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Cover Photograph: *Hyla chrysoscelis* is a common treefrog found throughout the Southeast United States and has been known to use anthropogenic ponds for breeding. This individual was found calling above a preformed scour hole during the 2012 field season. Photograph © Andrew J. B. Jennings.

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Preformed Scour Holes Associated with Road Building May Maintain Anuran Diversity in Urbanizing Areas

Andrew J.B. Jennings[1] and Stanley H. Faeth[1,*]

Abstract - To mitigate erosion and stream pollution from road runoff, the North Carolina Department of Transportation implemented new stormwater-control structures: preformed scour holes (PSH). PSH may also provide habitat for amphibians in the urbanizing southeast United States. We surveyed anuran species in PSH in the Piedmont region of North Carolina and correlated species richness with local and regional factors associated with PSH. Degree of urbanization was negatively associated with total species richness, and PSH surface area and the presence of riparian vegetation were positively associated with total species richness. Our results suggest that PSH and similar stormwater-control measures may help to mitigate anuran diversity loss due to urbanization. Further study is warranted to determine if PSH act positively or negatively (e.g., as ecological traps) on amphibian diversity in urbanizing areas.

Introduction

Human populations are rapidly becoming more urban and less rural. Currently, more than 50% of the world's population lives in urban areas, and that fraction is expected to rise to over 60% by 2035 (UN 2012). In the United States, over 80% of the population now lives in cities, with increases to over 85% anticipated by 2025 (UN 2012). Habitat fragmentation and loss (McKinney 2006), hydrographic changes (Walsh et al. 2005), changes in nutrient availability (Lewis et al. 2006), and introduction of non-native species (McKinney 2008) are very often coupled with increasing urbanizing populations and expanding cities. One consequence of changes attributable to urbanization is the loss of diversity of native flora and fauna (e.g., Faeth et al. 2011). As the degree of urbanization increases, native biodiversity usually decreases (Faeth et al. 2011; Hamer and McDonnell 2008, 2009; McKinney 2008).

Urban declines in native diversity have been documented for plants (e.g., Faeth et al. 2011), birds (e.g., Chace and Walsh 2006, McKinney 2008), arthropods (e.g., Faeth et al. 2011, Raupp et al. 2010), mammals (e.g., Wenguang et al. 2008), and reptiles and amphibians (e.g., Hamer and McDonnell 2008, Mitchell et al. 2008). Explanations for observed declines in biodiversity include local abiotic factors such as altered temperature (e.g., Brazel et al. 2000), hydrography (e.g., Walsh et al. 2005), and nutrient availability (e.g., Kaye et al. 2006, Shochat et al. 2006), and regional factors such as increased isolation and decreased connectivity due to fragmentation (e.g., Faeth and Kane 1978, Leibold et al. 2004).

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Similar to other taxonomic groups, the biodiversity of anurans (frogs and toads) also usually decreases with urbanization (Dodd and Smith 2003, Hamer and McDonnell 2008, Knutson et al. 1999, Scheffers and Paszkowski 2012). Scheffers and Paszkowski (2012) reviewed 24 studies of North American anuran responses to urbanization. Each study included more than one species, allowing Scheffers and Paszkowski (2012) to examine 144 responses to urbanization. Each response was defined by abundance, species occurrence (presence or absence), mortality, and/or recruitment. As an example, a negative response would be "characterized by having higher abundances, greater occurrence, higher species richness, lower mortality, and greater recruitment at non-urban (i.e., native habitat) over urban sites" (Scheffers and Paszkowski 2012). Many anurans had negative responses (31%), a few had positive responses (4%), and others had either a neutral response (17%) or an unknown response (48%) to increasing urbanization. The underlying causes of these responses were not identified.

The most commonly proposed cause for these declines are local processes related to habitat loss and degradation (Hamer and McDonnell 2008, Ostergaard et al. 2008). Anurans are sensitive to alterations to hydrography, pollutants, temperature, and habitat fragmentation, and thus are often used as indicators of environmental health (Brand et al. 2010, Lips et al. 2008). Whereas most taxa suffer some losses in diversity due to habitat loss, anurans are especially affected relative to other terrestrial animals due to their complex life cycle. Most anurans require two different habitats, terrestrial and aquatic, and the quantity and quality of both impact anuran biodiversity (Hamer and McDonnell 2008). Adults require suitable terrestrial habitat during the nonbreeding season for survival prior to dispersal to aquatic habitats during the breeding season (Semlitsch and Bodie 2003). Most anurans, and all those in the southeastern United States, require aquatic habitats for breeding and larval survival. The declining quantity and quality of terrestrial and aquatic habitats coupled with increases in temperature, due to the urban heat-island effect (Brazel et al. 2000), and noise pollution that affects the efficacy of mating calls (e.g., Kaiser and Hammers 2009) have been linked to reductions in anuran biodiversity in urban areas (Hamer and McDonnell 2008).

