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Physicochemical Characteristics and Benthic Macroinvertebrate Communities in Temporary Surface Waters of Northern Stark County, Ohio

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Abstract: Natural habitats located in urbanized regions are increasingly being impacted by residential, commercial and agricultural development, but little is known about their biotic and abiotic characteristics. Temporary aquatic habitats are less protected by environmental regulations than permanently flooded habitats, and they have been historically understudied. We sampled temporary aquatic habitats including vernal pools, other emergent wetlands and intermittent streams in northeastern Ohio over a two-year period to characterize the macroinvertebrate communities and abiotic characteristics of each habitat type. Duration of inundation of the habitat was the single largest contributing factor to benthic macroinvertebrate community structure. Macroinvertebrate community variability was greater among habitat types than within types suggesting that different habitats type do play a role in selecting for different invertebrate species. Macroinvertebrate abundance and diversity, and functional feeding group patterns differed among seasons. Dissolved oxygen, oxidation-reduction potential and conductivity explained a significant portion of the variability in macroinvertebrate community structure, and these differed among habitat types. Our results suggest that abiotic characteristics have a greater role in determining macroinvertebrate community structure than habitat type.

Keywords: Temporary waters, vernal pool, emergent wetland, intermittent streams, inundation, macroinvertebrates, physicochemical characteristics.

INTRODUCTION

Temporary waters are natural bodies of water that experience a recurrent dry phase [1]. They include large ecosystems such as forested vernal pools, intermittent streams, seasonal limestone lakes and salt marshes, and small ecosystems such as leaf axils, rain puddles, and rock pools. Temporary waters are ecologically important because they contain rare and endemic species that are important to global biodiversity, frequently contain species that are disease vectors, and may provide dispersal routes for some organisms [1,2]. For example, vernal pools in the Pacific region of the United States contain a unique assemblage of macroinvertebrates [3]. Vernal pools are habitat to several species of chirocephalid and streptocephalid fairy shrimp that are listed as threatened or endangered by the United States Fish and Wildlife Service [4]. Although all types of aquatic habitats are impacted by urban development and agriculture, temporary aquatic habitats are more endangered. For example, a recent study found 70% of all headwater stream channels in one urban area have been modified by culverts [5].

Lentic temporary waters are often referred to as ephemeral wetlands, which include vernal pools and emergent wetlands. Emergent wetlands are also known as wet or water meadows and are shallow, low-lying grasslands with saturated soils and standing water at some point during the year. They are usually more shallow (often no deeper than 30 cm in depth) and contain some combination of herbaceous and small woody vegetation. Vernal pools are perhaps the best studied of the temporary waters, and in the eastern United States they usually occur within mesic forests [6]. They are replenished by precipitation and sometimes groundwater [7,8]. Vernal pools are not permanently connected to adjacent lotic systems, but some have temporary surface water outflows during spring snowmelt or heavy precipitation [9]. Temporary lotic habitats are usually termed intermittent streams. Temporary streams are referred to by different names determined by the percent of time that they contain flowing water and presence or absence of a well-defined channel. Intermittent streams have significant flow only during wet times of the year such as times of heavy precipitation or snowmelt [10]. Intermittent streams typically have flowing water 30 – 90% of the time and a well-defined channel [11].

Factors influencing the invertebrate community assemblages of temporary waters include physicochemical characteristics and biotic interactions [1]. Duration of inundation has been reported as the single most important physical

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factor affecting invertebrate assemblages in a variety of temporary waters [12-17]. Different community assemblages can form in temporary waters of short, intermediate, and long duration habitats [12,18]. With increasing duration of inundation total species abundance and richness increases. The diversity of predators also increases [19-21]. Other physical factors that are important are habitat area and volume. Several studies have reported that size is a strong predictor of Odonata, Gastropoda and crustacean richness and numbers in temporary ponds [22, 23]. Others report that duration of inundation, vegetation structure, and habitat size also explains the variation in macroinvertebrate community structure in temporary habitats [15,18,21]. Furthermore, Snodgrass *et al.,* [13] and Baber *et al.,* [19] found a weak correlation of area to hydroperiod suggesting that the effect of several factors may be interrelated.

Key water chemical attributes of temporary waters include turbidity, dissolved oxygen, and pH [24]. For example, pH, conductivity, shading, and presence of predatory salamanders explained a third of the variation in invertebrate community assemblage [25]. However, Spencer *et al.,* [20] suggested that water chemical characteristics may not influence community structure as much as hydroperiod or habitat size because many inhabitants of temporary waters have a broad tolerance to changes in pH and dissolved oxygen.

We examined the following research questions in three common types of temporary aquatic habitats: (1) do invertebrate community structures in intermittent streams, emergent wetlands and vernal pools correlate with physicochemical characteristics of their habitat; (2) what seasonal variability occurs in invertebrate community structure in each habitat type; and (3) do the dominant taxa differ among intermittent streams, emergent wetlands and vernal pools and how does this affect the trophic structure of the invertebrate communities?

MATERIALS AND METHODS

Study Area

We sampled eleven temporary aquatic habitats in Quail Hollow State Park in northeastern Ohio (Stark Co.). Quail Hollow is a 284 hectare site that contains upland forests and meadows, wetlands and small streams. Surrounding land use ranged from urban to recreational and agricultural (Fig. **1**). The area was formerly glaciated and dominant vegetation is mixed oak-maple-beech deciduous forest. Underlying soils are Canfield and Wooster silt loam with pockets of gravelly loam [26].

The three habitat types we sampled included emergent wetlands (EW) (4 sites), intermittent stream reaches (STR) (3 sites), and vernal pools (VP) (4 sites). The emergent wetlands were seasonally flooded by surface flow and had occasionally had inflow and/or outflow channels. Emergent wetland vegetation included *Sphagnum* spp. moss and other bryophytes, grasses, and some shrubs. The streams were

