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Pond age and riparian zone proximity influence anuran occupancy of urban retention ponds

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Abstract Urbanization is widespread throughout the United States and negatively affects many wildlife populations. However, certain urban features, such as retention ponds, may provide habitat for some species, such as amphibians. This study examines the influence of riparian zone proximity and pond age on retention pond occupancy by anurans. We identified and estimated the age of 25 retention ponds near Charlotte, North Carolina, USA and used a geographic information system to determine the distance to the nearest riparian zone. Occupancy modeling indicated that anuran presence decreased with increasing distance to riparian zone. Pond age also appeared to be an important factor, but the effect varied among species. Although the results of this study demonstrate the potential value of retention ponds to anurans, it is important to be conservative in estimating the ability of these ponds to sustain amphibian populations in urbanized regions.

Keywords Anuran · Urbanization · Retention pond · Fragmented landscape · Riparian zone · Pond age

Introduction

On a global scale, many regions have experienced recent widespread urbanization (Hope 1998; Griffith et al. 2003; Antrop 2004; Murakami 2005). Urban development poses a significant threat to many wildlife populations. Numerous studies have demonstrated that negative correlations exist between urban land uses and abundance or species richness of various vertebrates (Mills et al. 1989; Weaver and Garman 1994; Czech and Krausman 1997; Yahner 2003; Rubbo and Kiesecker 2005). Consequences of development include habitat fragmentation and destruction as well as pollution of natural areas (Sukopp and

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Werner 1982; Medley et al. 1995; Collins et al. 2000; Pickett et al. 2001; Radeloff et al. 2005). Although some species may be able to survive and flourish in urban areas, most animals are sensitive to the effects of urbanization (Williamson and DeGraaf 1981; Dickman 1987; Mackin-Rogalska et al. 1988; Mitchell 1988; Blair 1996; Marzluff 2001; Ghert and Chelsvig 2003; Riley et al. 2005).

Amphibians are particularly susceptible to habitat alterations brought about by development because they require resources from both aquatic and terrestrial habitats (Knutson et al. 1999; Rubbo and Kiesecker 2005; Price et al. 2006; Gagné and Fahrig 2007). Amphibian habitats (e.g., riparian zones and wetlands) in urbanized watersheds are likely to contain exotic species (Riley et al. 2005; Chadwick et al. 2006) which disrupt ecological processes such as predator–prey relationships. In addition, urban development can reduce the local density of amphibian populations as a result of high road mortality rates (Fahrig et al. 1995; Lodé 2000; Andrews et al. 2008). Compounding such local-scale effects are consequences associated with habitat fragmentation and destruction at a landscape-scale. Amphibians require minimum amounts of inter-connected wetland and upland forested habitat for dispersal and maintenance of breeding populations, and these land cover-types become more fragmented with increasing urbanization (Gibbs 1998b; Lehtinen et al. 1999; Guerry and Hunter 2002; Ficetola and De Bernardi 2004; Hermann et al. 2005; Cushman 2006; Gardner et al. 2007; Windmiller et al. 2008). Additionally, urban development may lead to habitat split, which results in decreased species richness of amphibians that require connections between aquatic breeding sites and adult habitat (Becker et al. 2007).

Despite the negative effects of urbanization on amphibian populations, in certain cases urbanization can result in the creation of habitat suitable for some amphibians. Urban retention ponds are widespread throughout developed areas and may provide breeding habitat for amphibians (Bascietto and Adams 1983; Bishop et al. 2000; Scher and Thiéry 2005; Ostergaard et al. 2008; Simon et al. 2009). Both local and landscape factors may influence anuran occupancy and species richness at retention ponds. Forested area and impervious surfaces have been identified as predictors of anuran presence at urban ponds on a landscape-scale (Scher and Thiéry 2005; Ostergaard et al. 2008; Simon et al. 2009). However, because the primary purpose of such ponds is to collect contaminants in storm-water runoff, they may not act as suitable habitat for pollution-sensitive species (Birch et al. 2004; Casey et al. 2005, 2007; Massal et al. 2007; Snodgrass et al. 2008). Contamination and other factors such as hydroperiod and exotic fish presence may contribute to the possibility of retention ponds acting solely as ecological traps (Battin 2004; Hamer and McDonnell 2008). Bishop et al. (2000) found that amphibians occupied and bred in retention ponds but had decreased breeding success and species richness compared to natural aquatic habitats, due to local-scale effects such as lack of vegetation cover, chemical contamination, and algal blooms. It is important to determine which characteristics of these constructed ponds are beneficial to amphibian populations because they may replace or supplement natural habitats that have been destroyed or degraded by development.

