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CHARACTERIZATION OF VERNAL POOLS ACROSS NATIONAL PARKS IN THE GREAT LAKES REGION

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CHARACTERIZATION OF VERNAL POOLS ACROSS NATIONAL PARKS IN THE GREAT LAKES REGION

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Author Contribution Statement

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Abstract

Vernal pools are small, ephemeral wetlands that become inundated each spring and provide many ecosystem services to the surrounding upland forests. They also provide critical habitat for amphibians and invertebrates, as their temporary nature keeps them free of fish and reduces predator populations. As part of a mapping project, we collected baseline field data on vernal pool characteristics throughout five Great Lakes National Parks: Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, Apostle Islands National Lakeshore, Isle Royale National Park, and Voyagers National Parks. Our goals were to characterize and assess how vernal pools vary within and across the five national parks, and determine which characteristics are most correlated with the presence of vernal pool indicator species. We sampled 139 pools during spring of 2021 and 2022 where we collected data on pool characteristics related to hydrology, soils, vegetation, geomorphology, and indicator species. This baseline data shows that vernal pool characteristics do vary between the different parks. Many vernal pool qualities are driven by the type of substrate they occur on and overstory canopy species and amount of cover. The vegetation and canopy species present reflect the dominant vegetation of each park. We also created a classification system that describes which characteristics were most highly correlated to indicator species presence, resulting in a three-class system based on overstory species composition: Deciduous (>50% deciduous canopy), Coniferous (<50% deciduous canopy), and Open (<30% canopy cover). Indicator species were more likely to occur in pools with either a deciduous or open canopy than pools with a coniferous canopy. This information can be used to inform land managers within

the Great Lakes of vernal pool characteristics they can expect, and which pools are hotspots for indicator species.

1 Introduction

Vernal pools are small, temporary wetlands that are hydrologically isolated and can be found throughout the forests of the Upper Midwest and Northeastern United States. Most vernal pools fill up with water each spring to form pools that a variety of amphibians and invertebrates depend on for habitat and reproduction (Karraker and Gibbs 2009; Thomas et al. 2010). The temporary nature of vernal pools keeps them free of fish and reduces the populations of other predators, providing feeding and resting places for amphibians and allowing them to breed with greater success (Calhoun and deMaynadier 2008; Calhoun et al. 2017; Rothenberger and Baranovic 2021; Hofmeister et al. 2022

Vernal pools also contribute many ecosystem services to the surrounding forests, including increasing biodiversity of both plants and animals (Paton 2005; Flinn et al. 2008; Mitchell et al. 2008; Schrank et al. 2015, Dixneuf et al. 2021), influencing nutrient cycling (Davic and Welsh 2004; Capps et al. 2015; Fritz and Whiles 2018; Atkinson et al. 2021), and improving water quality and storage (Leibowitz 2003; Cohen et al. 2016). There are several wildlife species that rely exclusively on vernal pools for habitat and reproduction and are rarely found in other bodies of water, called vernal pool obligates or "indicator species". The vernal pool indicator species most widely used in the Northeast and Midwestern United States includes the wood frog (*Lithobates sylvaticus*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*), fairy shrimp (*Eubranchipus* spp.) and fingernail clam (Sphaeriidae) (MVPP 2021, Calhoun et al. 2003, Thomas et al. 2010). These organisms rely on vernal pools for habitat as well as serving their own important functions in the ecosystem such as nutrient translocation and role in the food web. For example, wood frogs have been found to disperse 19 kg C, 5.5 kg N, and 1.6 kg P annually from vernal pools into the surrounding forests (Capps et al. 2015). While they are not vernal pool obligates, other wildlife such as turtles, snakes, birds, and mammals also use vernal pools as a source of water, refuge, or food, but their presence is more difficult to document and measure (Silveira 1998; Mitchell et al. 2008; Eakin et al. 2018). Water storage is also improved as surface water is allowed to seep into the surrounding soil and into the deeper groundwater system when not restricted by clays. This allows for better water retention within the forest instead of losing water to the regional drainage system (Leibowitz 2003).

Although vernal pools are vital to forests and wildlife, management and conservation of these features is lacking due to their cryptic nature, small size, and the extent to which they are integrated into the forest matrix (Calhoun et al. 2003). The wide inter-annual variability in hydrologic conditions also makes it difficult to locate them, as pools may not always be inundated in spring, especially during dry years and they are typically dry in the summer (Calhoun et al. 2017). In terms of legislation, vernal pools remain unprotected at the federal level because they are temporary, isolated, and too small to meet the criteria of the Clean Water Act (Burne and Griffin 2005; Christie and Hausmann 2003). National parks and other large, protected areas are especially effective conservation tools because their continuous forests and lack of extractive industries means that pools do not need to be managed individually to remain intact. Considering the forest surrounding vernal pools as well as the pools themselves is equally important in maintaining functional vernal pools, as amphibians and other vernal pool users spend most of their life in the upland leaf litter after mating, and canopy cover helps vernal pools persist longer into the summer by reducing evaporation rates (Richter et al. 2013; Gibbons 2003). Without proper protection, vernal pools are vulnerable to land use changes, climate change, forestry and agricultural operations, and urbanization.

Vernal pools in the Great Lakes region are largely understudied, with few inventory resources for land managers despite the expansive forests that provide many opportunities for vernal pools to occur (Hofmeister et al. 2022; Calhoun et al. 2017). In actuality, vernal pools are abundant on the landscape and occur in at least three states in the western Great Lakes (Hofmeister et al. 2022). This study aims to provide descriptive baseline data for vernal pool charactieristcs in this region and how those characteristics change in response to differing landforms and forest types.

Remote sensing is becoming more widely used in vernal pool identification and significantly reduces the amount of time and money it takes to locate vernal pools (Bourgeau-Chavez et al. 2016). With this tool, land managers inside and outside protected areas will be able to determine the location of vernal pools within their parcels without doing intensive land-based surveys, making it easier for them to consider these small forest features. Mapping methods are currently being developed and honed to create accurate and reliable maps (Leonard et al. 2012; Wu et al. 2014; Bourgeau-Chavez et al. 2016; Varin et al. 2021). With growing mapping capabilities, understanding differences in vernal pool characteristics and determining whether certain pools should be given higher conservation priority is critical to utilizing mapping efforts effectively. By examining vernal pool characteristics and their relationship with indicator species occurrence, more detailed maps can be created, and land managers will be more likely to be able to use remote sensing products to aid conservation efforts (Campbell Grant 2005).

Our goals were to **1)** characterize vernal pools in five national parks across the Great Lakes region, **2)** assess how vernal pools vary within and across the five national parks, and **3)** determine which characteristics are most correlated with the presence of vernal pool indicator species. We hypothesized that canopy species, pool morphology, and soil organic matter would be significantly correlated with indicator species presence, with indicators occurring more frequently in pools with deciduous tree species, classic pool shape, and greater soil organic matter. These data will be utilized to improve ongoing vernal pool mapping efforts across these national parks and inform future remote sensing with a classification system describing characteristics correlated with indicator species presence.

2 Methods

2.1 Study Area

Five national parks were mapped and surveyed, including Apostle Islands National Lakeshore, Isle Royale National Park, Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Voyageurs National Park. These parks occur within the Laurentian Great Lakes region of the United States and are located in Michigan, Wisconsin, and Minnesota (Figure 2.1). The parks vary in size, from Sleeping Bear at 28,813 ha to Isle Royale at 231,395 ha. Voyageurs, Isle Royale, and the Apostle Islands are located on the Canadian Shield and have thin soils on top of the early Precambrian granite that makes up the continental crust underlying much of North America (Kurmis et al. 1986; Magnuson et al. 1997). Pictured Rocks lies on Cambrian bedrock which is predominantly sandstone and has abundant natural outcrops along the Lake Superior shoreline (VanderMeer et al. 2020). Sleeping Bear lies on sandy dune deposits overlying glacial sediment on the shore of Lake Michigan (Barnhardt et al. 2002). All the parks are strongly influenced by glaciation and have abundant post-glacial landforms. The climate throughout this region is mid-continental with warm summers, cold snowy winters, and a mean annual temperature between 1.4 and 5.8 °C (Magnuson et al. 1997). The average annual precipitation is between 784 and 1033 mm (Magnuson et al. 1997). Forests throughout the parks are representative of the dominant vegetation of their region. Boreal forests can be found in Isle Royale and Voyageurs, while beech-maple forest is present in Sleeping Bear and Pictured Rocks (Kurmis et al. 1986; Paulson et al. 2016). Northern hardwood forests are most common in Pictured Rocks and the Apostle Islands, but they can be found in every park (Paulson et al. 2016).

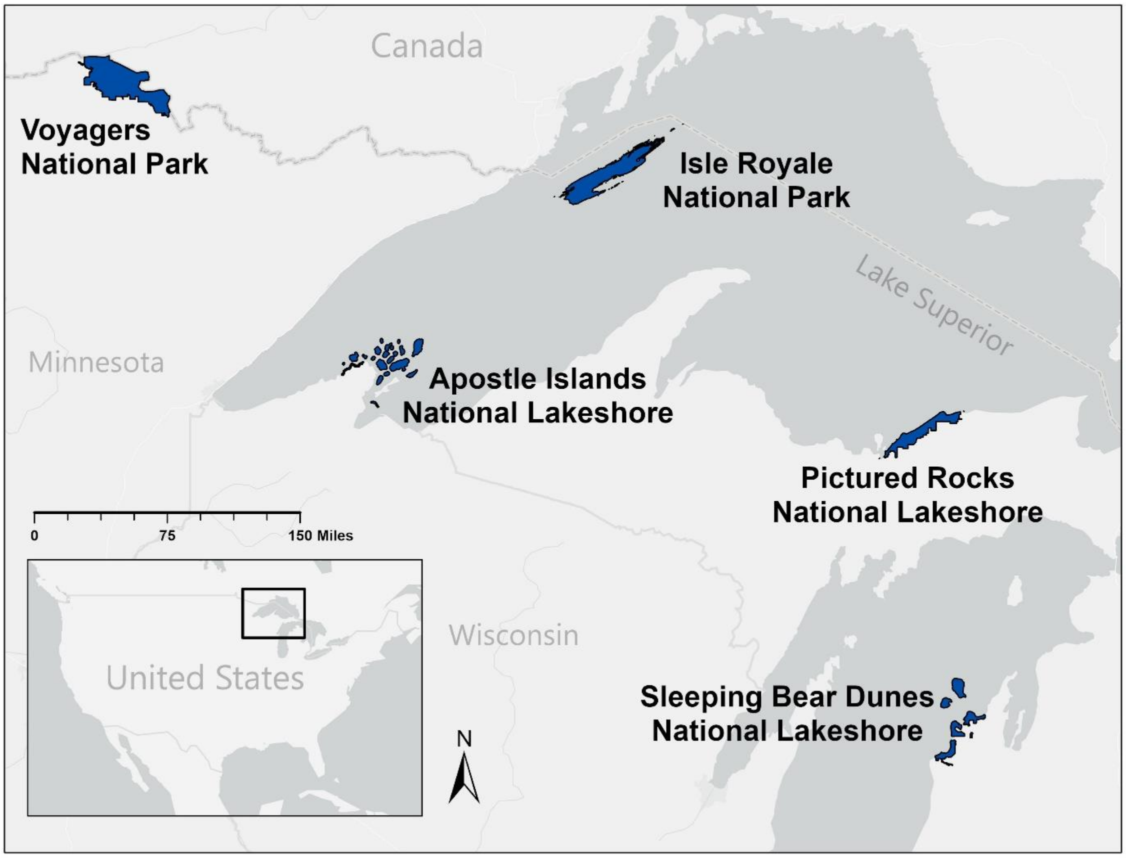

Figure 2.1. Map of the five national parks mapped and surveyed, all of which occur in the Great Lakes regions of the US.