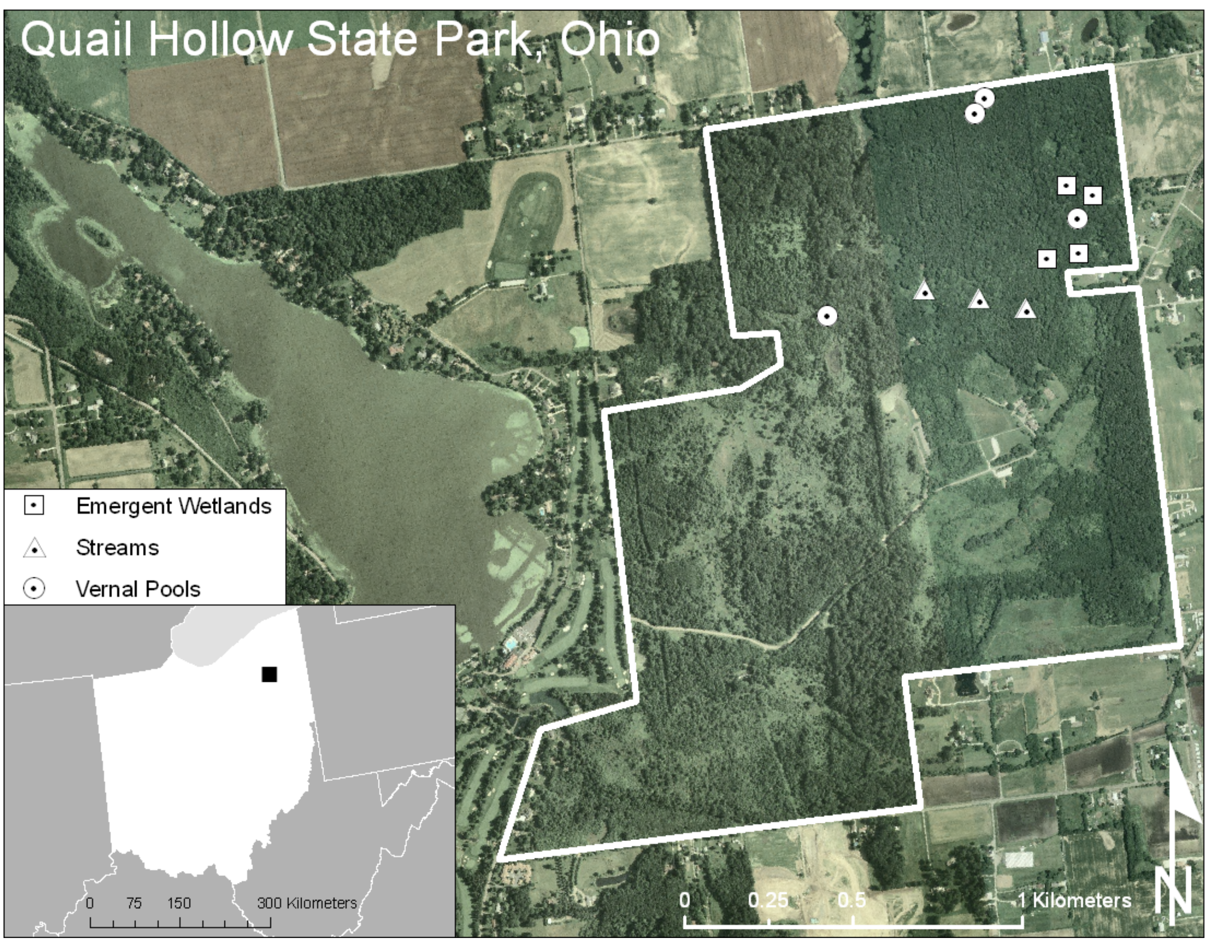

Fig. (1). Quail Hollow State Park (QHSP) outlined on landscape. Approximate location of sampling sites are depicted.

intermittently flooded reaches of low-order, headwater systems. They had a bankfull width of < 2 m, and channel sediments were fine sand and gravel. The vernal pools lacked rooted or emergent vegetation and were flooded by surface flow. They had no visible inflow or outflow channels and thus were hydrologically isolated from nearby streams. All habitat types had 100% canopy cover from deciduous hardwood vegetation (Fig. **1**). Trunk density in the adjacent riparian zones was estimated to be approximately 20% at all sites. Candidate sites were added or subtracted during the course of the study to maintain a balanced design. EW3, STR1, and VP4 were added in Fall 2009 and VP5 was added in Spring 2010. VP2 was eliminated during preliminary data collection and no data appear in this study.

Physico-Chemical Data

The habitats were sampled from November 2008 through May 2010, except for January and February 2009 due to weather. Two pieces of 1 meter length rebar were permanently installed on opposite sides of each emergent wetland or vernal pool. For stream reaches, we installed rebar at opposite ends of a 2-m segment. Water physicochemical sampling was conducted at the midpoint between the rebar pieces to ensure we took measurements at the same location. Physical variables (maximum length, width, and depth of the wetted portion of the habitat) were measured every two weeks with a measuring tape. Water chemistry data were collected biweekly on alternating weeks. Conductivity, pH, salinity, oxidation-reduction potential, and dissolved oxygen were measured with a WTW MultiLine® digital multi-parameter portable meter in the field. Turbidity, nitrate and phosphate were measured in the field using a LaMotte® water monitoring kit. Dry or frozen sites were not sampled.

Benthic Macroinvertebrate Collection and Identification

Benthic macroinvertebrates were sampled biweekly using D-frame dipnets (500 µm mesh) at two locations at each site. Sweep samples were collected adjacent to each rebar and

Table 1. Physical Characteristics of Three Types of Temporary Waters in Quail Hollow State Park OH: Emergent Wetlands (EW), Intermittent Streams (STR) and Vernal Pools (VP). Physical characteristics were measured over several seasons. During each season, sites were visited multiple times. The data presented here is the average value for each given season (standard deviation). In some seasons, we collected a single measurement for certain sites (sites were dry or inaccessible during all but one visit). Certain sites were added at a later time and were not initially sampled (denoted as NS)