At the regional level, the connectivity of, and dispersal among, terrestrial and aquatic patches is critical in determining anuran biodiversity. This connectivity is often disrupted in urban environments due to construction of buildings and roads. Indeed, intensity of urbanization is often measured by density of roads (McIntyre et al. 2000). Even non-urban roads can have negative effects on dispersal because roads are often implicated in direct mortality of adult anurans (van der Ree et al. 2011). As the connectivity between patches decreases, the persistence of a species within an area decreases due to less likelihood of rescue effects following a local extinction event (Leibold et al. 2004, Parris 2006). This isolation of adult upland forest and aquatic habitat used for breeding can lead to declines in anuran biodiversity within the highly fragmented urban environment. Correlative studies suggest that anuran biodiversity changes are due to both local (habitat quality and patch size) and regional (habitat quantity and connectedness) processes (Barrett and Guyer 2008, Birx-Raybuck et al. 2009, Ficetola and De Bernardi 2004, Gagné and Fahrig 2007, Parris 2006, Scheffers and Paszkowski 2012).

Although the overall effects of urbanization on anuran diversity are negative, some features of urbanization may promote diversity. For example, anthropogenic ponds associated with roadways and urbanization may indirectly but positively affect anuran diversity by providing habitat for survival and breeding. These ponds are primarily built for retention and erosion control, usually with little consideration of possible ecological cost or benefits. Brand and Snodgrass (2010) found a general decline in anuran diversity along an urban–rural gradient, but also showed that anthropogenic ponds had a higher level of anuran biodiversity when compared to naturally formed ponds with the same level of urbanization. These results suggest that human-made stormwater controls (i.e., retention ponds) may lessen anuran biodiversity loss caused by urbanization as anthropogenic ponds tend to retain more water for a longer period of time than natural ponds (Brand and Snodgrass 2010).

The most common type of stormwater control used in studies of urban anuran diversity is the retention pond (e.g., Birx-Raybuck et al.2009, Brand and Snodgrass 2010, Ostergaard et al. 2008). While conspicuous and fairly common, retention ponds are but one of many types of stormwater control used by cities, counties, and states. The North Carolina Department of Transportation (NCDOT) recently implemented a new stormwater control: preformed scour holes (PSH). PSH are pre-shaped basins that are located downhill from a stormwater outflow with permanent soil-reinforcement matting to prevent erosion (NCDOT 2008). The main purpose of PSH is to minimize erosion caused by roadside scour and secondarily to promote runoff infiltration (NCDOT 2008). Design features that address this secondary purpose, promoting runoff infiltration, allow stormwater to gather and form temporary pools that may provide habitat for pond breeding amphibians. PSH are ideal stormwater-control structures for the study of amphibian diversity because they are associated with new road construction and are found along an urban to rural gradient. The use of PSH by anurans has not been previously examined.

We examined the anuran biodiversity associated with PSHs and determined which local and regional-level factors associated with PSHs are correlated with changes in anuran biodiversity. Based on previous studies (Ficetola and De Bernardi 2004, Parris 2006), we predicted that PSH surface area would be positively correlated with anuran diversity and urbanization would be negatively correlated with anuran diversity. Although previous studies have shown that urbanization has a negative impact on anuran biodiversity (e.g., Barrett and Guyer 2008, Bunnell and Zampella 1999, Delis et al.1996, Hecner and M'Closkey 1997, Parris 2006), fewer studies have statistically modelled multiple possible explanatory factors that affect anuran biodiversity in urban environments, and none have specifically examined PSH. Similar to Ficetola and De Bernardi (2004), we examined local and regional factors to build an explanatory model that may be useful as a baseline for future studies on PSH and similar stormwater controls in the urbanizing southeastern United States.