2.2 Field Data Collection

A subset of potential vernal pools (PVPs) was selected from preliminary vernal pool maps for ground truthing and data collection at all five parks. Between 36-52 PVPs were chosen from each park. Parameters on PVP pool selection included being within the park boundary and within 600 m from a trail or lake edge to make it feasible to reach all PVPs in a timely manner. At Voyageurs National Park, pools were also selected based on accessibility due to record parkwide flooding in May of 2022. Sampling took place in the spring of 2021 and 2022 between April 25 and June 10. Pictured Rocks, Apostle Islands, and Sleeping Bear were visited in 2021 and Isle Royale and Voyageurs were visited in 2022. Visiting in the spring allowed for data collection during the period of pool inundation when the environment was most relevant to amphibian reproductive habitat.

At each PVP that was visited we confirmed if it was a vernal pool by using the following definition: “Vernal pools are small (less than 1 ha), temporarily flooded wetlands located in confined depressions with no continuously flowing inlets or outlets or fish populations. They may be connected to other wetlands or as part of a larger wetland complex as long as those wetlands are confined, and in most years, they must dry up or draw down to expose all or most (i.e., >50%) of the pool bottom” (MVPP 2018). A wide variety of pool characteristics were recorded addressing pool morphology, hydrology, substrate, vegetation, and indicator species following protocols from the Michigan Vernal Pools Partnership (MVPP 2021).

Measurements of pool morphology included pool width, length, depth, and shape. Width and length were measured at the widest part of the pool using a hypsometer (Nikon Forestry Pro II). Depth was measured by wading into the pool and estimating depth using the observer’s leg as a measuring tool and bins of 0-30 cm, 30-60 cm, and 60+ cm based on how far up their leg the water came. Pool shape was categorized into “classic” vernal pools and vernal pool “complexes” based on the shape of the basin and the complexity of the pool boundary (Schrank et al. 2015). Hydrologic characteristics included pH, how full the pool basin was, and whether or not the pool was isolated. Water level, or how full the pool basin was on the day of data collection, was measured by estimating how much of the basin was filled with water using bins from 0-25%, 25-50%, 50-75%, and 75-100%. The area surrounding the pool was inspected for inlets or outlets. If any were located, it was recorded whether they were temporary or permanent. The pH was measured using an EcoSense pH100A handheld meter placed into a section of the pool 30 cm deep if available.

Soil substrate under the pool was determined by collecting a 40 cm long soil core. The soil core was taken from a location one third of the way into the pool if the pool was shallow enough, and where the water reached 20 cm depth when the water got deep quickly. The substrate was then classified as fines (clay or silt), sand, peat, or bedrock based on its texture (Thein 1979). The thickness of the dark organic soil on top of the substrate was measured. Soil was determined to be organic and not mineral soil based on its dark color and its texture. A soil sample was collected from 0-10 cm and placed in whirl-pak-bags to be brought back to Michigan Technological University and analyzed for soil organic matter using the loss on ignition technique (Salehi et al. 2011, Konen et al. 2002).

Vernal pool vegetation examined in this study included canopy species and canopy cover. Canopy species was determined to be either deciduous (+50% deciduous trees) or coniferous (+50% coniferous trees). The percent canopy cover over the pool basin during leaf out was visually estimated using bins of 0%, 1-9%, 10-25%, 26-50%, 51-75%, and +75%. The canopy type of the pool was classified as closed (+30% tree cover) or open (-30% tree cover). Based on the existing literature that indicator species presence is most highly correlated with canopy species (Degraaf and Rudis 1990; Sugalski and Claussen

1997; Harper and Guynn 1999; Renaldo et al. 2011), we developed a canopy class consisting of deciduous, open, and coniferous pools, with deciduous pools having >50% deciduous tree cover, coniferous pools having >50% coniferous tree cover, and open pools having <30% of any canopy cover (Figure 2). A checklist of the in-pool cover present was recorded, including shrubs, branches, sphagnum, algae, leaf litter, logs, submergent vegetation, and emergent vegetation.

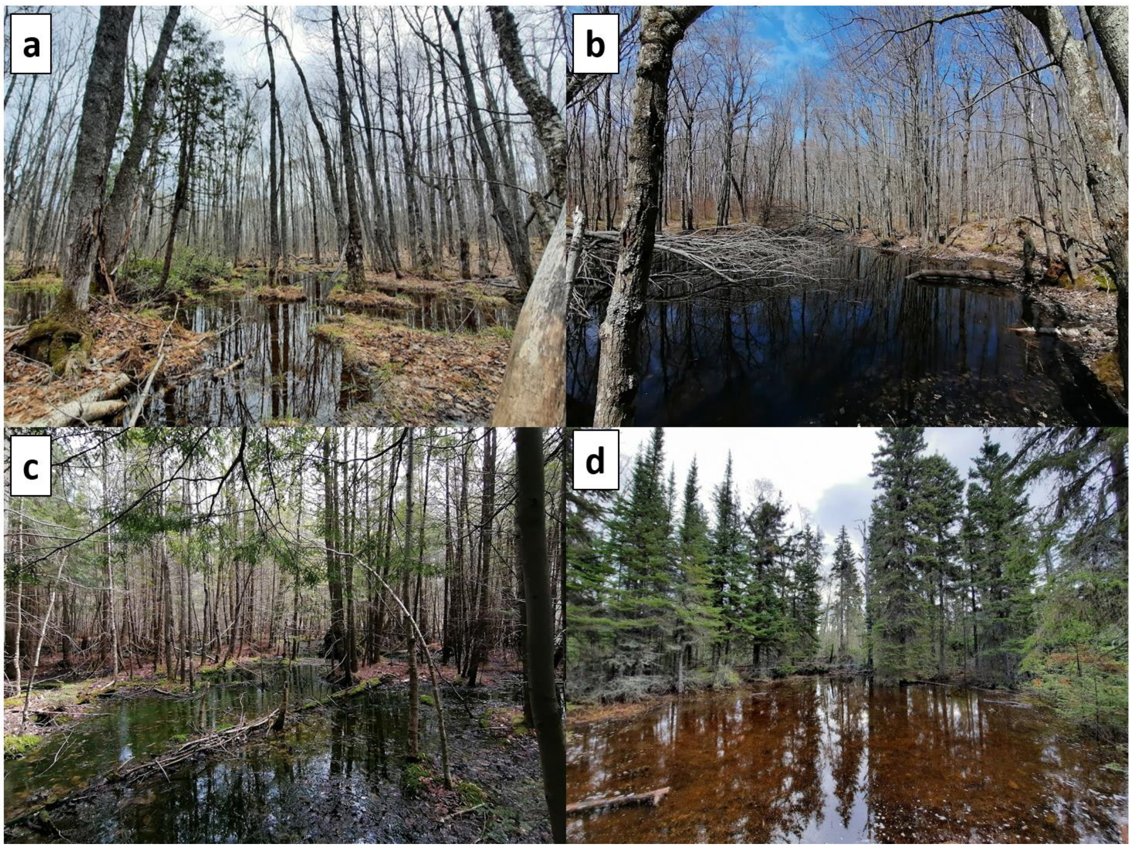

Figure 2.2. Examples of vernal pools with combinations of canopy species and cover, including deciduous closed (**a**), deciduous open (**b**), coniferous closed (**c**), and coniferous open (**d**). Closed canopies have tree limbs shading the entirety of the pool, although it is clear that closed deciduous canopies still allow abundant light into the pool in the spring during leaf-off. Open canopies have a permanent opening in the canopy that allows light into the pool year-round, often due to the size of the pool. Open pools were treated as a single category in analysis.

Indicator species surveys were simple and meant to reflect the main users of each pool, not to be exhaustive in which organisms were present. Surveys were conducted by searching within the pool for egg masses, fairy shrimp, and fingernail clams at the beginning of sampling, and searching the surrounding 7 meters of forest for adult amphibians for 10 minutes at the end of pool sampling. The vernal pool indicator species most widely used in the Northeast and Midwestern United States includes the wood frog (*Lithobates sylvaticus*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*), fairy shrimp (*Eubranchipus* spp.) and fingernail clam (Sphaeriidae) (MVPP 2021, Calhoun et al. 2003, Thomas et al. 2010). To search for amphibian egg-masses, the perimeter and center of the pool were traversed, and twigs, logs, and emergent vegetation were examined for egg masses. A white frisbee was used to look for fairy shrimp and amphibian juveniles (tadpoles and salamander larvae) by dipping the frisbee in the water at several locations around the pool and examining its contents. The frisbee was also used to search for fingernail clams by scraping the edge of the frisbee into the leaf litter in the shallow edges of the pool and then taking a scoop of water and searching for the clams. Adult amphibians were searched for by turning over logs surrounding the pool basin. Photographs of indicator species were taken, and any other amphibian species found that were not indicators were photographed and recorded. Macroinvertebrate surveys were not included in this study.

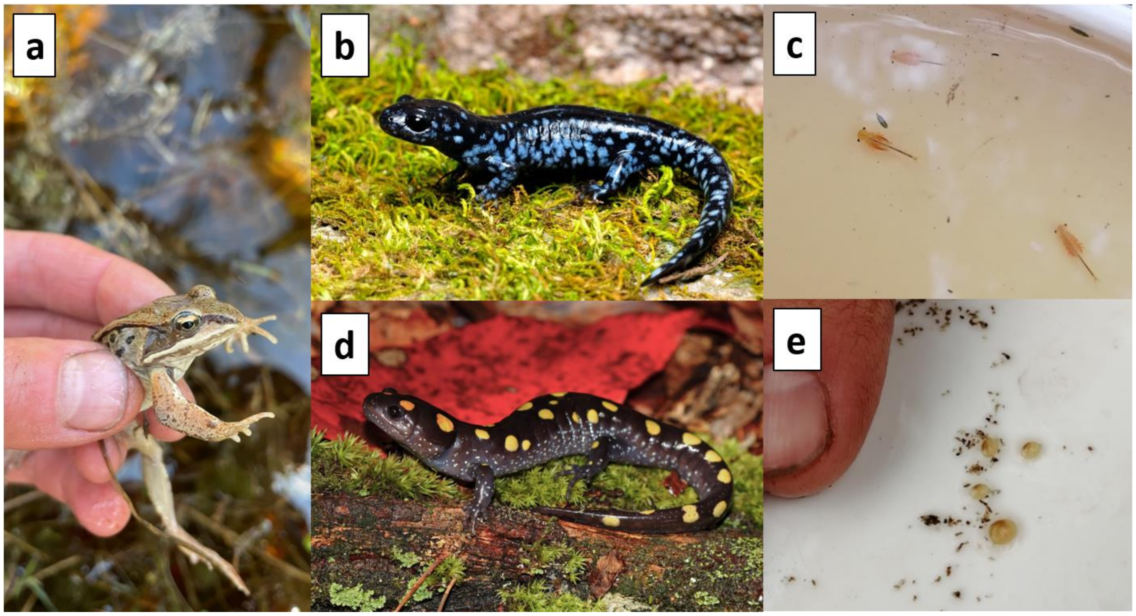

Figure 2.3. Indicator species used in this study including the **a**) wood frog (*Lithobates sylvaticus*), **b**) spotted salamander (*Ambystoma maculatum*), **c**) fairy shrimp (*Eubranchipus* spp.), **d**) blue-spotted salamander (*Ambystoma laterale*), **e**) and fingernail clam (Sphaeriidae).

