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Hydrology, Physiochemistry, and Amphibians in Natural and Created Vernal Pool Wetlands

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Abstract

This study compared the hydrology, physiochemistry, and amphibian biomass between a complex of created vernal pools and a complex of natural vernal pools in 2007 in central Ohio, United States. Hydrologic connectivity of surface water and groundwater differed between the natural and the created pool complexes. Surface inundation duration for created pools exceeded that of natural pools, although spring water depths were similar. Dissolved oxygen ($p = 0.05$) and hourly temperature ($p = 0.00$) were 1.2% and 1.1% higher, respectively, in the created pools, and conductivity was 1.5% higher ($p = 0.00$) in the natural pools. Amphibian dip net results found no significant difference in biomass between natural and created pools or family (hylid, ranid, and ambystomatid) biomass in both pool types. Amphibian families were evenly represented by both capture methods in the created wetlands; however, the distribution of families was not even in natural pools and the proportion of ranids was four times greater for samples obtained by funnel traps than dip netting. Eleven years after construction, the created vernal pools did not mimic natural pools in surface inundation and groundwater–surface water exchange, dissolved oxygen, and water temperature. The created pools are perched wetlands and are never likely to mimic reference pool hydrology. Dissolved oxygen and temperature differences are likely due to the separation of surface water and groundwater in the created pools. However, the created pools exhibited a higher taxa diversity than the natural pools due to a more even distribution of organisms between the three families.

Key words: amphibian biomass, conductivity, created wetlands, wetland biodiversity, wetland hydrology.

Introduction

Vernal pools are isolated, temporarily flooded, and depressional wetlands that are mainly filled by precipitation but may also receive input from surface run-off and groundwater exchange (Colburn 2004; Bauder 2005; Meester et al. 2005; Mitsch & Gosselink 2007). In Ohio, vernal pools collect water mostly from snowmelt and early spring rains and are inundated from late autumn through mid- to late summer. Eastern United States pools occur intermittently and occupy approximately 10% of the upland forested landscape (Colburn 2004). Vernal pools provide important habitat for both amphibians and invertebrates and seasonally store water to prevent flooding of surrounding areas. Vernal pools may also be called "temporary," "seasonal," or "ephemeral," describing their hydrologic tendency to vary in response to the season. Seasonal shifts in vernal pool hydrology shape the life histories of the biological organisms that inhabit these pools. Temporary pools often include highly specialized biota due to the adaptations necessary for survival (Colburn 2004).

Vernal pools play a small but significant role in several functions that humans find valuable. They are aesthetically pleasing, provide flood control, and create habitat complexity in the landscape. However, protecting temporary pools is more difficult to legally justify in the current U.S. wetland protection guidelines and regulations, specifically because vernal pools are isolated and consequently not "navigable waters of the U.S." (Environmental Library 1987; Mitsch & Gosselink 2007). These systems are often small and not easily discerned especially in late summer and early fall when they are dry. It is not unusual for temporary pools to disappear, unnoticed to humans, as development encroaches.

The more challenging issue in vernal pool restoration and creation is adequately mimicking proper hydrology to serve as suitable habitat for wetland biota. Hydrology is the driving component in structuring vernal pool community composition and specialist breeding success (Semlitsch et al. 1996; Snodgrass et al. 2000; Babbitt & Baber 2003; Mitsch & Gosselink 2007). Amphibian conservation is a rising area of concern, and ephemeral pools are imperative for breeding success of many amphibian species. Restoration research has shown that vernal pool complexes of greater than five pools varying in area and depth and along a hydrologic continuum are best suited for amphibian resiliency (Petranka et al. 2007). In Ohio, 16 of the state's 40

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amphibian species rely on vernal pools for breeding and development with impacts to these unique habitats already producing a decline in several sensitive amphibian species (Micacchion 2002).

Biotic organisms are being used with greater frequency to assess ecosystem function, and amphibians are environmentally sensitive taxa, which may be useful in assessing created pools. Amphibian species range in sensitivity to landscape alteration and pollutants in their environment, creating a scale, which may be used to differentiate between high- and low-quality forested pools (Micacchion 2002). A better understanding of the larval amphibian biomass produced in vernal pools may provide further justification for legal protection of such wetlands. Amphibian biomass is variable between wetlands and provides an appreciable portion of the energy transfer between aquatic and terrestrial habitats (Gibbons et al. 2006). Larval amphibian biomass may be correlated with species richness (Werner et al. 2007) and has potential as an assessment tool that would not require tedious identification.

This study compared created and natural vernal pools in central Ohio, United States, and focused on three specific areas where there are few data on vernal pools: hydrology, abiotic characteristics, and amphibians. Pool volume, period of inundation, and hydrologic connectivity between groundwater and surface water were expected to differ between natural and created pools due to construction of an impermeable substrate in created pools. Pool characteristics including conductivity, dissolved oxygen, pH, and temperature were expected to differ between natural and created pools in a manner that would follow trends set by the hydrology. Amphibian larval biomass was expected to be greater in natural than created pools, and trapping methods (dip net and funnel trap) were expected to yield similar results.

Methods

Site Descriptions

Gahanna Woods State Nature Preserve (Fig. 1a) is a 23.0-ha site located in a suburban area in central Ohio, United States. It includes Buttonbush (*Cephalanthus occidentalis*) swamps and six vernal pools surrounded by a Pin Oak (*Quercus palustris*)-Silver Maple (*Acer saccharinum*) swamp forest and upland comprised of m Mature Oak