The objective of this study was to examine the influence of landscape features on urban retention pond use by five species of anurans. Specifically, we investigated the effects of pond age and distance to nearest riparian zone on amphibian occupancy. The age of a pond may influence which species are encountered or the number of calling males and breeding frogs (Stumpel and van der Voet 1998; Merovich and Howard 2000; Stevens et al. 2006). Riparian zones may link amphibian populations, providing corridors for dispersal or potential breeding habitat (Dickman 1987; Gibbs 1998a). Based on the results of the aforementioned studies, we hypothesized that anuran occupancy would be negatively associated with the distance to the nearest riparian zone and positively correlated with pond age.

Materials and methods

Study sites

We conducted this study within the Charlotte-Mecklenburg metropolitan area of the western Piedmont of North Carolina during the spring and summer of 2008 (Fig. 1). The rate of urbanization in this region is the sixth highest in the country (Ewing et al. 2005), with significant growth taking place since 1972 (Griffith et al. 2003). The dominant land cover-types are a mix of suburban and high-density urban areas interspersed with forested and agricultural land. Twenty-five urban retention ponds in Mecklenburg, Iredell, and Cabarrus counties were selected as study sites. These ponds were chosen because they were at least 1.5 km apart, indicating that the sites were independent according to Rittenhouse and Semlitsch (2007) who defined the 95% dispersal isopleth of anurans to be 703 m. The sites also represented a variety of ages, locations, and types of drainages (e.g., parking lots, neighborhoods).

Landscape characteristics

To locate urban retention ponds in the study region, we used digital aerial photography from 2005 and current imagery obtained from Microsoft Virtual Earth (http://maps.live.com/). We then used a geographic information system (GIS; ArcGIS v. 9.1, Redlands, CA) to determine the distance to the nearest riparian zone, defined as the interface between forested area and a streambed. We determined pond ages through communications with developers and real estate agents. A Spearman rank correlation indicated that there was no significant association between retention pond age and distance from the pond to the nearest riparian zone ($r_s = -0.0077$, $p = 0.97$).

Anuran sampling

We employed a modified version of the North American Amphibian Monitoring Program (NAAMP; Weir and Mossman 2005) to detect anurans. Calling surveys were conducted on nine nights during each sampling period, March 9–March 27 and June 2–June 26, for a total

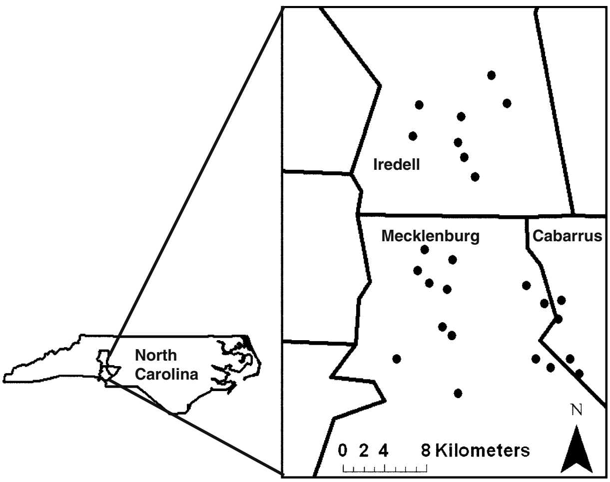

Fig. 1 Twenty-five urban retention ponds (indicated by *black dots*) were surveyed for anuran calling activity in Cabarrus, Iredell, and Mecklenburg counties, North Carolina, USA during spring and summer 2008

of six separate visits to each site. Sampling periods were set using the NAAMP protocols of peak breeding seasons as a general guideline; however, dates were modified slightly because of local weather. Listening time for the surveys began at approximately 30 min after sunset and concluded prior to 0100 h, with 5 min spent at each site. Calling data were recorded from within 3 m of the pond edge and in the same location during each visit to the site to ensure consistency. We also recorded the Beaufort Wind Code, sky code, and air temperature following the protocol in Weir and Mossman (2005).

Occupancy modeling

We selected five species for inclusion in occupancy modeling. These species were: spring peeper (*Pseudacris crucifer*), southern leopard frog (*Rana sphenocephala*), Cope's gray treefrog (*Hyla chrysoscelis*), bullfrog (*Rana catesbeiana*), and Fowler's toad (*Bufo fowleri*). We chose these species because they are common in our study region and represent a variety of life-history characteristics and habitat preferences (Wright and Wright 1949; Dorcas and Gibbons 2008).