2.3 Statistical Analyses

Differences in continuous vernal pool characteristics among the different national parks, including pool width, length, depth, spring water level, pH, soil organic matter, organic matter depth, and canopy cover, were evaluated using a general linear model (Minitab version 20.4, 2021). Tests were run on the mean values obtained for each characteristic, with park as the factor. Prior to running the general linear model, each characteristic was log transformed to better meet the assumption of normality of error terms (Rawlings et al. 1998). A Tukey HSD post-hoc test was performed on each significant model to investigate pairwise comparisons. Similar analyses were performed examining the differences between continuous characteristics among the three classification types, but with classification type as the factor instead of park.

Pearson chi-squared tests were used to determine if there were significant differences in the proportions of pool shape, substrate, and canopy species among the five parks visited. This test was also used to determine correlations between pool shape and canopy species among the substrate types. For analyses including substrate, peat and bedrock were combined into an "other" category due to few occurrences, resulting in three substrate categories: sand, fines, and other.

To determine which characteristics were most correlated with indicator species presence, binary logistic regression was used with indicator presence (1) or absence (0) as the response variable and vernal pool characteristics as the explanatory variable, with Park as a random effect. Explanatory variables used included pool width (m), pool depth (cm), water temperature (°C), pH, soil organic matter (%), substrate type (sand, fines (clay and silt), other (peat and bedrock)), pool shape (classic or complex), and canopy classification (deciduous, coniferous, open). Univariate regressions were run on each pool characteristics so effect size could be determined individually. Each characteristic was run against three response variables: any of the five indicator species, any amphibian species (wood frog (*Lithobates sylvaticus*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*)), and either fairy shrimp (*Eubranchipus* spp.) or fingernail clam (Sphaeriidae). Finally, a global model was run with all explanatory variables included and any indicator species presence as the response variable to investigate characteristic significance in conjunction with one another. The logistic regression was carried out in R Statistical Software (v4.2.1; R Core Team 2021) using the lme4 R package (v1.1.31; Bates et al. 2015) with binomial distribution and the logit link function.

3 Results

3.1 Vernal Pool Characteristics

Throughout the two field seasons, we sampled 139 confirmed vernal pools across the five national parks (Table 1; Figure 3). Pools are on average 30 m wide and 36 cm deep, although they can be as small as 7 m wide and 8 cm deep or as large as 100 m wide and 122 cm deep (Table 2). Apostle islands had the smallest vernal pools on average (18.8 ± 2.3 m) while Isle Royale had the largest pools (38.9 ± 2.9 m; Table 2). Voyageurs and Sleeping Bear Dunes had the shallowest pools (24.1 ± 2.3 cm) and deepest pools (47.2 ± 7.3 cm), respectively (Table 2). Among pool geomorphologic types, classic pools were more common, occuring 60% of the time, while vernal pool complexes occurred 40% of the time (Table 1). Classic pools were more common at Isle Royale, Pictured Rocks, and Sleeping Bear, while vernal pool complexes were more common at Apostle Islands and Voyageurs (X^2 (4, N = 139) = 19.60, p=0.0009). Most of the pool basins were only partially full at the time they were visited, resulting in a mean water level percent of 70 ± 2.1% (Table 2). The average pH of the pools was 6.1 ± 0.1, and was significantly higher at Apostle Islands and lower at all of the other parks (Table 2).

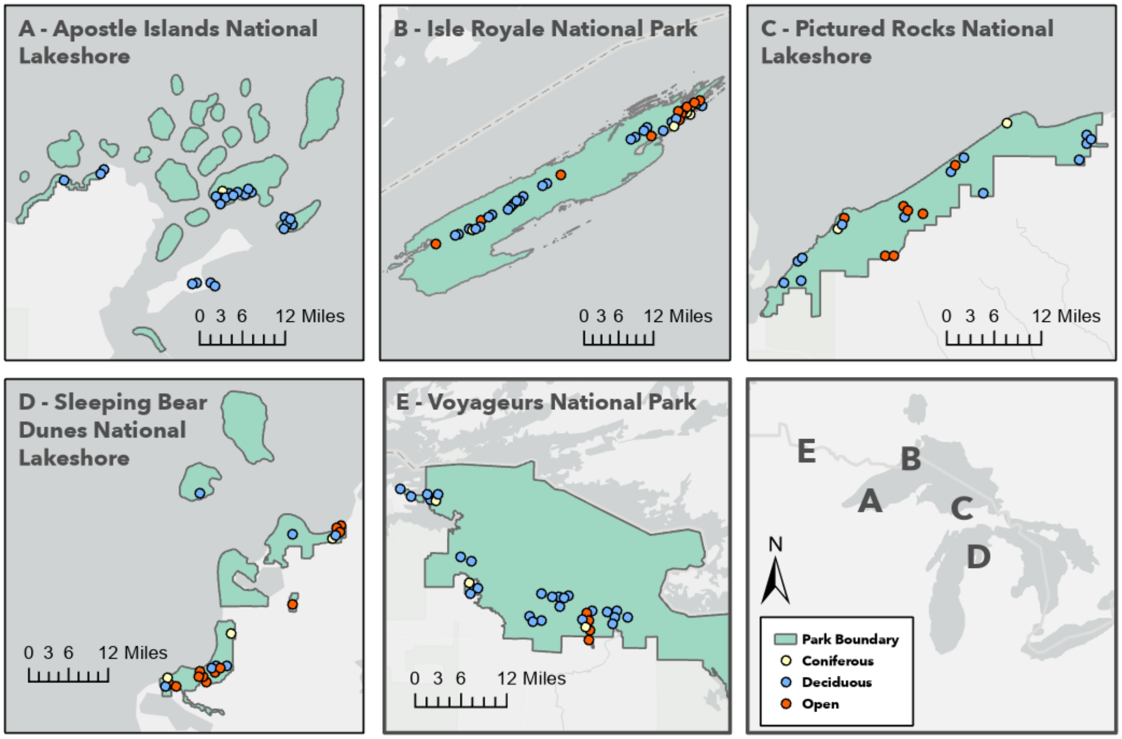

Figure 3.1. Sampled vernal pools at each of the five National Parks, color coded based on their classification type; red dots for Open pools, blue dots for Deciduous pools, yellow dots for Coniferous pools. Some pools hidden due to close proximity.

Sand was the most common substrate, closely followed by fines (clay + silt), with peat and bedrock occuring much less frequently (Table 1). Fine substrates were more common at Apostle Islands and Voyageurs, while sand was more common at Pictured Rocks and Sleeping Bear (X^2 (8, N = 139) = 35.45, p < 0.0001). Isle Royale had a fairly even distribution of sand and fine substrate types (Table 1). The mean soil organic matter content across all the parks was 27.9 ± 1.9% with a range of 2.3 to 94.4% (Table 2). Pool shape was correlated with substrate (X^2 (2, N = 139) = 16.60, p=0.0002), with sandy substrates correlating with classic pools while fine substrates were more commonly associated with complex pools. Deciduous pools were equally likely to occur on fine and sandy substrates, but conifers were more common among the “other” substrates (peat and bedrock) collectively (X^2 (2, N = 128) = 10.15, P=0.0063).

Summer canopy cover was 54.1 ± 2.5% on average (Table 2). Sleeping Bear had significantly less summer canopy cover than the other parks, while Apostle Islands had the greatest canopy cover (Table 2). Deciduous canopies were more common across all the parks (X^2 (4, N = 139) = 11.305, p=0.0233), with Isle Royale and Sleeping Bear being the only parks to have over 10% of the pools be coniferous (Table 1).

Indicator species were found at 100 of the 139 vernal pools sampled (Table 1). Very few other species besides indicators were found during sampling, with only few occurences of eastern red-backed salamanders (*Plethodon cinereus*) and green frog (*Lithobates clamitans*). Across all the parks, fingernail clams were found 45% of the time and were the most common indicator species found, followed by blue-spotted salamanders (33%), wood frogs (25%), and fairy shrimp (16%), with spotted salamanders being the least common (9%; Table 1). Isle Royale had the greatest occurrence of indicator species overall, while Pictured Rocks had the greatest diversity of indicators with all five of the indicator species present (Table 1). Conversely, Voyageurs and Apostle Islands had the lowest variety of indicators present and Voyageurs had the fewest indicators overall.

Table 3.1. Percent occurrence for categorical pool characteristics for each park sampled. Parks include Apostle Islands National Lakeshore (APIS), Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), Sleeping Bear Dunes National Lakeshore (SLBE), Voyageurs National Park (VOYA), and all of the parks combined.

Category	Characteristic	Percent Occurrence					
		APIS	ISRO	PIRO	SLBE	VOYA	Combined
	No. of pools visited	23	40	22	22	32	139
Pool shape	Classic	35%	73%	64%	86%	44%	60%
	Complex	65%	27%	36%	14%	56%	40%
Canopy species	Deciduous	96%	60%	59%	32%	78%	65%
	Coniferous	4%	13%	9%	14%	9%	10%
	Open	0%	28%	32%	55%	13%	24%
Substrate	Sand	30%	48%	86%	86%	25%	52%
	Fines	61%	45%	9%	9%	63%	40%
	Bedrock	0%	3%	0%	0%	6%	2%
	Peat	9%	5%	5%	5%	6%	6%
Indicators	Wood frog	48%	13%	27%	36%	16%	25%
	Spotted salamander	22%	0%	10%	23%	0%	9%
	Blue-spotted salamander	0%	63%	27%	36%	22%	33%
	Fairy shrimp	4%	37%	27%	0%	0%	16%
	Fingernail clams	4%	80%	41%	32%	41%	45%
	Total	65%	85%	77%	73%	56%	72%

Table 3.2. Mean values for continuous pool characteristics for each park along with their mean standard error. Parks include Apostle Islands National Lakeshore (APIS), Isle Royale National Park (ISRO), Pictured Rocks National Lakeshore (PIRO), Sleeping Bear Dunes National Lakeshore (SLBE), Voyageurs National Park (VOYA), and all of the parks combined. Superscripts with different letters denote significant differences to the 0.05 level.

Characteristic		APIS	ISRO	PIRO	SLBE	VOYA	Combined
Width (m)	Mean ± SE	18.8 ± 2.3^{A}	38.9 ± 2.9^{D}	36.7 ± 5.3^{CD}	19.5 ± 2.4^{AB}	27.2 ± 2.9^{BC}	29.8 ± 1.6
	Range	7-50	13-90	9-100	10-58	11-100	7-100
Length (m)	Mean ± SE	12.1 ± 1.5^{A}	18.5 ± 1.5^{B}	31.3 ± 7.2^{B}	27.8 ± 10.9^{AB}	18.1 ± 2.1^{AB}	18.6 ± 1.2
	Range	1-24	2-40	20-80	8-58	2-50	1-80
Depth (cm)	Mean ± SE	29.2 ± 4.3^{AB}	44.0 ± 3.4^{B}	36.8 ± 6.1^{AB}	47.2 ± 7.3^{B}	24.1 ± 2.3^{A}	36.4 ± 2.1
	Range	8-91	8-91	8-122	8-122	0-61	0-122
Water level (%)	Mean ± SE	54.7 ± 5.4^{A}	86.1 ± 1.1^{C}	66.0 ± 6.3^{AB}	79.8 ± 3.9^{BC}	57.6 ± 4.9^{A}	70 ± 2.15
	Range	12-100	62-100	12-100	12-100	12-100	12-100
pH	Mean ± SE	6.8 ± 0.1^{C}	6.0 ± 0.1^{AB}	6.5 ± 0.5^{BC}	5.6 ± 0.4^{A}	6.0 ± 0.1^{AB}	6.10 ± 0.07
	Range	5.5-7.6	4.9-7.2	4.0-6.7	3.8-7.6	4.8-7.2	3.8-7.6
Soil organic matter (%)	Mean ± SE	41.8 ± 5.2^{B}	29.7 ± 3.2^{AB}	17.0 ± 3.2^{A}	25.3 ± 5.0^{AB}	25.4 ± 4.2^{A}	27.9 ± 1.9
	Range	4.8-76.7	3.4-94.4	2.5-67.3	4.0-89.7	2.3-75.4	2.3-94.4
OM Depth (cm)	Mean ± SE	13.3 ± 2.4^{AB}	12.1 ± 1.6^{AB}	8.8 ± 2.0^{A}	11.6 ± 0.9^{A}	9.9 ± 1.8^{A}	11.7 ± 0.9
	Range	2-40	3-40	1-40	5-40	0-40	0-40
Summer canopy cover (%)	Mean ± SE	67.7 ± 2.4^{B}	58.2 ± 4.9^{B}	54.4 ± 5.6^{B}	23.6 ± 2.5^{A}	59.2 ± 4.6^{B}	54.1 ± 2.5
	Range	46-82	4.5-88	7-90	5-56	4.5-88	4.5-90