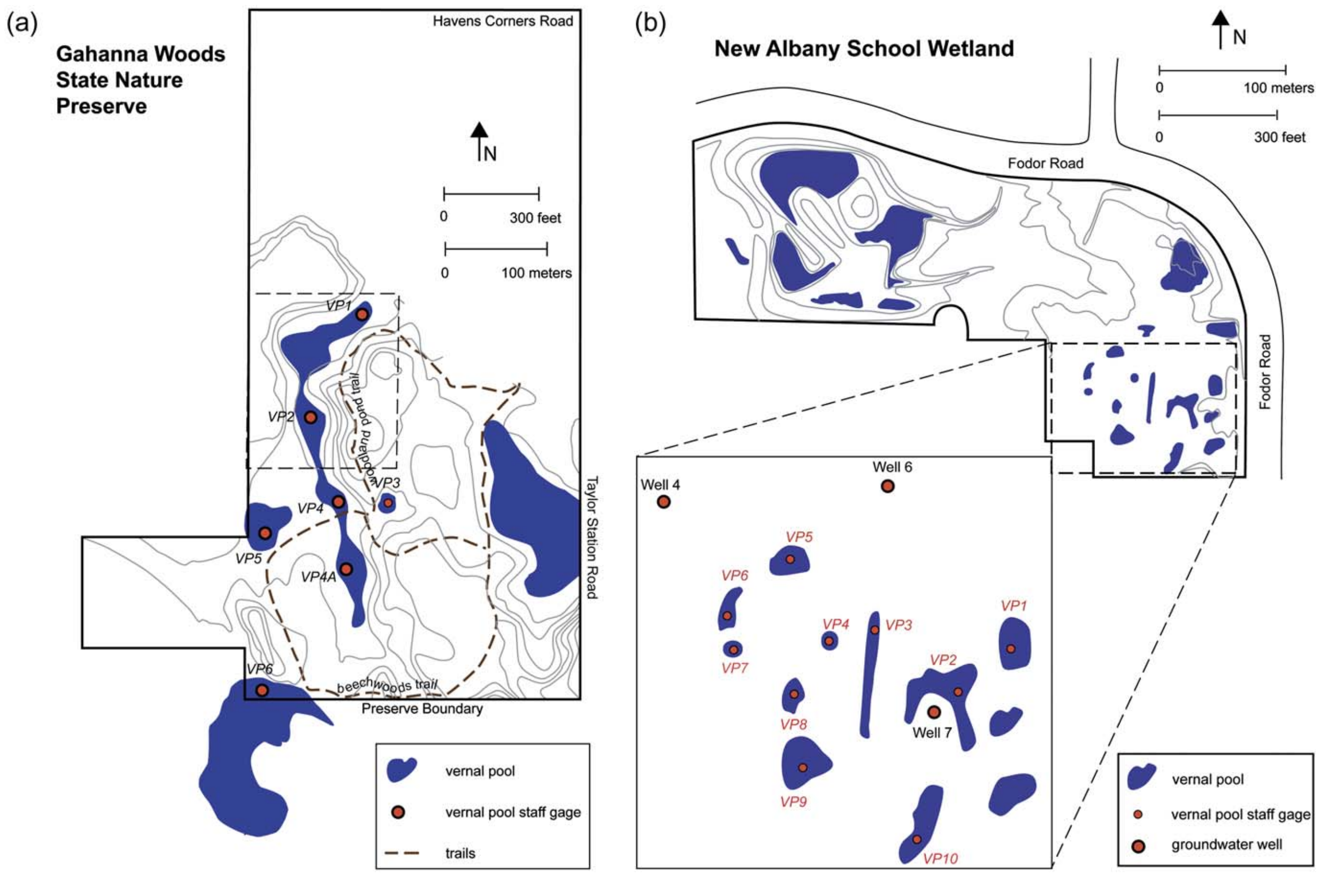

Figure 1. Site map of study vernal pools in central Ohio, United States (a) Gahanna Woods State Nature Preserve and (b) New Albany School Wetlands showing vernal pool complexes and surrounding upland habitat. Gahanna Woods is a naturally occurring complex of wetlands, and New Albany wetlands were created in 1996 as part of a mitigation project (from Gamble and Mitsch 2009, reprinted with permission).

(*Quercus*)–Hickory (*Carya*) and Beech (*Fagaceae*)–Maple (*Acer*) forest. It is most likely the highest quality remaining complex of Buttonbush swamps and vernal pools remaining in central Ohio and was used as a reference site in this study. Water found in the pools is derived from precipitation and direct run-off of surrounding upland area; there is no evidence of groundwater influence (Fineran 1999). The pools in the middle are hydrologically connected during wet periods, and all pools drain to the north into Windrush Creek (Johnson 1999). The soils found within the vernal pools consist of Carlisle muck (hydric) and Pewamo silty clay loam (hydric) as mapped by the U. S. Soil Conservation Service (1980).

The New Albany mitigation site (Fig. 1b) is a 16.0-ha site in a suburban community in central Ohio that was surrounded by farmland within the past 25 years. The mitigation site contains 9.4 ha of replaced or restored wetlands and 6.6 ha of surrounding upland buffer. Construction of the wetlands was completed in 1996 and contains three main areas including a complex of 10 vernal pools integrated into 2.0 ha of existing forested land (Gamble & Mitsch 2009). The wetland canopy comprised Red Maple (*Acer rubrum*), Green ash (*Fraxinus pennsylvanicum*), and Cottonwood (*Populus deltoides*). Soils found at the site consist of Pewamo silty clay loam (hydric) and Bennington silt loam and Cardington silt loam (both nonhydric with hydric components) as mapped by the U. S. Soil Conservation Service (1980).

Hydrology

Water level recorders (Remote Data Systems, Inc. 2004) were installed in March 2007 in pairs at 6 of the 12 pools. The remaining six pools contained staff gauges installed in the deepest point of each pool and read weekly through the sampling period. The paired water level recorders were installed with one at the deepest area within the pool so that surface water level would be recorded and the other just outside the pool so that shallow groundwater could be recorded. Wells were installed approximately 50–80 cm deep depending on the soil profile. When an impermeable clay layer was encountered, digging stopped. The hole around the well screen was then filled with sand, and the top was covered with impermeable bentonite clay. Water level recorders took hourly readings, and data were downloaded monthly. Precipitation data were acquired from the nearby (within 15 km of each study site) Columbus International Airport (Archived Climatological Data). A laser level was used to put the data collected at the surface and groundwater of the seven chosen pools on the same reference point. The ground surface at the point of installation for the groundwater level recorder was established as "0" and surface water data were adjusted relative to this reference point.

