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Effects of Stormwater Ponds on Calling Amphibian Communities in Monroe County, NY

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By

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By John A. Bateman

APPROVED BY:

Advisor	Date
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Chair, Graduate Committee	Date

Dedication:

I dedicate this thesis to the memory of my Grandmothers.

Selma A. Henchen

(8/11/1917 – 7/22/2006)

&

Dora M. Jones

(5/12/14 – 12/31/12)

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Abstract:

Many studies have investigated how urbanization affects calling amphibians and how stormwater retention ponds are utilized by anurans. Few studies, however, have investigated the combined effects of land use and within-pond conditions on these species. Thus, I studied calling amphibian communities at 38 stormwater ponds in Monroe County, NY to determine which factors at the local and landscape scale affected anuran presence, community composition, and breeding. I used aural surveys following Marsh Monitoring Program protocol to record presence and relative abundance and visual encounter surveys for signs of breeding. I used GIS to determine land use and also measured water quality and other habitat features within the ponds. I then used information theory to determine best models for my response variables.

American toad (*Anaxyrus americanus*) presence and spring peeper (*Pseudacis crucifer*) call code both responded negatively to increase in impervious area and loss of wooded habitat. Green frog (*Lithobates clamitans*) abundance and calling intensity were both negatively related to specific conductance and positively related to emergent vegetation cover. Bullfrog (*Lithobates catesbeianus*) calling intensity was also negatively related to specific conductance. Sites with high species richness associated most strongly with the absence of fish and responded negatively to higher pH, noise pollution, more impervious surface, and less upland habitat. Evidence of breeding was also lower at sites with more impervious surface and less terrestrial habitat. My results suggest that species respond differently to selective pressures within the pond and surrounding landscape, largely due to differences in life history

characteristics. When designing ponds to support diverse amphibian assemblages, ponds should be placed away from impervious surface and adjacent to woodlots. Ponds should be managed as groups rather than individually to ensure habitat requirements of individual species are being met, as well as to support source-sink dynamics.

Introduction:

Global amphibian population declines over the past several decades are well documented (Blaustein et al. 1994, Houlahan et al. 2003, Dodd, 2010). Due to their bi-phasic lifestyle, amphibians are subject to both aquatic and terrestrial threats, including habitat loss, pollution, biological invaders, and climate change (Berger et al. 1998, Kats and Ferrer 2003, Thomas et al. 2004, Todd et al. 2009, Becker et al. 2010, Bancroft et al. 2011, IUCN 2014). The need for both aquatic and terrestrial habitat makes amphibians vulnerable to disturbances from urbanization. Ephemeral pools, in particular, are vital to amphibians in forested landscapes, and loss of this habitat, or changes to the surrounding landscape due to urbanization, can threaten amphibian populations and affect amphibian community composition (Gibbs 2000, Semlitsch and Bodie 2003, Harper et al. 2008, Baldwin and DeMaynadier 2009). Degraded abiotic and biotic conditions within the urban setting also negatively affect amphibian populations (Bee and Swanson 2007, Collins and Russell 2009, Bommarito et al. 2010). While constructed aquatic habitats, including stormwater ponds, can potentially serve as valuable habitat in urban settings (Brand and Snodgrass 2009), the long-term effects of environmental stressors within these ecosystems are not well understood (Ostergaard et al. 2008, Brand and Snodgrass 2009).

Several biotic and abiotic stressors affecting the structure of amphibian communities associated with stormwater ponds have been identified, including lack of connectivity to upland habitat (Ostergaard et al. 2008, Birx-Raybuck et al. 2010), road salts (Sanzo and Hecnar 2006, Denoel et al. 2010), lack of emergent vegetation

(Ostergaard et al. 2008), and changes to the hydrologic cycle (Brand and Snodgras 2009). However, relatively few studies have examined how these stressors affect amphibian use of stormwater ponds at the local and landscape level (Ostergaard et al. 2008, Hamer and Parris 2011, Scheffers and Paszkowski 2013).

The main objective of this study was to use habitat modeling to identify within-pond characteristics and factors at the landscape level that affect anuran richness and abundance in stormwater ponds. I examined use of stormwater ponds at the species and community level, and as anuran breeding habitat. My secondary objective was to provide management recommendations for existing ponds and to provide design plans for future ponds. Results of this study add to our understanding of amphibian ecology in urbanized landscapes.

Methods:

Site Selection:

I non-randomly selected eight sites within Monroe County, NY containing a total of 38 stormwater ponds (Appendix A). For the purpose of this study, a pond with an inlet structure was considered a stormwater pond. I selected sites where I could safely sample, had permission from landowners to conduct my study, and which had two or more stormwater ponds. Sites were identified via aerial photography, and ponds located within landscapes with different intensities of urbanization were visited prior to the start of my first field season. A total of 72 visits to 25 ponds at seven sites were made during 2011 and 228 visits to 38 ponds at eight sites were made during 2012.

There were differences in weather between 2011 and 2012. In 2011, the month of February was > 1^{o} C cooler than the historical average. There was a cold spell between 23 Mar and 31 Mar when daily high temperatures were 4.2^{o} C below the historical monthly average. Snow was last reported on the ground on 28 Mar. The longest dry spell was from 29 Jun to 11 Jul, where no observed precipitation fell during those 13 d. In 2012, there was a warm spell between 11 Mar and 27 Mar where daily high temperatures were 13.2^{o}C above the historical monthly average. This warm spell was followed by a cooler than average month of Apr, when temperatures were < 1^{o} C cooler than average. The last day with snow on the ground was 25 Apr, and the longest dry spell fell between 9 May and 21 May, when 13 d passed with no precipitation.

Amphibian Sampling:

My first field season began on 10 May and ended on 20 Jul 2011. During the following season I sampled between 20 Mar and 20 Jul 2012. I surveyed amphibians using the Long Point Observatory's Marsh Monitoring Program (MMP) protocols (Bird Studies Canada 2000), with slight deviations. The MMP uses a 3-min aural survey in which all calling amphibians identified within an unlimited distance of a semi-circle radius for the point are recorded. A minimum distance of 500 m is used to separate sites while conducting MMP surveys. I deviated from these protocols by only recording amphibians heard calling from within or along the edge of each stormwater pond, rather than in surrounding habitats, because I wanted to record only individuals that were attempting to breed within the pond. I also used multiple points at larger ponds to ensure that these locations were adequately sampled for amphibians.

I visited each site three times during intervals covering the breeding period for anuran species (Figure 1). The first survey was conducted between onset of calling and 15 May when evening temperatures were above 5^{o}C, the second occurred between 15 May and 15 Jun once temperatures reached 10^{o}C, and the third occurred between 15 Jun and 15 Jul when temperatures were at least 17^{o}C. I waited at least 10 d between visits and made follow-up visits to each site within a week of sampling to look for evidence of breeding (egg masses, tadpoles, and metamorphs). Surveys commenced 30 min after sunset and continued for up to 4 h. I followed MMP protocol by not sampling during intense precipitation events or when the wind was above three on the Beaufort scale.

I used MMP call level codes to record calling intensity for each species. A call code of 1 indicates calls are not overlapping and individuals can be easily counted. Call code 2 is used when calls overlap and the number of individuals can be reliably estimated. Call Code three is used when individuals are calling in such number that an accurate estimate of individuals is not possible. Because many counts included call levels of 2 or 3, I used a modified Shannon-Weiner index that replaced abundance with call level to measure species diversity. A constant of 1.0 was added to all sites where amphibians were found so that sites without amphibians had an H' of zero ($H' = [-\sum p_i \ln p_i] + 1$).

Aquatic Habitat Measurements:

Prior to conducting point counts, I collected data on water quality and emergent vegetation. I measured pH, specific conductance, and water temperature with an ExStik II pH/conductivity meter (Extech Instruments, New Hampshire, USA). The meter was calibrated weekly with known pH and specific conductance standards. A water sample was collected during each count and later tested for chloride concentration using the mercuric nitrate method (APHA 2005). I first tested samples with a weak titrant used for concentrations < 100 mg/L. Additional titrations were performed using a strong titrant for chloride concentrations > 100 mg/L. Normality for the mercuric nitrate was calculated using a known standard. I estimated overall percent emergent vegetation cover in each pond using the midpoint value of 10 percent intervals. I recorded ambient noise by measuring the maximum decibel level during point counts with a sound-level meter (Pyle model #PSPL01, Pyle Audio, New York, USA).

Landscape Analyses:

I used basemap imagery from 2012 in GIS (ArcMap 10.1, ESRI, 2012) to heads-up digitize stormwater ponds and the surrounding landscape. I drew polygons around 15 classes of land use and calculated percent of each land use class within a 300-m buffer from the edge of each pond (Appendix B). Number of ponds within 300 m (pond count) and stormwater pond size also were calculated. A 300-m buffer was selected because land use within this area has the greatest impact on breeding amphibian populations (Semlitsch and Bodie 2003, Ritternhouse and Semlitsch 2007).

I used a cost-distance analysis in GIS (ArcMap 10.1, ESRI, 2012) to examine the risk of migrating from a stormwater pond to adjacent woodlots. A cost-distance analysis finds the “cheapest” path between start and end points, and the cost of being anywhere on the surface being analyzed can be calculated. Instead of finding the shortest distance, cost distance calculates the least expensive route to an endpoint from a source, based on an accumulation of cell values. While the exact resistance values of land uses in this study is unknown, I assigned a relative cost to each land use type, based on similar land uses in a study by Compton et al. (2007), to reflect with how dangerous it would be for an anuran to cross through it (Table 1). Land uses considered impassable or nearly impassable for frogs and toads were given higher scores relative to those that could be crossed. Land uses that could be used as habitat were given lower scores than for developed land. The starting point (stormwater pond being analyzed) and end points (woodlots within the 300 m buffer) were given costs of zero. I then converted land use vector data to raster data using cost. I used a cell output size of 10 m X 10 m, with maximum land use area within each cell used to determine the cost of the cell and the 300-m buffer as the processing extent. Since each pond had at least one woodlot within the 300-m buffer, I created a score for each site by multiplying the cost to get to each woodlot by the area of that woodlot. I then summed these values and divided the sum by the total area of woodlot within the 300-m buffer. I did this to account for both the total amount of wooded area surrounding the pond and the landscape resistance an anuran would encounter while migrating to its upland forested habitat.