Field-site Description

A PSH is a "structural stormwater control designed to dissipate energy and promote diffuse flow" (NCDOT 2008). Each PSH is pre-shaped, stabilized with filter fabric, and lined with rip-rap, medium-sized stones around 20 cm in diameter (NCDOT 2008). PSH mimic natural scour holes that prevent road run-off erosion from point discharges. The intended water-quality benefits of PSH are to "reduce the amount of end-of-pipe erosion by eliminating unabated scour" and "promote runoff infiltration and reduce downgrade erosion" (NCDOT 2008). To date, no one, including the NCDOT, has conducted any studies of the potential effects of PSH on the diversity of urban flora and fauna.

The NCDOT provided access to PSH erosion-control sites throughout central North Carolina. Greensboro, the urban center for this research, is located in the Piedmont region of North Carolina and is typified by temperate deciduous forests. All of the PSHs in Guilford, Alamance, Randolph, and Caswell counties were considered candidates and screened on the basis of holding water for at least two months during the anuran breeding season (February to June). After being initially screened in February 2012, each PSH was re-examined in early May 2012, and of the 54 PSH found in the study area, 21 PSH held water for longer than two months (Fig. 1, Table1).

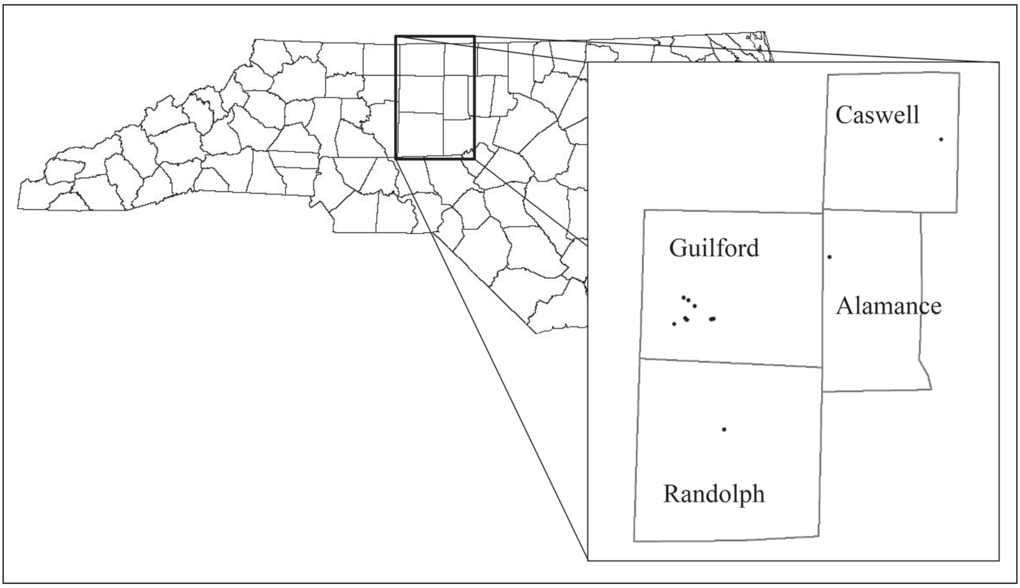

Figure 1. The four North Carolina counties and locations of PSHs. Top: Caswell County ($n = 1$), middle: Guilford County ($n = 18$), Alamance County ($n = 1$), and bottom: Randolph County ($n = 1$).

Methods

Study organisms

In the study area, there are 12 species of anurans: *Anaxyrus americanus* (Holbrook) (American Toad), *Anaxyrus fowleri* (Hinckley) (Fowler's Toad), *Acris crepitans* (Baird) (Northern Cricket Frog), *Hyla chyrsoscelis* (Cope) (Cope's Gray Treefrog), *Hyla versicolor* (LeConte) (Gray Treefrog), *Gastrophryne carolinensis* (Holbrook) (Eastern Narrowmouth Toad), *Pseudacris feriarum* (Baird) (Upland Chorus Frog), *Pseudacris crucifer* (Wied-Neuwid) (Spring Peeper), *Lithobates sphenocephalus* (Cope) (Southern Leopard Frog), *Lithobates palustris* (LeConte) (Pickeral Frog), *Lithobates clamitans* (Latreille) (Green Frog), and *Lithobates catesbeianus* (Shaw) (Bullfrog) (Dorcas and Gibbons 2008). Each of these species has a unique and distinct call that is typically heard only during the breeding season, and thus, calling activity indicates reproductive activity and not simply migration. Our sampling was based on detecting calls and therefore coincided with the breeding season for all species.