3.2 Indicator Species Correlations

Based on univariate logistic regression models, the presence of any indicator species was most strongly correlated with canopy class (deciduous, coniferous, and open) (Table 3). Indicator species presence was equally common between deciduous and coniferous open pools (X^2 (1, N = 36) =1.403, p=0.236) while deciduous and coniferous closed pools had singificantly different counts of indicator species presence (X^2 (1, N = 103) = 19.189, p<0.0001). This resulted in combining both deciduous and coniferous open pools into a single category, "Open" pools, while leaving closed canopy pools separate based on their canopy species, "Deciuous" or "Coniferous". Deciduous and open pools were much more likely to contain indicator species than coniferous pools (X^2 (2, N = 139) = 20.063, p<0.0001), with deciduous and open pools having nearly the same proportions of indicator species (Figure 4, Table 5). Pool width was also correlated with indicator presence but to a lesser extent, with indicators being more likely to occur in larger pools (Table 3). Regression models for amphibian and either fairy shrimp or fingernail clam presence followed a similar pattern to models including any of the five indicators, differing only in that amphibians were correlated with deeper vernal pools instead of larger pools (Table 3). The stepwise multivariate logistic regression included pool width, pool depth, and the classification system in the final model (Table 4). Within the stepwise model, deciduous and open pools were highly significant predictors of any indicator species being present, followed by pool depth to a lesser extent. Deciduous pools were the most common pool type and coniferous pools were the least common at every park (Table 1, Figure 3). Open pools occurred on sandy soils most frequently and were deeper than deciduous or coniferous pools (Table 5). Deciduous and coniferous pools occurred on all soil types and tended to be shallower (Table 5).

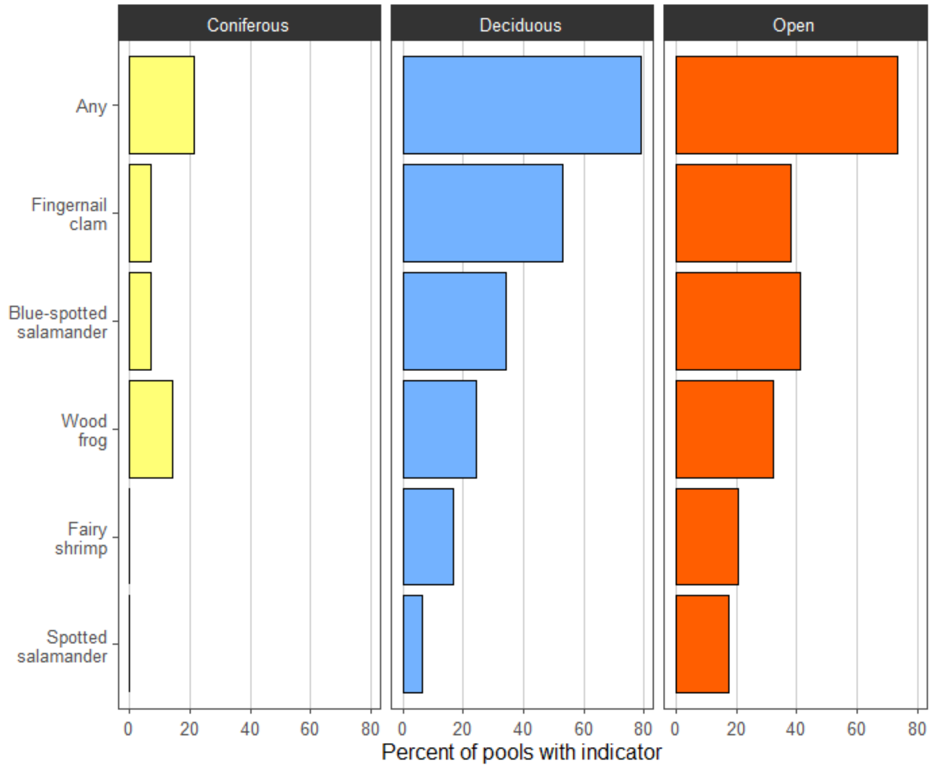

Figure 3.2. Percent occurrence for each indicator species (wood frog (*Lithobates sylvaticus*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*), fairy shrimp (*Eubranchipus* spp.) and fingernail clam (Sphaeriidae)) by classification type; Deciduous, Coniferous, and Open.

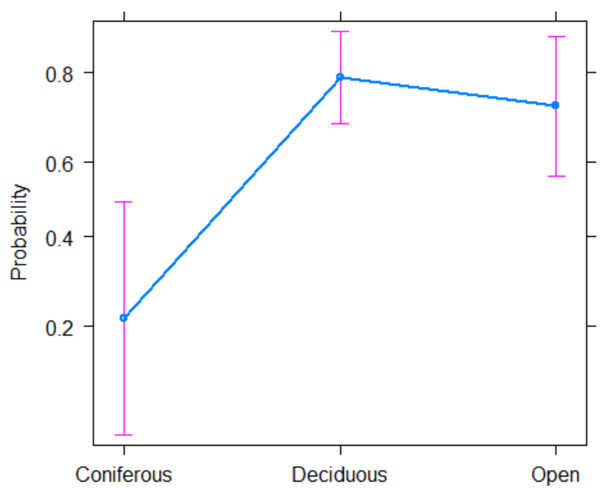

Figure 3.3. Probability of indicator species presence for each class based on binary logistic regression model.

Table 3.3. Results from logistic regression models predicting occurrence of indicator species in vernal pools. Variables grouped by response variable, examining occurrence of any indicator species, only amphibian species (wood frog (*Lithobates sylvaticus*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*)) and either fairy shrimp (*Eubranchipus* spp.) or fingernail clams (Sphaeriidae).

Independent Variable	Estimate Coefficeints ± SE	Odds Ratio	Odds Ratio CI	*z*	*P*	AIC
Any Indicator						
Pool width (m)	0.033 ± 0.014	1.03	(1.0049, 1.0637)	2.296	**0.022**	163.4
Pool depth (cm)	0.015 ± 0.009	1.02	(0.9974, 1.0339)	1.676	*0.094*	168.9
pH	0.360 ± 0.242	1.43	(0.8923, 2.3042)	1.489	0.136	167.4
Soil organic matter (%)	-0.005 ± 0.008	0.99	(0.9784, 1.0122)	-0.556	0.578	169.5
Substrate						170.3
Sand v fines	-0.094 ± 0.445	0.91	(0.3807, 2.1748)	-0.212	0.832	
Other v fines	-0.847 ± 0.689	0.43	(0.1109, 1.6559)	-1.229	0.219	
Pool shape	-0.612 ± 0.401	0.54	(0.2470, 1.1889)	-1.528	0.126	167.6
Classification						150.8
Dec v Con	3.154 ± 0.807	23.45	(4.8111, 113.9998)	3.905	**0.0001**	
Open v Con	2.402 ± 0.800	11.04	(2.3019, 52.9642)	3.002	**0.002**	
Amphibians						
Pool width (m)	0.014 ± 0.010	1.01	(0.9948, 1.0346)	1.439	0.150	194.7
Pool depth (cm)	0.019 ± 0.007	1.02	(1.0042, 1.0345)	2.511	**0.012**	191.5
pH	0.438 ± 0.234	1.55	(0.9793, 2.4513)	1.871	*0.061*	169.0
Soil organic matter (%)	-0.001 ± 0.008	1.00	(0.9833, 1.0145)	-0.150	0.881	192.0
Substrate						197.0
Sand v fines	-0.927 ± 0.688	0.39	(0.1028, 1.5224)	-1.349	0.177	
Other v fines	-0.192 ± 0.392	0.82	(0.3829, 1.7779)	-0.491	0.623	
Pool shape	-0.142 ± 0.359	0.66	(0.3277, 1.3394)	-1.146	0.252	195.6
Classification						191.1
Dec v Con	1.683 ± 0.698	5.38	(1.3720, 21.1328)	2.413	**0.016**	
Open v Con	1.775 ± 0.746	5.90	(1.3681, 25.4522)	2.380	**0.017**	
Fairy shrimp and Fingernail clam						
Pool width (m)	0.014 ± 0.012	1.01	(0.9916, 1.0380)	1.235	0.217	171.5
Pool depth (cm)	0.006 ± 0.009	1.01	(0.9888, 1.0239)	0.697	0.486	172.9
pH	0.016 ± 0.214	1.01	(0.6684, 1.5457)	0.076	0.939	154.1
Soil organic matter (%)	-0.007 ± 0.009	0.99	(0.9751, 1.0115)	-0.736	0.462	169.5
Substrate						173.9
Sand v fines	-0.294 ± 0.475	0.74	(0.2933, 1.8930)	-0.619	0.536	
Other v fines	-0.768 ± 0.782	0.46	(0.1001, 2.1491)	-0.982	0.326	
Pool shape	-0.428 ± 0.418	0.65	(0.2873, 1.4776)	-1.025	0.305	172.0
Classification						150.5
Dec v Con	4.348 ± 1.249	77.29	(6.6807, 894.2910)	3.480	**0.0005**	
Open v Con	3.178 ± 1.244	24.01	(2.0980, 274.7811)	2.556	**0.011**	

Table 3.4. Results from global multivariate logistic regression model with all explanatory variables included, correlating explanatory variables with any of the five indicator species in vernal pools.

Any Indicator						
Intercept						152.9
Pool width (m)	0.040 ± 0.015	1.04	(1.0095, 1.0724)	2.576	**0.010**	
Pool depth (cm)	0.009 ± 0.012	1.01	(0.9857, 1.0331)	0.761	0.446	
pH	0.408 ± 0.307	1.50	(0.8234, 2.7471)	1.328	0.184	
Soil organic matter (%)	0.006 ± 0.012	1.01	(0.9827, 1.0296)	0.492	0.622	
Substrate						
Sand v fines	-0.207 ± 0.594	0.81	(0.2538, 2.6030)	-0.349	0.727	
Other v fines	-0.431 ± 0.854	0.65	(0.1216, 3.4707)	-0.505	0.614	
Pool shape	-0.475 ± 0.573	0.62	(0.2022, 1.9103)	-0.830	0.406	
Classification						
Dec v Con	3.290 ± 0.959	26.83	(4.0955, 175.8506)	3.430	**0.0006**	
Open v Con	2.420 ± 0.972	11.25	(1.6739, 75.6190)	2.490	**0.013**	

Table 3.5. Number of occurrences for each location, pool depressional type, and soil type for each classification type: Deciduous, Coniferous, and Open. Percent occurrence of each indicator species and mean and standard deviation for several characteristic for each class. Superscripts with different letters denote significant differences to the 0.05 level.