A handheld GPS unit (Thales Navigation, Inc., Santa Clara, CA, U.S.A.) with accuracy 1.0/100 m was used to calculate the perimeter and surface area of each pool at the beginning of May, June, and July. Pool area was used to standardize amphibian sampling and to calculate pool volume ($r = 0.95$) throughout the season for depressional wetlands: volume (m^3) = area (m^2) $\times$ max depth (m) $\times$ 0.3135 (Gamble et al. 2007).

Physiochemistry

A YSI 600 series data sonde (YSI Inc., Yellow Springs, OH, U.S.A.) was used to determine dissolved oxygen, redox potential, temperature, conductivity, and pH at each of the 12 pools between April and July. Data were gathered near the staff gauge and approximately 10 cm above the substrate at each pool. A HOBO water temperature recording device (Onset Computer Corporation, Contoocook, NH, U.S.A.) was deployed at each pool and readings were taken hourly. The temperature was obtained just above the substrate within each pool.

Amphibians

Larval amphibian sampling was conducted between May and July 2007 by two methods. Dip nets were used to catch amphibians during three sampling periods (May, June, and July) at all 12 pools. Capture was standardized between pools by timing for 1 minute for the first 25 m^2 and an additional minute for each doubling in area or for each different habitat (e.g., open water, submerged vegetation, and Buttonbush) (Heyer et al. 1994). Pools were dipnetted by starting at a random point within the pool and using a sweeping motion to work through the pool until the 1 minute ended.

Funnel traps were placed in only one natural and one created pool and were set weekly between mid-May and early July. Funnel traps were constructed with mesh wire screen and plastic screen for the inverted funnels, then reinforced with gauge wire to keep from collapsing. One trap was placed for the first 25 m^2 and an additional trap was added for each doubling of area or different habitat feature. They were left for approximately 24 hours so that diurnal and nocturnal species would both be sampled. In this study, samples collected 5.0 m apart were considered independent. Catch from both dip netting and funnel traps were analyzed in the same manner. Organisms were sorted into three family groups: hylid, ranid, and ambystomatids (Table 1), which were then counted and weighed using a spring scale.

Amphibian family diversity based on the Shannon–Weaver index and evenness based on Pielou's methods (Pielou 1984) were calculated for both capture methods at both study sites.

MiniTab 14 was used for statistical analysis of all amphibian data, and one-way analysis of variance (ANOVA) tests (95% confidence intervals) were performed to compare biomass of natural and created pools, biomass of different sampling months, and biomass collected by the two trap methods. All amphibian biomass data (except individual wet weight) were log transformed

Table 1. Amphibian species known to inhabit the natural and created pool complexes.

Family	*CoC*	*Gahanna Woods*	*New Albany*
Hylid	2	*Pseudacris crucifer*	*P. crucifer*
	5	*Hyla versicolor*	
Ranid	3	*Rana clamitans*	*R. clamitans*
	2	*R. pipiens*	
Ambystomatids	4	*Ambystoma texanum*	*A. texanum*
	5	*A. jeffersonianum*	*A. jeffersonianum*
	8	*A. maculatum*	

Species have been divided into categories, which were used to group similar organisms for amphibian analysis. Coefficient of Conservatism values (CoC) were determined by the Amphibian Index of Biological Integrity of Ohio wetlands (Micacchion 2002). Data for Gahanna Woods species courtesy of Mick Micacchion and data for New Albany courtesy of Bill Resch and Bill Somerlot.

to satisfy the assumptions of the tests. General linear models were created to look at multiple variables within the same test.

Data Analysis

Hydrology data were investigated using a general linear model in MiniTab 14. The model was based on (1) the difference between natural and created pools, (2) the connectivity changes between groundwater and surface water over time in all pools, and (3) the difference between natural and created pools in change in groundwater and surface water connectivity over time. Physical data were analyzed for differences in natural and created pools using MiniTab 14 univariate ANOVA tests, and all parameters were assessed individually for differences in created and natural pools.

MiniTab 14 was used for statistical analysis of all amphibian data, and one-way ANOVA tests ($\acute{a} = 0.05$) were performed to compare biomass of natural and created pools, biomass of different sampling months, and biomass collected by the two trap methods. All amphibian biomass data (except individual wet weight) were log transformed to satisfy the assumptions of the tests. General linear models were created to look at multiple variables within the same test. The model-assessed month (May and June), pool type (natural or created), and capture method (dip net and funnel trap) as potential factors affecting amphibian biomass results.

Results

Precipitation and Pool Volume

The year 2007 was hotter and drier than averages from the previous 30 years (Fig. 2). All pools did not dry down by the end of data collection for this study and compared with previous hydrologic studies of the same pools, this year the pools dried earlier than previous years (Table 2). The created pools decreased consistently in both surface

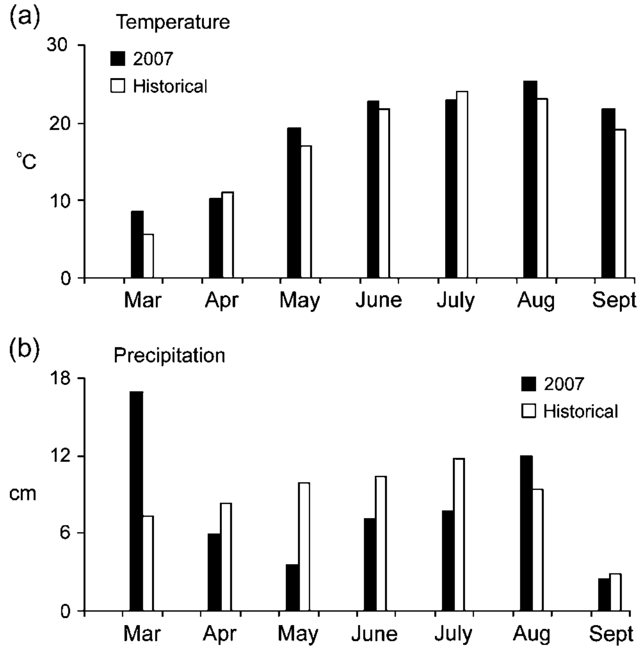

Figure 2. Monthly temperature and precipitation averages for the study period (March to September 2007) and historical averages for the same months over the past 30 years (National Oceanic and Atmospheric Administration 2007).

water level and volume throughout the season, whereas the natural pools decreased abruptly in surface water level and volume in June (Table 3).