We identified and recorded all species in situ. Recorded calls were listened to again for confirmation using the database created and managed by Davidson Herpetology (Price and Dorcas 2011). Visual inspections confirmed species presence when and where possible. If an individual (or individuals) of a species was detected calling from a PSH, then the species was considered present. We sampled PSH from late February 2012 to late June 2012. Each site was visited once every

Table I. Study site locations in decimal degrees organized by year of construction. Included is county of site location, year of site construction, and government-determined identification number (ID #). This ID Number was the designation used by the researchers to identify sites.

ID #	County	Year built	Latitude (°N)	Longitude (°W)
1344	Caswell	2009	36.39833069	79.19750214
2059	Guilford	2009	35.99288940	79.94513702
2276	Guilford	2010	36.05199814	79.91819763
2278	Guilford	2010	36.04610825	79.90554810
2283	Guilford	2010	36.03264999	79.88883972
2284	Guilford	2010	36.03192902	79.88761139
2286	Guilford	2010	36.00239944	79.84303284
2287	Guilford	2010	36.00251007	79.84217834
2288	Guilford	2010	36.00262833	79.84185791
2289	Guilford	2010	36.00308990	79.83764648
2290	Guilford	2010	36.00313187	79.83676147
2487	Guilford	2011	36.00294113	79.91243744
2492	Guilford	2011	36.00217056	79.91074371
2493	Guilford	2011	36.00201035	79.91059875
2494	Guilford	2011	36.00196075	79.91027832
2495	Guilford	2011	36.00175095	79.91001892
2496	Guilford	2011	36.00151062	79.90959167
2500	Guilford	2011	36.00503922	79.9149704
2501	Guilford	2011	36.00566864	79.91606903
2505	Randolph	2011	35.75416183	79.81050110
2532	Alamance	2011	36.13832855	79.51278687

two weeks from 1 March 2012 to 24 April 2012, and each site was visited once a week from 30 April 2012 to 28 June 2012, for a total of 12 site visits for each site throughout the breeding period of 2012. Due to the frequency of site visits, it is unlikely that any species went undetected at a given site (see Appendix 1).

Our auditory survey based on presence/absence identification utilized the manual calling surveys (MCS) approach (Wright and Wright 1949). In addition to presence, we assigned a relative abundance category using the MCS abundance one, two, three classification system (1 = a single calling individual; 2 = multiple, distinct individuals; and 3 = multiple, indistinguishable individuals or a chorus; Dorcas et al. 2009)). If a species was observed visually within 1 m of the bank of the PSH but not recorded calling, that species was given an MCS number of one.

Explanatory factors

Following Ficetola and De Bernardi (2004), we performed a study that examined environmental (local-level) factors (Table 2) and isolation or dispersal (regional-

Table 2. Values of local-scale factors that were measured in the study. Preformed scour holes (PSH) are identified using the number assigned by the NCDOT. Area = PSH surface area (m^2), Depth = depth at center of each PSH (m), Angle = angle in degrees of the incline of the bank of each PSH, Wetland = presence (1) or absence (0) of an additional man-made drainage area less than 10 m from each PSH, Soil = presence (1) or absence (0) of soil in each PSH, SubVeg = presence (1) or absence (0) of submerged terrestrial vegetation in each PSH, Float = presence (1) or absence (0) of floating non-algal vegetation in each PSH, Rip = presence (1) or absence (0) of riparian (aquatic) vegetation in each PSH, Surround = the type of terrestrial vegetation surrounding each PSH (1 = grass, 2 = scrub, nonwoody vegetation, 3 = woody forest), and Shade = shade covered at each PSH during solar noon in May (0 = full sun/no shade, 1 = less than 25% shade, 2 = 25–50% shade, 3 = 50–75% shade, 4 = more than 75% shade). Area was log-transformed for statistical analysis.