	Attribute[a]	FALL 08	SPRING 09	SUMMER 09	FALL09	SPRING 10
EW1	W [m]	20.3 (3.8)	17.2 (0.1)	Dry	Dry	Flooded (sampling impossible)
	D [cm]	47.0 (4.2)	30.0 (1.3)			
	WT [ºC]	6.5 (5.6)	4.2 (2.5)			
EW2	W [m]	5.1 (0.0)	7.1 (1.0)	Dry	Dry	10.2 (3.6)
	D [cm]	13.0 (0.0)	8.0 (0.3)			14.2 (3.0)
	WT [ºC]	13.4 (0.0)	1.3 (0.1)			12.5 (6.4)
EW3	W [m]	NS	NS	NS	48.2 (0.0)	17.8 (0.0)
	D [cm]				44.0 (0.0)	29.0 (0.0)
	WT [ºC]				8.4 (0.0)	6.3 (0.0)
EW4	W [m]	Dry	40.1 (2.3)	34.7 (0.0)	Dry	30.0 (0.0)
	D [cm]		14.3 (3.1)	29.0 (0.0)		27.0 (0.0)
	WT [ºC]		8.3 (3.0)	18.4 (0.0)		6.9 (0.0)
STR1	W [m]	NS	NS	NS	2.7 (0.5)	2.8 (0.4)
	D [cm]				12.8 (2.0)	13.8 (7.5)
	WT [ºC]				9.3 (4.0)	10.4 (3.6)
STR2	W [m]	2.4 (0.2)	2.6 (0.4)	2.3 (0.2)	2.6 (0.4)	2.8 (0.1)
	D [cm]	5.5 (3.5)	10.9 (4.7)	5.9 (1.6)	7.6 (3.6)	16.6 (7.1)
	WT [ºC]	3.7 (3.2)	9.6 (2.5)	21.2 (0.4)	11.0 (5.0)	10.3 (4.2)
STR3	W [m]	2.6 (0.2)	3.4 (1.3)	2.1 (0.1)	2.0 (0.7)	3.6 (1.9)
	D [cm]	11.3 (5.3)	15.9 (11.6)	11.5 (2.1)	7.7 (3.9)	17.0 (11.2)
	WT [ºC]	3.7 (3.6)	9.1 (2.2)	20.0 (0.1)	11.0 (5.4)	10.4 (4.2)
VP1	W [m]	5.3 (0.8)	6.4 (1.1)	5.2 (0.7)	4.5 (0.7)	10.1 (6.3)
	D [cm]	13.0 (0.8)	24.5 (6.8)	19.2 (5.3)	15.9 (1.9)	20.5 (8.2)
	WT [ºC]	3.8 (5.3)	8.6 (3.1)	18.3 (1.0)	12.2 (4.6)	10.7 (4.4)
VP3	W [m]	12.7 (1.0)	13.6 (0.9)	12.6 (1.5)	12.2 (1.6)	22.5 (12.0)
	D [cm]	40.0 (0.1)	43.0 (9.9)	58.5 (19.7)	61.0 (17.8)	52.2 (5.1)
	WT [ºC]	9.9 (5.6)	7.3 (3.6)	18.2 (1.7)	10.5 (3.9)	11.8 (6.4)
VP4	W [m]	NS	NS	NS	33.7 (0.0)	31.0 (21.6)
	D [cm]				13.0 (0.0)	51.6 (22.4)
	WT [ºC]				6.0 (0.0)	10.2 (2.4)
VP5	W [m]	NS	NS	NS	NS	19.0
	D [cm]					53.1
	WT [ºC]					9.5

[a] – W = width, D = depth, WT = water temperature.

combined. All benthic macroinvertebrates were sorted and identified in the lab under a dissecting microscope with 10-50 X magnification. Benthic macroinvertebrates were identified to lowest practical taxonomic unit, which was usually to family level. McCafferty [27], Voshell [28] and Merritt *et al.,* [29] were used for insect identification. Peckarsky *et al.,* [30] was used to identify non-insect organisms. All invertebrate nomenclature is compatible with USDA's Integrated Taxonomic Information System – North America (ITIS) [31]. Insects were assigned to functional feeding groups according to Merritt *et al.* [29], and non-insect invertebrates according to Voshell [28] and Barbour *et al.* [32].

Statistical Analyses

All statistical analyses were performed in the statistical package R (http://www.r-project.org/). We collected data in our 11 sites during 1.5 years, but many sites were dry or frozen on some dates due to the temporary nature of these systems. We pooled our invertebrate (numbers were added) and physicochemical data (numbers were averaged) collected on different dates into Fall 2008, Spring, Summer, Fall, Winter 2009 and Spring 2010.

We used ANOVA to compare the richness of invertebrate families across habitat types only in Fall 2009 and Spring 2010 when all sites were flooded. When the ANOVA was significantly different, we applied Tukey's test to test pairwise comparisons among habitat types. We also used multivariate statistics that were not impaired by the large number of missing data points at each site. We used Principle Component Analysis (PCA) to visualize differences in water chemical parameters at our sites. Principle Coordinate Analysis (PCoA) was employed to visualize differences between invertebrate communities. For the PCoA analysis, we used family-level presence/absence data and Jaccard distances between sites. Finally, Canonical Correspondence Analysis examined the relationship between chemical parameters of sites and their invertebrate communities. The function *adonis* in the statistical package R was applied to perform a non-parametric permutational MANOVA to compare the invertebrate communities in different habitat types and during different seasons [33,34]. *Adonis* partitions the sums of squares of distances in a distance matrix based on pre-defined groups and calculates the significance of the grouping by performing multiple permutations of the data and constructing a pseudo-F distribution.

RESULTS

Physico-Chemical Characteristics

Some of the sites in our study were never fully dry or frozen over the course of the study. Notably, vernal pools never dried during the study period. Two vernal pools (VP1, VP3) were frozen 60% and 100% of the time, respectively, during the winter of 2008. The other two vernal pools (VP 4 and VP5) were not frozen. In contrast, all emergent wetland were the most consistently dry or frozen habitat, providing the shortest period of inundation. All emergent wetlands

Table 2. Chemical Characteristics of Three Types of Temporary Waters (Emergent Wetlands (EW), Intermittent Streams (STR) and Vernal Pools (VP)) in Quail Hollow State Park OH. Chemical Characteristics were Measured in Fall of 2009 and Spring of 2010. During each Season, Sites were Visited Multiple Times. The Data Presented here is the Average Value for each given Season (Standard Deviation). EW4 was dry during the fall of 2009. EW2 and VP5 were added to the study in Spring 2010 and were not sampled (NS) during Fall 2009. Dissolved oxygen was not measured (ND) in VP5 in Spring 2010 due to meter malfunction. In some seasons, we collected a single measurement for certain sites (sites were dry or inaccessible during all but one visit). In those cases standard deviation is marked as (0.0)

