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The Impact of Urbanization on Water and Sediment Chemistry of Ephemeral Forest Pools

ABSTRACT

We compared the water and sediment composition of two ephemeral pools located in forested settings in a developed suburban area with two similar pools located in extensive forest in Massachusetts. We also compared the macroinvertebrate communities. The sediments of the forest pools were 100% organic material, while those of the urban pools were predominantly silt. The sediments of the urban pools were contaminated with elevated levels of barium, chromium, and lead. The water of the urban pools had higher pH, conductivity, and alkalinity and less dissolved oxygen than did the forest pools. Both urban and forest pool macroinvertebrate communities were dominated by Oligochaeta and Chironomidae, and while we expected to find differences in the macroinvertebrate communities, no commonly used metric or index clearly indicated differences. More extensive surveys of urban and reference pools may lead to the development of invertebrate biomonitoring protocols for ephemeral forest pools.

Urban development has affected considerable area of forestland in the northeastern United States, and urbanization likely affects ephemeral forest pools by altering their hydrology and increasing the amount and type of contaminants in surface runoff. While the effects of residential, commercial, and industrial development on lotic systems have been widely studied and standard protocols for assessing disturbance effects are widely accepted and implemented (Barbour et al. 1999), the effects on ephemeral pools are mostly unknown and there are no standard protocols. We characterized the differences in sediment and water physicochemistry between two ephemeral pools located in an urban area and two in a forested region, with the objective being to determine if differences existed in the benthic macroinvertebrate communities. The urban pools were located in forested settings in predominantly residential and commercial areas while the forest pools were within an extensive forest. Both sites were in Massachusetts.

Triplicate core samples were taken 20 cm into the substrate of each pool. Samples were composited and analyzed for arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver using inductively coupled plasma-atomic emission spectroscopy. Mercury was measured by cold vapor atomic absorption spectrophotometry. Organic matter content was measured by loss on ignition. Grain size of mineral sediments was determined by sedimentation analysis. Aquatic macroinvertebrates were sampled using both leaf-pack artificial substrates and dip nets. Leaf packs were constructed from leaf litter gathered in the adjacent catchment to each pool, and three leaf packs were placed at five sites in each pool as soon as ice melted from the pools. A set of five leaf packs was removed from each pool in April, May, and July from each location that was still inundated. Dip-net samples were taken at three random locations within each pool in April, May, and July. Invertebrate specimens were sorted, identified to the lowest practical classification using Merritt and Cummins (1995) and Smith (1991), and enumerated by taxa.

Water chemistry was assessed at the time of macroinvertebrate surveys. Dissolved oxygen (DO), conductivity, and temperature were measured using a YSI meter. Alkalinity and pH were measured with HACH kits from a grab sample.

Macroinvertebrate indices and metrics were calculated separately for leaf-pack and dip-net samples. Diversity (D') was calculated according to Margalef (1968). Similarity between pools was assessed with Jaccard's (IS_J) index for taxa presence and Ellenberg's (IS_E) modification for taxa abundance (Muller-Dombois and Ellenberg 1974). Other metrics and indices included total richness, abundance, and diversity, EOT (Ephemeroptera, Odonata, and Trichoptera) richness as well as percent composition of major taxa, of EOTs, and of predators, family biotic index, the community taxa similarity index, and the community trophic similarity index. Functional trophic group and tolerance classifications used in the calculation of the indices came from Hicks and Nedeau (2000), which combined the trophic and functional feeding groups of Merritt and Cummins (1995). Macroinvertebrate indices and metrics were analyzed using the Friedman's Test (X^2), a nonparametric randomized block or repeated-measures analysis of variance (Marascuilo and McSweeney 1977, Zar 1996).

Metal concentrations in urban-pool sediments were generally greater than those in forest-pool sediments (Table 1). The sediments of the forest pools were composed of 100% organic matter, whereas those of the urban pools were dominated by silt, with variable amounts of sand and clay. Generally the temperature, pH, alkalinity, and conductivity of urban-pool water were greater than those measured in the forest pools. Dissolved oxygen concentrations were greater in the forest pools, although the difference disappeared by July.