PSH	Area	Depth	Angle	Wetland	Soil	SubVeg	Float	Rip	Surround	Shade
2284	3.60	0.27	14.93	0	1	1	1	0	1	4
2278	30.55	0.04	1.32	1	0	0	0	0	1	1
2276	12.57	0.58	16.28	0	1	1	1	0	2	1
2283	4.52	0.27	12.53	0	0	0	0	0	3	3
2059	4.00	0.33	18.27	0	0	0	0	0	3	4
2487	37.11	0.17	6.97	1	1	0	1	0	1	2
2492	10.40	0.38	10.79	0	1	0	1	0	1	0
2493	4.91	0.17	7.52	0	0	0	1	0	1	0
2494	6.61	0.19	7.48	0	0	0	0	0	1	1
2495	16.15	0.23	7.66	1	1	0	1	0	1	0
2496	7.07	0.13	4.84	0	0	1	0	0	1	0
2500	16.80	0.13	5.64	1	1	1	0	0	1	2
2501	12.50	0.37	16.49	0	1	1	0	0	1	1
2286	18.86	0.56	12.85	0	1	1	1	1	1	3
2287	13.85	0.13	3.46	0	1	0	0	0	3	3
2288	18.10	0.24	5.74	0	0	0	0	0	3	3
2289	13.20	0.51	14.08	0	0	0	0	0	2	0
2290	19.15	0.27	7.24	1	0	0	1	0	2	1
2505	3.46	0.25	13.27	0	0	0	0	0	1	0
2532	51.70	0.25	11.66	1	0	0	0	0	1	0
1344	11.34	0.20	8.75	1	0	1	1	1	2	2

level) factors (Table 3) that may explain patterns of anuran diversity in PSH. The local-level factors were: presence or absence of 1) human-made additional wetland at the PSH, 2) submerged nonaquatic vegetation (including detritus), 3) floating non-algal vegetation, 4) riparian vegetation (common riparian species such as cattails), and 5) soil in PSH (categorized as no soil if the bottom of PSH was rip-rap or stone), as well as 6) surrounding vegetation, 7) shade percentage, 8) PSH surface area, 9) depth at center of PSH, and 10) angle of the slope of the bank of the PSH (Table 2).

Regional or landscape-level factors (see Table 3) include 1) an estimate of the degree of urbanization, 2) distance from a riparian zone, 3) distance from road, 4) distance to nearest upland forest patch, and 5) distance from nearest PSH. Impervious cover was chosen as the estimate of urbanization to ensure consistency for each PSH. Impervious cover increases with urbanization (Pauleit and Breuste 2011), has been used as an indicator of urbanization (Pauleit and Breuste 2011), and allows for a quantitative comparison of sites. We estimated the percent of impervious cover surrounding each site at a radius of 1000 m using the

Table 3. Values of regional-scale factors measured in the study. Preformed scour holes (PSH) are identified using the number assigned by the NCDOT. UTM North, East, and Zone are location data provided by the NCDOT. County = county each PSH is located in, Road = distance (in meters) from center of each PSH to the nearest edge of the road, Patch = distance (in meters) from center of each PSH to the nearest patch of forest, H2O = distance (in meters) from center of each PSH to the nearest riparian zone, DistPSH = distance (in meters) from center of each PSH to the center of the nearest PSH, and Urb1000 = percent of impervious cover within a 1000-m radius of each PSH. Road, Patch, H2O, and DistPSH were all log-transformed for statistical analysis.

PSH	UTM North	UTM East	UTM Zone	County	Road	Patch	H2O	DistPSH	Urb1000
2284	3988064	600221	17	Guilford	15.70	2.22	29.93	136.13	78.09
2278	3989615	598585	17	Guilford	16.70	17.49	28.05	1221.31	91.16
2276	3990256	597436	17	Guilford	20.60	30.89	417.42	1221.31	73.20
2283	3988140	600107	17	Guilford	8.90	1.00	90.65	136.13	77.92
2059	3983680	595081	17	Guilford	17.00	1.00	29.74	3007.53	52.57
2487	3984830	598022	17	Guilford	18.40	3.61	63.71	171.28	62.51
2492	3984741	598169	17	Guilford	13.00	11.41	103.43	22.06	75.00
2493	3984729	598190	17	Guilford	12.30	16.33	120.48	22.06	75.00
2494	3984715	598209	17	Guilford	11.80	6.91	149.76	24.60	75.00
2495	3984692	598240	17	Guilford	11.40	31.98	189.23	36.86	75.00
2496	3984665	598274	17	Guilford	10.70	75.79	229.61	41.32	75.00
2500	3985052	597787	17	Guilford	23.10	5.12	304.95	41.31	54.32
2501	3985080	597753	17	Guilford	21.40	4.74	266.44	41.31	54.32
2286	3984832	604274	17	Guilford	30.70	1.00	64.73	77.17	66.06
2287	3984842	604352	17	Guilford	26.10	1.00	7.45	30.11	65.89
2288	3984858	604379	17	Guilford	23.80	1.00	25.75	30.11	65.89
2289	3984915	604757	17	Guilford	9.10	16.01	4.47	78.08	63.40
2290	3984919	604838	17	Guilford	9.00	10.28	7.76	78.08	63.40
2505	3957333	607539	17	Randolph	11.50	5.44	15.60	27,389.29	56.15
2532	4000325	633813	17	Alamance	7.00	9.42	15.22	32,744.82	11.14
1344	4029610	661645	17	Caswell	15.30	13.33	60.62	40,302.57	8.45