Hydrologic Connectivity

According to the general linear model of connectivity with time as a covariate, and drawing conclusions at $\acute{a} = 0.01$ significance, three statements can be made as follows: (1) the connectivity between groundwater and surface water in natural pools was different from the connectivity in created pools ($C_{\mathrm{natural}} > C_{\mathrm{created}}$), (2) the connectivity in both sets of pools changes seasonally, and (3) the connectivity in natural pools changed differently than the connectivity in created pools.

Surface water and groundwater hydrographs for 7 of the 12 pools studied show that in both natural and created systems, the groundwater and surface water responded to the same precipitation events, although the groundwater often lagged slightly behind or showed little response to the surface water (Fig. 3). In some natural pools, surface water continued to increase slowly over several days, and in all studied natural vernal pools, there were little differences between the level of groundwater and surface water. However, in created pools, the difference was much greater and surface water remained fairly constant throughout the season. The differences in surface water and groundwater were much greater for created pools (52.4 ± 0.0 cm) than for natural pools (4.5 ± 0.0 cm). Groundwater and surface water in the natural pools

Table 2. Drawdown dates for the pools studied at Gahanna Woods State Nature Preserve and New Albany School Wetlands for the years 2004, 2005, and 2007.

	2004	*2005*	*2006*
Gahanna Woods	20 September to 11 October	24 June to 29 July	15 June to 15 July
New Albany	27 September	24 June	15 June

2004 was an El Nino year, and rainfall and storm intensity were much greater than the other years studied; 2004 and 2005 data from Gamble and Mitsch (2009).

fluctuated in concert, whereas the groundwater and surface water fluctuations at created pools were uncorrelated. A large increase in the difference between surface water and groundwater in created pools developed in May (Fig. 4). Typically, surface water was higher than the groundwater in all pools, but after drawdown occurred, there were several occasions where groundwater levels exceeded surface water levels in response to major precipitation events around natural pools. Groundwater level never intersected with the ground level at the bottom of the created pools.

Physiochemistry

Significant differences between natural and created pools were found for dissolved oxygen, $t(1) = 4.10$, $p = 0.05$; conductivity, $t(1) = 62.17$, $p = 0.00$; and hourly temperature measurements, $t(1) = 280.20$, $p = 0.00$, but not for redox potential, $t(1) = 0.10$, $p = 0.75$; pH, $t(1) = 0.25$, $p = 0.62$; and weekly temperature measurements, $t(1) = 1.49$, $p = 0.23$, at $\acute{a} = 0.05$ (Table 4). The mean conductivity for natural pools was significantly higher than the mean conductivity for created pools (174 vs. 113 μS/cm, respectively) (Table 4). A seasonal increase in conductivity was not observed in either the natural or the created pools. Weekly water temperature measurements did not show a difference between natural and created pools; however, hourly measurements differed significantly (Table 4). Diurnal water temperature patterns followed the same trends in natural and created pools; however, the range of temperature fluctuations (water temperature range) was greater in created pools than in natural pools (Fig. 5).

Amphibian Family Numbers and Diversity

A maximum of three families were encountered at any one site; the species comprising each family are listed in Table 1. The New Albany pools exhibited a higher diversity due primarily to an even distribution of organisms between the three families for both capture methods ($E_{\text{funnel trap}} = 0.99$, $E_{\text{dip net}} = 0.86$); however, Gahanna Woods pools exhibited a medium spread of evenness with dip netting as the capture method ($E_{\text{dip net}} = 0.64$) and low spread of evenness between the families with funnel trapping as the capture method ($E_{\text{funnel trap}} = 0.27$) (Table 5).

Factors Affecting Total Larval Amphibian Biomass

There was a difference in amphibian biomass for the months, $t(2) = 4.46$, $p = 0.017$, and also for the two capture methods, $t(1) = 10.60$, $p = 0.002$, when all samples were considered. However, there was not evidence of a difference in amphibian biomass based on pool type, $t(1) = 0.55$, $p = 0.464$, when seasonality and capture method were taken into account. For both created and natural pools, no significant difference in total larval amphibian biomass or in biomass grouped by family was found between May and June samples. However, July samples for both natural and created pools were significantly less in total larval amphibian biomass from May and June samples ($\acute{a} = 0.05$) (Table 6).

Differences in Larval Amphibian Capture Methods

Comparing dip net data, total amphibian biomass was significantly greater in created pools than in natural pools (Table 7). However, the inverse was supported by comparing funnel trap data where the natural pools contained significantly greater amphibian biomass than the created pools (Table 7). Figure 6 shows the seasonal trends found in all 12 pools by both capture methods. Dip netting consistently captured more amphibian biomass in created pools, whereas funnel trapping consistently captured more

Table 3. Pool volumes estimated from area and depth measurements for May, June, and July 2007 at all pools.

Date	*Pool*	*Area (m^2)*	*Depth (m)*	*Volume (m^3)**
1 May 2007	New Albany (created)	226 ± 16	0.4 ± 0.0	28 ± 3
	Gahanna Woods (natural)	2,830 ± 446	0.5 ± 0.0	470 ± 74
7 June 2007	New Albany (created)	184 ± 28	0.3 ± 0.0	26 ± 6
	Gahanna Woods (natural)	3,053 ± 430	0.5 ± 0.0	471 ± 69
5 July 2007	New Albany (created)	57 ± 15	0.2 ± 0.1	8 ± 2
	Gahanna Woods (natural)	0	0.0	0

All values are reported as mean ± standard error.
*Volume estimates were based on the equation: volume (m^3) = area (m^2) × max depth (m) × 0.3135 (Gamble et al. 2007).

