern varied based on degree of wetness of the pool.

**Table 5.** Average percent cover of common plant species by community type.

| | **Vegetation Community (percent cover)** | | | | |
|---|---|---|---|---|---|
| **Species** | *sedge* | *mudflat/ graminoid* | *grass* | *red maple* | *sugar maple* |
| *Acer rubrum* | 0 | 0 | 8 | 47 | 1 |
| *Carex brunnescens* | 1 | 0 | 1 | 13 | 1 |
| *Tsuga canadensis* | 0 | 0 | 0 | 9 | 0 |
| *Dryopteris carthusiana* | 1 | 0 | 0 | 7 | 0 |
| *Osmunda claytoniana* | 0 | 0 | 0 | 5 | 0 |
| *Trientalis borealis* | 0 | 0 | 8 | 4 | 0 |
| *Athyrium filix-femina* | 1 | 0 | 0 | 5 | 5 |
| *Carex tuckermanii* | 0 | 0 | 0 | 5 | 1 |
| *Fagus grandifolia* | 0 | 0 | 2 | 5 | 8 |
| *Dryopteris intermedia* | 4 | 0 | 1 | 15 | 5 |
| *Betula alleghaniensis* | 0 | 0 | 2 | 10 | 22 |
| *Matteuccia struthiopteris* | 0 | 0 | 0 | 2 | 86 |
| *Impatiens capensis* | 0 | 0 | 0 | 2 | 21 |
| *Fraxinus nigra* | 0 | 0 | 0 | 0 | 9 |
| *Onoclea sensibilis* | 28 | 0 | 0 | 4 | 11 |
| *Acer saccharum* | 0 | 0 | 8 | 4 | 21 |
| *Carex crinita* | 10 | 0 | 1 | 7 | 0 |
| *Iris versicolor* | 8 | 8 | 4 | 1 | 0 |
| *Osmunda regalis* | 5 | 2 | 1 | 2 | 0 |
| *Lycopus uniflorus* | 18 | 17 | 2 | 10 | 1 |
| *Scutellaria lateriflora* | 41 | 0 | 9 | 5 | 0 |
| *Ilex verticillata* | 21 | 0 | 0 | 0 | 0 |
| *Torreyochloa pallida* | 16 | 0 | 0 | 0 | 0 |
| *Scirpus cyperinus* | 7 | 10 | 2 | 0 | 0 |
| *Myrica gale* | 0 | 22 | 0 | 0 | 0 |
| *Thelypteris phegopteris* | 11 | 0 | 0 | 0 | 0 |
| *Alopecurus aequalis* | 10 | 0 | 0 | 0 | 0 |
| *Poa* sp. | 0 | 17 | 1 | 0 | 0 |
| *Dulichium arundinaceum* | 3 | 12 | 0 | 0 | 0 |
| *Potamogeton* sp. | 0 | 12 | 0 | 0 | 0 |
| *Milium effusum* | 0 | 0 | 0 | 0 | 9 |
| *Carex intumescens* | 0 | 0 | 8 | 5 | 0 |
| *Viola sp.* | 0 | 0 | 8 | 5 | 0 |
| *Carex vesicaria* | 0 | 5 | 52 | 0 | 0 |
| *Calamagrostis canadensis* | 0 | 10 | 17 | 1 | 0 |

Soil C content varied with pool vegetation community types (Figure 4). Sedge pools had the greatest soil C content (ca. 30%), followed by red maple communities (ca. 12%). Both of these communities had high enough soil C content to be classified as organic soils. At the other extreme, classic grass pools had less than 1% soil C.

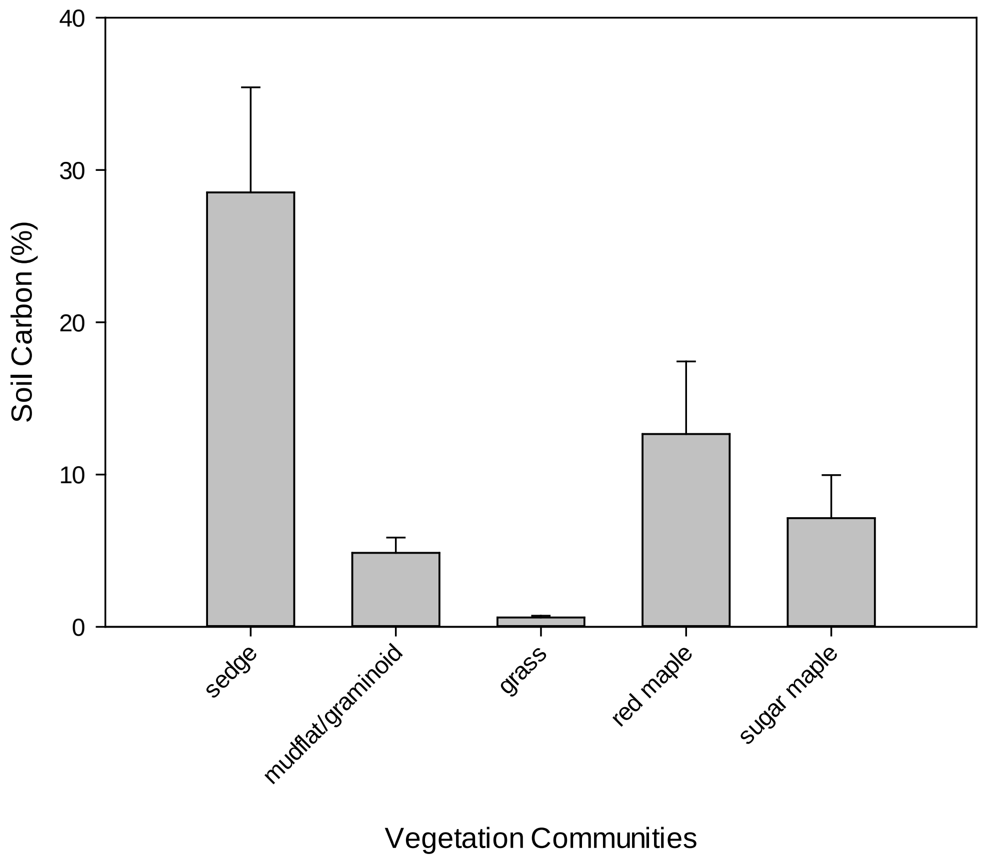


**Figure 4.** Average soil carbon percentage of vernal pools (error bars are 1 standard error) at each vegetation community.