	Season	pH	Conductivity [µS cm^{-1}]	Redox potential [mV]	Dissolved oxygen [mg L^{-1}]	Dissolved O_2 saturation [%]	Turbidity [JTU]	Dissolved phosphate [mg L^{-1}]
EW2	F09	NS	NS	NS	NS	NS	NS	NS
	S10	6.5 (0.2)	91.3 (36.0)	1.3 (64.6)	3.2 (0.6)	33.3 (0.4)	17.5 (5.0)	0.9 (1.0)
EW3	F09	5.2 (0.1)	160.5 (16.3)	122.5 (20.5)	0.8 (0.3)	7.8 (3.0)	0.0 (0.0)	0.0 (0.0)
	S10	7.4 (0.0)	29.0 (0.0)	-85.0 (0.0)	3.73 (0.0)	31.6 (0.0)	5.0 (0.0)	0.3 (0.0)
EW4	F09	Dry	Dry	Dry	Dry	Dry	Dry	Dry
	S10	8.4 (0.0)	74.0 (0.0)	-10.0 (0.0)	3.9 (0.0)	42.0 (0.0)	30.0 (0.0)	0.5 (0.0)
STR1	F09	6.9 (0.2)	293.7 (27.3)	20.3 (11.0)	9.4 (1.8)	84.9 (20.8)	1.7 (2.9)	0.0 (0.0)
	S10	7.5 (0.5)	215.6 (17.1)	-51.0 (90.0)	11.6 (1.6)	110.2 (13.0)	8.3 (6.8)	0.3 (0.4)
STR2	F09	7.3 (0.4)	292.3 (27.1)	5.8 (18.19)	7.0 (4.0)	71.5 (24.9)	17.0 (17.9)	0.2 (0.5)
	S10	8.2 (0.8)	116.5 (213.9)	-47.8 (63.3)	12.6 (0.9)	118.9 (9.4)	13.0 (12.0)	1.1 (1.3)
STR3	F09	7.3 (0.2)	292.7 (28.0)	-14.0 (11.5)	6.4 (3.1)	66.0 (18.9)	3.0 (4.5)	0.2 (0.5)
	S10	8.1 (0.5)	148.8 (153.0)	50 (153.0_	10.9 (4.0)	102.8 (46.0)	10.0 (10.0)	0.9 (1.0)
VP1	F09	6.3 (0.7)	103.0 (43.0)	66.0 (29.6)	2.8 (2.5)	11.4 (2.7)	13.3 (13.7)	0.7 (1.0)
	S10	6.6 (0.7)	41.2 (6.8)	33.4 (18.9)	3.62 (0.7)	33.9 (5.5)	29.2 (32.9)	0.4 (0.8)
VP3	F09	6.1 (0.5)	250.3 (161.0)	59.0 (36.4)	1.5 (0.3)	12.4 (1.8)	22.0 (43.9)	0.4 (0.9)
	S10	6.0 (0.4)	72.0 (13.3)	-40.8 (18.8)	3.9 (1.3)	38.1 (4.1)	14.0 (7.5)	1.3 (1.7)
VP4	F09	6.6 (0.0)	107.0 (0.0)	32.0 (0.0)	2.3 (0.0)	19.2 (0.0)	0.0 (0.0)	0.0 (0.0)
	S10	7.3 (0.3)	472.3 (44.6)	10.7 (16.2)	4.5 (0.0	55.8 (0.0)	13.8 (7.5)	0.0 (0.0)
VP5	F09	6.5 (0.0)	369.0 (0.0)	34.0 (0.0)	4.8 (0.0)	38.2 (0.0)	0.0 (0.0)	0.0 (0.0)
	S10	7.2	165.3 (17.2)	-18.0 (35.3)	ND	ND	15.0	0.0 (0.0)

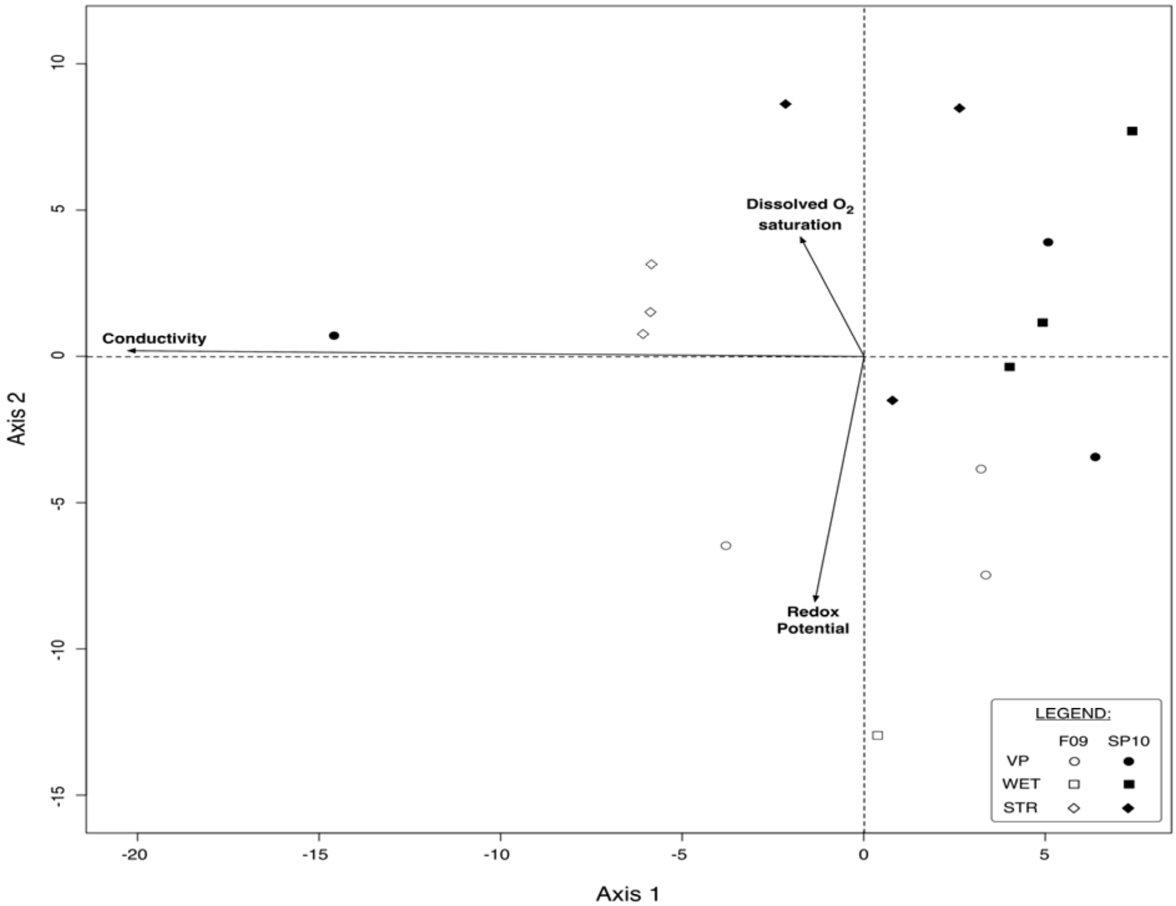

Fig. (2). Principle component analysis of chemical characteristics in three temporary waters (emergent wetlands (EW), intermittent streams (STR) and vernal pools (VP) in Quail Hollow State Park, OH. Chemical characteristics were measured in Fall of 2009 and Spring of 2010. During each season, sites were visited multiple times. For each site, values recorded during a season were averaged and used in the ordination. Numbers in parentheses indicate the percent variation explained by the corresponding principle component.

were dry in summer and fall 2009 (Table **1**). All emergent wetlands were frozen during Fall 2008 and Winter 2008 and 2009. Stream sites were often under low-flow conditions with isolated pools partially dry or frozen at certain sample times. All stream sites were completely dry 40% of the time during Summer 2009 and dry 13% of the time during Fall 2009. Intermittent streams were intermediate between the other habitat types in terms of period of inundation.

Temporary aquatic habitats in Quail Hollow Park exhibited considerable variability in physical characteristics (Table **1**). Maximum width, length and depth varied considerably in all habitat types (Table **1**). Stream sites had similar physical attributes on all dates, but wetland and vernal pool sites exhibited considerable variability within seasons. Emergent wetlands, when present were the widest sites, yet usually 30 cm or less deep. Vernal pools were generally deeper than emergent wetlands. Water temperature varied with season, but was similar among habitat types.