		Deciduous	Coniferous	Open
Percent Occurrence				
Total		65%	10%	24%
Sand		29%	4%	19%
Fines		33%	4%	4%
Peat		4%	2%	0%
Bedrock		0%	1%	1%
Any		79%	21%	74%
Wood frog		24%	14%	32%
Spotted salamander		7%	0%	18%
Blue-spotted salamander		34%	7%	41%
Fairy shrimp		16%	0%	21%
Fingernail clam		53%	7%	38%
None		21%	79%	26%
Mean and Std Error				
Width (m)	Mean ± SE	29.5 ± 1.9^{A}	31.5 ± 7.7^{A}	29.8 ± 2.9^{A}
	Range	7-100	10-100	10-65
Depth (cm)	Mean ± SE	30.5 ± 2.1^{A}	28.6 ± 3.6^{A}	56.3 ± 5.4^{B}
	Range	0-91	8-61	12-122
pH	Mean ± SE	6.3 ± 0.1^{A}	6.0 ± 0.3^{A}	6.0 ± 0.2^{A}
	Range	4.0-7.6	3.8-7.6	3.8-7.6
Soil organic matter (%)	Mean ± SE	27.5 ± 2.4^{A}	40.0 ± 7.1^{A}	23.9 ± 3.3^{A}
	Range	2.3-94.4	9.8-89.7	2.5-72.2
Summer canopy cover (%)	Mean ± SE	66.4 ± 2.3^{C}	51.2 ± 7.1^{B}	21.7 ± 2.7^{A}
	Range	11-90	12-100	4.5-71

4 Discussion

4.1 Pool Characteristics

While there is a broad body of work regarding vernal pools in the Northeastern US, there is little information about vernal pools in the Great Lakes region. We found that vernal pools were abundant within five National Parks across the Great Lakes region and generally resembled vernal pools in the northeastern United States (Calhoun 2003; Tiner 2003). This allows for research and knowledge about Northeast vernal pools to be applied to pools in the Great Lakes. Great Lakes vernal pools that we sampled ranged between 20 to 6000 m^2 in surface area, with depths between 8 and 122 cm, which is similar to northeastern vernal pools that vary in size from 50 to 3000 m^2 in surface area and 10 to 150 cm in depth (Brooks and Hayashi 2002; Calhoun et al. 2003). Great Lakes vernal pools also occur in forested settings surrounded by uplands or as part of larger forested wetlands (Tiner 2003). Northeastern forests are similar to forests in the Great Lakes region, as they are dominated by northern hardwoods and mixed conifer forests with common species such as maples, spruce, and fir (Calhoun et al. 2003). Pools in both regions also exhibit similar hydrology, with inundation occuring in the spring and potentially in the fall, and experiencing high variability of surface water duration depending on the timing and volume of precipitation each year (Brooks and Hayaski 2002; Calhoun et al. 2003). Differences between northeastern and Great Lakes region vernal pools can be found in the substrate they occur on. While it is common to find vernal pools in both regions on fine and sandy substrates, the granite outcrops of the

Canadian Shield and the sand dunes found along the shore of the Great Lakes are different than landforms of the northeast (Tiner 2003; Reinhardt and Hollands 2008).

When comparing pools within the Great Lakes region, broad trends in pool characteristics were evident. Many vernal pool charcteristics were driven by the type of substrate they occur on, their overstory canopy species, and the amount of canopy cover, which varied from park to park based on the soils and vegetation present in each area.

All parks visited occur on glacially deposited or altered soil, but the types of landforms left by the glaciers differ across the region. Soils within Voyageurs and the eastern two thirds of Isle Royale are thin, largely fine textured, and have abundant exposed bedrock in the area (Huber 1973; Magnuson et al. 1997). Isle Royale is unique in that the soils on the east and west sides of the island differ substantially. The western third of the island has much deeper soils consisting of loamy sand (Huber 1973). Fine soils were also more abundant at Apostle Islands, due to its position on the southern edge of the Canadian Shield (Table 1; Magnuson et al. 1997). Pictured Rocks and Sleeping Bear had much deeper soils, almost entirely made up of sandy substrate, as they are located on sandstone and dunes formed by Lake Superior and Lake Michigan, respectively (Table 1; Barnhardt et al. 2002; VanderMeer et al. 2020).

The soils that vernal pools occur on are important because different soil types drive many of the differences in pool morphology and vegetation. Generally, we found that fine substrates (clay and silt) correlated with a complex pool morphology and sandy substrates correlated with classic pool morphology. Complex pools were shallower, made up of several smaller, interconnected pools, and had closed canopies while classic pools had a single larger depression that was typically deeper and has a mixture of closed and open canopies, depending on the size of the pool. Substrate and pool morphology are related because of the varying ability of soil particles to retain water based on particle size (Evans and Freeland 2001; Liebowitz and Brooks 2007). Sandy soils drain more readily than clay soils, frequently resulting in larger and deeper pool sizes than on fine soils where water is more easily retained, even in shallow depressions. We saw that Voyageurs had the shallowest pools on average, and it was most common to find pools that were large, shallow complexes. Sleeping Bear had the deepest pools on average, which were commonly classic pools that resembled small ponds. The other three parks followed this pattern as well based on the substrate most common in each area.

Different soil types can also impact the type of vegetation that is present. Soils are one of the many environmental factors that influence forest type, with moisture and nutreint availability varying based on soil traits (Braun 1935; Boerner 2006). While not a difinitive rule, species such as oaks, pines, and other conifers gererally occur more frequently on sandy soils, and northern hardwoods such as maples tend to be found on more loamy soils (Pastor and Broschart 1990; Pakil et al. 2007). When examining vernal pool vegetation, we focused on overstory functional groups (deciduous and coniferous) and canopy cover and did not examine vegetation to the species level. Although we did not measure it, it is known that vernal pool vegetation does differ at the species level from pool to pool based on hydrology and geomorphology, particularly at the functional group level of shrub, emergent, and forested vernal pools (Palik et al. 2007; Flinn et al. 2008). However, there are no specific vegetation species that are vernal pool obligates. Many species that are found in vernal pools can also be found in other wetland types or in the surruonding upland habitat, depending on the hydrology of the pool (Cutko and Rawinski 2008; Flinn et al. 2008). Within our data, which examined functional groups in overstory trees, differences in vegetation composition between the parks was not as evident as with differences in soils. Deciduous tree species were more common overall, with few conifer pools and occasional open pools (Table 1). All five parks are located within the same climatic zone, and although some extend into the hemi-boreal zone, they all occur within range of nothern hardwood forests (Magnuson et al. 1997). Any differences in overstory species or functional group will reflect the dominant vegetation within each park (Kurmis et al. 1986; Paulson et al. 2016).

4.2 Mapping Vernal Pools

This study collected and analyzed in-situ data on vernal pool characteristics to provide verification of vernal pool status and context for maps based on multi-source remote sensing. Most vernal pool maps describe only one class: vernal pool. Even without additional information about each vernal pool, these maps are incredibly useful and effective in locating vernal pools. Providing more information to vernal pool maps could further extend their use by assigning context to each pool and expanding what is known about vernal pools in a given area. The challenge in assigning context lies in determining what information should be considered, and thus which vernal pool charactieristics should be included in finished mapped products. It is well established in the literature that salamanders and other amphibians use deciduous stands more frequently than conifer stands (Degraaf and Rudis 1990; Sugalski and Claussen 1997; Harper and Guynn 1999; Skelly et al. 2005; Renaldo et al. 2011). Based on the literature, we developed a three-class system separating vernal pools into deciduous, coniferous, and open based on their canopy species and cover. Although three classes are reported in the final results of this study, there are four combinations of canopy cover and species that can be made: deciduous closed (89 of the 139 sampled pools), deciduous open (22 pools), coniferous closed (14 pools), and coniferous open (14 pools). Our data supports the hypothesis that indicator species are more likely to occur in deciduous or open pools than coniferous pools. This does not discount the ecological value of coniferous vernal pools, as they still improve water quality and increase biodiversity of vegetation and other wildlife species. Instead, it highlights that deciduous pools are particular hotspots of biodiversity for indicator species and allows those pools to be located. Whether or not a pool has indicator species does not change its identity as a vernal pool, as it is still a temporary body of water on the landscape that influences the dynamics of water, vegetation, and wildlife. We similarly hypothesized that pool morphology (i.e. classic or complex) and soil organic matter would influence indicator species, but our data does not support these conclusions.

Considering this three-canopy class classification system that relies on tree functional type and canopy cover, we are able to use remote sensing to map these characteristics from Li-DAR and optical-IR data over the parks. Such classified map products for each identified potential vernal pool would allow land managers to use this classification system on all the mapped pools in a given area, not just ones that have been field verified. It also means including this information is low cost in terms of funds and labor. The higher likelihood of indicator species occurring in deciduous or open pools is likely due to the lack of leaves shading the pool in the spring, increasing light availability and water temperature, and the different chemistry of deciduous leaf litter.

Increased light availability in the spring months is important to early spring vegetation, providing much-needed energy after the winter months. Both emergent vegetation and organisms growing in the water such as algae and periphyton benefit from increased light levels (Skelly et al. 2002), which in turn benefits amphibians. Emergent vegetation serves as a structure to lay eggs on and as cover for both amphibian adults and larvae, allowing them to hide from predators. Algae and periphyton are important food sources for tadpoles, and increased algal growth increases available resources for tadpoles to feed on (Skelly et al. 2002; Schiesari et al 2009; Montana et al. 2019). After collecting data in 2021 that pointed towards the importance of canopy species, we collected additional data on coniferous and spring canopy cover during the 2022 field season. The amount of coniferous canopy cover over a pool had a significant relationship with spring canopy cover, with greater conifer cover resulting in greater spring canopy cover. While we did not measure light concentrations, it was very apparent that pools with less spring canopy cover were brighter.

In addition to light itself benefiting amphibians, increased light levels likely also lead to an increase in spring water temperature. Within the framework of this study, increased water temperatures are relative to cold snowmelt and are only beneficial during the early spring. During this time, warmer water temperatures are more favorable to amphibians, as lower water temperature leads to slower growth, reduced survival, and fewer amphibians in pools that are heavily shaded in the spring (Stewart 1956; Newman

1998; Skelly et al. 2005). Warmer water is only beneficial to vernal pool indicator species within the context of forested pools. All pools in this study occurred with trees above the pool or nearby, including open pools which were surrounded by forest and had trees growing on or near their edge and were merely open in the center of the pool. When summer arrives and leaves come out, most pools become shaded, and evaporation is slowed enough for the pool to persist longer into the summer. This is extremely important, because without the nearby canopy, these pools would dry too quickly, and many amphibian populations would not survive. Nearby trees also provide leaf litter to the area surrounding the pool which is important to amphibians' moisture retention and survival after they leave the pool.

Leaf litter quantity and quality are also important characteristics in habitat quality. Deciduous leaf litter is often thicker on the forest floor and more abundant than conifer litter and holds moisture more effectively (Degraaf and Rudis 1990; Harper and Guymm 1999). This is beneficial to amphibians because they lack their own mechanism for retaining moisture and instead depend on their environment to fulfill this task (Grover 1998; Rittenhouse et al. 2004; Homan et al. 2008). Conifer needles are also of "lower quality" for dietary purposes than deciduous broad leaves, meaning they have fewer available nutrients and more abundant difficult to break down compounds like waxes, lignins, and phenolics (Don and Kalbitz 2005; Hart et al. 2013; Joly et al. 2016). Some amphibians such as tadpoles use leaf litter and detritus as food sources, meaning pools with lower quality conifer litter will have poorer food sources (Scheisari et al. 2009; Fritz and Whiles 2018; Montana et al. 2018). This can have negative effects on tadpoles, reducing survival rates and affecting tadpole development (Stoler and Relyea 2013).

While there are certainly differences in litter chemistry at the species level, differences in litter characteristics are more strongly influenced by plant functional type than by individual species (Joly et al. 2016). In addition to canopy species directly above the pool, the forest type of the habitat surrounding breeding pools or ponds is also likely to be important. Salamanders spend most of their lives in the adjacent upland habitat surrounding the pools, and having litter that can help them retain moisture and serve as a productive food source would be beneficial (Gibbons 2003; Semlitsch and Bodie 2003; Rittenhouse and Semlitsch 2007; Harper et al. 2008).