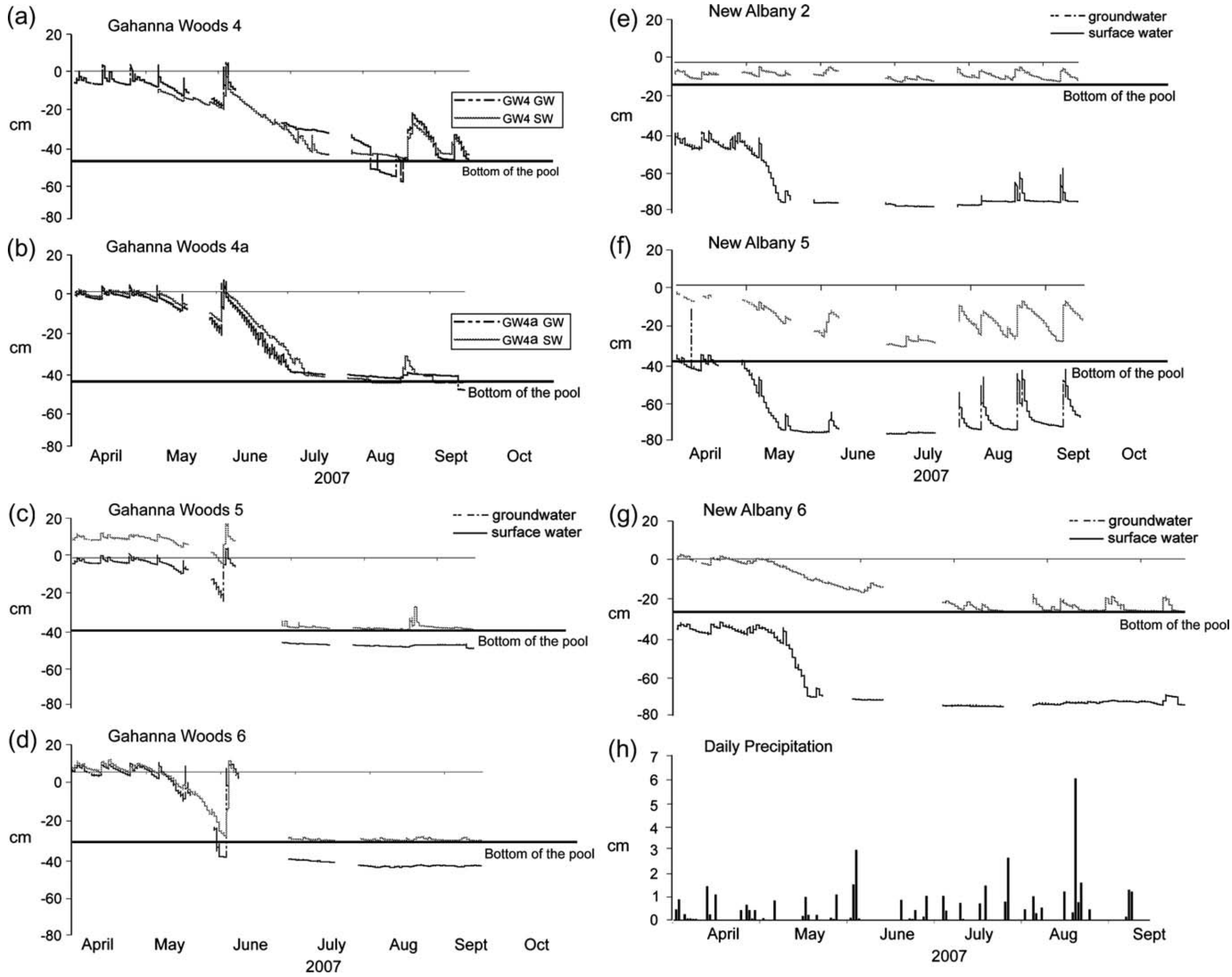

Figure 3. (a–d) Natural vernal pool hydrographs of groundwater and surface water level, (e–g) created vernal pool hydrographs of groundwater and surface water level, and (h) precipitation for the months April through September 2007. Daily precipitation was collected from Port Columbus (National Oceanic and Atmospheric Administration 2007).

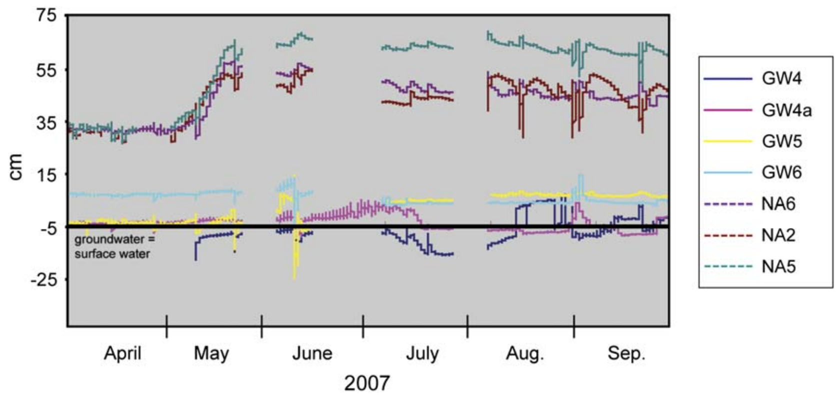

Figure 4. Connectivity as determined by the difference between surface water and groundwater measurements for both New Albany (NA, created) and Gahanna Woods (GW, natural) vernal pools from April through September.

Table 4. ANOVA test results for physiochemical parameters of pool water: weekly water temperature, hourly water temperature, dissolved oxygen, conductivity, redox potential, and pH for natural versus created pools measured April to July 2007.

Parameter	*p*	*f Test*	*df*	*Created*	*Natural*
Water temperature (°C) (weekly)	0.23	1.49	1	18.8 ± 0.1	17.7 ± 0.1
Water temperature (°C) (hourly)	0.00	280.20	1	20.4 ± 0.0	19.5 ± 0.0
Dissolved oxygen (mg/L)	0.05	4.10	1	8.2 ± 0.1	6.9 ± 0.1
Conductivity (μS/cm)	0.00	62.17	1	113.4 ± 0.4	173.6 ± 0.9
Redox potential (mv)	0.75	0.10	1	85.8 ± 1.2	81.4 ± 1.1
pH	0.62	0.25	1	7.4 ± 0.3	7.2 ± 0.3

Hourly water temperature was measured until September 2007. $N = 70$ for created pool weekly measurements and $n = 61$ for natural pool weekly measurements. For hourly temperature measurements, $n = 13{,}954$ for created pools and $n = 8{,}188$ for natural pools. Data are mean ± standard error.

biomass in natural pools. Funnel traps caught more total amphibian biomass in both pool types than dip net capture (Table 7).