In fall 2009 and spring 2010, water chemical characteristics had patterns similar to those observed for physical attributes (Table **2**). Principle component analysis of the chemical data also revealed stream sites had relatively uniform water chemistry while emergent wetlands and vernal pool sites were more variable (Fig. **2**). The PCA ordination also showed clear seasonal changes in chemical characteristics of all habitat types. Stream sites exhibited higher dissolved oxygen saturation and pH, and lower redox potential and turbidity than the other two habitat types. Vernal pools and emergent wetland sites appeared to overlap in their water chemistry properties (Fig. **2**).

Invertebrate Communities

Overall we identified 64 invertebrate families across all sites and seasons (Appendix **1**). Invertebrate family richness varied among the three types of temporary aquatic habitats and among seasons. The highest richness in all sites was in Spring 2010 (mean number of families ± SE across all sites: 13.7 ± 1.7). During winter and summer months many of the sites were dry or frozen, and therefore did not have active aquatic invertebrates. Most sites had some water in Fall 2009 and Spring 2010, and we used ANOVA to compare family richness on these dates. ANOVA indicated that both season and habitat type exhibited different richness, and there was no significant Season X Habitat Type interaction (habitat type: $F=4.8$, $p<0.05$; season: $F=17.1$, $p<0.01$). All habitat types had higher family richness in the spring (13.7 ± 1.7 (SE)) than in the fall (6.3 ± 1.4 (SE)). Vernal pool habitats had significantly higher richness (13.2 ± 2.6 (SE)) than

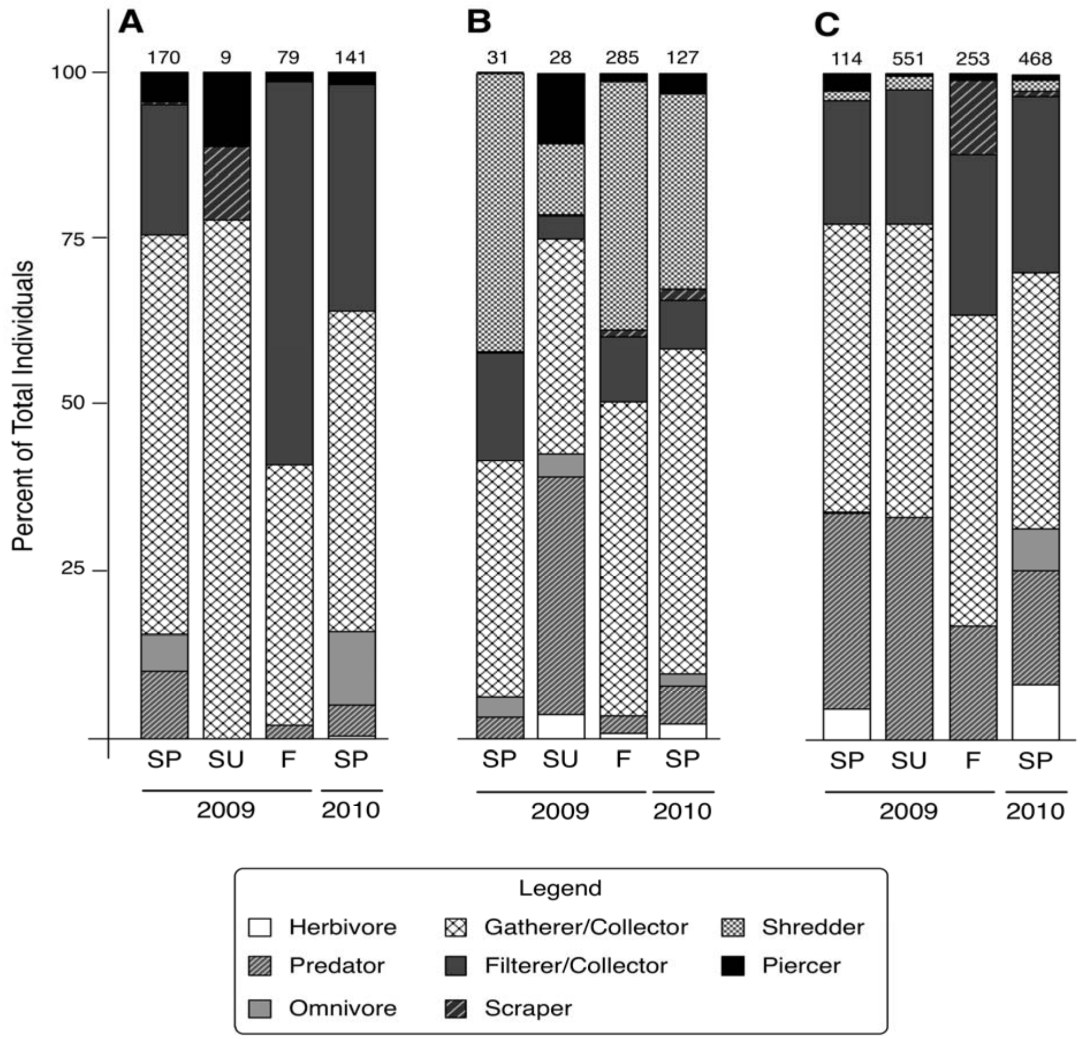

Fig. (3). Distribution of feeding functional groups of invertebrates in three temporary waters during Fall 2009 and Spring 2010 sampling seasons: emergent wetlands (**A**), intermittent streams (**B**), and vernal pools (**C**). Invertebrates were monitored over several seasons. Sites were visited multiple times during each season. For each season and site, the invertebrate data was pooled by families, which were then classified into one of eight functional groups. Numbers on top of the bars represent the total number of invertebrates found at all sites of a specific habitat type during a particular season.

emergent wetland habitats (6.2 ± 1.6 (SE)), and intermittent streams had intermediate richness (10.7 ± 2.4 (SE)).

The three temporary aquatic habitats had also markedly different proportions of functional feeding groups in 2009 and 2010 (Fig. **3**). Emergent wetlands were always dominated by gatherer/collectors and filterer/collectors, which made up more than 75% of the invertebrates at all sampled dates. In contrast, streams and vernal pools exhibited more diverse functional assemblages and the proportions changed among dates. Streams were dominated by gatherer/collectors and shredders, and predators became common only in summer 2009. Vernal pools were consistently dominated by gatherer/collectors, filterer/collectors, and predators. Scrapers were only common in emergent wetland and vernal pools in summer 2009 and fall 2009, respectively. The dominant trophic group did not change with season, but the functional feeding group or dominant taxon did (e.g. gatherer-collector and filterer-collector functional feeding groups are both detritivores.) In addition, the relative dominance of functional feeding groups changed with season. Vernal pools consistently had higher biodiversity and more functional feeding groups. In vernal pools predators comprised a greater percentage of the community than the other two habitats.