most recent data on impervious cover from the National Land Cover Database (USGS 2006) using ArcMap (ArcGIS version 10.1). Percent of impervious cover was measured as the number of 30 m x 30 m pixels within 1000 m that were covered in impervious cover divided by the total number of pixels in each circle. Pixel size used was the smallest pixel size available for the National Land Cover Database (USGS 2006). We defined upland forest patches as any patch of canopy-producing trees that covered a minimum of 450 m^2, and riparian zones as areas surrounding permanent flowing or standing water; these zones include, but are not limited to, streams, rivers, and lakes. Distance from each PSH to road, forest patch, riparian zone, and next PSH was determined using Google Earth® and the most recent satellite image.

Statistical analysis: diversity

To determine which of the local and regional factors were associated with species diversity, we used a step-wise linear regression model (R version 2.15.1) with species richness and relative abundance (as estimated by MCS) as the dependent variable. PSH surface area, distance from riparian zone, distance from upland forest patch, distance from road, and distance from nearest PSH were log-transformed to ensure normality. We used BIC criteria to create a model that employed forward/backward stepwise linear regression to determine which variable should be added to the model (see Ficetola and De Bernardi 2004 for details).

Results

Species presence

The species richness of the 21 PSH ranged from one to six species (mean = 3 ± 1.10 SD, median = 3). One species (Cope's Gray Treefrog) was detected at all 21 sites, and two species (Fowler's Toad and the Southern Leopard Frog) were not detected at any site (Appendix 1).

Species richness model

The best-fit stepwise linear regression model to explain species richness (as measured using the maximum MCS abundance number for each species) included urbanization, log surface area of each scour hole, and the presence of riparian vegetation. This model began with all available explanatory factors minus urbanization and no interactions to determine which non-urban factors affect diversity. Following the step-wise regression, urbanization was introduced to the model (Table 4).

Table 4. The stepwise linear regression model for the diversity of anuran species in PSHs. logArea = log transformed surface area of PSH, RipVeg = the presence of riparian vegetation, and Urb100 = urbanization at 100-m radius. Adjusted R^2 = 0.7003.

	Estimate	Std. Error	*t* value	Pr(>|*t*|)
Intercept	5.996	1.548	3.873	0.001
logArea	1.487	0.459	3.241	0.005
RipVeg	4.069	1.191	3.416	0.003
Urb100	-0.050	0.013	-3.815	0.001

Presence of riparian vegetation had the strongest positive effect on amphibian richness followed by surface area of the PSH. In contrast, urbanization had a significant, but weaker, negative effect on richness compared to vegetation presence and area.

Discussion

Preformed scour holes associated with road building may provide habitat for anuran species and may help maintain some of the regional biodiversity in the face of urbanization. Our findings are consistent with other studies showing that stormwater controls can provide habitat for anurans in urban areas. For example Parris (2006) found 10 species of anurans using stormwater controls for breeding in Melbourne, Australia, and Birx-Raybuck et al. (2009) showed five species used stormwater controls for breeding in the western Piedmont of North Carolina. Most PSHs harbored more than one species during the breeding season (with a mean of three species), indicating that PSH have features that are attractive to breeding males of multiple species of anurans.

The suitability of PSHs as breeding habitats appeared to vary among anuran species. For example, Cope's Gray Treefrog was found at all sites. Cope's Gray Treefrog is a fairly common anuran species that is tolerant of a variety of conditions at both the local and landscape scales (Brand and Snodgrass 2010, Brand et al. 2010). Seven of the other 10 species were found at multiple sites, and only three species were observed at a single site. Of the probable regional pool of anuran species, only Fowler's Toad and the Southern Leopard Frog were not observed.