We used site-occupancy modeling (MacKenzie et al. 2002) to assess anuran occurrence and its relationship with landscape variables surrounding urban retention ponds. Analyses were performed using program PRESENCE, which allowed us to differentiate between probability of occupancy (Ψ) and probability of detection (p). All continuous data were standardized (given a Z score) before entering in the program. To focus on the effect of landscape variables on anuran presence and to minimize the adverse effect of excessive parameters, a constant detection parameter was used in the analyses. We considered four models for each of the five anuran species, resulting in a total of 20 models. The models were (1) Global (includes pond age and distance to the nearest riparian zone), (2) Age (pond age), (3) Distance (distance to nearest riparian zone), and (4) Constant Ψ (detection parameter only).

For each model, we calculated the AIC_c value, a measure of the strength of the given model adjusted for smaller sample sizes (n=25 ponds), or the $QAIC_c$ value, adjusted for small sample sizes and over-dispersion, as in Burnham and Anderson (2002). Models were ranked according to their AIC_c or $QAIC_c$ values, with the best model having the smallest AIC_c or $QAIC_c$ value. We then calculated ΔAIC_c or $\Delta QAIC_c$ for each model, which is the difference in AIC_c or $QAIC_c$ between each model and the best model in the set for a given species. A Δ less than 2 suggests that there is substantial support for the model; a Δ between 3 and 7 suggests that there is considerably less support for the model; and a Δ greater than 10 suggests that the model is unlikely to explain reality (Burnham and Anderson 2002). We also calculated Akaike weights (ω_i) for each model, which represent the probability that the given model is the best among the entire set of candidate models for a species.

Results

The 25 ponds sampled ranged from 1–15 years (mean = 5.84; SE = 0.716) in age and 0–501 m (mean = 123; SE = 25.4) in distance to the nearest riparian zone. During our sampling periods in the spring and summer of 2008, we detected a total of 12 species (five spring-breeding and seven summer-breeding species). However, only five species were included in occupancy modeling: spring peeper (detected at 10 sites), southern leopard frog (13 sites), Cope's gray treefrog (14 sites), bullfrog (11 sites), and Fowler's toad (14 sites). Species that were detected but not included in modeling were the green frog (*Rana*

Table 1 Candidate occupancy models of spring peeper (*Pseudacris crucifer*) at urban retention ponds

Anuran species	PRESENCE Model	*K*	$QAIC_c$	$\Delta QAIC_c$	ω_i
Pseudacris crucifer	psi(AgeDistance),p(.)	4	41.66	0.00	0.58
Pseudacris crucifer	psi(Distance),p(.)	3	42.67	1.01	0.35
Pseudacris crucifer	psi(.),p(.)	2	46.65	4.99	0.05
Pseudacris crucifer	psi(Age),p(.)	3	48.56	6.90	0.02

PRESENCE Model names are based on included parameters (DisToStream = distance to nearest riparian zone, Age = pond age). The detection parameter is constant [p(.)]. *K* refers to the number of parameters included in the model, $QAIC_c$ refers to the Quasi-Akaike Information Criterion corrected for small sample sizes and over-dispersion, $\Delta QAIC_c$ refers to the difference between the given model and the top model, and ω_i refers to the Akaike weight

clamitans; detected at 5 sites), northern cricket frog (*Acris crepitans*; 2 sites), green treefrog (*Hyla cinerea*; 6 sites), pickerel frog (*Rana palustris*; 6 sites) and upland chorus frog (*Pseudacris feriarum*; 13 sites). American toads (*Bufo americanus*) were heard vocalizing at only one site, as was the eastern narrowmouth toad (*Gastrophryne carolinensis*). At least one species of anuran was heard vocalizing on at least one occasion at 22 ponds, however, at three ponds, no anuran species were detected during the entire sampling period.

The four candidate models varied in their amount of support among species. For spring peeper, the global model received the most support (ω_i=0.58, see Table 1), but the model which included distance to nearest riparian zone was also supported (ω_i=0.35, see Table 1). The global model was also the best supported for Cope's gray treefrog (ω_i=1.00, see Table 2). The model which included the pond age parameter received the most support for bullfrog (ω_i=0.53, see Table 3). The top model for Fowler's toad included the distance to the nearest riparian zone parameter (ω_i=0.42, see Table 4), although the global model also received support (ω_i=0.35, see Table 4). For southern leopard frog, the constant detection model and models including distance to nearest riparian zone and pond age were supported (ω_i=0.37, 0.34, and 0.16 respectively; see Table 5).