Several invertebrate families were consistently dominant across multiple sites and seasons (Table **3**). Asellidae, sphaeriids, oligochaetes, culicids were the most common taxa in emergent wetlands. Lestid damselflies were found only in emergent wetlands. In streams, chironomids, siphlonurids, leuctrids, nemourids, and cyclopoid copepods were the most abundant taxa. Leptophlebiids, capniids, cambarids, elaterids, *Daphnia*, elmids and conchostracans were found only in streams. Vernal pools were more diverse and had asellids, cyclopoid copepods, sphaeriids, planorbids, hydrophilids, pleurocerids, chirocephalids as dominant taxa. Chirocephalids and corydalids were found only in vernal pools.

We visualized overall patterns of invertebrate communities across seasons and habitat types with PCoA, which

Table 3. Dominant Invertebrate Families in Three Temporary Waters (emergent wetlands (EW), intermittent streams (STR) and vernal pools (VP)) in Quail Hollow State Park OH. Invertebrates were sampled over several seasons. Each season, sites were visited multiple times and at the end of the season invertebrate numbers were summed up. In some sites, excessive flooding did not allow sampling of invertebrates during certain seasons. Some sites were subsequently added to the study and were not sampled (NS) during some of the early seasons

	SPRING 09	SUMMER 09	FALL09	SPRING 10
EW1	Asellidae (96%)	Dry	Dry	Flooded
EW2	Culicidae (46%)	Dry	Sphaeriidae (91%)	Culicidae (48%)
EW3	Flooded	Flooded	Oligochaeta (77%)	Asellidae (50%)
EW4	Asellidae (34%)	Asellidae (78%)	Sphaeriidae (68%)	Culicidae (38%)
STR1	NS	NS	Chironomidae (54%)	Siphlonuridae (35%)
STR2	Nemouridae (26%)	Cyclopoida (29%)	Sphaeriidae (28%)	Leuctridae (29%)
STR3	Dry	Dry	Chironomidae (60%)	Siphlonuridae (22%)
VP1	Cyclopoida (23%)	Cyclopoida (57%)	Sphaeriidae (59%)	Chirocephalidae (27%)
VP3	Asellidae (63%)	Asellidae (71%)	Planorbidae (47%)	Sphaeriidae (33%)
VP4	NS	NS	Asellidae, Hydrophilidae, Pleuroceridae (each 33%)	Chironomidae (26%)
VP5	NS	NS	NS	Chironomidae (30%)

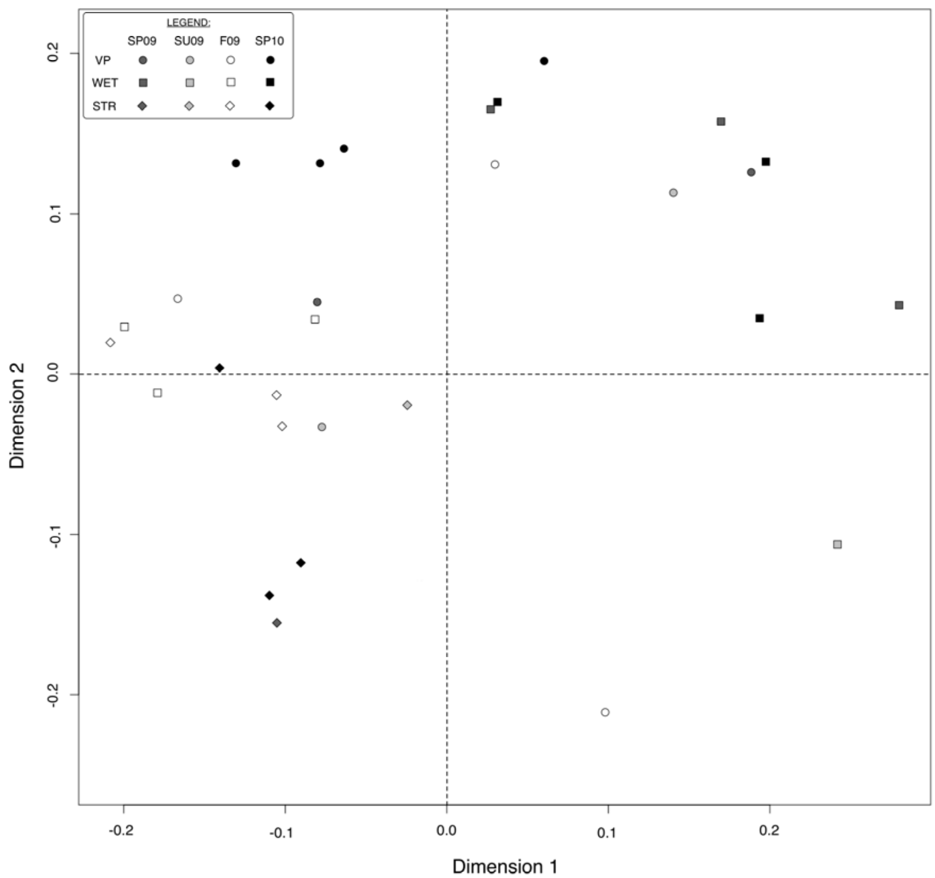

Fig. (4). Principle Coordinates Analysis of invertebrate families found in three temporary waters (emergent wetlands (EW), intermittent streams (STR) and vernal pools (VP)) in Quail Hollow State Park, OH. Invertebrates were monitored over several seasons. Sites were visited multiple times during each season. For each season and site, the invertebrate data was pooled by families and subsequently used in the PCoA.

showed that the three types of temporary surface waters harbor distinct invertebrate communities (Fig. **4**). However, there was considerable variability between sites of the same type. Permutational MANOVA indicated that there were significant differences between habitat types and across seasons (effect of season F=1.8, r^2=0.1, $p<0.01$; effect of site type F=2.5, r^2=0.13, $p<0.001$). The low r^2 values suggest that groupings of sites by type and/or season, while significantly different, were not well defined.

Relationship between Water Chemistry and Invertebrate Communities

We explored the relationship between water chemistry and invertebrate taxa using canonical correspondence analysis. Only data from Fall 2009 and Spring 2010 was used because at those times, almost all sites had water. Intermittent stream sites were clearly separated from vernal pool and emergent wetlands sites by the CCA ordination. In addition, all three habitat types were separated by season (Fig. **5**). The most important chemical attributes that correlated with invertebrate communities were dissolved oxygen, pH, turbidity, dissolved phosphorus, conductivity and redox potential. Streams had higher dissolved oxygen and pH, and lower turbidity and redox potential than the other two habitat types. Turbidity and dissolved phosphate were higher in all habitat types in spring, and conductivity was higher in fall. CCA revealed that many invertebrate families respond differently to variations in the chemical properties of water. For example, members of Asellidae and Planorbidae were mostly found at sites with low dissolved oxygen and pH, while members of Cladocera and Chaoboridae appeared to be correlated with higher levels of turbidity and dissolved phosphate (Fig. **5**).