## Combined Classification System

Vegetation classification strongly followed the physical classification of vernal pools, especially in the classic and complex categories. Therefore, we created a vernal pool classification that merged physical characteristics and vegetation community characteristics into three broad types:

A. Non-forested with open canopies and single, classic pools

B. Forested (red maple) with closed canopies and *wet* pool complexes (many small, interconnected pools)

C. Forested (sugar maple) with closed canopies and *dry* pool complexes (many small, interconnected pools)

Further details, based on the vegetation cluster analysis from this study, are added to the three types listed above to more fully classify PIRO's vernal pools.

### *A. Non-forested with open canopies and single, classic pools*

1. Classic sedge pool (*Carex retrorsa*/*Onoclea sensibilis*). Open canopy dominated by various sedges and ferns. Common species included: *Alopecurus aequalis, Bidens* sp., *Carex retrorsa*, *Carex utriculata*, *Comarum palustre*, *Dulichium arundinaceum*, *Eupatorium maculatum*, *Osmunda regalis*, *Menyanthes trifoliata*, *Onoclea sensibilis*, *Scutellaria lateriflora*, *Solanum dulcamara*, *Thelypteris palustris*, and *Torreyochloa pallida*. Most plants in this group were obligate wetland plants, and soil carbon was very high, indicating that this was probably the wettest pool type. Classic sedge pools tended to have larger maximum water surface areas than all other community types (Figure 3). Pools #161, #165, #280, #281, and #290.

2. Classic mudflat/graminoid pool (*Juncus effusus*/*Scirpus cyperinus*). Open canopy dominated by various grasses, sedges and ferns. Common species included: *Carex cryptolepis, Euthamia graminifolia, Glyceria canadensis, Juncus effuses, Iris versicolor, Lycopus americanus, Panicum* sp., *Polygonum amphibium, Potentilla norvegica, Scirpus cyperinus,* and *Verbena* sp. Most species were facultative wet to obligate wetlands plants with soils that had low to medium soil carbon contents, indicating mesic conditions. Pools #199 and #265.

3. Classic grass pool (*Calamagrostis canadensis*/*Carex vesicaria*). Open canopy with dominant species that included: *Acer rubrum, Calamagrostis canadensis, Carex intumescens, Carex vesicaria*, and *Viola* sp. Plants were facultative wetland plants and soil had very low carbon content, indicating that these were normally dry. Pools #304 and #415.

### *B. Forested (red maple) with closed canopies and wet pool complexes*

4. Red maple complex (*Acer rubrum*/*Tsuga canadensis*). Forested, closed canopy, wet pool community with many small interconnecting pools. Common species included: *Acer rubrum, Acer pensylvanicum, Betula alleghaniensis, Carex stipata, Carex tuckermanii, Lycopodium annotinum, Osmunda claytoniana, Scutellaria lateriflora, Populus tremuloides, Thuja occidentalis,* and *Tsuga canadensis*. Most plants were facultative wet to obligate wetlands species, combined with second highest soil carbon content indicate that this is a wet community. This pool type tended to be the largest and most species rich in vascular plants. This type also had the lowest pH. In many respects, this vernal pool vegetation was similar to a red maple swamp. Pools #122, #125, #152, #153, #181, #305, #312, and #445.

### *C. Forested (sugar maple) with closed canopies and dry pool complexes*

5. Sugar maple complex (*Acer saccharum*/*Matteuccia struthiopteris*). Forested, closed canopy, dry pool community with many small interconnecting pools. Common species included: *Acer saccharum, Acer spicatum, Adiantum pedatum, Allium*

*tricoccum, Arisaema triphyllum, Symphyotrichum lateriflorum, Rubus pubescens, Veronica officinalis, Matteuccia struthiopteris, Myosotis* sp., *Populus balsamifera*, and *Fraxinus nigra*. Most plants were upland to facultative wet species and, when combined with low soil carbon content, indicated that this was a dry community. Pools #147, #347, #394, and #444.

## Macroinvertebrates

A total of 108 individual macroinvertebrates in 15 taxonomic groups were collected in the four vernal pools that contained standing water (Table 6). In larger pools (#199 and #181) macroinvertebrates were sampled from the middle of the pool and from the edge. In smaller pools (#445 and #280), only one macroinvertebrate sample was collected. Pool #280 contained the highest abundance of macroinvertebrates whereas pool #445 contained the lowest (Table 7). Trichoptera and the bivalve Sphaeriidae were the most abundant across all pools.

Primary consumers including filter-feeders (Scirtidae, Sphaeriidae), shredders (Limnephilidae, Haliplidae), and collector-gatherers (Chironomidae, Culicidae, Oligochaeta) dominated macroinvertebrate communities (Table 8). Predators (Carabidae, Dytiscidae, Chaoboridae, Tabanidae, Libeluliduae, Hirudinea) were more diverse but less abundant, and only one scraper (Hydrobiidae) was collected.