Our predictions concerning the relationship between PSH surface size and anuran diversity were supported. Overall anuran species diversity was positively related to PSH area. The presence of riparian vegetation was also positively correlated with anuran diversity. We expected that larger PSHs with riparian vegetation should support higher diversity of anurans than smaller habitats with less vegetation (e.g., Ficetola and De Bernardi, 2004; Parris 2006; Shulse et al. 2010, 2012). Larger sites may support higher population sizes and thus reduce local extinction. Larger and more vegetated sites also provide more structural and habitat complexity for breeding and sustenance that support a wider diversity of species. All the anurans in the study area are herbivorous until metamorphosis. Many adult anurans use riparian vegetation as oviposition sites. In addition, *Hyla* and *Pseudacris* species use vegetation to avoid predation and as vertical calling structures so their calls carry over a large area. However, larger non-PSH sites may also be riskier than smaller sites because large pools support aquatic predators such as fish (Ficetola and De Bernardi 2004). However, the PSH in our study are separated from larger water bodies and are ephemeral pools, and therefore usually do not harbor fish.

Urbanization effects on anuran diversity

Whereas anuran diversity was positively correlated with size and vegetation, diversity was negatively correlated with degree of urbanization, as we predicted. However, although significant, urbanization had weaker effects in the model than vegetation or area. Urbanization was the only regional factor to remain in the best-fit regression model. Urbanization was measured as percent of impervious surfaces and is thus likely an indirect measure of other regional factors such as reduced connectivity due to upland forest loss and increased impediments to dispersal. Urbanization may also be associated with local factors such as increased mortality from air and water pollutants, altered climate (i.e., heat-island effects), and reduced reproduction due to elevated noise or light pollution that interferes with mating (Kaiser and Hammers 2009). These results are consistent with previous research showing that urbanization generally has a negative effect on anuran biodiversity (Birx-Raybuck et al. 2009, Brand and Snodgrass 2010, Ficetola and De Bernardi 2004, Parris 2006, Scheffers and Paszkowski 2012). For example, Parris (2006) found that as road cover (or degree of urbanization) increased in proximity to stormwater controls, anuran biodiversity decreased.

Our results are similar to those found by Parris (2006) in that a model that includes two local factors and one regional factor best explains the trends in biodiversity. In fact, the model proposed by Parris (2006) included two of the same three factors found in our model of anuran biodiversity: surface area of stormwater control and degree of urbanization as measured by amount of impervious surface cover. Because our study was correlational, the specific local and regional factors that affect anuran diversity associated with PSHs cannot be disentangled without further studies and controlled experiments. Nonetheless, there was strong evidence that patch-specific factors as well as connectivity affects anuran biodiversity. Thus, metacommunity theory (Liebold et al. 2004), which incorporates both local and regional factors and processes may be a good framework to examine anuran biodiversity in human-dominated environments (Birx-Raybuck et al. 2009, Ficetola and De Bernardi 2004, Parris 2006).

Stormwater controls and ecological reconciliation

Many anuran species are declining due to habitat loss and other factors, and the creation of anthropogenic ponds and stormwater controls may mediate, and possibly halt, some of the loss in biodiversity due to urbanization. Thus, as advocated by Rosenzweig (2003), anthropogenic habitats can be designed so that they are compatible with use by a broad array of species. Because similar stormwater and erosion-control structures are employed by multiple states in the US, these structures may serve a meaningful ecological purpose as habitats for aquatic and amphibious species.

Our results suggest that stormwater controls should be designed to be as large as possible and contain riparian vegetation to promote anuran use of stormwater controls for breeding. Our results did not ascertain if there is a threshold size for stormwater controls, a size where biodiversity either increases or declines, as has been found for wetland areas in general (Ficetola and De Bernardi 2004).

There are limitations of our study. The study was observational and correlational; thus, the causes that underlie patterns of anuran diversity cannot be understood without additional studies. This study encompassed only one field season and was limited to 21 sites. Therefore, caution is required in extrapolating to different urban environments, larger spatial scales, and longer time frames. Also this study did not address fitness of anurans. Although it appears that PSHs can provide breeding habitat, and possibly mediate anuran biodiversity loss, our study cannot exclude the possibility that PSHs act as ecological traps (e.g., Battin 2004). Stormwater controls in general, and PSHs in particular, need to be examined for fitness effects before any one type of stormwater control is endorsed to mediate biodiversity loss. Nonetheless, our study indicates that PSHs may be effective, especially with modifications, to mitigate anuran diversity loss in urbanizing areas.