Statistical Analyses:

Because I did not have equal sampling intensity for all ponds in 2011 I used non-parametric statistical tests to identify significant predictor variables for those data, rather than using a modeling approach. I used a Mann-Whitney U non-parametric test to compare sites with and without signs of frogs breeding, green frog (*Lithobates clamitans*) presence (binomial), and gray tree frog (*Hyla* versicolor) presence (binomial) during 2011. I limited my statistical analyses to these two species because I had the most site visits during their calling periods, thus I had more data to analyze. This test was used to test for significance ($p < 0.05$) among predictor variables, including chloride concentration, maximum decibel level, specific conductance, hydrogen ion concentration, percent emergent vegetation, percent impervious area, and percent natural habitat. I also used a Kruskal-Wallis non-parametric test to examine how the same set of predictor variables affected calling intensity of green frogs and gray treefrogs in 2011.

In addition to non-parametric tests, I used Generalized Linear Models (GLM) for 2012 data to predict amphibian diversity, species presence, and green frog abundance based on within-pond and landscape-level habitat variables. I chose to examine green frog abundance because they were the most commonly occurring species during both years and also called at low enough intensity where abundance could be approximated (call code < 3). I examined presence-absence for several species, included spring peeper (*Pseudacris crucifer*), green frog, northern leopard frog (*Lithobates pipiens*), gray treefrog, and American toad (*Anaxyrus americanus*). I included several within-pond predictor variables in my models, included pond size (m^2), maximum decibel level, chloride concentration, hydrogen ion concentration, specific conductance, pond permanence (binomial), fish presence (binomial), and percent emergent vegetation. I also included landscape-level predictors, such as the cost-distance score and artificial variables created from a Principal Component Analysis (PCA). I ran a PCA both with and without Varimax rotation to reduce the number of landscape-level predictor variables (Appendix C) into a smaller set of artificial variables (components). I used this analysis because it removes redundancy and multicollinearity yet retains most of the variance in the original variables. I examined the PCA for sampling adequacy using the Kaiser-Meyer-Olkin (KMO) score and used Bartlett's Test of Sphericity to test for equal variances. Prior to running the analysis I tested each group for normality. In cases where normality was not met, I used the transformation that most closely approached a normal distribution. I standardized variables (Z-scores) prior to the analysis to remove any unit effects. I retained principal components with an eigenvalue greater than 1.0 for further analysis. I also standardized predictor variables (Z-scores) not included in the PCA, such as chloride concentration, specific conductance, and hydrogen ion concentration (pH). I first included all predictor variables in the models and used backwards selection to remove non-significant ($p > 0.05$) values, with the exception of cases where I had few observations. In these instances, I first used binary logistic regression to reduce the number of predictor variables by eliminating variables that showed poor correlation ($p > 0.200$) with the binary response variable being tested, and then used backwards selection on the remaining variables. I used Akaike's Information Criterion with a correction term for small sample size (AIC_c) to select the most parsimonious models by considering models with a $\Delta AIC_c < 2.0$ (Burnham and Anderson 2002). I used weighted models to identify the probability that the model had the greatest chance of being the 'best' model. AIC considers the number of variables in the model (complexity) and amount of variation explained by the variables (goodness of fit), allowing multiple models to be compared at once (Johnson and Omland 2004). For each response variable, I considered the best model to be the one with the lowest AIC_c value, as it should explain the least amount of variation lost between the fitted model and the true, unknown model (Anderson et al. 1994). I performed all statistical tests with SPSS version 21 (IBM 2012).

Results:

General observations:

In 2011 and 2012, I observed six calling amphibian species during point counts in my eight sites: spring peeper, American toad, northern leopard frog, green frog, American bullfrog (*Lithobates catesbeianus*), and gray treefrog (Table 3). I did not hear wood frogs (*Lithobates sylvaticus*) during either year, although they are present in other parts of Monroe County. Green frogs were the most common species in 2011 (40% of sites), followed by gray treefrogs (28%), spring peepers (8%), and bullfrogs (8%) (Table 4). American toads and leopard frogs were not heard during 2011. Green frogs were the most common species during 2012 (84.2% of sites), followed by bullfrog (28.9%), gray treefrog (23.7%), spring peeper (15.8%), American toad (15.8%), and northern leopard frog (13.2%) (Table 4). I found evidence of breeding at two sites in 2011 (8% of sites) and eight sites in 2012 (21.1%). Additional natural history observations on the study species at my sites are reported in Appendix D.

During 2011 and 2012, I began to associate site-level characteristics with either the presence or absence of anurans. My observations suggested that emergent vegetation was a strong positive predictor for several species, including green frogs and gray treefrogs. I observed green frogs calling from the vegetated edges of ponds, but rarely in open water. I also observed that gray treefrogs and spring peepers would perch on cattail stalks and call from there. Gray treefrogs appeared to pass over ponds closer to a woodlot that were less vegetated in favor of ponds further away with more emergent growth. I noticed that northern leopard frogs, especially post-metamorphs, were found most often in wet meadows surrounding stormwater ponds. I found amplexed pairs in shallow water at the edge of ponds over exposed substrate and submersed aquatic vegetation.

Amphibian presence and relative abundance:

I examined green frog and gray treefrog presence and calling intensity during 2011 as responses to chloride concentration, hydrogen ion concentration, noise pollution, specific conductance, percent emergent vegetation, percent total impervious surface, and percent natural habitat. Results of Mann-Whitney U tests found significantly higher mean values for noise pollution (U= 7.000, z = -2.807, p= 0.003) and percent impervious surface (U= 9.000, z = -2.635, p=0.007) at sites where green frogs were absent (Figures 2 and 3). Green frog calling intensity also significantly decreased in response to an increase in noise pollution (Kruskal-Wallis Test: $H(2)$= 8.411, p= 0.015) and to an increase in impervious area (Kruskal-Wallis Test: $H(2)$= 7.317, p= 0.026) (Figure 4). Gray treefrog presence was negatively associated with specific conductance (Mann-Whitney: U= 13.000, z= -2.613, p=

0.009) and noise pollution (Mann-Whitney: $U= 20.000$, $z= -2.041$, $p=0.041$) (Figure 5) but was positively associated with an increase in emergent vegetation (Mann-Whitney: $U= 69.500$, $z= 2.039$, $p= 0.041$) (Figure 6). A Kruskal-Wallis Independent Samples test found the relation between gray treefrog calling intensity and increases in emergent vegetation to be marginally significant ($H=7.745$, $p= 0.052$) (Figure 7), however, further inspection of this test suggests calling intensity is greater at sites with hemi-marsh conditions.

The Principal Component Analysis with Varimax rotation reduced 11 landscape predictor variables to three components (Table 2). There were slightly different loadings when the components were not rotated (Appendix E). Inspection of the correlation matrix showed that each variable had at least one correlation coefficient > 0.3. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.606 and Bartlett's Test of Sphericity was significant ($P< 0.001$). The first component (PC 1) was positively associated with total percent impervious area, percent impervious surface, percent building, and negatively associated with percent woodlot and percent fallow (Table 2). This component represents an increase in development and reduction in upland habitat. The second component (PC 2) was positively associated with percent stormwater pond, percent stone, and pond count. This component represents areas with an increased number of ponds in an area. The third component (PC 3) was positively associated with percent road, percent residential, and was negatively associated with percent lawn (Table 2). This component represents suburban areas with an increased number of housing tracts and roads.

For 2012, there were three closely ranked models that explained spring peeper calling intensity. The models suggested that spring peeper calling intensity declined with increased development but responded positively to an increase in stormwater pond density (Table 5). Results of a Mann-Whitney U test found a marginally significant relationship between spring peeper presence and a decrease in PC 1 (U= 48.000, z= -1.922, p=0.055) (Figure 8). American toad presence was negatively associated with decreases in impervious surface and pond count, and responded positively to increased natural habitat. The best model for green frog calling intensity included an increase in emergent vegetation during the first calling period and less noise pollution and lower chloride concentration during the second calling period. Specific conductance during the second calling period had a negative effect on calling intensity in two other closely ranked models (Table 6). Bullfrog calling intensity had four closely ranked models, with greater calling intensity in areas with greater pond density and lower specific conductance during the second calling period in the best model. Three other models found a positive relationship in bullfrog calling intensity with an increase in residential area (Table 6). The best model that explained green frog abundance showed increased detections at sites with lower specific conductance during the second calling period, less impervious surface, increased cost associated with traveling, more emergent vegetation within the stormwater ponds, and a longer pond hydroperiod (Table 7). The amount of emergent vegetation within ponds was a significant predictor of green frog presence, with green frogs occupying ponds with higher percentages of vegetation cover (Mann-Whitney U: U= 149.500, z=2.249, p= 0.024). Green frogs also called more from sites with more emergent vegetation

(Kruskall-Wallis: *H*: 7.687, p= 0.021) (Figures 9 and 10). Although the relationship was not significant, visual inspection of non-parametric tests suggested gray treefrogs often were detected more frequently and had greater calling intensity at ponds with hemi-marsh conditions (Figures 11 and 12)

In summary, findings from 2011 and 2012 show how factors at the local and landscape scale influenced calling intensity. Water quality, presence of emergent vegetation, and pond density were positively correlated with the presence of several amphibian species at my study sites. Ponds surrounded by less natural habitat, increased impervious surface, and more noise pollution were significantly associated with sites that had fewer amphibians.