Most of the stated reasons so far correspond to amphibians, but fairy shrimp and fingernail clams are important indicators as well. It is less clear why deciduous pools would be favorable to these species, as fairy shrimp and fingernail clams have no life history traits of their own that correspond with the characteristics of deciduous pools better than coniferous pools (McKee and Mackie 1981; Woodward and Kiesecker 1994). However, our data show that these species use deciduous pools more frequently than coniferous pools. The most likely scenario is based on their passive dispersal methods (i.e. depending on other organisms for dispersal instead of moving themselves). Because fairy shrimp and fingernail clams depend mainly on salamanders and birds to transport them from one pool to the next (Bohonak and Whiteman 1999; Colburn et al. 2007), it is logical that they would mainly occur in pools that suit the needs of their dispersers. Since it has been established that fairy shrimp and fingernail clam dispersers use deciduous pools more frequently than coniferous pools, these species will also be found primarily in these locations.

The data found in this study show that deciduous and open vernal pools are hotspots of biodiversity, but coniferous vernal pools are also valuable parts of the forest. All vernal pools serve important ecosystem services including providing water sources to wildlife, improving water storage, and increasing the biodiversity of the landscape (Leibowitz 2003; Eakin et al. 2018; Hofmeister 2022). Indicator species are most heavily reliant on vernal pools, but many other species benefit from their presence and are simply more difficult to document and measure, including birds and mammals. It is also well established that it is important to conserve a range of vernal pool characteristics in order to improve their resilience to climate change, as well as forest pests and disease (Calhoun et al. 2003; Petranka et al. 2007; Karraker and Gibbs 2009). As temperatures warm and precipitation patterns change, which water bodies serve as a vernal pool will likely change as well, making it increasingly important to protect a wide variety of vernal pool characteristics to ensure that vernal pools persist on the landscape. The benefit of applying this classification system to maps is not to eliminate certain vernal pools from conservation efforts but to highlight areas of increased biodiversity while providing relevant information and context to land managers with little added cost or effort. With or without indicator species, vernal pools are still biophysically temporary bodies of water on the landscape that influence the dynamics of water, vegetation, and wildlife.

In addition to the classification system developed in this study, landscape connectivity of vernal pools may also be influencing where biodiversity hotspots are occurring (Rothermel and Semlitsch 2002; Compton et al. 2007; Crawford et al. 2016; Allen et al. 2020). Limitations to amphibian dispersal such as human disturbance and development or natural barriers such as cliffs, rivers, and large open expanses could isolate certain vernal pools. Amphibians tend to operate as a metapopulation across a larger area (Marsh and Trenham 2001; Bertasello et al. 2022), meaning dispersal limitations that isolate pools from one another may limit population viability. High intra-annual variability in vernal pool hydroperiods necessitates occasional recolonization of pools after years of drought (Bertasello et al. 2022). Barriers to movement between pools would stop recolonization attempts and may explain the absence of amphibians at vernal pools that are otherwise excellent habitat. In order to determine landscape connectivity of pools within the parks surveyed in this study, further work is needed to create connectivity models for each area.

5 Conclusion

In summary, vernal pools are critical habitats for maintaining forest functions and increasing biodiversity, and they deserve the attention and action of conservation efforts. This study provides descriptive baseline data for the Great Lakes region which will allow land managers to have a better understanding of the systems they are working with. We found that substrate and vegetation within vernal pools reflects those of the areas they inhabit, and that substrate type can have significant impacts on other vernal pool characteristics such as size, pool morphology, and vegetation type. Vernal pools examined in this study were similar to those found in the Northeastern US and differed from other temporary water bodies such as vernal pools from California or Prairie potholes, thus outlining what research from other regions can be applied in the Great Lakes. Our data also supports the hypothesis that deciduous and open vernal pools are more likely to support indicator species populations than coniferous pools, with pool width and depth being secondarily important. Even without this added information, remote sensing of vernal pools is incredibly useful to land managers and will allow them to make land use decisions with the locations of vernal pools in mind. A wide range of vernal pool characteristics should be preserved in order to maintain biodiversity and forest functions. Utilizing our classification system in tandem with remote sensing efforts will provide additional context to vernal pool maps, and increased understanding of vernal pool functions empowers land managers to make better land use decisions.

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Appendix A. Tables and Figures

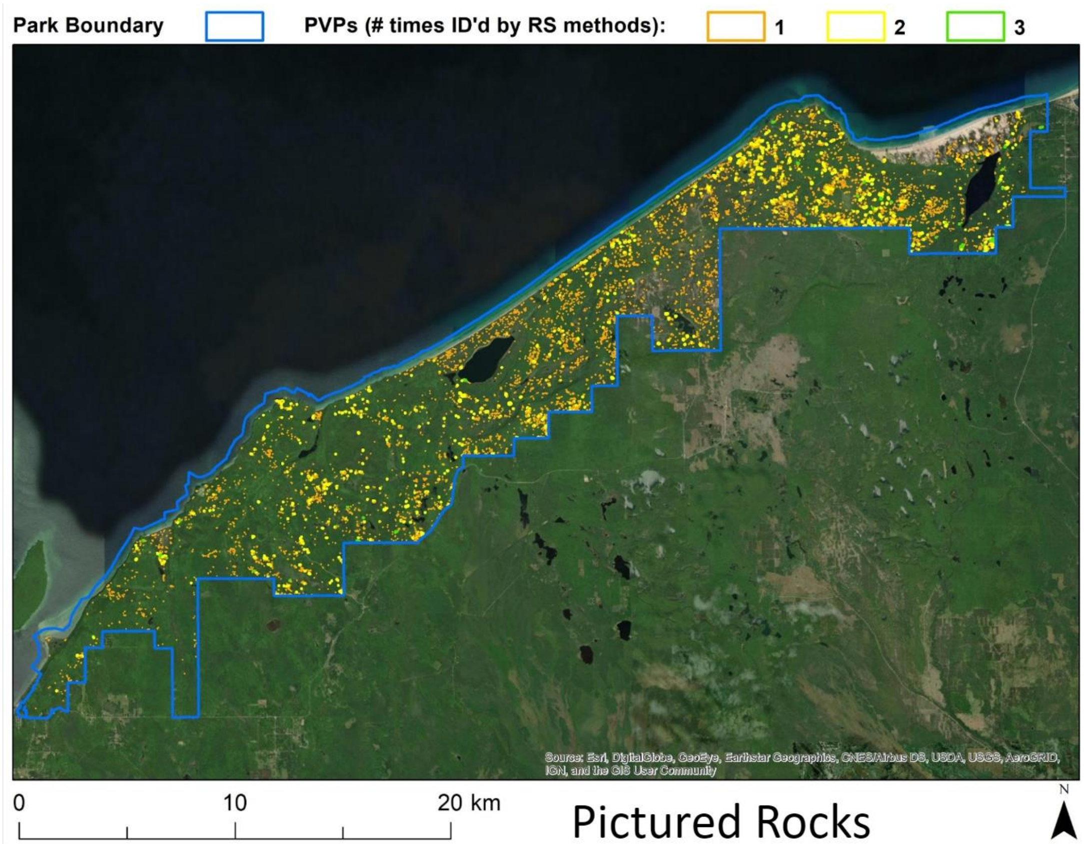

Figure A.1. All mapped vernal pools at Pictured Rocks National Lakeshore. Different colored pools correspond to the number of times the pool was identified using three different remote sensing methods.

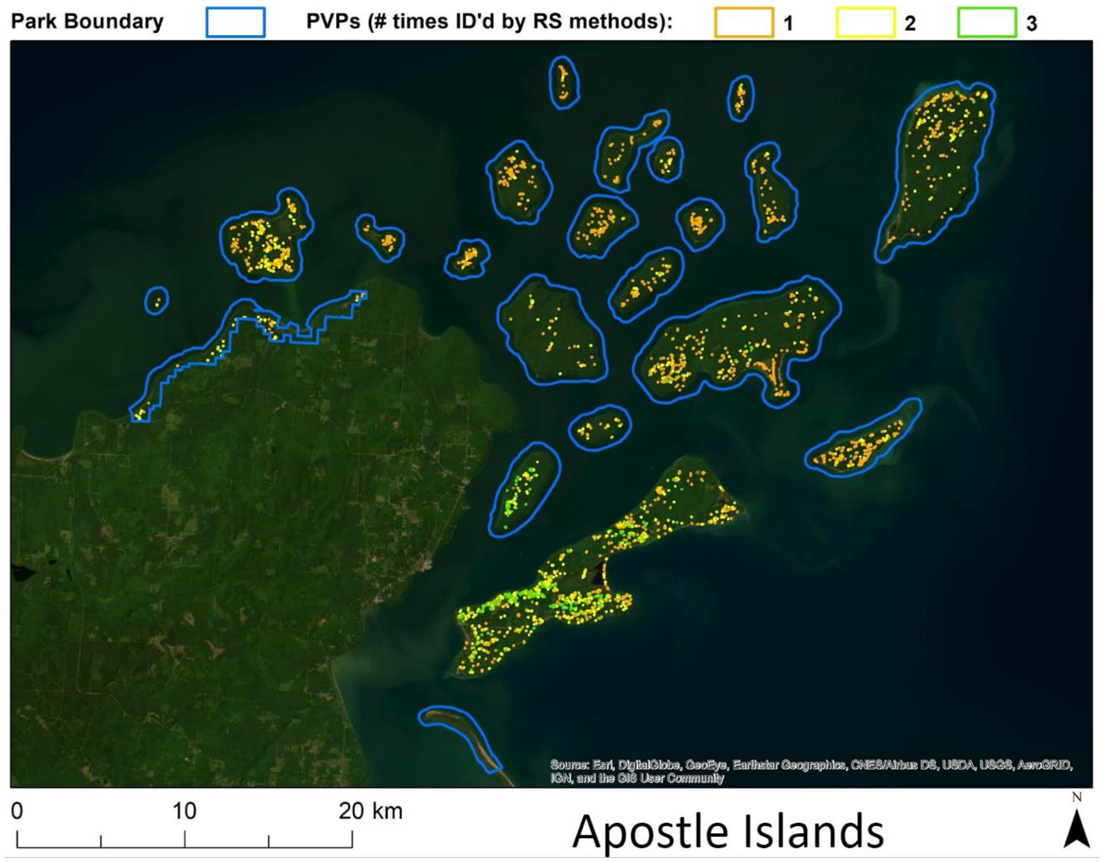

Figure A.2. All mapped vernal pools at Apostle Islands National Lakeshore. Different colored pools correspond to the number of times the pool was identified using three different remote sensing methods.