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Appendix 1. Species presence and activity level for each site for each sampling period in 2012. Preformed scour holes (PSH) are identified using the number assigned by the NCDOT. Activity level is shown using the 1, 2, 3 MCS abundance level (1 = single individual calling/visual of adult/visual of distinct egg-mass, 2 = multiple distinguishable individuals calling, 3 = multiple indistinguishable individuals calling) Hc = *Hyla chrysoscelis*, Pf = *Pseudacris feriarum*, La = *Lithobates catesbeianus*, Lc = *Lithobates clamitans*, Pc = *Pseudacris crucifer*, Ba = *Anaxrynus americanus*, Gc = *Gastrophyrne carolinensis*, Lp = *Lithobates palustris*, Hv = *Hyla versicolor*, Ac = *Acris crepitans*, Bf = *Anaxrynus fowleri*, and Ls = *Lithobates sphenocephalus*.

	Sampling period					
PSH	March 1–7	March 21–30	April 11–24	April 30 – May 3	May 7–10	May 14–17
2284						
2278	Pf (1), Pc (1)	Pc (2)				
2276	Pf (1), Pc (1)					Hc (2), La (1)
2283	Pf (2)			Hc (2), La (1)		Hc (1)
2059						
2487	Pf (2)	Lc (1)		La (1), Lc (1)	La (1), Lc (1)	Hc (3), La (1), Lc (1)
2492		Lc (1)	La (1)	La (1), Lc (1)	Lc (1)	Hc (2), Lc (1)
2493	Pf (1)				Lc (1)	Pf (2), Hc (2)
2494		Lc (1)		Lc (1)	Hc (1)	Hc (3), Lc (1)
2495	Pf (1)			La (1)	Hc (1)	Hc (2), La (1)
2496						Hc (2)
2500		Pc (3)		Hc (2), Lc (1)	Lc (1)	Hc (3), Lc (1)
2501	Pf (1)	Pc (3)	Pc (2)	Hc (1), Lc (1)		Hc (3), Lc (2)
2286		Pf (2), Pc (3)		Aa (1)		Gc (1), Hc (3)
2287		Pf (3)			Hc (1)	Pf (2), Hc (3)
2288		Pf (1)				Pf (1)
2289				Lc (1)		
2290	Pf (1)	Pc (3)		Hc (2)	Hc (2)	
2505	Pc (1), Aa (1)			Hc (3)	Lc (1)	Hc (3)
2532	Pf (1), Pc (1)	Pf (1), Pc (3), Ac (1), La (1)	Ac (1), Hc (3), La (1)	Hc (3), La (1)	Ac (3), Hc (3)	
1344	Pf (1)	Pf (3), Pc (3)		Hc (3), Hv (2)		Pc (1), Hc (3), Hv (3)

	Sampling period					
PSH	May 21–24	May 28–31	June 4–7	June 11–14	June 18–21	June 25–28
2284	Hc (3), La (1)		Hc (3), Lc (1)		Hc (1), La (1)	
2278	Hc (2)		Hc (2)			
2276	Hc (2)		La (1)	Hc (2), Lc (1)	Hc (1), Lc (1)	Lc (1)
2283	Hc (3)	Hc (2), La (1), Lp (1)	La (1)		Hc (3)	La (1)
2059	Hc (3)	Hc (2), La (1)		Hc (2), La (1)	Hc (1)	
2487	Hc (3), Lc (1)	Hc (2), Lc (1)	Lc (1)	Hc (1*)	Lc (1)	La (1), Lc (1)
2492	Hc (2), Lc (2)	Hc (2), Lc (2)	Lc (1)	Hc (1*)	La (1), Lc (1)	La (1)
2493	Hc (2)	Hc (2)		Hc (1*)		La (1)
2494		Hc (3)		Hc (1*)	Hc (1)	
2495	Hc (2)	Hc (2)		Hc (1*)	Lc (1)	
2496						
2500	Hc (3), Lc (2)	Hc (3), La (1), Lc (1)	La (1), Lc (1)	Hc (1*)	Lc (1)	La (1), Lc (1)
2501	Hc (3), Lc (1)	Hc (1), Lc (1)	Lc (1)	Lc (1*)	Lc (3)	Lc (1)
2286				Gc (3), Hc (3)		Hc (1)
2287				Hc (2)		
2288		Hc (2)		Hc (2)		Hc (1)
2289	Lc (1)	Gc (3), Hc (2), Lc (1)	Lc (1)	Gc (2), Lc (1)	Gc (1), Lc (1)	Lc (1)
2290	Lc (1)		Lc (1)	Hc (3)	Hc (2), Lc (1)	Hc (2)
2505	Hc (2)			Hc (2)	Dry	Dry
2532	Ac (1), Hc (1)	Ac (2)	Lc (1)	Ac (3), Hc (2), La (1)	Hc (1)	
1344		Hc (1)				