**Table 6.** Aquatic macroinvertebrates of vernal pools found during spring 2010. Total abundance of each taxonomic group from all pools (n=4) is given for the functional feeding group.

| Taxonomic group (**Order**/Family) | **Common name** | **Functional feeding group** | **Total abundance** |
|---|---|---|---|
| **Coleoptera** | | | **15** |
| Carabidae | ground beetles | predator | 1 |
| Scirtidae | marsh beetles | collector-filterer | 4 |
| Dytiscidae | predaceous diving beetles | predator | 4 |
| Haliplidae | crawling water beetles | shredder | 1 |
| family unknown | NA | NA | 5 |
| **Diptera** | | | **21** |
| Chaoboridae | phantom midges | predator | 5 |
| Chironomidae | non-biting midges | collector-gatherer | 11 |
| Tabanidae | horse flies | predator | 4 |
| Culicidae | mosquitoes | collector-gatherer | 1 |
| **Gastropoda** | | | **1** |
| Hydrobiidae | mud snails | scraper | 1 |
| **Odonata** | | | **6** |
| Libelulidae | skimmer dragonflies | predator | 6 |
| **Trichoptera** | | | **29** |
| Limnephilidae | northern caddisflies | shredder | 29 |

**Table 6.** Aquatic macroinvertebrates of vernal pools found during spring 2010. Total abundance of each taxonomic group from all pools (n=4) is given for the functional feeding group (continued).

| **Taxonomic group** (**Order**/Family) | **Common name** | **Functional feeding group** | **Total abundance** |
|---|---|---|---|
| **Bivalvia** | | | **29** |
| Sphaeriidae | fingernail clams | collector-filterer | 29 |
| **Oligochaeta** | worms | collector-gatherer | **5** |
| **Hirudinea** | leeches | predator | **2** |

**Table 7.** Aquatic macroinvertebrate abundance, richness, and diversity (Shannon-Wiener, H) by physical pool type.

| **Pool #** | **Vegetation classification** | **Physical classification** | **Total macroinvertebrate abundance (# per sample)** | **Taxa richness** | **Taxa diversity (H)** |
|---|---|---|---|---|---|
| 280 | sedge | classic | 66 | 7 | 1.45 |
| 199 | mudflat/graminoid | kettle/kame | 9 | 7 | 1.75 |
| 181 | red maple | complex | 12 | 7 | 1.78 |
| 445 | red maple | complex | 1 | 1 | 0.00 |

**Table 8.** Proportional abundance of aquatic macroinvertebrate functional feeding groups in vernal pools (n=4).

| **Functional feeding group** | **Percent of total abundance** |
|---|---|
| filter-feeder | 35% |
| shredder | 34% |
| collector-gatherer | 15% |
| predator | 15% |
| scraper | 1% |

## Amphibians

Five amphibian species were observed in 17 of 21 vernal pools sampled for amphibians during May 2010 (Table 9). Amphibians were encountered during our area-based survey at seven vernal pools (41%) and were noted outside of our survey at an additional four pools (65% of total pools sampled) (Table 10). Average abundance tended to be highest at classic, non-forested vernal pools (Table 11).

Amphibians observed during surveys conducted specifically to detect them were found most frequently at classic sedge pools (80% of type sampled), followed by the classic mudflat/graminoid pools (50% of type sampled) and the red maple complex pools (33% of type sampled). When all encounters and sightings of amphibians are combined, the trend is similar, although amphibians were found in 1 out of 1 classic grass pools sampled (100%) (Table 10). When classified by physical pool type, amphibians were found most frequently in classic vernal pools and least frequently in dune and swale pools (Table 10).

Wood frogs and red-backed salamanders were observed most frequently (in 22% of vernal pools sampled). Leopard frogs and eastern newts were observed the least, in one vernal pool each (10% of pools sampled; Tables 12 and 13). Wood frogs were found only in classic sedge pools, classic mudflat/graminoid pools, and classic grass pools, whereas red-backed salamanders were found near all of the above classic pools as well as red maple complex and sugar maple complex (forested) pool complexes. The American toad (*Anaxyrus americanus*) was the only amphibian found in the sugar maple complex.

**Table 9.** Amphibian species encountered at vernal pools in 2010 compared to those previously documented at PIRO.

| **Order**<br>*Latin name* | **Common name** | **Found in 2004 survey by Casper (2005)** | **Found in 2007 survey by Bowen and Beever (2010)** | **Found during 2010 survey** |
|---|---|---|---|---|
| **Anura** | **frogs** | | | |
| *Anaxyrus americanus* | American toad | yes | yes | yes |
| *Hyla versicolor* | eastern grey treefrog | yes | yes | no |
| *Pseudacris crucifer* | spring peeper | yes | yes | no |
| *Lithobates clamitans* | green frog | yes | yes | no |
| *Lithobates pipiens* | leopard frog | no | yes | yes |
| *Lithobates septentrionalis* | mink frog | no | yes | no |
| *Lithobates sylvaticus* | wood frog | yes | yes | yes |
| **Caudata** | **salamanders** | | | |
| *Notophthalmus viridescens* | eastern newt | yes | yes | yes |
| *Plethodon cinereus* | red-backed salamander | yes | yes | yes |
| *Hemidactylium scutatum* | four-toed salamander | yes | no | no |
| *Ambystoma maculatum* | spotted salamander | yes | no | no |
| *Ambystoma laterale* | blue spotted salamander | yes | no | no |

**Table 10.** Amphibian sightings by vernal pool vegetation community type and physical type. Both species richness and total abundance (all juvenile and/or adult individuals of all species) are given for only the survey and for all sightings.

| Pool # | Vegetation type | Physical type | Species richness survey only | Species richness all sightings | Total abundance survey only | Total abundance all sightings |
|---|---|---|---|---|---|---|
| 290 | sedge | classic | 0 | 0 | 0 | eggs |
| [1]280 | sedge | classic | 2 | 3 | 4 | 8 |
| 281 | sedge | classic | 1 | 2 | 2 | 3 |
| 165 | sedge | classic | 1 | 1 | 1 | 1 |
| 161 | sedge | classic | 1 | 1 | 1 | 1 |
| 265 | mudflat/graminoid | kettle/kame | 0 | 0 | 0 | 0 |
| [1]199 | mudflat/graminoid | kettle/kame | 1 | 2 | 1 | 2 |
| 415 | grass | classic | 0 | 1 | 0 | 1 |
| [1]445 | red maple | complex | 0 | 0 | 0 | 0 |
| 152 | red maple | complex | 1 | 1 | 1 | 1 |
| 153 | red maple | complex | 1 | 1 | 1 | 1 |
| 125 | red maple | dune and swale | 0 | 0 | 0 | 0 |
| 122 | red maple | dune and swale | 0 | 0 | 0 | 0 |
| [1]181 | red maple | complex | 0 | 1 | 0 | 2 |
| 394 | sugar maple | complex | 0 | 0 | 0 | 0 |
| 444 | sugar maple | complex | 0 | 0 | 0 | 0 |
| 147 | sugar maple | complex | 0 | 1 | 0 | 1 |

[1]Indicates pool had standing water of a depth ≥ 2cm. All other pools were without standing water.