Parameter estimates for the most supported model indicated that pond age was positively associated with the presence of bullfrog (estimate = 1.05±0.71) and spring peeper (estimate = 5.18±3.98). Pond age negatively impacted occupancy of Cope's gray treefrog[1] (estimate = −1.15±0.61) and Fowler's toad (estimate = −0.67±0.52). Distance to the nearest riparian zone was consistently negatively associated with anuran occupancy (southern leopard frog: estimate = −0.76±0.54; bullfrog: estimate = −0.25±0.53; spring peeper: estimate = −14.92± 12.28; Cope's gray treefrog[1]: estimate = −3.20±1.41; Fowler's toad: estimate = −1.02±0.59).

Discussion

Twelve of thirteen anuran species known to inhabit the Charlotte-Mecklenburg metropolitan area (Dorcas and Gibbons 2008) were detected calling at least once at urban retention ponds during this study, indicating that urban retention ponds provide calling habitat for many frog and toad species. The responses to landscape variables were species-specific, with no two species having the same candidate model rankings. However, we did find common trends in the occupancy modeling results. As anticipated, anuran presence was

[1] Non-convergence of the variance-covariance matrix did not allow us to estimate parameters for the top model for Cope's gray treefrog; therefore, we have reported here estimates from models with less support.

Table 2 Candidate occupancy models of Cope's gray treefrog (*Hyla chrysoscelis*) at urban retention ponds

Anuran species	PRESENCE Model	K	AIC_c	ΔAIC_c	ω_i
Hyla chrysoscelis	psi(AgeDistance),p(.)	4	68.57	0.00	1.00
Hyla chrysoscelis	psi(Distance),p(.)	3	79.68	11.11	0.00
Hyla chrysoscelis	psi(Age),p(.)	3	88.52	19.95	0.00
Hyla chrysoscelis	psi(.),p(.)	2	91.52	22.95	0.00

PRESENCE Model names are based on included parameters (DisToStream = distance to nearest riparian zone, Age = pond age). The detection parameter is constant [p(.)]. K refers to the number of parameters included in the model, AIC_c refers to the Akaike Information Criterion corrected for small sample sizes, ΔAIC_c refers to the difference between the given model and the top model, and ω_i refers to the Akaike weight

consistently negatively influenced by the distance to the nearest riparian zone. Pond age also appeared to be an important factor for the five species studied, but was differently associated with the occupancy of various species.

The presence of all five anuran species was negatively correlated with riparian zone proximity, indicating that urban retention ponds that are closer to riparian zones may support more anuran activity than comparable ponds that are farther away. Previous studies have shown that the presence of many amphibian species is often associated with the distance to the nearest occupied wetland (Knutson et al. 1999; Ficetola and De Bernardi 2004), suggesting that animals may travel between water bodies. Streams, canals, ditches, and other semi-permanent water bodies also permit the movement and dispersal of amphibian species (Schroeder 1976; Bascietto and Adams 1983; Gibbs 1998a; Ficetola and De Bernardi 2004). These studies support our results that anuran presence can be predicted by the nearness of riparian zones.

The presence of four anuran species was associated with the age of retention ponds. Spring peepers and bullfrogs were heard vocalizing more often at older ponds, whereas Cope's gray treefrogs and Fowler's toad were detected most often at newer ponds. Despite these results, many studies have noted the ability of amphibians, including spring peeper and bullfrog, to colonize new or restored ponds, sometimes migrating to wetlands within a year of their creation (Stumpel and van der Voet 1998; Pechmann et al. 2001). Some anurans were able to establish breeding populations at new water bodies within 1 year (Lehtinen and Galatowitsch 2001; Vasconcelos and Calhoun 2006). These findings suggest that spring peeper and bullfrog presence could be expected at newer ponds, contrary to our

Table 3 Candidate occupancy models of bullfrog (*Rana catesbeiana*) at urban retention ponds

Anuran species	PRESENCE Model	K	AIC_c	ΔAIC_c	ω_i
Rana catesbeiana	psi(Age),p(.)	3	72.64	0.00	0.53
Rana catesbeiana	psi(AgeDistance),p(.)	4	74.72	2.08	0.19
Rana catesbeiana	psi(.),p(.)	2	74.60	1.96	0.20
Rana catesbeiana	psi(Distance),p(.)	3	76.42	3.78	0.08