Breeding:

Sites where I found evidence of breeding in 2011 had significantly higher mean values of percent natural habitat (Mann-Whitney: U=160.000, z= 2.340, p= 0.019) and significantly lower means for noise pollution (Mann-Whitney: U=20.000, z= -3.258, p= 0.001) (Figure 13) and total impervious area (Mann-Whitney: U=23.000, z= -3.140, p=0.002) Figure 14). During 2012, there were two closely related models that explained evidence of breeding. The best model indicated that evidence of breeding was negatively associated with PC 1 and PC 2, which represent sites with very little natural habitat, a high degree of urbanization, and use of stone in and around stormwater ponds. Greater landscape resistance was an additional factor found to negatively influence anuran breeding in the second-best model (Table 8). While PC 1 was included in both models, it was only a marginally significant predictor of breeding when examined alone (Mann-Whitney U: U: 70.000, z= -1.790, p=0.076) (Figure 15).

Species Richness:

In 2011, sites with fish had significantly lower species diversity than sites without fish (Mann-Whitney U: u= 44.000, z= -2.339, p= 0.019) (Figures 16a and 16b). There were four closely related models that explained species richness during 2012. These models suggested that sites with less natural habitat, greater percentage of impervious area, and more noise pollution during the second calling period had lower species richness. Fish presence and lower pH during the first calling period were also included in the model with the lowest AIC_c score (Table 8). Fish presence by itself was not a significant predictor of species diversity in 2012 (Mann-Whitney U: U= 85.500, z= -1.590, p=0.112) (Figure 17).

Discussion:

My study examined structural and functional ecosystem properties of urban stormwater ponds to determine factors at the local and landscape scale that affect anurans to provide management recommendations for design and placement of future ponds. I observed six species of calling amphibians during the two seasons, with green frogs being most abundant (40% of sites in 2011 and 84.2% in 2012). Lower detection rates in 2011 for all species were likely due to less intensive sampling than in 2012. During 2012, when three visits were made to each site, non-migratory species (green frogs and bullfrogs) were detected more than migratory species (gray treefrog, spring peeper, and American toad). Northern leopard frogs, which utilize forested and wetland sites throughout the spring and summer (Blomquist and Hunter 2009), had the fewest detections of any species during 2012 (13.2%).

Amphibian presence and relative abundance:

Habitat models for response variables (spring peeper calling intensity and American toad presence) of two migratory species were both negatively associated with PC 1, which represents an increase in impervious surface and decrease in natural habitat. Pillsbury and Miller (2008) had similar findings. They found that while all anuran species were affected by urbanization, species associated with upland habitat that bred early in the season were impacted most. Habitat models for a third migratory species in my study, the gray treefrog, failed to detect any significant relationships with predictor variables. This was in contrast to models for non-migratory species (green frogs and bullfrogs), where PC 1 was not a significant predictor of calling intensity for either species, but conditions within the pond (as well as pond density) were significant predictors of calling intensity. However, PC 1 was negatively associated with the number of green frogs heard calling within ponds, meaning fewer green frogs were detected in ponds surrounded by buildings and other impervious surfaces. These findings suggest that the natural history of a species affects responses to selective pressures within the landscape. Species migrating between aquatic and terrestrial habitats to complete their life cycles are less likely to be detected in ponds cut off from a woodlot than by species that can live their entire life within a pond. During dispersal, post-metamorphs of migrant species must make their way from their natal environment to upland habitat. An increase in impervious surface not only subjects frogs to desiccation and other lethal hazards, but also limits the amount of buffer zone around the pond that may act as a corridor. Todd et al. (2009) found that wood frogs moved from wetlands through woodlots in significantly greater numbers than those moving through areas where forest had been clear cut, and that those that entered cleared areas were more likely to reverse route and return to the wetland. Becker et al. (2010) also found that juveniles lack behavioral adaptations that direct adult frogs to upland habitat. Reduction of adjacent woodlots and dispersal corridors decrease the amount of available upland habitat for dispersing juveniles, as well as the likelihood of them reaching it. Poor juvenile recruitment over time could have deleterious effects on a local population (Semlitsch and Brodie 1998).

While landscape-level variables had a strong influence on migratory species and generalists, conditions within ponds significantly affected green frogs and bullfrogs. Bullfrog calling intensity was best explained by the density and surface area of ponds, along with decreased specific conductance during the second calling period. Lower specific conductance was also found in two of the top three green frog call code models, with greater calling intensity occurring at sites with less noise pollution during the first calling period, lower chloride concentration in the second calling period, and higher emergent vegetation cover in the second calling period resulting in increased calling activity. Specific conductance did not vary significantly with chloride levels; however, it may further indicate use of road salts, along with other pollutants. For example, Wu et al. (1998) recorded evidence of heavy metals (Cu, Cd, Cr, Ni, and Pb) and nutrients in highway runoff. Conway (2007) found impervious surface influenced pH and specific conductance. Water quality may also impact the food web within stormwater ponds. Van Meter et al. (2011) found that high specific conductance resulted in decreased zooplankton, which in turn freed up more algae for tadpoles to consumed, due to less grazing pressure on algae by zooplankton. Tadpoles used in their experiment in ponds grew larger and metamorphed faster as a result of increased resources. These findings suggest specific conductance may be beneficial or harmful to anurans, depending on which life history stage they are in.

Increases in emergent vegetation was a significant predictor of green frog calling intensity and abundance in each of the best models. Whitaker (1961) found that green frogs prefer marsh and pond edge habitat, with very few captures occurring in more upland areas. Areas with emergent vegetation may allow green frogs to forage while remaining camouflaged from some of their predators. Noise pollution was evident at many of my sites, especially those near busy roads or industrial sites. While amphibian calling intensity was lower at sites with more noise pollution, the decrease was likely due to conditions or activities at the sites associated with more noise, such as high traffic density. These factors could have decreased detectability, although I am fairly confident that I would have heard frogs calling if they were there due to the relatively small size of most ponds and the proximity of my sampling point(s) to the ponds. Despite this concern, calling surveys can result in false negatives (Pellet and Schmidt 2005) and do not always detect species during their peak calling periods (Bridges and Dorcas 2000). Alternative explanations of why noise pollution impacts call code and abundance exist. Bee and Swanson (2007) found that gray treefrog females oriented less towards advertisement calls when road traffic noise was played with the call. Sun and Narins (2005) subjected a mixed anuran assemblage to playback of airplane flyovers and motorcycle sounds and found that calling rate and frequency were negatively affected. There is also evidence that frogs will call at a different pitch when traffic noise is present (Parris et al. 2009). This might impact the reproductive fitness of some males as female frogs of some species prefer low-pitched calls (Ryan et al. 1992), which can indicate a larger male (Ramer et al. 1983). It is unlikely that green frogs rely on the calls of conspecifics to migrate, as vocal cues do not affect their movement (Oldham 1967).

Breeding:

The models that best explained breeding presence included a significant negative relationship with both PC 1 (increased impervious surface, decreased natural habitat) and PC 2 (increased pond surface area, pond density, and stone). A negative relationship with cost was also included in the second model. As upland habitat and corridors disappear, there is less available upland habitat for migratory species and generalists to use as adults, which in turn means that fewer individuals will move to the ponds to breed. The higher cost associated with moving through a developed area also results in fewer frogs surviving the trip to or from the ponds. While little is known about anuran post-metamorph dispersal, Vasconcelos and Calhoun (2004) found juvenile wood frogs non-randomly oriented in the direction of adjacent woodlots. If movements are random or non-random in the direction of surrounding forest, then the likelihood of juvenile recruitment will be greater at sites with large, close woodlots, or where the cost of travelling to the woodlot is relatively low. Because several of the anurans species found in my study show high site fidelity

(Vasconcelos and Calhoun 2004, Homan et al. 2010), those that survive the initial dispersion as metamorphs have a greater likelihood of returning as adults. The negative response to PC 2 may be due to ponds with a stone base or perimeter. Anurans may be deterred by ponds surrounded by stone, and a stone substrate may not be suitable for oviposition.

Species Richness:

There were four closely related models that explained species richness. Presence of fish and noise pollution during the second calling period reduced diversity in each of the significant models. Additionally, decreased pH and PC 1 affected diversity negatively in the model with the lowest AIC_c score. Fish were present at 23.7% of sites, with ponds that held fish having an average diversity index of 0.94, and sites without fish having an average of 1.48. Fifty percent of sites with fish had a diversity index of 1.000 or less, while those without had a score of 1.637. There are several examples where fish have been negatively affected anuran community structure and species richness. Knudson et al. (2004) looked at species richness in agricultural ponds with five of the six species included in this study and found that species richness was lower in ponds with fish. Porej and Hetherington (2005) found similar results, although they also mentioned that the addition of shallow littoral areas had a positive association with species richness in ponds with predatory fish because shallow areas offered both refuge from fish and suitable breeding habitat. In an experimental study, Kurzava and Morin (1998) found that banded sunfish (*Enneacanthus obesus*) eliminated spring peeper and gray treefrog tadpoles from stocked ponds. However, there have also been instances where fish presence can benefit amphibian species richness. In a study by Lehtinen et al. (1999), the presence of fish that did not predate amphibian larvae resulted in greater species richness, possibly due to fish predating zooplankton and increasing food resources. Other studies have found that fish presence can affect populations of odonates, which prey upon amphibian larvae. In one study, fish presence affected odonate community composition by reducing the abundance of two odonate species (Johansson and Brodin 2003). Dragonfly larvae also have decreased activity levels when fish are present, resulting in reduced feedings (Dixon and Baker 1988). These findings suggest that ponds with fish have amphibian assemblages comprised of species that are resistant to predation, either directly or indirectly due to fish presence, and these communities are unique from ponds without fish.

Urbanization has also been linked to decreases in amphibian richness. Wood frogs and ambystomid (Family Ambystomatidae) salamanders are sensitive to loss of forested habitat and increases in pond hydroperiod, which in turn can help support fish (Rubbo and Kiesecker 2005). Reinelt et al. (1998) found that urbanization altered pond hydrology by creating longer hydroperiods and larger water-level fluctuations, and that amphibian species richness was lower in ponds within an urbanized watershed. As the best model for diversity suggests, factors at the pond and landscape level both impact anuran assemblages. Urbanization, however, may ultimately affect within-pond parameters, including water quality, fish presence, and ambient noise levels.