**Table 11.** Average abundance of amphibians summarized by vernal pool physical and vegetation classifications for survey results only and all sightings.

| Vernal pool classification | | n | Average abundance survey | Average abundance all sightings |
|---|---|---|---|---|
| Physical Type | classic | 6 | 1.3 | 2.3 |
| | complex | 7 | 0.3 | 0.7 |
| | dune and swale | 2 | 0 | 0 |
| | kettle/kame | 2 | 0.5 | 1.0 |
| Vegetation Type | sedge | 5 | 1.6 | 2.6 |
| | mudflat/graminoid | 2 | 0.5 | 1.0 |
| | grass | 1 | 0.0 | 1.0 |
| | red maple complex | 6 | 0.3 | 0.7 |
| | sugar maple complex | 3 | 0.0 | 0.3 |

**Table 12.** Amphibian total abundances across all pools for survey (non-survey) sightings by physical classification.

| Physical classification | Red-backed salamander | Eastern newt | Wood frog | Leopard frog | American toad | Unidentified frog |
|---|---|---|---|---|---|---|
| classic | 2 (0) | 0 (1) | 6 (4) | 0 (0) | 0 (1) | 0 (0) |
| complex | 2 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (1) | 0 (2) |
| dune and swale | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| kettle/kame | 0 (0) | 0 (0) | 0 (0) | 0 (1) | 1 (0) | 0 (0) |
| **Total** | 4 (0) | 0 (1) | 6 (4) | 0 (1) | 1 (2) | 0 (2) |

**Table 13.** Amphibian total abundances across all pools for survey (non-survey) sightings by vegetation classification.

| Vegetation classification | Red-backed salamander | Eastern newt | Wood frog | Leopard frog | American toad | Unidentified frog |
|---|---|---|---|---|---|---|
| classic sedge | 2 (0) | 0 (1) | 6 (3) | 0 (0) | 0 (1) | 0 (0) |
| mudflat/graminoid | 0 (0) | 0 (0) | 0 (0) | 0 (1) | 1 (0) | 0 (0) |
| grass | 0 (0) | 0 (0) | 0 (1) | 0 (0) | 0 (0) | 0 (0) |
| red maple | 2 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (2) |
| sugar maple | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (1) | 0 (0) |
| **Total** | 4 (0) | 0 (1) | 6 (4) | 0 (1) | 1 (2) | 0 (2) |

# Discussion

## Vernal Pool Identification

PIRO vernal pool densities are on the lower range of those reported in other northeastern U.S. surveys, which generally encompass the extent of the Late-Wisconsin glaciations (PIRO = 0.17 pools/km$^2$; northeastern range of 0.17 to 13.5 pools/km$^2$; Burne 2001, Lathrop et al. 2005, Palik et al. 2007, Calhoun and deMaynadier 2001). Vernal pool densities may be lower in PIRO because of unsuitable terrain for vernal pool formation. For instance, a large area of PIRO is comprised of either mesic conifers (ca. 10%), upland pines (ca. 10%), both with a small vernal pool contingent, or other cover types (e.g., dunes, beaches, water, etc.; ca. 10%) that are unlikely to have vernal pools. PIRO vernal pool densities reported here might be low due to conifer overstory in some habitats that make detection from aerial photographs difficult. Currently, the only way to find vernal pools under closed conifer canopy is to conduct field surveys. If radar mapping can successfully find vernal pools under conifers (work being done by Laura Bourgeau-Chavez at MTRI), the estimate of vernal pool density in PIRO will likely increase.

Based on aerial photography, the error of commission was approximately 69%, likely a result of the purposeful inclusion of all the water features that might be vernal pools. The intent was to ground-truth all water features that might be vernal pools, however, only 80% of the water features were visited, and 31% of the water features were confirmed as vernal pools. The estimate of PIRO vernal pool density is based on the ground-truthed data, whereas the vernal pool density calculations in the other studies were based on data with varying errors of commission.

## Vernal Pool Classifications

Vernal pools are not one type but are a variety of different physical types that may contain different species and require different management actions. Therefore, we have classified vernal pools by both physical characteristics, which may be useful on a regional scale, and also by vegetation community types. We also devised a third classification system, which is more specific to PIRO and combines both the physical and vegetation community characteristics.

Vernal pools have been found to be associated with a variety of glacial landforms, slopes, and soil types (Palik et al. 2007 and Rheinhardt and Hollands 2008), and those at PIRO are no exception. A total of eight soil series occur within PIRO, and, of these, six have at least one type of vernal pool. The vast majority of vernal pools in PIRO are on sands from glacial outwash and moraines. For example, the most common soil series associated with vernal pools is Kalkaska-Rubicon-Duel (26 of the 49 or 53% of occurrences), with Rubicon-Rousseau-Ocqueoc (18% or 9 of the 49) and Shelldrake-Wallace-Roscommon (12%) being second and third most common, respectively. Only 7 out of 49 pools occurred on loamy soils and include Munising-Onota-Deerton (8%) and Onota-Deerton-Munising (6%). Only one vernal pool was found on Dawson-Markey-Carbondale muck (2%). This pattern is similar to what was found in northern Minnesota, where vernal pools were associated with glacial outwash, end moraines, and ground moraines (Palik et al. 2007).