Evidence for a difference in both pool type and capture method was supported ($\acute{a} = 0.05$) when assessing potential factors affecting total amphibian biomass. Pool type was not considered because there was only one pool of each type sampled by both capture methods, and a total of two dip netting and six funnel trapping samples had been collected at each pool. When capture methods were compared, there was evidence of a significant difference ($\acute{a} = 0.05$). Funnel trapping (4.6 g ± 0.2) captured significantly more amphibian biomass than dip netting (2.1 g ± 0.3) at both pools.

Differences Between Amphibian Families and Dominance Effects

A comparison of dip net samples found no significant differences between natural and created vernal pools among

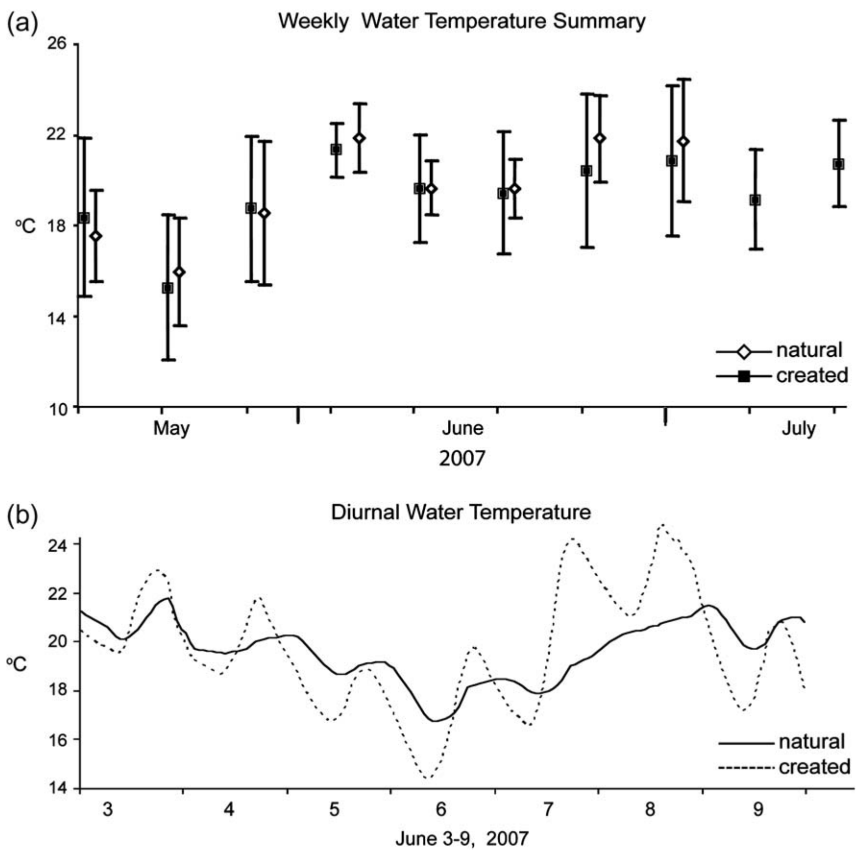

Figure 5. (a) Weekly temperature summaries (°C) of hourly data for two representative pools (Gahanna Woods 1 [natural] and New Albany 6 [created]). Error bars show standard deviation. (b) Diurnal water temperatures (°C) for 1 week of data obtained from the same created and natural pools illustrating differences in daily ranges of temperature.

Table 5. Amphibian total individual counts (C), Shannon diversity index (H'), and evenness (E) for family for natural and created pool types and dip net and funnel trap capture methods.

Results	*Natural*	*Created*
Dip net		
C	139	496
H'	0.70	0.95
E	0.64	0.86
Funnel trap		
C	2,132	78
H'	0.30	1.09
E	0.27	0.99

biomass of the three family categories: hylid, ranid, and ambystomatids (Table 8). Data comparing samples collected by funnel traps found hylids and ambystomatids were not significantly different, but both were significantly less than ranids ($\acute{a} = 0.01$) (Table 8).

Total count of ranid larvae and calculations of evenness support that the proportion of ranids caught by funnel traps was greater than the proportion caught by dip netting and that the proportion caught at the natural pools was greater than the proportion caught at the created pools when captured by funnel traps but not when captured by dip nets (Table 8). Total biomass was greater at both pools when sampled by funnel traps than by dip nets and also obtained greater catch of ranids in both pools.

Influence of Pool Volume on Larval Amphibian Biomass

A strong positive correlation between pool volume and amphibian biomass was found when data for both sampling methods were combined. Differences in pool volume were significant between the natural and the created pools ($\acute{a} = 0.01$); however, pool volume reflects pool type. A significant relationship between pool volume/type and total amphibian biomass for dip netting data was not supported. However, there was a significant positive relationship between amphibian total biomass and pool volume/type when funnel trap data were analyzed.

Table 6. ANOVA test results for average individual weight by family for month using dip net samples.

				Biomass (g/pool)	
Family	*p*	*f Test*	*df*	*May*	*June*
Hylid	0.27	1.29	1	0.5 ± 0.4	0.3 ± 0.2
Ranid	0.21	1.68	1	1.0 ± 0.2	2.3 ± 0.2
Ambystomatid	0.67	0.19	1	0.5 ± 0.1	0.4 ± 0.0

p Values, means, and standard error are reported for average individual body weight for each species category. For all samples, $n = 12$ except May; ambystomatids, $n = 7$. Data are mean ± standard error.

Discussion

Precipitation and Pool Volume

Conditions specific to 2007 led to shorter periods of surface inundation. Brooks (2004) found similar results where over a period of 10 years natural pools dried down earlier in dry years and later or not at all in wet years. Throughout the season, pool volume varied in response to local weather events and evapotranspiration (Boix et al. 2004; Brooks 2002, 2004; Bauder 2005; Otto et al. 2007). Bauder (2005) found that hydroperiod, a measure that takes all the above characteristics into account, correlated with precipitation. Differences in hydroperiods are likely the result of clay liners at the created pools but may also result from differences in vegetation and canopy cover, source and connectivity of water, and initial size of the pools.