Conservation and Management Implications:

My findings for anuran communities occurring in stormwater ponds in Monroe County, New York show that 1) life history constraints on a species may ultimately determine whether stormwater ponds in an urbanized landscape can be suitable habitat; 2) connectivity to upland habitat with dispersal corridors is necessary for certain species to breed successfully and persist in stormwater ponds; 3) factors at both the landscape and pond level affect anuran species richness within ponds. Given the current global status of amphibians and drivers of their declines, focus needs to be placed on habitat conservation. While stormwater ponds are not designed with the primary purpose of creating wildlife habitat, species of various taxa may ultimately end up in these sites. For instance, I observed algae, plants, arthropods, mollusks, amphibians, reptiles, birds, and mammals in my study sites, and species of other taxa were most likely present. Ideally, stormwater ponds should act as functional wetlands by providing flood storage, removing contaminants, and providing wildlife habitat whenever possible. These needs can be met by designing individual ponds and pond clusters so local flora and fauna can persist in them.

While road salt did not have a significant negative effect on anuran community structure or breeding, other studies have demonstrated how high concentrations of this pollutant affects species differently both as adults (Collins and Russell 2009) and prior to metamorphing (Brown et al. 2012, Gallagher et al. 2014). Salt concentration can be addressed by limiting its use, as well as by installing additional ponds to absorb drainage and runoff from impervious surfaces. Effectively treating chloride may result in more diverse vegetation. Crowe et al. (2007) found that the number of plant species decreases in response to greater chloride levels.

Wilcox (1986) found that *Typha angustifolia* cover in an invaded wetland decreased over a four-year period after a road salt contamination had been eliminated. In another study, Landi et al. (2012) found specific conductance, pond size, and pond depth influenced plant community composition, which in turn affected anuran assemblages. The response of plants to water quality suggests that managing adjacent ponds as a group, as opposed to taking a single pond approach, might be the best management strategy for anuran diversity. For example, different sized ponds draining the same amount of impervious surface would have different water quality, resulting in unique floral assemblages. Altering topography to incorporate shallow areas would also result in different plant communities and also provide refuge from fish. By applying different management for adjacent ponds, the resulting variability between plant communities would provide habitat for different anuran species, resulting in greater site diversity.

A multi-pond approach to management should also be considered when managing amphibian species and communities. Petranka et al. (2004) suggested anuran populations occupying ponds within a few hundred meters of one another are not independent; that amphibians view ponds as patches and exploit ponds that best serve their needs. Another finding from that study was anurans are more likely to change the pond in which they breed when the area is subject to disturbance. Jeliazkov et al. (2014) also recommended managing ponds as a system. This practice would allow for management of an anuran community, with individual ponds being designed and placed in the landscape where they would best suit different species. Larger, deep ponds with tall emergent vegetation growing along the edges in shallower areas could be used to benefit green frogs, while smaller, shallow ponds within close proximity to upland forested habitat would benefit migratory species, such as the spring peeper or gray treefrog. Larger ponds draining smaller areas of impervious surface have potential for better water quality, which was a significant predictor of green frog and bullfrog calling intensity in this study. The addition of shallow areas would provide breeding habitat and refuge from predators. Landscape resistance had a significant impact on migratory species in this study, including spring peepers and American toads. Placing shallow ponds close to woodlots would relieve pressure from predation by fish, and also make their migration to and from the ponds lest dangerous. Multiple ponds also allow for additional refuges for species should ponds dry out, along with source-sink dynamics. These designs, however, face constraints. It may be economically infeasible to implement additional stormwater ponds at existing sites. Also, the amount of available land decreases and its cost potentially increases as urban sprawl continues. Land owners might not be receptive to purchasing and setting aside land for additional ponds when a single large pond is capable of storing water.

A different set of management guidelines can be used to benefit anurans in existing ponds. Pesticides have negative effects on amphibians (Hayes et al. 2002, Relyea 2005); thus, eliminating or reducing the amount applied could have beneficial effects. Land managers should also examine where and how much road salt is being applied. Not only would this be more cost-effective, it would also reduce the salt concentration in ponds. Land management around ponds should also be considered when managing for calling amphibians. Lawn mowing and manicuring around ponds was prevalent among my sites. This practice has the potential to reduce the effectiveness of what could be natural corridors for dispersal. Stormwater ponds also would benefit from protective practices given to other wetlands, including sediment fences. While purely observational, I noticed that sediment from runoff covered egg masses at two sites where construction was taking place. In these instances, sediment fences could have been used to protect species within the pond during construction and force amphibians trying to enter those ponds to move to other, potentially more suitable habitat. Lastly, more research could be done to identify which species are breeding in these ponds. I noted evidence of breeding at my sites but did not associate the breeding with any species. It would be important from a best management perspective to understand which species are successfully breeding and which are not. This additional information could be used when designing ponds to meet the needs of a particular anuran species.

In summary, land managers should consider several best management practices when creating stormwater ponds for new developments or maintaining ponds at existing sites to provide adequate habitat for amphibians to breed in. These include:

- Considering the life history of species being managed when creating habitat.
- Creating complexes of adjacent ponds that vary in size, topography, and placement within the landscape.
    - Deeper ponds with shallow, vegetated areas for species that inhabit ponds throughout the spring and summer, such as green frogs and bullfrogs.

  - Shallow, vegetated ponds placed near forested areas with a corridor to disperse though for migratory species, such as spring peepers and American toads.
  - Variation in topography, such as the inclusion of shallow, vegetated areas, may also allow other species to persist in these ponds with amphibians, including birds and fish.
- Managing adjacent ponds as a pond complex to ensure adequate habitat is available when environmental conditions are not ideal, such as during drought.
- Using eco-friendly alternatives for pests and either reducing, eliminating, or choosing alternatives to road salts, such as construction grade sand.

Tables:

Land use	Cost
Agriculture	20
Building	1000
Canal	500
Creek	10
Drain run	10
Fallow	10
Highway	500
Impervious	60
Lawn	20
Pond	10
Residential	40
Road	80
Stone	30
Stormwater pond [a]	10
Woodlot	0

a: *Stormwater pond being analyzed assigned a cost of zero*

Table 1: Relative scores assigned to land use classes identified during heads-up digitizing for cost distance analysis. Scores indicate the relative amount of resistance an anuran would encounter while crossing through a particular land use.

Rotated component matrix				
Items	**Rotated component coefficients**			
	Component 1	**Component 2**	**Component 3**	**Communalities**
Impervious total	**0.956**	0.172	0.066	0.948
Impervious	**0.912**	0.265	-0.21	0.902
Building	**0.895**	0.009	-0.002	0.801
Woodlot	**-0.632**	0.392	-0.327	0.659
Fallow	**-0.632**	0.048	0.386	0.552
Stormwater pond	-0.277	**0.784**	-0.157	0.715
Stone	0.28	**0.753**	-0.128	0.662
Pond count	0.211	**0.721**	0.478	0.793
Road	0.293	0.025	**0.736**	0.628
Residential	-0.36	-0.389	**0.711**	0.787
Lawn	0.552	-0.02	**-0.611**	0.679

Table 2: Rotated component matrix for PCA with Varimax rotation. Bold values indicate major loadings for each item. Variable definitions are found in Appendix F.

Species list for 2011 and 2012		
Common name	Binomial	Alpha code
American bullfrog	*Lithobates catesbeianus*	BULL
American toad	*Anaxyrus americanus*	AMTO
Gray treefrog	*Hyla versicolor*	GRTR
Green frog	*Lithobates clamitans*	GRFR
Northern leopard frog	*Lithobates pipiens*	NLFR
Spring peeper	*Pseudacris crucifer*	SPPE

Table 3: Anuran species list for stormwater ponds within Monroe County, NY during 2011 and 2012.

Common name	Sites occupied in 2011 (%)	Sites occupied in 2012 (%)
Green frog	40	84.2
Gray treefrog	28	23.7
American bullfrog	8	28.9
Spring peeper	8	15.8
American toad	0	15.8
Northern leopard frog	0	13.2

Table 4: Site occupancy by calling amphibian species in 2011 and 2012.

Response Variable	Rank	AICc	ΔAICc	Wi	K	Predictor Variable	β
SPPE CC 2012	1	47.188	0	0.34801	2	PC2	1.089
						PC1	-1.281
	2	47.416	0.228	0.31052	1	PC1	-1.260
	3	48.043	0.855	0.22695	3	Round 1 chloride	0.885
						PC2	1.350
						PC1	-1.485

Table 5: Best habitat models for spring peeper (*Pseudacris crucifer*) calling intensity. Models with $\Delta AIC_c < 2.0$ were considered. Principal components are explained in Table 2 and variable definitions are found in Appendix F.

Response Variable	Rank	AICc	ΔAICc	Wi	K	Predictor Variable	β
GRFR CC 2012	1	72.832	0	0.49713	3	Round 1 decibel	-0.721
						Round 2 chloride	-0.805
						Round 1 emergent	0.936
	2	73.931	1.099	0.28696	4	Round 2 conductivity	-0.466
						Round 2 chloride	-0.670
						Round 1 decibel	-0.719
						Round 1 emergent	0.950
	3	74.500	1.668	0.21591	5	Round 2 conductivity	-0.703
						Cost	0.704
						Round 2 chloride	-0.845
						Round 1 decibel	-0.847
						Round 1 emergent	1.148
BULL CC 2012	1	55.247	0	0.32400	2	PC2	1.073
						Round 2 conductivity	-1.182
	2	55.807	0.56	0.24487	3	PC3	0.869
						PC2	0.991
						Round 2 conductivity	-1.233
	3	55.835	0.588	0.24147	4	Round 3 decibel	-0.737
						PC2	1.090
						PC3	1.234
						Round 2 conductivity	-1.274
	4	56.318	1.071	0.18966	5	Round 2 hydrogen[a]	-0.848
						Round 3 decibel	-1.134
						PC2	1.354
						PC3	1.383
						Round 2 conductivity	-1.566

a: Hydrogen ion concentration is a measurement of pH, however the two are inversely proportional. A negative β for hydrogen ion indicates a positive β for pH

Table 6: Best habitat models for green frog (*Lithobates clamitans*) and Bullfrog (*Lithobates catesbeianus*) calling intensity. Models with ΔAIC_c <2.0 were considered. Principle Components are explained in Table 2 and variable definitions are found in Appendix F.