The physical vernal pool classification system (i.e., classic, complex, kettle/kame, and dune and swale) is based on characteristics such as shape, degree of tree canopy closure, pool depression depth, as well as glacial and Lake Superior shoreline features. There are no direct analogs in the literature, although Rheinhardt and Hollands (2008) classified vernal pools based on hydrogeomorphic features, requiring detailed hydrologic understanding of vernal pools. Our terms “classic” and “complex” have been used to describe vernal pools in concept or terminology in a few sources (Brooks and Hayashi 2002, Leibowitz and Brooks 2008, Rheinhardt and Hollands 2008). For a regional scale classification system, physical classes provide a repeatable and meaningful classification from a managerial perspective (see amphibian discussion below).

For vernal pool classification specific to PIRO, we created a vegetation classification system. Although a direct association between vernal pool vegetation types and vernal pool fauna may not exist (Ray and Evans 2004), the variety of vernal pool vegetation communities is important from a research and conservation perspective (Cutko and Rawinski 2008). The vernal pool vegetation communities in PIRO can be grouped meaningfully, providing information such as canopy cover, size, shape, soil C, and soil moisture. These communities are similar to those described by Palik et al. (2007). For example, Palik et al. (2007) found a dichotomy in pool canopy cover similar to PIRO’s forested and non-forested pools. They also found that shorter hydroperiods were associated with more upland plant functional groups, while longer hydroperiods were associated with wetland plant functional groups. Vegetation also can indicate potential habitat for species that use vernal pools. For example, only two amphibians, both American toads, were observed in sugar maple complexes and classic grass pools; American toads tolerate drier conditions than other anurans, although standing water is required for breeding. Thus, these two pool types might not provide important habitats for amphibians.

### Soil Carbon As a Proxy for Hydroperiod

One of the main difficulties in assessing the hydrologic conditions of vernal pools is that they fluctuate rapidly, and the pools are often remotely located. Vernal pools are also difficult to quantify hydrologically because of the annual variation in precipitation. Therefore, a system to characterize hydroperiods with easily measured parameters would be beneficial. Brooks and Hayashi (2002) found that pools with higher maximum volumes, larger surface areas, or greater depths were more likely to have surface water when visited, but that relationship became highly variable with decreased maximum volume, surface area, or depth. We did not find a relationship between pool maximum surface area and relative hydroperiod index at PIRO. This may be because only two of the pools were larger than 0.1 ha, the lower limit for the relationship found by Brooks and Hayashi (2002). Brooks and Hayashi (2002) suggest that smaller pools and shallower pools would likely have high variability in hydroperiods due to other factors such as precipitation, evapotranspiration, and ground water exchange.

Preliminary analysis of PIRO vernal pools indicates that quantifying soil C might be a way to assess hydroperiod, even when the pools are dry (Figure 2). The variability in these data, especially in the longer hydroperiod portion of the curve may be due to the low sample size or the method for evaluating hydroperiod in this study. However, the variability in soil C is more complicated than a simple relationship between soil C and hydroperiod. Soil C is also affected by the length and seasonality of the hydroperiod, depth of water, and amount of plant growth. For instance, deep water pools can have lower soil C than expected because they have less plant growth and more oxygen in the water column. Conversely, some pools may have higher soil C than expected because the water table may stay just below the soil surface (lower hydroperiod index), but have a dense cover of sedges and grasses that increases soil C. Despite the complicating factors, soil C is a good metric for rapid assessment of vernal pool wetness. It is particularly significant that a good relationship was detectable during the driest spring on record, underscoring the potential of this tool for evaluation of hydroperiod despite conditions at the time of sampling.

Further research should be conducted on the relationship between soil C, vernal pool hydroperiod, and amphibian occurrence. The idea of using soil C as a proxy for hydroperiod is not about finding complete correspondence, but whether there is enough of a predictive capability to identify vernal pools of significance for amphibian habitat. If potential amphibian habitat could be assessed with a soil carbon sample, which requires only one visitation and simple laboratory analysis, a manager would have a relatively easy method of focusing vernal pool preservation on those pools with the highest potential of providing amphibian habitat without the need of monitoring all vernal pools for amphibians. This is even more promising if the soil carbon is related to the physical and vegetation characteristics of the pools.

## Macroinvertebrates

The 2010 spring sampling design was expected to occur after most of the snow had melted but while vernal pools had standing water so macroinvertebrates could be sampled and amphibians could be observed during their breeding periods. However, because of the anomalous climate conditions, most pools had already dried and we were able to sample only four vernal pools for aquatic invertebrates. Therefore, we were unable to detect any large-scale patterns in the presence of macroinvertebrates in relation to vegetation community type, vernal pool type, or amphibian presence. The dominant macroinvertebrate groups included Coleoptera, Diptera, Trichoptera, Odonata and Sphaeriidae. These taxa commonly occur in other seasonal woodland pools in the Midwest and eastern USA (Batzer et al. 2004, Brooks 2000).

Although macroinvertebrate sampling was not spatially extensive, patterns of occurrence were apparent. Overall, Limnephilidae and Sphaeriidae were the most common macroinvertebrates collected, primarily as a result of the large number collected in pool #280. This pool exhibited a floating sedge mat, as well as the most abundant and diverse amphibian community. Both Limnephilidae and Sphaeriidae were widespread in other vernal pools in PIRO. Limnephilids were found in three out of four vernal pools sampled and many empty cases of the same family were encountered, along with empty Sphaeriidae shells in the dry pools. Both groups are adapted to live in temporary ponds. For example, some Limnephilids are able to diapause as eggs or larvae to survive drought (Voshell 2002). Likewise, some Sphaeriidae species have very short development times, and others can withstand drought by burrowing into the substrate (Voshell 2002). Both of these survival strategies are common in vernal pool macroinvertebrate species (Colburn et al. 2008).

Macroinvertebrate communities in the vernal pools we sampled were dominated by primary consumers (35% filter-feeders and 34% shredders). Predators were among the least abundant macroinvertebrates found, with the exception of one scraper. This trend is typical of vernal pools; relatively few predators occur in ponds that dry frequently. Abundance, species richness and diversity of predator taxa increase with increasing permanence of pools (Schneider 1997). In general, larger sizes and longer generation times of predators may limit them to pools that have longer hydroperiods (Spencer et al. 1999).