DISCUSSION

It is difficult to make generalizations about the physical characteristics maximum width, length and depth, of

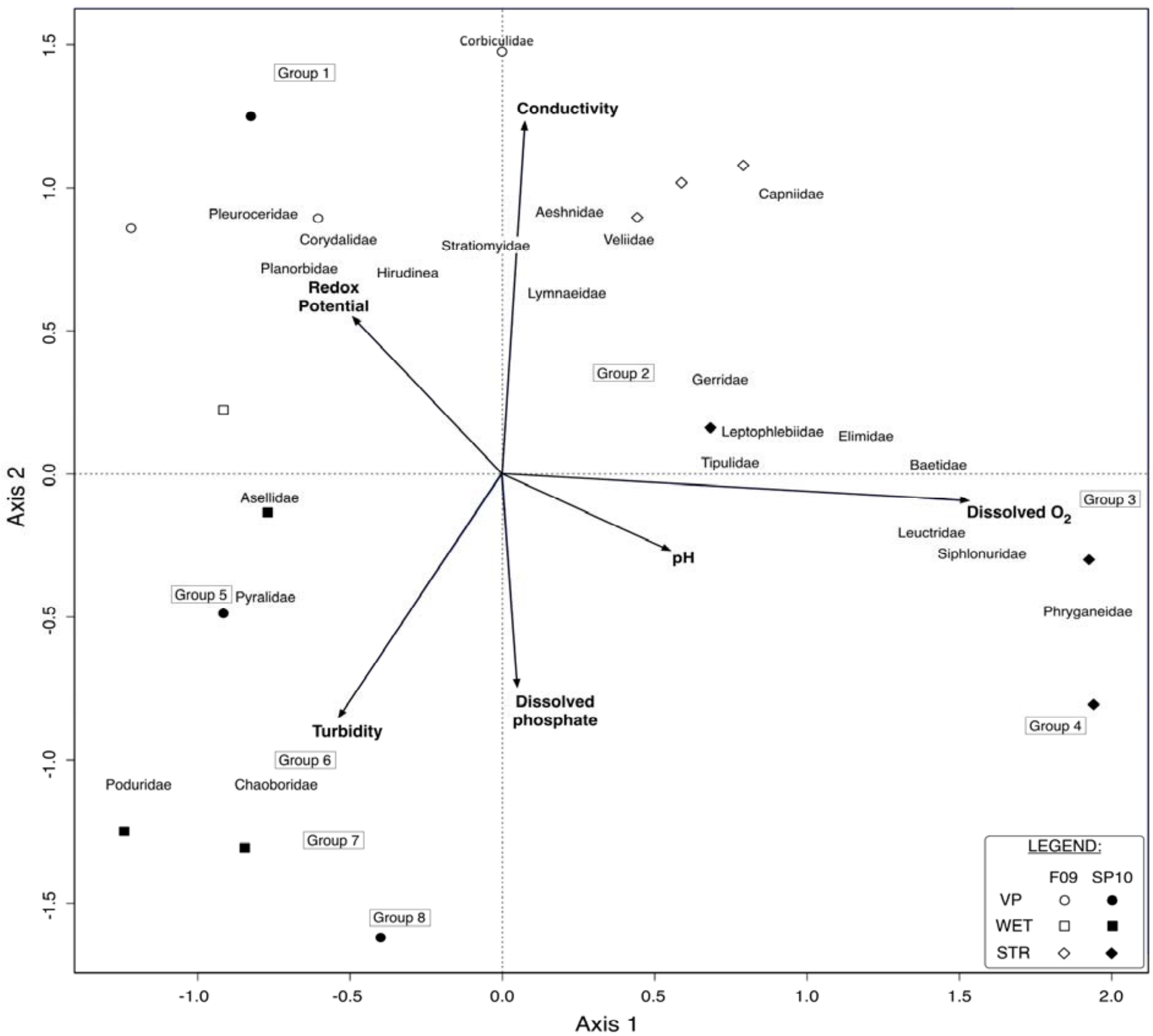

Fig. (5). Canonical correspondence analysis of invertebrate communities in three temporary waters (emergent wetlands (EW), intermittent streams (STR) and vernal pools (VP)) in Quail Hollow State Park, OH. The ordination of sites and invertebrate families was constrained by an environmental matrix consisting of chemical parameters of the water at the sites. Data from the Fall of 2009 and Spring of 2010 was used in the ordination. See Figs. (**2** and **4**) for an explanation of data collection and processing. Certain invertebrate families had identical coordinates on the bi-plot and are represented in groups as follows. Group 1: Amphizoidae, Libellulidae, Pentatomidae, and Sphecidae; Group 2: Conchostraca, Sialidae, and Tortricidae; Group 3: Corixidae and Elateridae; Group 4: Cosmopterigidae and Dolichopodidae; Group 5: Ceratopogonidae, Curculionidae, Eylaoidea, and Lestidae; Group 6: Cladocera and Helodidae; Group 7: Chelodidae, Lepidostomatidae, and Staphylinidae; Group 8: Chirocephalidae, Cyclopoida, and Tabanidae.

temporary aquatic habitats in Quail Hollow Park due to considerable variability. Water temperature was the most consistent across habitat types. It varied seasonally, but was similar among habitat types, possibly because all sites are relatively shallow and small, thus responding in similar fashion to diurnal temperature fluctuations. Intermittent stream reaches had similar physical attributes on all dates, but wetland and vernal pool sites exhibited considerable variability within seasons. Similar results are reported by Williams [1].

Stream water chemistry differed from both vernal pools or emergent wetlands. It is not surprising that lotic water chemistry differed from the two lentic habitats. With sufficient stream flow there would be higher concentrations of dissolved oxygen and lower turbidity. Turbidity and dissolved phosphate were higher in all habitat types in spring, and conductivity was higher in fall. These seasonal increase in turbidity and dissolved phosphate likely corresponds to spring snow melt and rains, which would transport soil and dissolved particles into the habitats. Fall conductivity increases likely correspond to leaf abscission from the deciduous trees adjacent to all sites. This idea is bolstered by the stream reaches having the highest density of adjacent trees and the highest conductivity. The streams also receive leaf inputs from upstream sources. Our results are mostly consistent with Spencer *et al.* [20] that suggested water chemical characteristics may not influence community structure as much as hydroperiod or habitat size. The benthic macroinvertebrate community structure appears to be responding more strongly to length of inundation rather than differences in water chemistry.

Vernal pools had the longest periods of inundation. No vernal pool dried out during the study and two were frozen part of the time during one winter season. This is consistent with reports that in some ecosystems vernal pools completely dry out only in years with less than normal precipitation [35].