Response Variable	Rank	AICc	ΔAICc	Wi	K	Predictor Variable	β
GRFR Abundance 2012	1	173.518	0	0.61456	5	Round 2 conductivity	-0.765
						PC1	-0.956
						Cost	1.15
						Round 1 emergent	1.721
						Permanence	2.9
	2	174.451	0.933	0.38544	6	Round 1 decibel	-0.524
						PC1	-0.718
						Round 2 conductivity	-0.811
						Cost	1.075
						Round 1 emergent	1.564
						Permanence	2.431

Table 7: Best habitat models for green frog (*Lithobates clamitans*) abundance. Models with $\Delta AIC_c < 2.0$ were considered. Principal components are explained in Table 2 and variable definitions are found in Appendix F.

Response Variable	Rank	AICc	ΔAICc	Wi	K	Predictor Variable	β
Breeding 2012	1	23.984	0	0.58528	2	PC1	-3.606
						PC2	-3.884
	2	24.673	0.689	0.41472	3	Cost	-0.920
						PC1	-3.812
						PC2	-4.783
Diversity 2012	1	72.659	0	0.33853	4	Round 1 hydrogen[a]	-0.170
						Round 2 decibel	-0.270
						PC1	-0.394
						Fish presence	-0.478
	2	73.138	0.479	0.26643	3	Round 2 decibel	-0.244
						PC1	-0.363
						Fish presence	-0.383
	3	73.456	0.797	0.22726	2	Round 2 decibel	-0.282
						PC1	-0.369
	4	74.063	1.404	0.16777	5	Round 1 decibel	-0.126
						Round 1 hydrogen[a]	-0.195
						Round 2 decibel	-0.238
						PC1	-0.350
						Fish presence	-0.564

a: Hydrogen ion concentration is a measurement of pH, however the two are inversely proportional. A negative β for hydrogen ion indicates a positive β for pH

Table 8: Best habitat models for sites with signs of breeding and for species richness. Models with ΔAIC_c <2.0 were considered. Principal components are explained in Table 2 and variable definitions are found in Appendix F.

Figures:

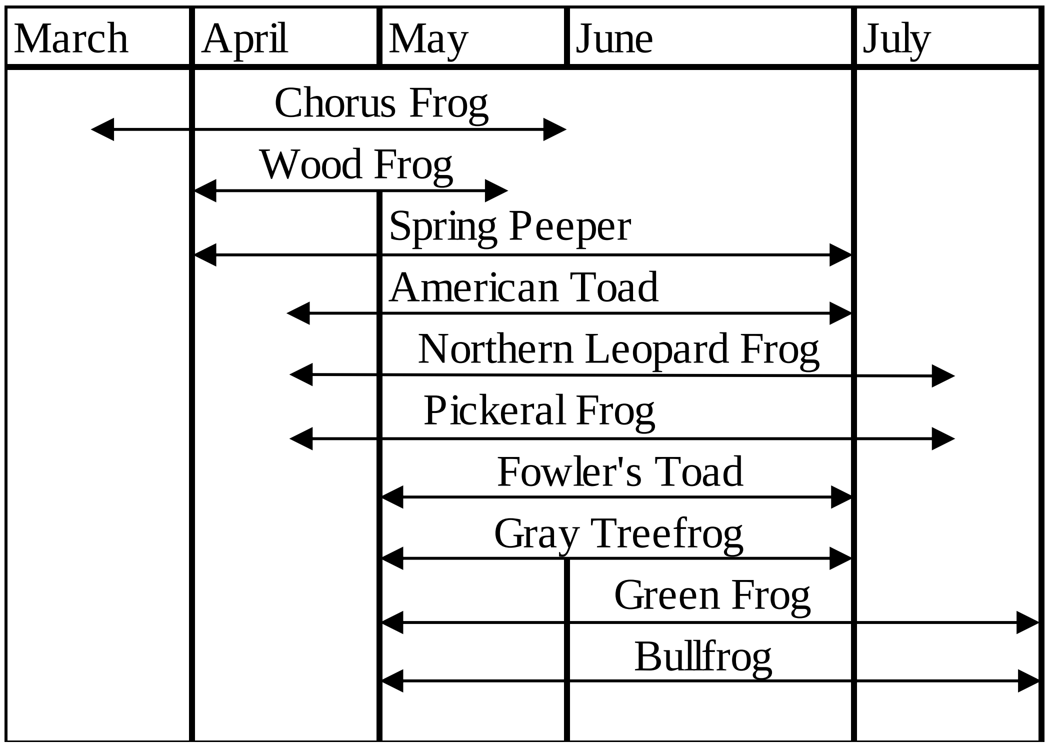

Figure 1: Breeding periods for calling amphibians of the Central Great Lakes Basin (Chabot and Helferty 1995).

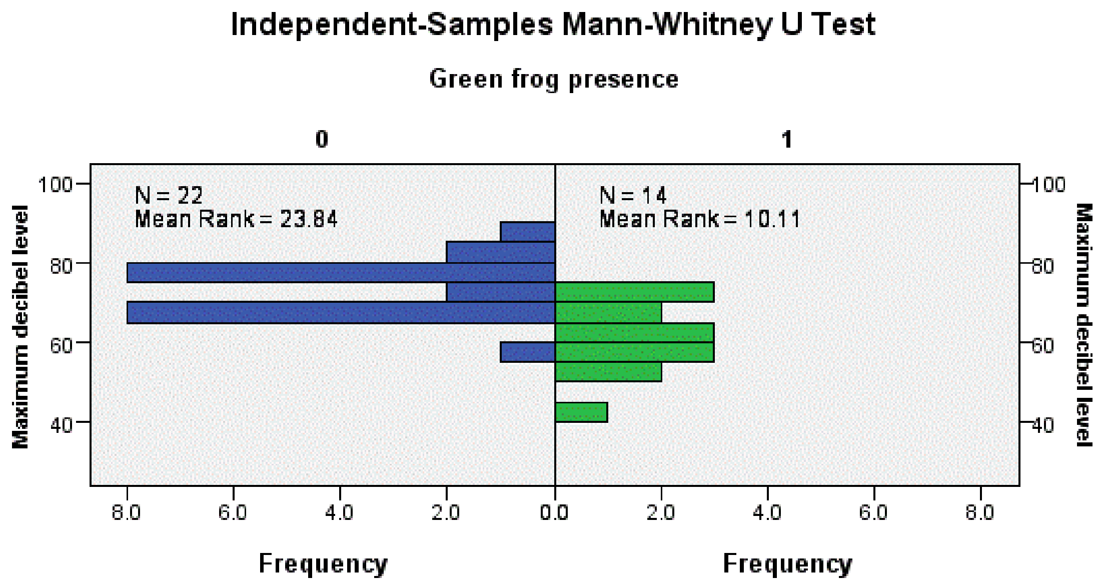

Figure 2: Results of Mann-Whitney U test comparing response of green frog (*Lithobates clamitans*) presence in 2011 to maximum decibel level recorded during point count. Instances where green frogs were not detected are represented by “0”, while presence is indicated by “1”.

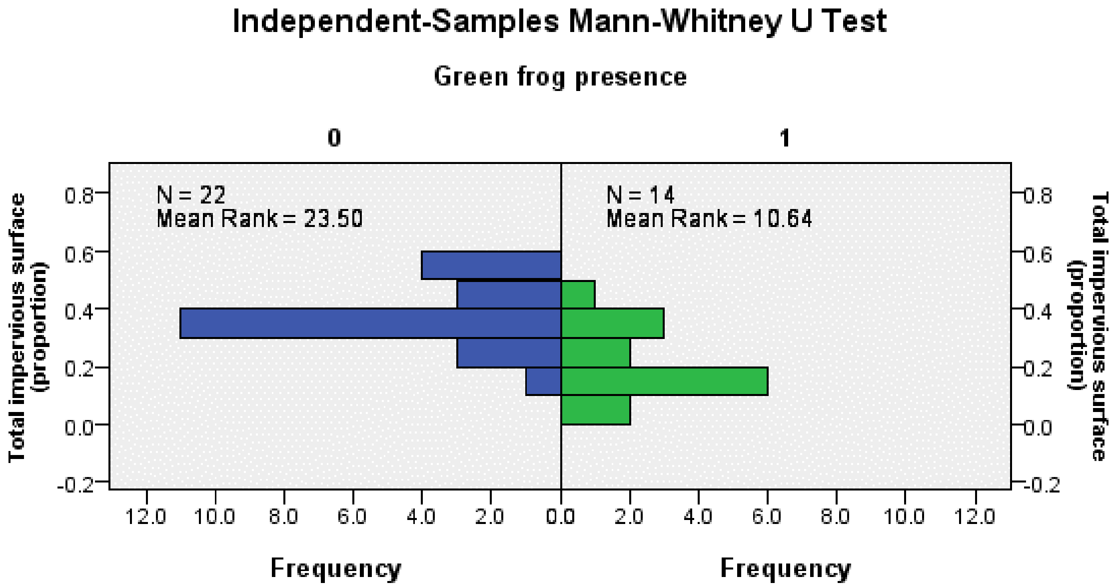

Figure 3: Results of Mann-Whitney U test comparing response of green frog (*Lithobates clamitans*) presence in 2011 to the proportion of impervious surface within 300m of the stormwater pond where the count took place. Instances where green frogs were detected are represented by “0”, while presence is indicated by “1”.