The effects of environmental variables on macroinvertebrates in vernal pools are unclear. For example, Brooks (2000) found that as hydroperiod increased in vernal pools, macroinvertebrate communities were richer. However this effect was somewhat confounded by the interaction of hydroperiod and pond size. Batzer et al. (2004) concluded that there were surprisingly weak relationships between seasonal pond macroinvertebrate communities and environmental variables, though hydroperiod seemed to have some influence on taxon richness. They suggested that hydroperiod affects communities because only rare taxa survived in the wettest ponds, however Batzer et al. (2004) emphasized that hydroperiod had little effect on the most widespread, generalist taxa.

### Amphibians

PIRO is within the native range of 12 species of amphibians (Casper 2005, Harding 1997; Table 9). Of these, three are considered obligate vernal pool species (*Ambystoma maculatum*, *A. laterale*, and *Lithobates sylvaticus*) (Preisser et al. 2000), and six other species use vernal pools as breeding sites (*Hemidactylium scutatum*, *Notophthalmus viridescens*, *Pseudacris crucifer*, *Hyla versicolor*, *Lithobates pipiens*, *Anaxyrus americanus*) (Harding 1997). We encountered six species of amphibians during the vernal pool surveys. Bowen and Beever (2010) documented nine amphibian species in PIRO wetlands using a variety of survey methods. Casper (2005) encountered 10 amphibian species in 2004 (Table 7). Fewer amphibians may have been encountered in this study than in other years because spring 2010 was unusually warm and dry. In addition, based on evidence of dried eggs and larvae at some sites, amphibian breeding season had ended prematurely.

Overall, we encountered amphibians most frequently at classic sedge pools and classic mudflat/graminoid pools. In fact, if both survey and non-survey sightings are taken into account, amphibians occurred at 100% of these two classic vernal pool types (Table 10), indicating that focusing preservation efforts on these pool types would be beneficial for amphibians. We encountered amphibians at 44% of the red maple complex and sugar maple complex vernal pools, 50% of kettle/kame pools, and 0% of dune and swale pools, although only two pools were sampled in each of the latter two physical classes. In general, the classic sedge pools and classic mudflat/graminoid pools where amphibians were present tended to have soils with a greater proportion of carbon, indicating that they are more reliably wet (Figures 2 and 4). This consistency is important for amphibian breeding, as many species tend to be philopatric (Berven and Grudzien 1990, Semlitsch 2008).

Because amphibian species depend on vernal pools for breeding sites, the loss of these temporary ponds is a major reason for the decline of many species (Baldwin and deMaynadier 2009). The variable hydroperiod and lack of permanent water in vernal pools allows larval amphibians time to develop into juveniles, but prevents pools from being colonized by fish and other amphibian predators such as green frog tadpoles (Vasconcelos and Calhoun 2006). A key ingredient to successful amphibian production in vernal pools is the length of the hydroperiod (Boone et al. 2006, Paton and Crouch 2002). Pools must be inundated early enough for breeding to take place and long enough for larvae to metamorphose into terrestrial juveniles. Wood frogs have a six to 14 day breeding season; depending on temperature eggs incubate anywhere from four days to four weeks, and metamorphosis can occur in six to 15 weeks (Harding 1997). In southern Rhode Island, wood frogs needed ponds that were filled for about 115 days in order for larvae to emerge as juveniles (Paton and Crouch 2002). At PIRO mean snowfall and resulting snowmelt have provided early inundation in the past.

Amphibian breeding might not have been as successful in 2010 compared to years with more snowpack and/or early spring precipitation. Although vernal pools were examined for amphibians during May, usually a wet month, 13 of the 18 pools visited had no standing water. Muddy soil at many sites as well as evidence of empty caddis fly cases and fingernail clam shells indicated that most sites were inundated at some point earlier in the spring. We observed egg masses and live embryos in muddy soil in pools #290 and #161, indicating that these pools had recently dried. Evidently, eggs at some pools did not have sufficient time to develop into juveniles before pools dried. Early spring 2010 was particularly dry, though later in the season, many of the dry pools subsequently filled with rain water. Although some amphibians may not have survived from eggs to juveniles, evidence of recently metamorphosed wood frogs was observed at pools #165 (saturated), #415 (dry), #280 (standing water), and #281 (dry).

In addition to being critical for obligate vernal pool species, vernal pools are beneficial to other amphibian species. The American toad (*Anaxyrus americanus*) is an upland species with habitat preferences ranging from open woodlands to agricultural areas. However, the preferred breeding habitat for American toads is shallow, temporary pools (Harding 1997). We encountered American toads in three of 18 vernal pools (#281, #147 and #199) and in three of the five vegetation communities in the drier areas (Table 12). This species was the only amphibian found in sugar maple complexes.

Though the importance of vernal pools as safe breeding sites for amphibians is clear, it is likely that vernal ponds can provide important habitat for amphibians that do not use them directly. For example, even though the red-backed salamander (*Plethodon cinereus*), an upland species, does not use vernal pool habitat explicitly, it does require moist conditions and will avoid dry areas (Harding 1997). We found *P. cinereus* at 22% of vernal pools, in both forested and non-forested community types, suggesting that the moist habitat under logs and leaf litter existing as vernal pools dry could be important for this species.

The leopard frog (*Lithobates pipiens*) is another beneficiary of vernal pool habitat even though it is most commonly found close to permanent water sources. Leopard frogs often migrate to temporary ponds in early spring for breeding (Harding 1997). We encountered at least one leopard frog in pool #199, a classic mudflat/graminoid pool, in a kettle/kame feature. This pool is close to Kingston Lake and leopard frogs inhabiting the lake may migrate to this and other vernal pools in the area during breeding season to mate and lay eggs in a predator free environment.