We had expected that urbanization adjacent to ephemeral forest pools would result in a decrease in overall macroinvertebrate diversity and other richness measures and in differing responses of individual taxa or functional trophic groups, based on their tolerance to habitat degradation. However, there were minimal differences in the aquatic invertebrate communities between the urban and forest pools (Table 1). The only significant ($p \leq 0.05$) differences were in the percent of oligochaetes and chironomids, which comprised a greater component of the urban samples. The differences in pool hydroperiod among the four pools appear to have had greater effects on the composition of the invertebrate communities than did the effects due to urbanization. Community taxa and trophic similarity indices, using leaf-pack samples, indicated a significant difference between urban and forest pools and the difference was due to the singular dominance of oligochaetes in the urban pools and the paired dominance of oligochaetes and chironomids in the forest pools. However, these differences were obscure in the dip-net samples. Furthermore, the ephemeral nature of the pools results in natural eutrophication, with concentration of nutrients and minerals, increase in temperature, and reduction of dissolved oxygen. Thus, the predominance of Oligochaeta in ephemeral pool macroinvertebrate communities and their general tolerance of eutrophication tends to invalidate their use as an index in models of these pools. The vast predominance of Oligochaeta and Chironomidae, comprising more than 90% of most samples tends to invalidate the usefulness of similarity indices for ephemeral pool evaluations.

Hicks (1995) identified the number of total organisms, total taxa and EOT richness, EOT:Chironomidae ratio, percent composition of dominant families, Ephemeroptera, Trichoptera, Oligochaeta, Sphaeriidae, Gammaridae, and Chironomidae, and family biotic and community similarity indices to be the most sensitive metrics of urbanization and the extent of impervious cover in Connecticut wetlands. EOTs appeared to be more abundant and diverse in the forest pools, especially in the leaf-pack samples. These effects need to be more rigorously evaluated with a larger sample of pools and with a careful selection of pools of similar hydroperiod.

Table 1. Characterization of Massachusetts urban and forested ephemeral pools based on sediment, water, and macroinvertebrates. ND = not detected.

	Urban pools		Forest pools	
Metals (mg·kg^{-1})				
Arsenic	ND	18.7	24.7	ND
Barium	97.8	104.0	36.8	106.0
Cadmium	2.0	1.7	ND	ND
Chromium	59.1	2.6	5.4	ND
Lead	1170.0	776.0	30.7	29.2
Mercury	0.3	0.6	ND	ND
Selenium	ND	ND	ND	ND
Silver	ND	ND	ND	ND
Sediment composition (%)				
Organic matter	0.0	0.0	100.0	100.0
Sand	13.0	35.6	0.0	0.0
Silt	75.0	48.9	0.0	0.0
Clay	12.0	15.5	0.0	0.0
Water physicochemistry (means over 3 mo)				
Temperature (°C)	20.1	17.3	16.2	14.2
pH	6.6	6.1	6.2	5.6
Dissolved oxygen (mg·L^{-1})	6.3	2.3	7.1	8.2
Conductivity (µS)	368.0	93.0	21.7	16.5
Alkalinity (mg·L^{-1})	38.5	12.9	9.5	0.5
Depth range (cm)	6-122	8-122	76-107	0-61
Macroinvertebrate metrics and indices – leaf-pack samples (mean over 3 mo)				
Total number	2817	783	457	479
Number of taxa	9	8	16	9
Diversity (D')	1.18	1.08	2.56	1.21
Number of EOT taxa	<1	0	4	2
% Chironomidae	2.4	31.69	39.2	19.6
% Oligochaeta	92.3	66.4	4.3	76.4
% EOT taxa	<0.1	0	6.6	0.2
% predators	1.9	1.2	4.0	2.2
Jaccard's index (%)		23.6		
Ellenberg's index (%)		94.6		
Family biotic index	8.4	7.8	8.1	7.1
Community taxa similarity index (%)		53.8		
Community trophic similarity index (%)		56.6		
Macroinvertebrate metrics and indices – dip-net samples (mean over 3 mo)				
Total number	195	164	184	174
Number of taxa	18	7	15	8
Diversity (D')	3.19	1.25	2.78	1.27
Number of EOT taxa	3	0	3	1
% Chironomidae	6.5	12.7	26.9	0.2
% Oligochaeta	21.3	6.1	0.9	2.4
% EOT taxa	17.5	0	4.4	1.1
% predators	45.5	80.2	43.2	97.1
Jaccard's index (%)		31.3		
Ellenberg's index (%)		72.2		
Family biotic index	8.4	8.0	9.4	7.8
Community taxa similarity index (%)		46.9		
Community trophic similarity index (%)		75.0		

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