PRESENCE Model names are based on included parameters (DisToStream = distance to nearest riparian zone, Age = pond age). The detection parameter is constant [p(.)]. K refers to the number of parameters included in the model, AIC_c refers to the Akaike Information Criterion corrected for small sample sizes, ΔAIC_c refers to the difference between the given model and the top model, and ω_i refers to the Akaike weight

Table 4 Candidate occupancy models of Fowler's toad (*Bufo fowleri*) at urban retention ponds

Anuran species	PRESENCE Model	*K*	AIC_c	ΔAIC_c	ω_i
Bufo fowleri	psi(Distance),p(.)	3	81.99	0.00	0.42
Bufo fowleri	psi(AgeDistance),p(.)	4	82.36	0.37	0.35
Bufo fowleri	psi(.),p(.)	2	84.08	2.09	0.15
Bufo fowleri	psi(Age),p(.)	3	84.97	2.98	0.09

PRESENCE Model names are based on included parameters (DisToStream = distance to nearest riparian zone, Age = pond age). The detection parameter is constant [p(.)]. *K* refers to the number of parameters included in the model, AIC_c refers to the Akaike Information Criterion corrected for small sample sizes, ΔAIC_c refers to the difference between the given model and the top model, and ω_i refers to the Akaike weight

occupancy modeling results. Similar to our study, Merovich and Howard (2000) frequently collected Fowler's toad adults at new ponds, and Pechmann et al. (2001) also documented a positive correlation between Cope's gray treefrog occupancy and recently constructed ponds. Additionally, Lehtinen and Galatowitsch (2001) observed colonization and successful breeding by Cope's gray treefrog, but not spring peeper, at newly created ponds. Anuran presence at younger ponds may also be explained by a related factor, the degree of permanence of the pond. Newer retention basins are more likely to dry occasionally than older ponds, which would provide ephemeral wetlands that certain species, including Fowler's toad and Cope's gray treefrog, may prefer (Dorcas and Gibbons 2008). Other species may be slower to colonize new wetlands and thus are more likely to occupy older ponds (Merovich and Howard 2000; Stevens et al. 2006), as we found with spring peepers and bullfrogs. Therefore, based on our results and those of other studies, colonization ability appears to vary not only among species, but also within the same species as a result of local or regional landscape factors.

Our results demonstrate that anurans utilize urban retention ponds as calling sites and that the presence of vocalizing male anurans can be predicted by certain factors, such as riparian zone proximity and the age of the pond. Future investigations are required to ascertain the extent to which anurans use these ponds for reproduction. Parameters such as recruitment patterns and reproductive success must be quantified in order to conclude that retention ponds support annual breeding populations. Although the results of this study demonstrate the potential importance of retention ponds to anurans in urban landscapes, the

Table 5 Candidate occupancy models of southern leopard frog (*Rana sphenocephala*) at urban retention ponds

Anuran species	PRESENCE Model	*K*	$QAIC_c$	$\Delta QAIC_c$	ω_i
Rana sphenocephala	psi(.),p(.)	2	73.93	0.00	0.37
Rana sphenocephala	psi(Distance),p(.)	3	74.08	0.15	0.34
Rana sphenocephala	psi(Age),p(.)	3	75.65	1.72	0.16
Rana sphenocephala	psi(AgeDistance),p(.)	4	76.07	2.14	0.13

PRESENCE Model names are based on included parameters (DisToStream = distance to nearest riparian zone, Age = pond age). The detection parameter is constant [p(.)]. *K* refers to the number of parameters included in the model, $QAIC_c$ refers to the Quasi-Akaike Information Criterion corrected for small sample sizes and over-dispersion, $\Delta QAIC_c$ refers to the difference between the given model and the top model, and ω_i refers to the Akaike weight retention ponds and the developments around them were built relatively recently. It is likely that amphibian populations are declining in the region because of urbanization (Price et al. 2006), and a possibility exists that these ponds may function as ecological traps (Battin 2004; Hamer and McDonnell 2008). Long-term studies are therefore needed to determine the efficacy of urban retention ponds in maintaining breeding populations of amphibians, especially in light of possible time lags associated with changes in land use and its effects on amphibian species occurrence (Löfvenhaft et al. 2004). Therefore, it is important to be conservative when estimating the ability of these ponds to sustain amphibian populations.

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