## Management Considerations

Almost half of the confirmed vernal pools (23 of 49 pools) were located within the IBZ. Five of those 23 pools were subsampled. Of those five pools, amphibians were observed in three. Furthermore, several pools were located close to roads or trails within the shoreline zone and IBZ. There is a strong potential for negative impacts on the vernal pool flora and fauna from road and trail activities, related to recreation within the shoreline zone and to logging and recreation within the IBZ. For example, wood frogs and spotted salamanders require surface water (i.e., primarily vernal pools) for breeding habitat, but migrate substantial distances from water to surrounding upland habitat after breeding (Semlitsch and Skelly 2008). Therefore, disturbance to either breeding or other year-round habitat will negatively impact these species. Furthermore, invasive species could also impact vernal pool ecology within both the shoreline zone and IBZ. The wetland invasive species, *Phalaris arundianacea* (reed canary grass), *Cirsium palustre* (European swamp thistle), and *Myosotis* spp. (forget-me-not) have all been documented within PIRO, with the latter two found in low abundance in a few of the vernal pools sampled. Land-use (i.e., roads, trails, logging) is the biggest threat for spread due to vehicular and hiker vectors.

Vernal pool hydroperiod is strongly linked to weather and climatic factors, which are changing rapidly in the Great Lakes region. For example, air temperatures are increasing, and warm spring weather events are expected to occur earlier than they have in the past (Schramm and Loehman 2010). Such factors would tend to increase evaporation and reduce vernal pool hydroperiods, making dry springs, as seen in our 2010 study, more common. Additionally, based on historical records, winter precipitation is becoming more variable than summer precipitation (Wuebbles et al. 2003), with potential effects on winter snowpack and vernal pool recharge. However, Wright et al. (2013) recently predicted an increase in lake effect snowfall, which could affect places like PIRO. Such a trend could help offset the effects of warming temperatures on vernal pool hydroperiod. In any case, continued attention to the interactions between climate change, vernal pool hydroperiod, and amphibian abundance and breeding success is recommended.

We encourage increasing the understanding of vernal pools in PIRO, particularly how they function individually and at a landscape scale. For example, repeated ground-truthing in future years to encompass wetter conditions would give a better picture of what vernal pools in PIRO look like during typical spring conditions. Additional biological monitoring has the potential to capture rare taxa, or taxa that were not found due to dry conditions in 2010. We recommend annual spring monitoring of the cover boards we placed at three vernal pools (Appendix B and C). Furthermore, our amphibian data suggest that installation of additional cover board arrays, particularly at classic vernal pools, would be a relatively quick and easy way to monitor amphibians such as snakes and salamanders in PIRO. These cover board surveys could be coupled with calling surveys in the spring to easily and inexpensively monitor frogs at the same time. With an increased understanding of the pools and associated species, managers will be more capable of maintaining a population of pools that provide habitat for important fauna that rely on the conditions of vernal pools and surrounding uplands to survive.

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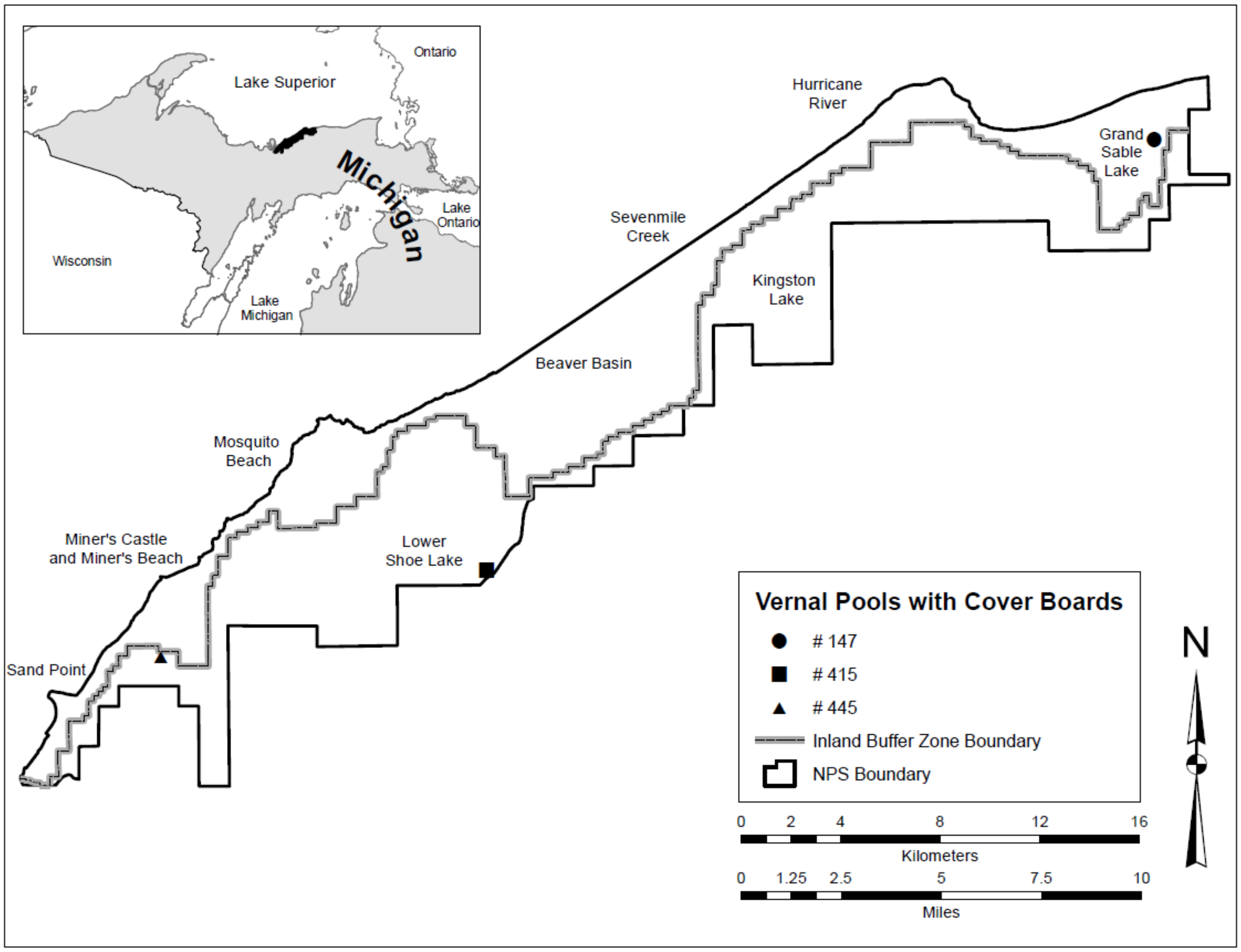
# Appendix A: Preliminary List of Water Features of Vernal Pools (determined by C. Olsen of Michigan Technological Research Institute)