Benthic macroinvertebrate community structure in temporary waters at Quail Hollow State Park follows patterns predicted by patch dynamics theory. Patch dynamics theory predicts that in dominance-controlled communities such as temporary waters, diversity starts out low, as opportunistic, early successional species colonize the patch, and diversity later increases during mid-succession as more species invade each patch. In the late-succession stages, diversity can decline again as the most efficient competitors exclude all other species. If all invading species are good colonizers and are roughly equivalent in their ability to invade patches and survive abiotic conditions, a founder-controlled community is observed. In those cases, theory predicts that patches will be inhabited by a random assemblage of species [36-38].

Our results are mostly consistent with those of previous studies. Lake *et al.* [39] found when the period of inundation is long enough community succession occurs in three phases where the dominant functional group changes over time. Detritivores dominate first, then the community shifts to slow-growing primary consumers, and finally predators become more abundant, but not necessarily dominant. In the absence of fish, larval amphibians and/or predatory macroinvertebrates are the top predators. Vernal pools and other short-duration temporary waters are considered to be predator-reduced habitats due to the absence of fish [3] and lack of time for amphibian and macroinvertebrate predators to achieve high densities [14,25]. However, in our study the vernal pools always contained water and thus had sufficient time for predators to achieve high densities relative to the rest of the populations. Several previous studies have reported a similar increase in predators with increases in the period of inundation [19-21].

All sites had a high percentage of detritivores. Patch dynamics theory predicts that these organisms would recolonize the habitats first after dry-off. In our study the detritivores, gatherer-collectors and filterer-collectors were the dominant groups at all sites during all seasons.

Shredders were collected in large numbers only from the intermittent streams and were completely absent from emergent wetlands. Spatial orientation of the trees likely played a role in the presence of shredders. The trees were directly adjacent to the stream channel, but were only adjacent to the wetted portion of the vernal pools and emergent wetlands at times when they were near maximum inundation. Given the size of the emergent wetlands and only herbaceous vegetation and shrubs within them, it is possible that leaf litter might be more concentrated at the site edges. In contrast, in streams, leaf litter could also be carried to the stream sampling spots from additional upstream sources.

The invertebrate communities exhibited little endemism, and was dominated primarily by widespread taxonomic groups. Vernal pools contained chirocephalids, or fairy shrimp, which are found only in vernal pools in Ohio [35]. Vernal pools were also the only habitat of corydalid fishflies. While not endemic, they have little tolerance for pollution [32] and the hydrologic isolation of the vernal pools may provide superior habitat than the others. Most groups in this study that were unique to streams and emergent wetlands have been reported in vernal pools in Ohio [35,40] or elsewhere [27,28]. Two exceptions are the capniid stoneflies and elmid beetles, which are almost exclusively found in or near cool streams.

These vernal pools in this study contain few rare and endemic species, but those present are strongly impacted by period of inundation and water chemistry; which in turn is affected surface runoff. These two factors have strong conservation implications. Changes in nearby land use could potentially severely and irreparably alter these habitats. Urbanization, which is a potential threat to these site and many others, can result in an increase or decrease of water inputs. Either action would change the disturbance regime and duration of inundation. This is a likely outcome given current development trends and since the lentic habitats are no longer protected by the 1977 Clean Water Act.

CONCLUSIONS

The results of this study provide evidence that endemic environmental conditions play a greater role in determining macroinvertebrate community structure than habitat type. There was considerable variation of environmental conditions within habitats. Duration of inundation, or conversely, the interval between disturbance (dry-off) is the largest single determinant of the benthic macroinvertebrate community in temporary waters. Diversity increased across all habitats in response to increasing duration of inundation. Water chemistry also explains a large portion of the variation in macroinvertebrate community structure. Biodiversity does differ with habitat type, but there is wide variability within habitats. The benthic macroinvertebrate community structure varies on a seasonal basis across all habitat types. These results also suggest that these temporary waters could be significantly altered by changes in nearby land use.

CONFLICT OF INTEREST

None declared.

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Appendix

Appendix 1. Presence/absence of invertebrate taxonomic groups in vernal pools (VP), emergent wetlands (WET) and intermittent streams (STR), located in Stark County, Ohio at different seasons spanning 2009-2010. (X) Denotes presence of taxonomic group.

Taxonomic Group	Spring 2009			Summer 2009			Fall 2009			Spring 2010		
	VP	WET	STR	VP	WET	STR	VP	WET	STR	VP	WET	STR
Collembola : Poduridae		X										
Coleoptera : Amphizoidae										X		
Coleoptera : Dytiscidae	X	X		X	X	X				X		X
Coleoptera : Elateridae												X
Coleoptera : Elmidae									X			
Coleoptera : Hydrophilidae	X	X		X			X					X
Coleoptera : Scirtidae										X	X	
Diptera : Chaoboridae	X	X									X	
Diptera : Chironomidae	X	X		X		X	X		X	X		
Diptera : Culicidae	X	X		X				X			X	
Diptera : Dolichopodidae												X
Diptera : Simuliidae			X							X		
Diptera : Stratiomyidae										X		
Diptera : Tabanidae						X				X		
Diptera : Tipulidae		X		X								
Ephemeroptera : Siphlonuridae		X	X									X
Ephemeroptera : Leptophlebiidae			X									
Hemiptera : Gerridae							X		X			X
Hemiptera : Pentatomidae										X		
Hemiptera : Veliidae							X					
Hymenoptera : Icheneumonidae		X										
Lepidoptera : Noctuidae										X		X
Lepidoptera : Pyralidae										X		
Megaloptera : Corydalidae	X						X			X		
Odonata : Aeshnidae							X		X			
Odonata : Lestidae					X							
Odonata : Libellulidae		X				X						

(Appendix 1) Contd…..

Taxonomic Group	Spring 2009			Summer 2009			Fall 2009			Spring 2010		
	VP	WET	STR	VP	WET	STR	VP	WET	STR	VP	WET	STR
Plecoptera : Capniidae			X						X			
Plecoptera : Leuctridae									X			
Plecoptera : Nemouridae			X			X			X	X		X
Plecoptera : Perlidae		X					X					
Pleocoptera : Perlodidae										X		
Trichoptera : Brachycentridae		X										
Trichoptera : Limnephilidae		X	X							X	X	X
Trichoptera : Phryganeidae	X					X						
Decapoda : Cambaridae						X						
Isopoda : Isopoda		X		X	X	X	X			X		
Amphipoda : Amphipoda						X		X				X
Anostraca : Chirocephalidae	X									X		
Conchostraca : Conchostraca									X			
Cyclopoida : Copepoda	X	X		X		X						
Cladocera : Daphniidae									X			
Isoptera : Isoptera						X						
Veneroida : Sphaeridae	X			X			X		X	X		
Veneroida : Corbiculidae	X			X			X					
Bassommatophora : Planorbidae	X			X		X	X			X		
Bassommatophora : Lymnaeidae												X
Hirudinea : Hirudinea	X	X	X				X			X		
Oligochaeta : Oligochaeta	X			X			X			X		X

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