Vernal Pool


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

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

Fisheries and Wildlife 2009, Maine Department of Environmental Protection Bureau of Land & Water Quality 2009, Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission 2005, Sullivan 2009).

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

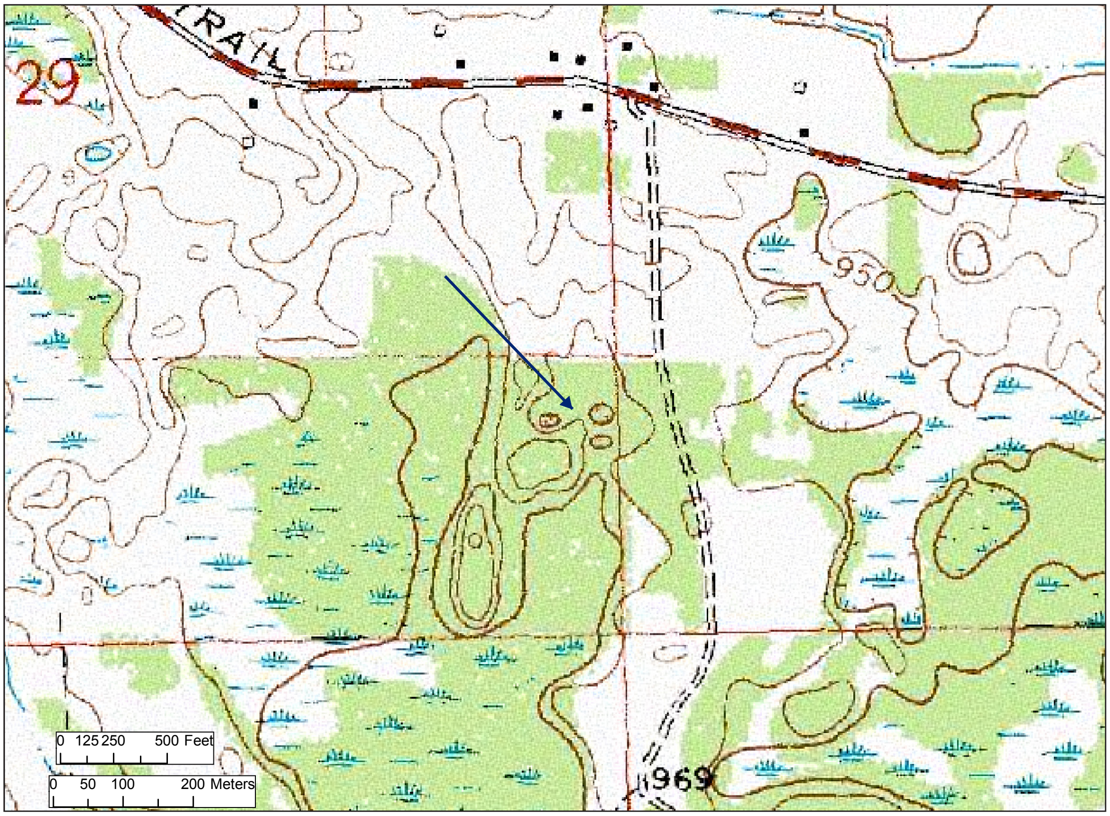
To distinguish vernal pools from briefly puddled upland depressions, true ponds, flowing waterbodies, and a variety of open wetland types, their definition can be further narrowed to sites that meet the following criteria:

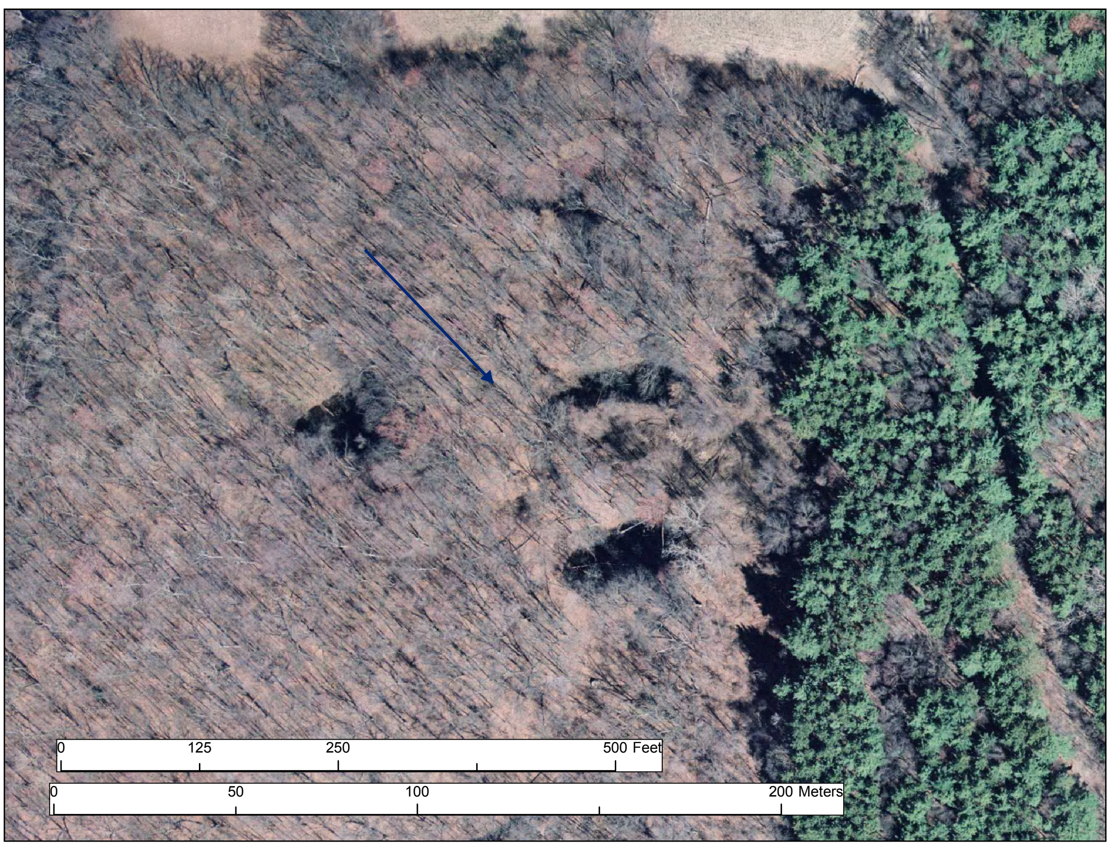
- flooded long enough and frequently enough, *and* dried out long enough and frequently enough to harbor flora and/or fauna that have specialized adaptations or life cycles for coping with both inundation and water drawdown. Notably, permanent fish populations do not occur in vernal pools because they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

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

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

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





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

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

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

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

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Vernal pool in early spring.

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

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

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

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

Vernal pool in late spring.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Vernal pool in September after water levels have dropped.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

NJ: Vernal pool (Tesauro 2009).

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

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

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

VT: Vernal pool (Thompson and Sorenson 2005).

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

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

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