| Water Feature # | Description |
|---|---|
| 11 | Snow/ice at north base of rock outcrop close to (at backside of) beach. |
| 12 | Snow/ice on or at back of beach without a visible outcrop. There may be a small outcrop with a seep; but, if so, it's masked by vegetation. |
| 13 | Snow/ice back from beach but near the coast. These are usually in the first swale behind the beach but without visible inflow or outflow. Many may simply be accumulations of melt water in low places with frozen ground below. |
| 14 | Snow/ice inland from beach but not associated with a road. |
| 15 | Snow/ice near top of bluff overlooking the beach. |
| 16 | Snow/ice along inland two-track (or other) roads. Some of these are along roads with bluffs rising on the south side of the road. Similar to water feature #11 but inland. |
| 21 | Visible puddle in or adjacent to a road - usually an interior two-track road. |
| 23 | Open water immediately inland of beach (in first swale). Similar to #13 but water is not frozen. |
| 31 | Open water (pond) without apparent inflow or outflow. Many of these are ground-water fed and may not qualify. |
| 32 | Isolated wet area near the beach. Similar to water feature #12 but not frozen. |
| 41 | Isolated wet areas with tree overstory. Coniferous overstory obscures the boundary of the pools. Many of these may occur during snowmelt as accumulations of melt water in shallow depressions that are frozen below. |

# Appendix B: Map of Vernal Pools with Amphibian Cover Boards.



# Appendix C: Locations of Amphibian Cover Boards

| Date of Placement | Pool # | GPS northing | GPS easting | Notes |
|---|---|---|---|---|
| 5/19/2010 | 415 | not available | not available | see Figure C1 below. |
| 5/20/2010 | 445 | 46°27.888 | 086° 33.076 | set 1 – approximately 2 m away from edge of pool (an estimate because no water was there), these are on the N side of vernal pool. |
| | 445 | 46°27.894 | 086° 33.076 | set 2 - approximately 2 m away from edge, 1m apart, straight SE across pool from set 1 - hummock with hemlocks and a big maple. |
| 5/25/2010 | 147 | 46°38.917 | 086° 01.683 | set 1 - at wettest point, they are on the bank towards Sable lake (W side). |
| | 147 | 46°38.920 | 086° 01.683 | set 2 - on east (NE) side of pool, on hummock created by big rotting log (within each set, boards are about 1 m apart). |

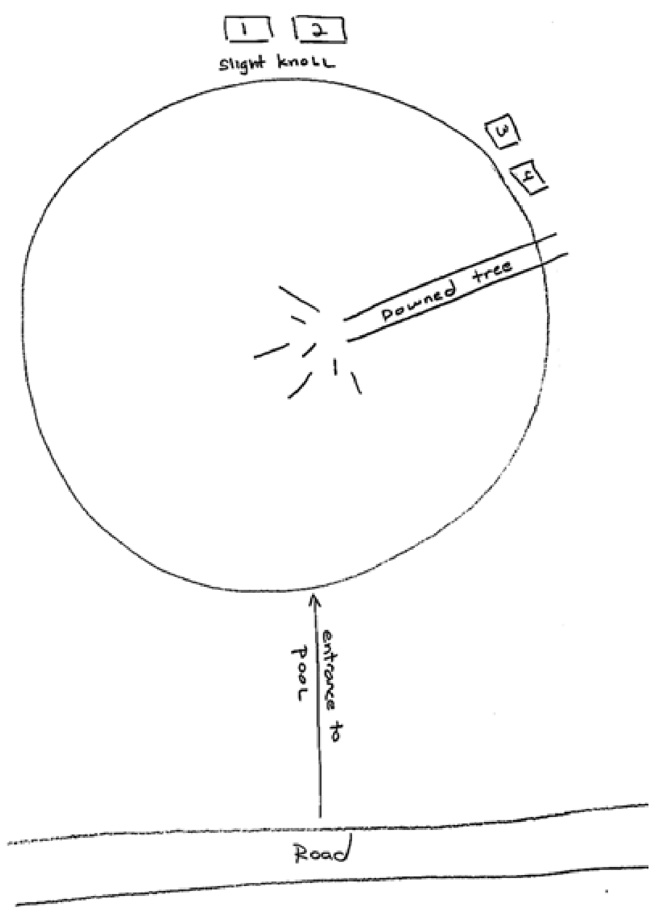



**Figure C1.** Locations of four cover boards at vernal pool #415.

# Appendix D: Photos of Vernal Pool Types.

**Figure D1.** Example of a classic sedge pool. Sedges mask the standing water. Photo by J. Marr.

**Figure D2.** Example of classic mudflat/graminoid pool. Photo by J. Marr.

**Figure D3.** Example of a classic grass pool. Photo by J. Marr.

**Figure D4.** Example of a red maple complex pool. Photo by J. Marr.

**Figure D5.** Example of vegetation growing on downed logs in red maple complex pool. Photo by J. Marr.

**Figure D6.** Example of vegetation growing on mesic hummocks in red maple complex pool. Photo by J. Marr.

**Figure D7.** Example of sugar maple complex pool (dry in 2010). Photo by J. Marr.

**Figure D8.** Example of hummock in sugar maple complex pool (dry in 2010). Photo by J. Marr.

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