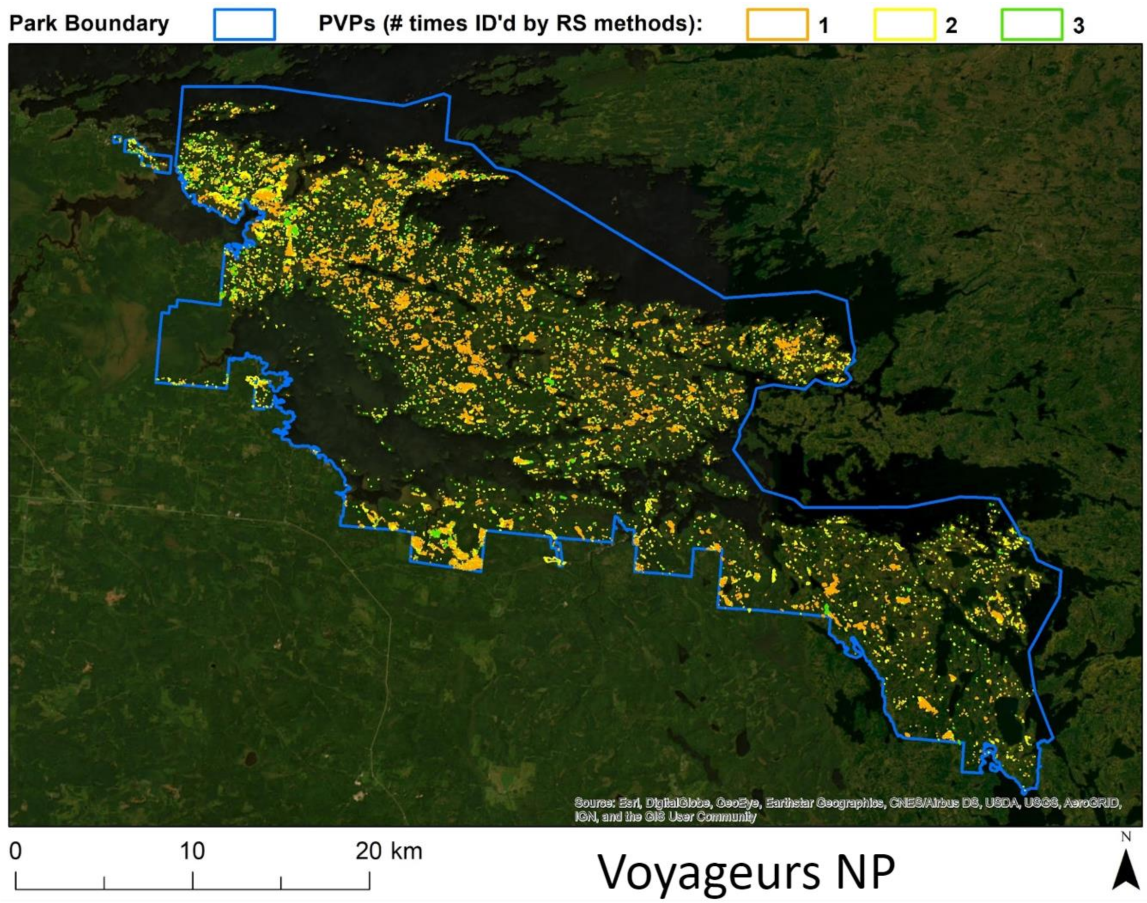

Figure A.3. All mapped vernal pools at Voyageurs National Park. Different colored pools correspond to the number of times the pool was identified using three different remote sensing methods.

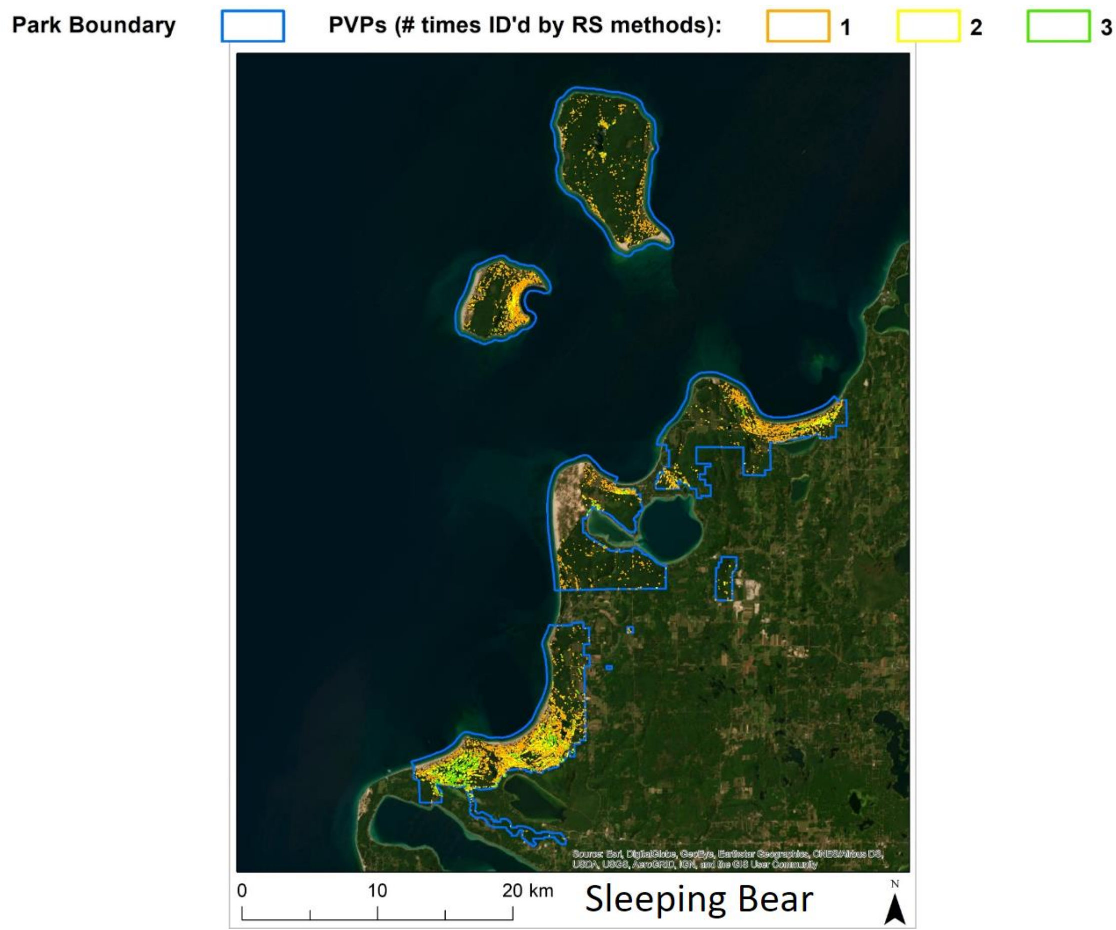

Figure A.4. All mapped vernal pools at Sleeping Bear Dunes National Lakeshore. Different colored pools correspond to the number of times the pool was identified using three different remote sensing methods.

Table A.1. Complete dataset of vernal pools from all five National Parks visited in this study. Continued on next page.

Pool ID	Lat	Long	Pool width (m)	Pool length (m)	Pool depth (cm)	Substrate	Classification	Indicator species
AI113	46.953843	-90.874164	25	5	61	Clay	Dec	Spotted salamander (tadpoles/larvae/egg masses)
AI115	46.948481	-90.879969	9	8	15	Clay	Dec	Wood frog (tadpoles/larvae/egg masses)
AI117	46.926813	-90.580763	18	18	30	Clay	Dec	Wood frog (adults), Wood frog (tadpoles/larvae/egg masses)
AI120	46.921613	-90.586332	18	7	30	Clay	Dec	Wood frog (adults)
AI123	46.919944	-90.626262	17	17	30	Silt	Dec	Wood frog (tadpoles/larvae/egg masses)
AI126	46.919794	-90.630622	30	20	30	Clay	Con	None
AI128	46.918902	-90.632024	50	7	30	Clay	Dec	Wood frog (adults)
AI132	46.9158	-90.628015	20	NA	91	Sand	Dec	Wood frog (tadpoles/larvae/egg masses)
AI134	46.914237	-90.638659	20	20	15	Sand	Dec	None
AI135	46.913835	-90.636626	15	15	61	Clay	Dec	None
AI148	46.879813	-90.502802	8	1	15	Peat	Dec	Spotted salamander (tadpoles/larvae/egg masses)
AI149	46.879732	-90.500685	7	1	15	Sand	Dec	Fingernail clams, Wood frog (adults), Wood frog (tadpoles/larvae/egg masses), Spotted salamander (tadpoles/larvae/egg masses)
AI150	46.879158	-90.502557	14	4	15	Sand	Dec	None
AI156	46.796212	-90.658652	13	10	30	Sand	Dec	Wood frog (adults), Spotted salamander (tadpoles/larvae/egg masses)
AI157	46.795326	-90.656573	50	24	15	Sand	Dec	Fairy shrimp
AI171	46.927525	-90.581894	18	18	61	Clay	Dec	Wood frog (tadpoles/larvae/egg masses)
AI186	46.919458	-90.617579	18	18	15	Clay	Dec	Wood frog (tadpoles/larvae/egg masses)
AI188	46.91932	-90.61885	15	8	15	Clay	Dec	None
AI198	46.879768	-90.501896	12	5	15	Sand	Dec	Spotted salamander (tadpoles/larvae/egg masses)
AI199	46.876501	-90.50465	14	16	8	Peat	Dec	None
AI40	46.797208	-90.685985	10	15	30	Clay	Dec	None
AI44	46.795327	-90.692508	20	20	15	Clay	Dec	None
AI5	46.938553	-90.957139	11	9	30	Clay	Dec	Wood frog (adults)
IR10	48.132593	-88.516266	13	2	30	Sand	Con	None
IR113	47.985516	-88.931174	55	22	30	Clay	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR114	47.979	-88.947346	60	40	61	Silt	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR115	47.977356	-88.94938	38	32	30	Sand	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR116	47.955213	-89.012631	44	25	30	Peat	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR117	47.95111	-89.030832	36	30	91	Sand	Open	Fingernail clams, Wood frog (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
IR118	47.9403	-89.032391	18	14	61	Silt	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR119	47.934801	-89.055323	24	21	30	Silt	Dec	Fairy shrimp, Fingernail clams, Wood frog (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
IR12	48.131229	-88.518893	17	6	61	Sand	Con	None
IR120	47.934009	-89.051817	90	20	15	Peat	Con	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR121	47.92696	-89.08641	30	10	61	Silt	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR122	47.925964	-89.093777	25	18	30	Clay	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR123	47.955219	-89.012671	18	15	30	Clay	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR13	48.131563	-88.521251	20	3	30	Clay	Con	None
IR136	47.910596	-89.144049	40	25	61	Silt	Open	Fingernail clams, Wood frog (adults), Wood frog (tadpoles/larvae/egg masses), Blue-spotted salamander (adults), Blue-spotted salamander (tadpoles/larvae/egg masses), Other
IR138	47.967528	-88.964198	30	15	61	Clay	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)