Hydrologic Connectivity

Groundwater at the natural pools was affected very little or only over a longer period of time in response to a rain event, whereas at the created pools, it responded abruptly. A perched groundwater table is responsible for the continual rise of surface water several days following a precipitation event, but clay pans can cause surface water to remain stable even as the water table declines (Rains et al. 2006). Differences between natural and created vernal pool connectivity of groundwater and surface water

Table 7. ANOVA test results for (1) dip net average individual weight by family and (2) amphibian capture methods of total larval amphibian biomass versus pool type.

				Biomass (g/pool)	
Capture Method	*p*	*f Test*	*df*	*Created*	*Natural*
(1)					
Hylid	0.08	3.44	1	0.2 ± 0.0	0.5 ± 0.0
Ranid	0.32	1.05	1	2.2 ± 0.2	1.2 ± 0.2
Ambystomatid	0.32	1.04	1	0.6 ± 0.0	0.3 ± 0.1
(2)					
Dip net	0.01	8.05	1	2.7 ± 0.0	1.1 ± 0.1
Funnel trap	0.01	11.08	1	3.0 ± 0.1	6.2 ± 0.4

p Values, means, and standard error are reported. $N = 18$ for both created and natural dip net samples and $n = 6$ for both created and natural funnel trap samples. Data are mean ± standard error.

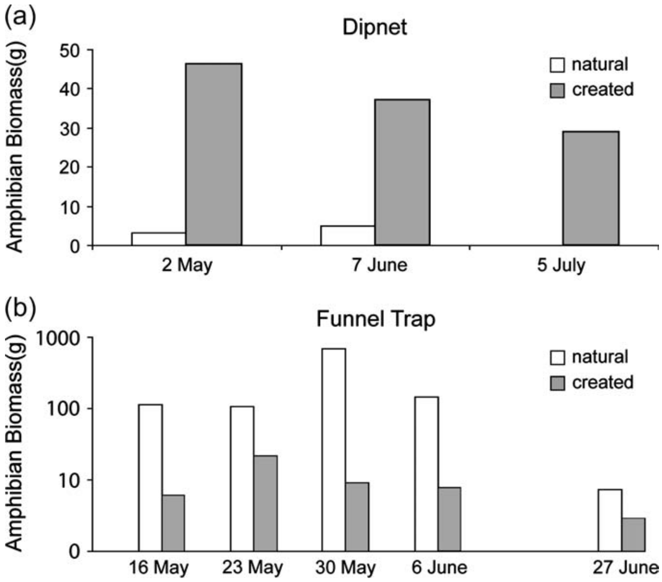

Figure 6. Seasonal total larval biomass for both capture methods: (a) dip netting and (b) funnel trapping. Sample results compare catch of total amphibian biomass in natural and created vernal pools.

are likely the result of an impermeable clay layer lining the created pools and preventing water exchange.

The connectivity between surface water and groundwater in both sets of pools changed over time as a result of precipitation and evapotranspiration. Water seepage flows from surface water to groundwater as long as water can flow and surface water is higher than groundwater (Boone et al. 2006). Underlying perching layers reduce the rate of exchange with underlying aquifers and redirect subsurface water flow horizontally (Rains et al. 2006). In all cases, vernal pools are underlain by low-permeability layers and either surface water or surface water and groundwater is perched above the regional water table (Rains et al. 2006).

Abrupt differences between pool hydroperiods (an abrupt increase in difference) are likely related to leaf out effects (a response to full leaf out) (Brooks 2004). The Gahanna Woods vernal pool complex hosts much more vegetation (especially trees) than the New Albany pools; however, the groundwater levels at New Albany decreased dramatically in May, whereas surface water levels remained stable. Evapotranspiration probably peaked during this time, and plant root systems used water at a faster rate than evaporation affected surface water. During this time, the same events were occurring at the natural pools but because the groundwater and surface water are connected, the decrease in groundwater was replenished by surface water and the surface water decreased. The rapid drop in groundwater with little drop in surface water at the created pools is evidence to support that the ground and surface water are disconnected.

Table 8. Biomass of amphibians in all wetland pools for families and all species combined for amphibian capture methods.

	Biomass (g/pool)	
Species Category	*Dip net*	*Funnel Trap*
Hylid	0.8 ± 0.3	0.9 ± 0.1
Ranid	1.1 ± 0.1	4.2 ± 0.2
Ambystomatid	0.6 ± 0.0	1.6 ± 0.1

ANOVA tests ($p = 0.02$) indicate a significant difference between each species category and the total larval amphibian biomass ($p = 0.00$ for funnel trap samples); and ambystomatid and hylid families are not significantly different, but both are significantly different from ranid biomass. Funnel trap ranid biomass was not significantly different from total larval amphibian biomass. $N = 36$ for all dip net samples and $n = 12$ for funnel trap samples. Data are mean ± standard error.

Physiochemistry

Differences in conductivity may indicate differences in hydrologic source. Low conductivity (<50–100) indicates that precipitation is likely the source. Higher conductivity (more dissociated ions) suggests that the pool is likely receiving surface run-off or groundwater input. If evapotranspiration were the primary water loss from vernal pools then conductivity would increase over time due to evapoconcentration; however, perched groundwater discharge can buffer this effect (Rains et al. 2006). Seasonal increase in conductivity may not have been observed because water volume in the created pools did not decline appreciably, whereas the natural pools may have been buffered by groundwater inputs.

Hourly temperature measurements for both sets of pools suggest a response to solar heating and radiant cooling. The greater daily temperature fluctuation in created pools likely resulted from reduced canopy shading. Groundwater-fed pools are generally cooler and more stable in temperature than pools maintained by precipitation and surface run-off.

Amphibian Family Numbers and Diversity

The composition of families could vary from year to year based on different environmental conditions at each site, and a study done by Werner et al. (2007) found that over a 7-year period, only half of the total species found were present in any given year. Amphibian populations typically fluctuate in response to local weather conditions and predator populations. These data are limited by the small number of families found at each site, and using these methods for any less than 10 groups for diversity calculations should warrant caution in interpretation (Heyer et al. 1994).