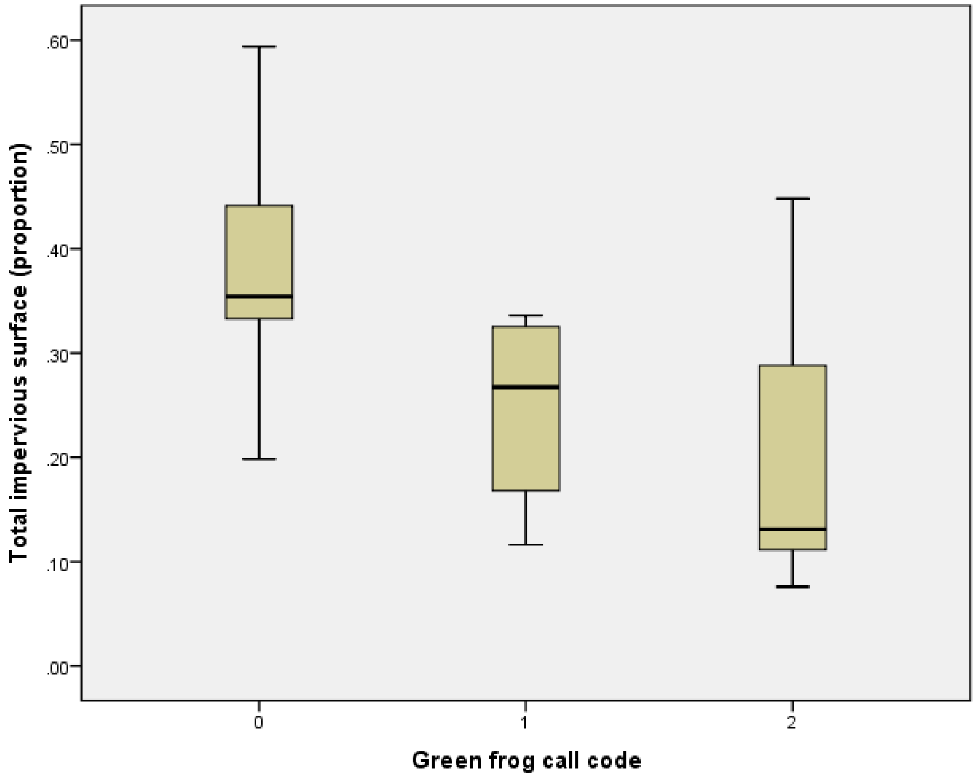

Figure 4: Results of Kruskal-Wallis test comparing response of green frog (*Lithobates clamitans*) calling intensity in 2011 to the proportion of impervious surface within 300 m of the stormwater pond where the count took place.

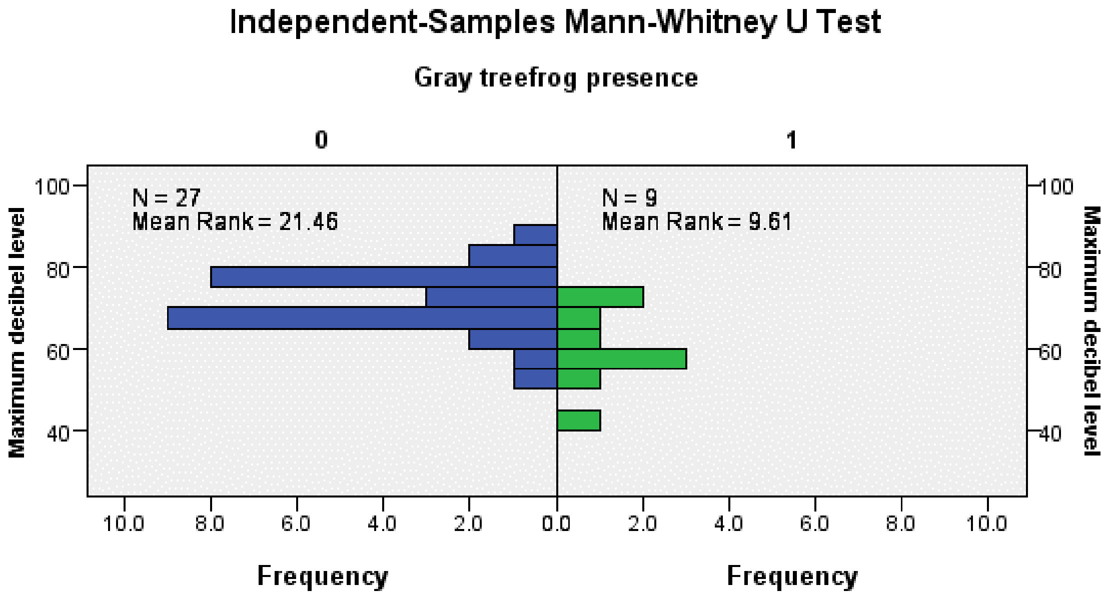

Figure 5: Results of Mann-Whitney U test comparing response of gray treefrog (*Hyla versicolor*) presence in 2011 to the proportion of impervious surface within 300m of the stormwater pond where the count took place. Sites where gray treefrogs were not detected are indicated by “0”, while presence is indicated by “1”

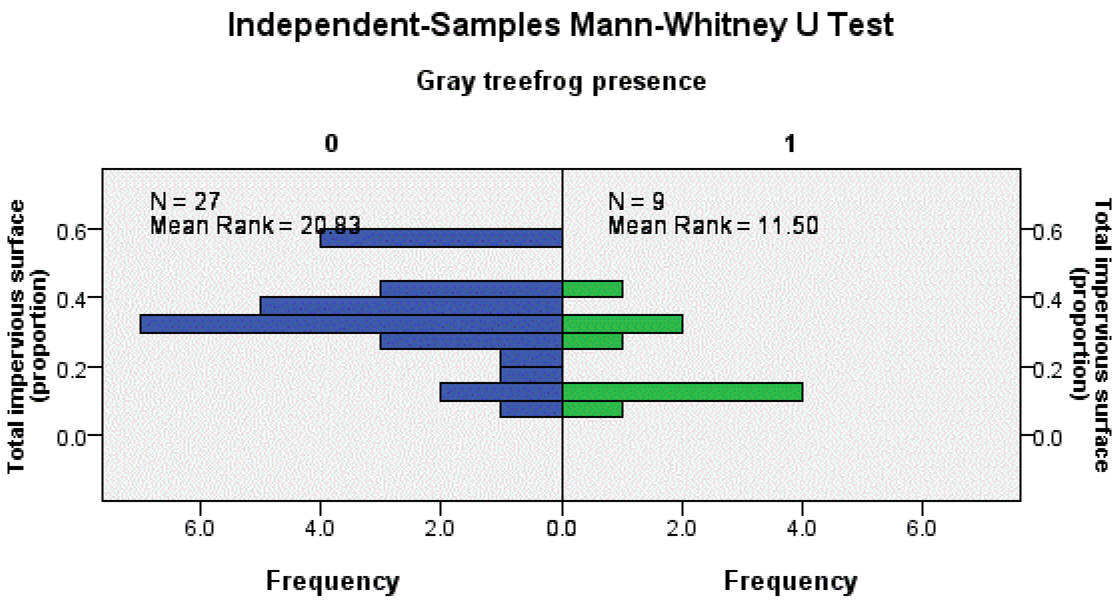

Figure 6: Results of Mann-Whitney U test comparing response of gray treefrog (*Hyla versicolor*) presence in 2011 to maximum decibel level recorded during point count. Instances where gray treefrogs were not detected are represented by “0”, while presence is indicated by “1”.

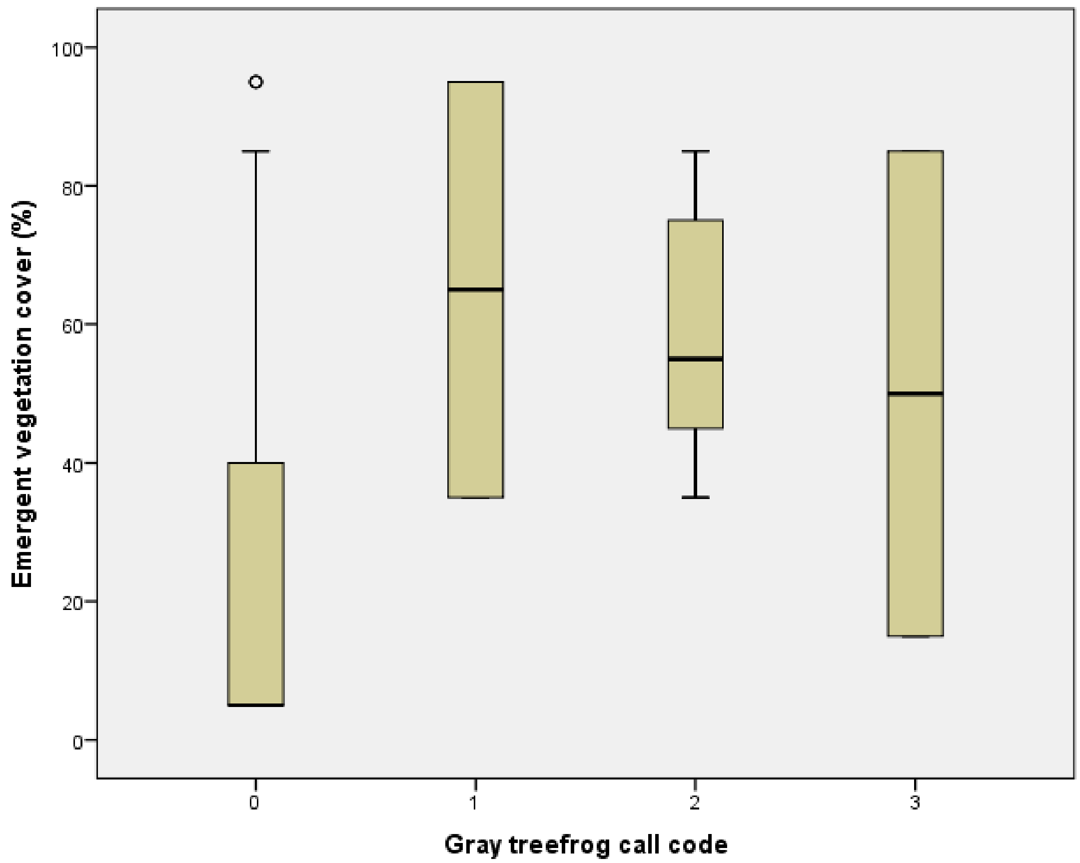

Figure 7: Results of Kruskal-Wallis test comparing response of gray treefrog (*Hyla versicolor*) calling intensity during 2011 to percent emergent vegetation within the stormwater pond where the point count was taken.