IR154	48.089933	-88.644429	35	27	61	Silt	Dec	Fingernail clams
IR155	48.100432	-88.623114	40	9	30	Sand	Dec	Fingernail clams
IR156	48.117249	-88.54691	60	15	30	Sand	Dec	Fairy shrimp, Fingernail clams
IR158	48.129792	-88.526477	60	26	61	Sand	Open	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR159	48.131666	-88.521168	50	17	61	Sand	Open	Wood frog (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
IR16	48.127622	-88.527996	60	10	61	Sand	Open	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR160	48.14686	-88.483535	30	15	61	Sand	Dec	Fingernail clams
IR162	48.144994	-88.489648	34	30	15	Sand	Dec	Fingernail clams
IR163	48.145026	-88.489773	31	13	61	Sand	Open	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR165	48.123594	-88.529837	24	17	61	Sand	Open	None
IR166	48.011594	-88.865381	40	40	30	Clay	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR167	48.009068	-88.876591	40	30	61	Sand	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR17	48.127589	-88.52785	15	11	61	Bedrock	Open	Fairy shrimp, Fingernail clams
IR20	48.119608	-88.542554	54	15	61	Silt	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR22	48.113543	-88.547113	25	7	30	Sand	Con	None
IR24	48.100364	-88.623189	45	13	30	Sand	Dec	Fingernail clams
IR25	48.100677	-88.574295	50	15	61	Sand	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR27	48.092021	-88.602221	40	20	91	Silt	Open	Fairy shrimp, Wood frog (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
IR31	48.086344	-88.654821	20	10	8	Sand	Dec	Fingernail clams
IR70	48.025859	-88.83172	50	15	30	Silt	Open	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR80	47.983242	-88.935323	90	15	15	Clay	Dec	Fingernail clams
IR82	47.977308	-88.949373	43	27	30	Silt	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR83	47.93512	-89.04803	40	35	8	Silt	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
IR9	48.135089	-88.512477	22	10	30	Sand	Open	None
PR1	46.574204	-86.21673	20	NA	91	Sand	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses), Eastern red -backed salamander
PR12	46.601594	-86.276797	100	25	30	Sand	Dec	Blue-spotted salamander (tadpoles/larvae/egg masses)
PR13	46.496161	-86.396462	65	NA	15	Sand	Open	Fairy shrimp
PR21	46.553757	-86.357185	20	20	61	Sand	Open	None
PR31	46.619895	-86.25355	40	NA	30	Sand	Dec	Fingernail clams, Fairy shrimp, Blue-spotted salamander (tadpoles/larvae/egg masses), Spotted salamander (tadpoles/larvae/egg masses)
PR32	46.609726	-86.268814	55	NA	122	Sand	Open	Wood frog (tadpoles/larvae/egg masses), Spotted salamander (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses), Eastern red-backed salamander
PR33	46.534437	-86.477845	100	80	30	Peat	Con	None
PR35	46.662637	-86.173254	10	30	8	Sand	Con	None
PR37	46.549345	-86.327227	45	NA	61	Sand	Open	Fingernail clams, Spotted salamander (tadpoles/larvae/egg masses)
PR38	46.637411	-86.027305	30	NA	15	Sand	Dec	Fingernail clams
PR39	46.616915	-86.041761	24	NA	61	Sand	Dec	Fairy shrimp, Fingernail clams, Wood frog (tadpoles/larvae/egg masses)
PR4	46.49155	-86.553742	25	NA	15	Sand	Dec	Fairy shrimp

PR40	46.550768	-86.357158	31	NA	15	Sand	Dec	Fairy shrimp, Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses), Spotted salamander (tadpoles/larvae/egg masses)
PR42	46.49557	-86.380521	27	NA	30	Sand	Open	Other, Wood frog (tadpoles/larvae/egg masses), Wood frog (adults)
PR44	46.648598	-86.028003	20	NA	15	Sand	Dec	Blue-spotted salamander (tadpoles/larvae/egg masses), Fingernail clams
PR45	46.637307	-86.027396	60	NA	30	Sand	Dec	Fingernail clams, Wood frog (tadpoles/larvae/egg masses), Other
PR47	46.552771	-86.355773	35	35	61	Sand	Open	Fairy shrimp
PR48	46.493442	-86.549	20	20	15	Clay	Dec	None
PR49	46.462704	-86.582988	9	NA	15	Clay	Dec	Fingernail clams
PR50	46.464855	-86.551414	50	20	30	Sand	Dec	None
PR51	46.536201	-86.475691	30	20	30	Sand	Open	Wood frog (tadpoles/larvae/egg masses)
PR52	46.535517	-86.476115	35	NA	30	Sand	Dec	Wood frog (adults)
SB1	44.708847	-86.184227	12	NA	61	Sand	Open	Fingernail clams, Wood frog (tadpoles/larvae/egg masses), Spotted salamander (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
SB12	44.735973	-86.057615	13	NA	8	Clay	Dec	Fingernail clams, Eastern red-backed salamander
SB15	44.716918	-86.107015	10	NA	61	Sand	Open	Fingernail clams, Other, Spotted salamander (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
SB16	44.941843	-85.912944	17	17	61	Sand	Dec	Wood frog (adults)
SB19	44.707832	-86.186536	22	NA	61	Sand	Dec	Fingernail clams, Spotted salamander (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses), Eastern red-backed salamander
SB23	44.705149	-86.168313	22	NA	30	Sand	Open	Spotted salamander (tadpoles/larvae/egg masses), Other
SB27	44.833214	-85.912377	58	58	122	Sand	Open	Wood frog (tadpoles/larvae/egg masses)
SB2t	44.941798	-85.816655	15	NA	15	Sand	Open	None
SB3	44.719494	-86.109148	12	NA	30	Sand	Open	Blue-spotted salamander (tadpoles/larvae/egg masses)
SB30	44.719771	-86.11546	25	NA	30	Sand	Open	None
SB33	44.736476	-86.081711	19	NA	30	Sand	Dec	Fingernail clams
SB36	44.726061	-86.083263	25	NA	30	Sand	Open	Fingernail clams, Wood frog (adults), Other
SB42	44.786448	-86.047714	27	NA	30	Clay	Con	None
SB45	45.005064	-86.117253	39	28	30	Sand	Dec	Blue-spotted salamander (tadpoles/larvae/egg masses), Eastern red-backed salamander
SB4t	44.941205	-85.816803	10	NA	122	Sand	Open	None
SB502t	44.719429	-86.115442	20	NA	61	Sand	Open	None
SB505O	44.733817	-86.090184	23	NA	30	Sand	Dec	Blue-spotted salamander (tadpoles/larvae/egg masses), Wood frog (adults)
SB511O	44.735357	-86.078402	10	NA	30	Sand	Open	Fingernail clams, Spotted salamander (tadpoles/larvae/egg masses), Blue-spotted salamander (tadpoles/larvae/egg masses)
SB6t	44.940595	-85.816902	10	NA	122	Sand	Open	None
SB8	44.937086	-85.823616	11	8	30	Peat	Con	Wood frog (adults)
SB9	44.713264	-86.186016	13	NA	30	Sand	Con	Wood frog (adults), Wood frog (tadpoles/larvae/egg masses)
SB9t	44.939757	-85.818417	17	NA	15	Sand	Dec	Wood frog (adults), Blue-spotted salamander (tadpoles/larvae/egg masses), Eastern red-backed salamander
Voy001	48.596424	-93.202814	30	15	8	Clay	Dec	Fingernail clams
Voy1250	48.511853	-93.088201	18	14	30	Peat	Dec	None
Voy1349	48.506865	-93.067871	21	18	30	Peat	Dec	None
Voy1600	48.473146	-93.055991	21	11	8	Sand	Dec	None
Voy1649	48.466302	-93.070258	18	16	61	Clay	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1655	48.465048	-92.936368	20	15	15	Sand	Dec	None
Voy1666	48.46221	-92.887191	18	16	8	Clay	Dec	Fingernail clams, Wood frog (adults)
Voy1668	48.461666	-92.902729	30	18	30	Sand	Dec	Fingernail clams, Wood frog (adults)

Voy1669	48.461301	-92.915689	35	8	30	Clay	Dec	Wood frog (adults), Fingernail clams
Voy1672	48.460278	-92.894951	20	10	15	Sand	Dec	None
Voy1692	48.449466	-92.900118	17	10	15	Clay	Dec	Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1705	48.44414	-92.839096	100	50	30	Clay	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1708	48.442631	-92.810808	38	13	30	Clay	Dec	Fingernail clams
Voy1714	48.441396	-92.849946	11	9	15	Clay	Open	Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1722	48.439122	-92.794214	25	10	30	Clay	Dec	Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1729	48.437408	-92.956955	30	25	30	Sand	Dec	Fingernail clams
Voy1732	48.43642	-92.771767	20	10	0	Clay	Dec	None
Voy1736	48.435408	-92.796464	15	15	61	Clay	Dec	Fingernail clams
Voy1756	48.431875	-92.846314	24	18	15	Sand	Open	Wood frog (adults)
Voy1763	48.4313	-92.934617	20	20	30	Clay	Dec	None
Voy1768	48.430599	-92.951532	50	50	15	Clay	Dec	Wood frog (adults)
Voy1772	48.429904	-92.853401	11	2	8	Clay	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1776	48.429323	-92.800443	30	20	15	Sand	Dec	Fingernail clams, Blue-spotted salamander (tadpoles/larvae/egg masses)
Voy1838	48.421316	-92.845458	16	10	61	Bedrock	Open	Fingernail clams
Voy2	48.587865	-93.182665	28	15	30	Clay	Dec	Fingernail clams
Voy21	48.478701	-93.072008	50	50	15	Clay	Con	None
Voy38	48.407241	-92.844978	30	25	61	Clay	Open	None
Voy4	48.582691	-93.145815	40	20	15	Clay	Dec	None
Voy6	48.581908	-93.138618	15	11	8	Bedrock	Con	None
Voy7	48.583188	-93.137608	20	7	8	Sand	Dec	None
Voy8	48.588458	-93.150652	30	28	30	Clay	Dec	None
Voyuntitled	48.427168	-92.849581	20	20	15	Clay	Con	None

Appendix B. Data Sheet

Vernal Pool Monitoring Form

QC Date: ____________
QC Initials: ____________
Date Entered: ____________

Michigan Natural Features Inventory
MICHIGAN STATE UNIVERSITY | Extension

Modified- for NPS 2020 - Standard MVPP Monitoring Data Form
Michigan Vernal Pools Project
Vernal Pool Patrol Hub - Contact MNFI at (517) 284-6200

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.g. Latitude: 44.764322 Longitude: -72.654222)

Township/Range/Section/1/4 info : ____________ Latitude: ____________ Longitude: ____________

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? ☐ In the Field Latitude: ____________ Longitude: ____________

☐ GPS ☐ Topo Map ☐ Google Earth ☐ Air Photo Crossroad names: ____________

2b) Brief Site Directions to Pool **

Spring canopy cover
☐ 0% ☐ 1-9%
☐ 10-25% ☐ 26-50%
☐ 50-75% ☐ +75%
Exact ☐

Coniferous canopy cover (over pool)
☐ 0% ☐ 1-9%
☐ 10-25% ☐ 25-50%
☐ 50-75% ☐ +75%

Coniferous basl area w/in 30m
☐ 0% ☐ 1-9%
☐ 10-25% ☐ 26-50%
☐ 50-75% ☐ +75%

** **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): Classic Complex

Open Closed

3b) Presence of Inlet or Outlet

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

☐ Yes, pool is isolated ☐ No, 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 **Disturbances:** ☐ Powerline right-of-way ☐ Other: ________

☐ Upland Coniferous Forest ☐ Lowland Coniferous Forest ☐ Agriculture ☐ Light development (<25%) ☐ No disturbances

☐ Upland Mixed Forest ☐ Lowland Mixed Forest ☐ Road/driveway ☐ Intensive development (>25%)

☐ Floodplain ☐ Grassland or open ☐ paved ☐ Minor logging (>or = 70% canopy remaining)

☐ Emergent Wetland (marsh, bog) ☐ dirt/gravel ☐ 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

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

Width: ________ feet
Length: ________ feet
Size determined by: ☐ Pacing ☐ Measuring ☐ Using GPS

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%

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

☐ Leaf litter ☐ Sand - Gravel ☐ Unknown
☐ Bedrock ☐ Muck - Peat ☐ Other: ________
☐ Loam ☐ Silt - Clay

4c) Water temperature (°F): ________

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

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Figure B.1. Page one of the Michigan Vernal Pools Project data sheet, edited for this study.

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?	Notes/Photo ID#
			Number	Estimated	Counted	Yes	
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:

Water color ☐ pH ☐

Pool condition (circle): poor good excellent

Ash tree presence (y/n) ☐ % Ash trees dead ☐

Invasive species

individual/few/several ☐ 1000 ft^2 (half tennis court) ☐

1000 ft^2 to 0.5 acre ☐ 0.5 acre to 1 acre ☐ >1 acre ☐

Restoration potential

disturbance easily fixed, site in fair to poor conditions ☐

disturbance fairly easily fixed, site in fair to poor condition ☐

disturbance hard to fix/expensive, site in good condition ☐

in good to excellent condition, site is very difficult to fix ☐

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

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

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Figure B.2. Page two of the Michigan Vernal Pools Project data sheet, edited for this study.