Potentially more important than species diversity or evenness when comparing pools are the actual species present. Coefficient of conservatism values have been established for amphibians in Ohio (Micacchion 2002). However, this study is limited in applying those values to analyze either vernal pool complex because organisms were only identified to family. Based on records of species known to occur at each wetland complex, the average coefficient of conservatism is higher at the natural pools than the created pools.

Factors Affecting Total Larval Amphibian Biomass

Canopy cover was not assessed at these vernal pools but likely differed based on estimated forest maturity with the natural pools being more shaded than the created pools. Werner et al. (2007) found that closed canopy ponds contained twice the biomass as open canopy ponds and that biomass and species richness were positively correlated at 11 of 20 pools studied.

Seasonal Shifts in Larval Amphibian Biomass

Different amphibian species breed and metamorphose at different times and rates throughout the season. Temperature and precipitation may influence breeding events and rates of growth. Confounding variables such as time to reach metamorphosis, decrease in body size immediately prior to metamorphosis, and predation could cause a sharp decrease in seasonal biomass.

Differences in Larval Amphibian Capture Methods

The literature contains contradictory recommendations about sampling methods where sometimes funnel traps are preferred (Fennessy et al. 1998) and sometimes dip netting is preferred (Ghioca & Smith 2005). In this study, dip netting seemed to be an effective way to monitor small pools, but in large pools, there may be greater opportunity for escape of larger organisms so funnel traps were more effective. All 12 pools were sampled by dip netting and only 2 were sampled by funnel traps.

Differences Between Amphibian Families and Dominance Effects

Ranids were the dominant contributor to total amphibian biomass when funnel traps were used to sample amphibians. If funnel traps are more likely to catch ranids, and ranids dominate species biomass in these natural pools, then this likely explains the difference that was demonstrated earlier between the total biomass captured by the different sampling methods.

Influence of Pool Volume on Larval Amphibian Biomass

Pool volume may be a more appropriate predictor for amphibian biomass than "natural" or "created" in this dataset. Werner et al. (2007) found that larger pools contain greater species richness, but that pool volume may only be a predictor of amphibian when competition is not a limiting factor. In the pools used for this study, species present in smaller, created pools were a subset of species found in the larger, natural pools. The methodology of correlating biomass directly with pool volume may leave out important information about species richness in each.

Limitations

The results of this study may have limited applicability to other vernal pool systems. Data collection was limited to two complexes of pools and one season of amphibian breeding, growth, and metamorphosis. More pools or a longer time frame may have provided more generalizable results. Previous studies were referenced to augment 2007 data.

The vernal pool complexes studied were representative of other natural and created pools in central Ohio, but results throughout the study suggest that it is unlikely individual pools within the sites were independent. Early spring flooding caused many of the pools at both locations to be connected in surface water. As pools drew down, the pools became independent topically; however, hydrologic data suggest that it is likely some or even all the natural pools are connected by groundwater. This lack of independence may affect physiochemical data.

Unexpected results were obtained by a comparison of trapping methods in this study, suggesting that the primary method (dip netting) was not sufficient for comparing the vernal pool complexes. Additionally, the secondary method was only tested in one natural and one created pool, making it impossible to draw conclusions about amphibian biomass obtained from the two pool types. Finally, comparing sampling methods is difficult because of the many variables that complicate standardization.

Conclusions

After 11 years, the New Albany created vernal pools do not mimic natural hydrology of the Gahanna Woods reference wetlands in connectivity of groundwater and surface water or in seasonal inundation. Three of the six created pools did not dry down before 1 October, and all six of the natural pools dried down completely by mid-July. Connectivity between surface water and groundwater appears to be more pronounced in the Gahanna Woods natural pools compared with the New Albany created pools based on the differences between surface water and groundwater levels, conductivity measurements in the pools, and daily water temperature fluctuations. Daily water temperature, dissolved oxygen, and conductivity were different between the natural and the created vernal pools. These differences are possibly due to differences in canopy cover, nutrient concentrations, landscape, and source of water. When comparing the pools at each site that were sampled by both dip netting and funnel trapping, we found contradictory results. Greater biomass was found in the created pool by dip netting and in the natural pool by funnel trapping; however, funnel traps yielded higher total biomass than dip netting at both sites. These different results might be attributed to pool volume and species evenness. Much greater ranid biomass was captured in both created and natural pools by funnel trapping than dip netting, suggesting that funnel traps are more appropriate for sampling amphibian communities that include these larger tadpoles. The same three amphibian families (hylids, ranids, and ambystomatids) were encountered at both created and natural vernal pools. Distribution of individuals among the three families was found to be more even in community composition in the created pools than in the natural pools. The natural and created pools differed most pointedly in hydrology, and significant differences were also found in water physiochemistry and amphibian composition. Hydrology is the dominant factor in wetland ecosystems (Brooks 2004; Bauder 2005; Mitsch & Gosselink 2007), and without mimicking the drawdown periods of natural pools, the created pools are unlikely to recreate these other characteristics typical of natural vernal pool wetlands.

Implications for Practice

- Clay liners impede groundwater–surface water exchange and increase duration of surface water. They prevent created vernal pools from adequately mimicking seasonal drawdown characteristics, cause wetlands to respond differently to major precipitation events, and consequently influence water physiochemistry.
- Research must be done to develop methods that allow created vernal pools to maintain adequate water levels through spring and early summer while still allowing the pools to draw down completely in late summer or early fall.
- Created pools experienced a broader range of temperatures throughout a 24-hour period than natural pools. This likely resulted from the combined effects of depth and volume, groundwater exchange, and canopy cover differences. Temperature extremes can negatively impact biotic communities, so care should be taken to regulate water temperature in wetland creation projects.
- Amphibian capture methods are likely biased toward different pool types. The created pools that were sampled were smaller and had much less vegetation growing in the pools. Dip netting seemed to more accurately represent the amphibians present in created than natural pools. Funnel trapping caught more of the larger ranid tadpoles than dip netting, particularly in larger pools. Funnel traps captured more total amphibian biomass in both sets of pools than dip netting, were easier to set and collect because they did not require sorting through copious amounts of leaf litter, and typically resulted in lower mortality than dip netting. Funnel traps are recommended for future amphibian collection in vernal pool wetlands.

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