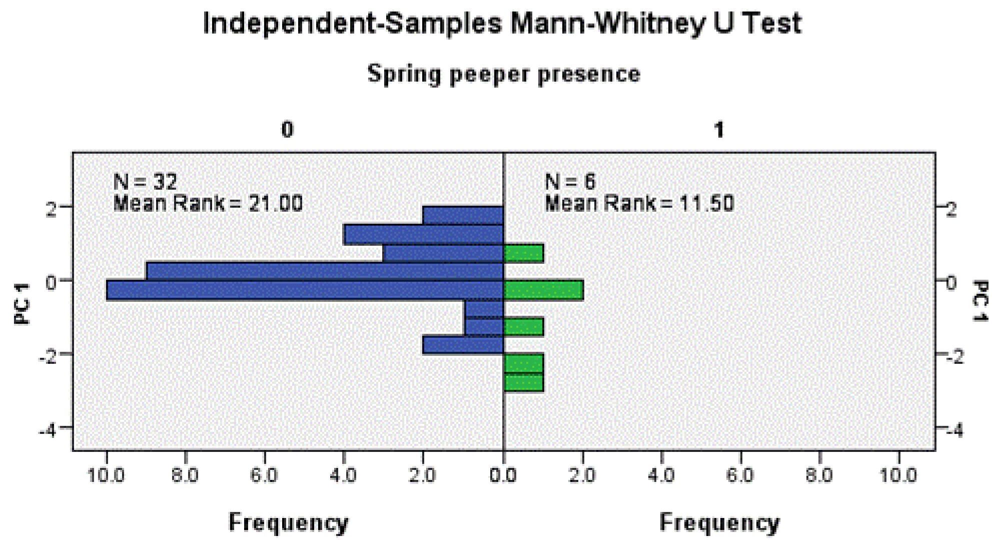

Figure 8: Results of Mann-Whitney U test comparing response of spring peeper (*Pseudacris crucifer*) presence in 2012 to Principal Component 1. This component is explained in Table 2. Instances where spring peepers were not detected are represented by “0”, while presence is indicated by “1”.

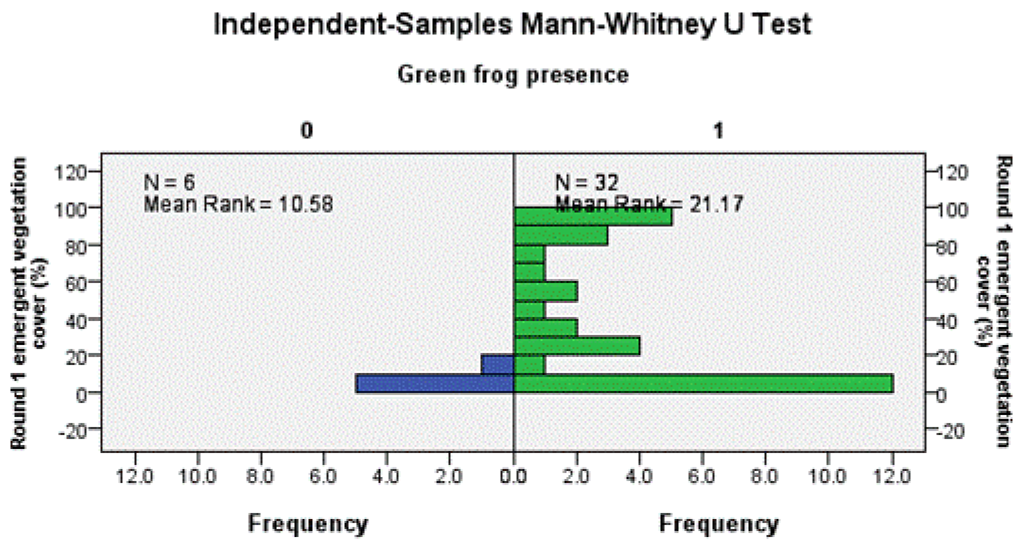

Figure 9: Results of Mann-Whitney U test comparing response of green frog (*Lithobates clamitans*) presence in 2012 to percent emergent vegetation within the stormwater pond during the first calling period. Instances where green frogs were detected are represented by "0", while presence is indicated by "1".

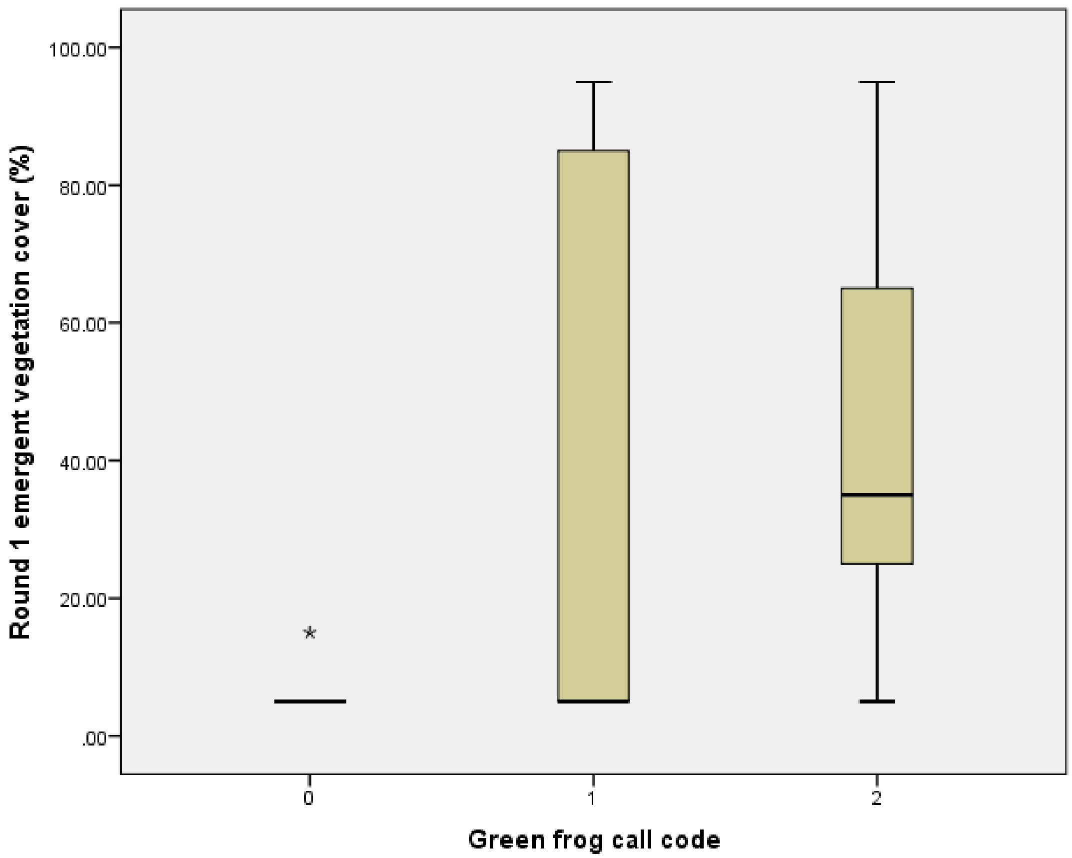

Figure 10: Results of Kruskal-Wallis test comparing response of green frog (*Lithobates clamitans*) calling intensity in 2012 to percent emergent vegetation during the first calling period.

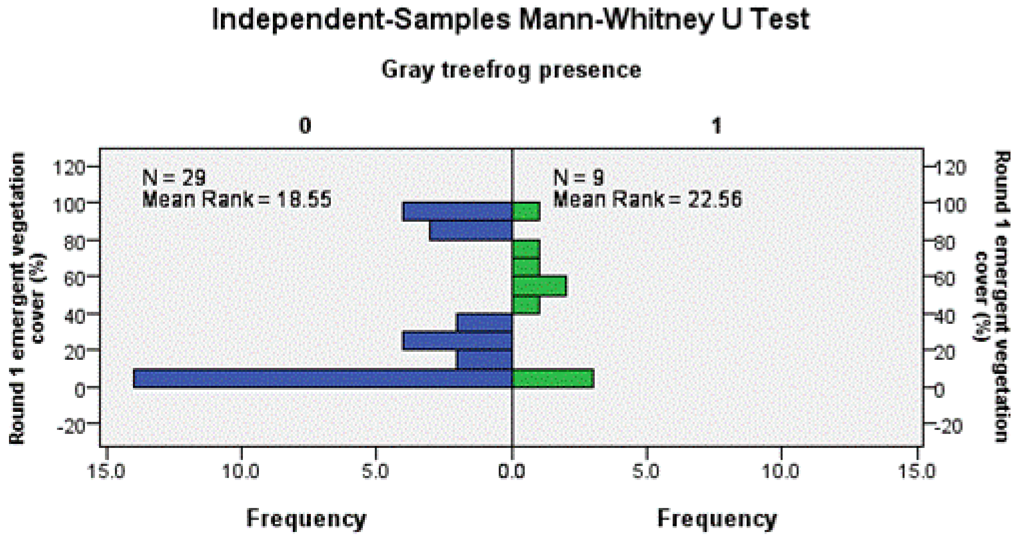

Figure 11: Results of Mann-Whitney U test comparing response of gray treefrog (*Hyla versicolor*) presence in 2012 to percent emergent vegetation within the stormwater pond during the first calling period. Instances where gray treefrogs were not detected are represented by “0”, while presence is indicated by “1”.

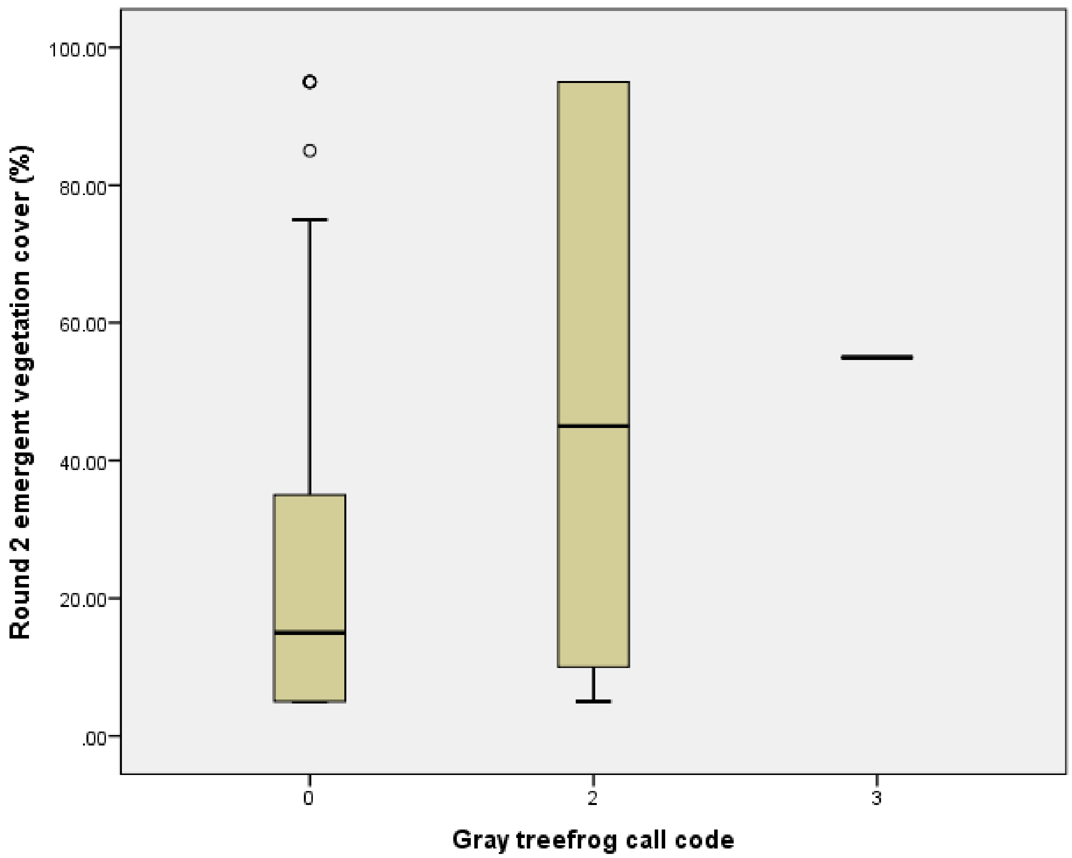

Figure 12: Results of Mann-Whitney U test comparing response of gray treefrog (*Hyla versicolor*) calling intensity in 2012 to percent emergent vegetation within the stormwater pond during the second calling period.

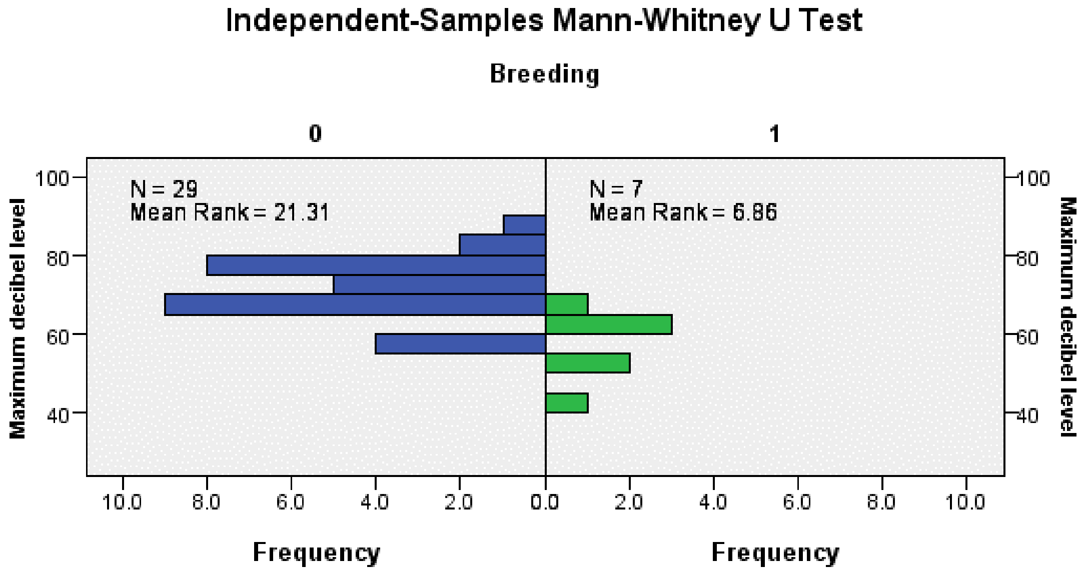

Figure 13: Results of Mann-Whitney U test comparing evidence of breeding in 2011 to maximum decibel level recorded during point count. Sites where breeding was not detected are represented by “0”, while “1” is used where breeding was observed.

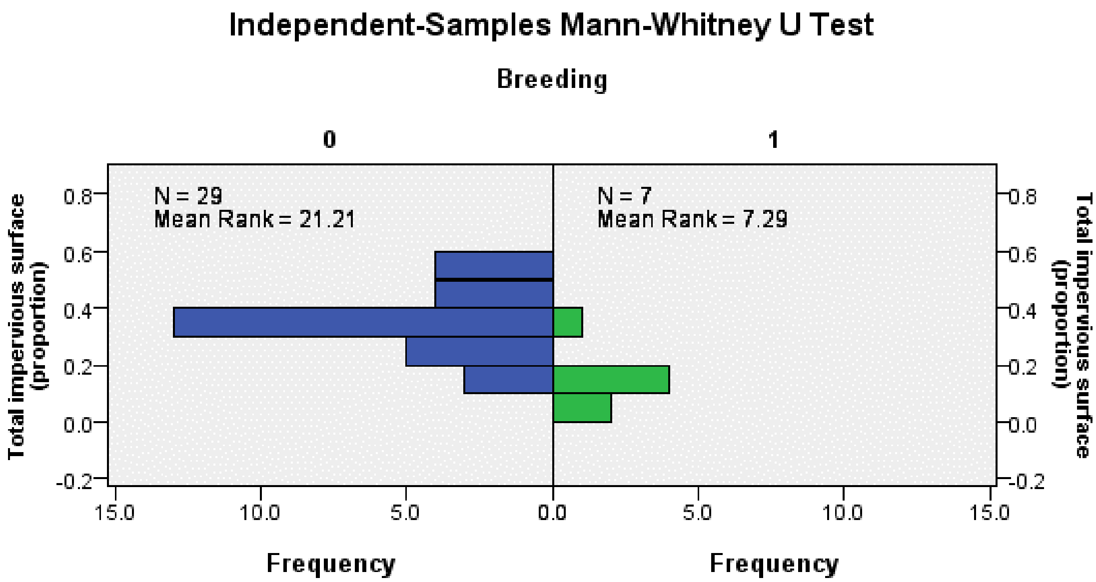

Figure 14: Results of Mann-Whitney U test comparing evidence of breeding in 2011 to the proportion of impervious surface within 300 m of the stormwater pond where the count took place. Sites where breeding was not detected are represented by “0”, while “1” is used where breeding was observed.

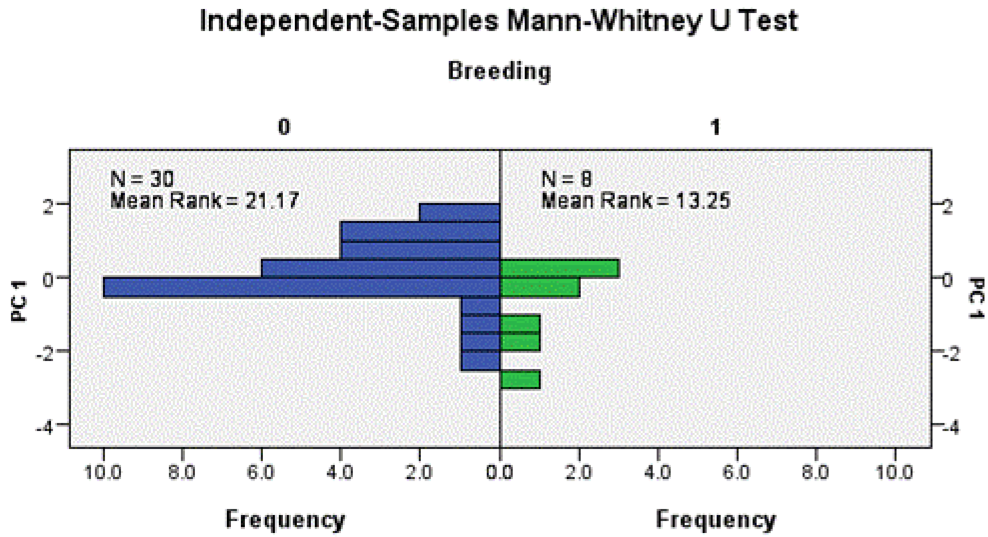

Figure 15: Results of Mann-Whitney U test comparing evidence of breeding in 2012 to Principal Component 1. This component is explained in Table 2. Sites where breeding was not detected are represented by “0”, while “1” is used where breeding was observed.

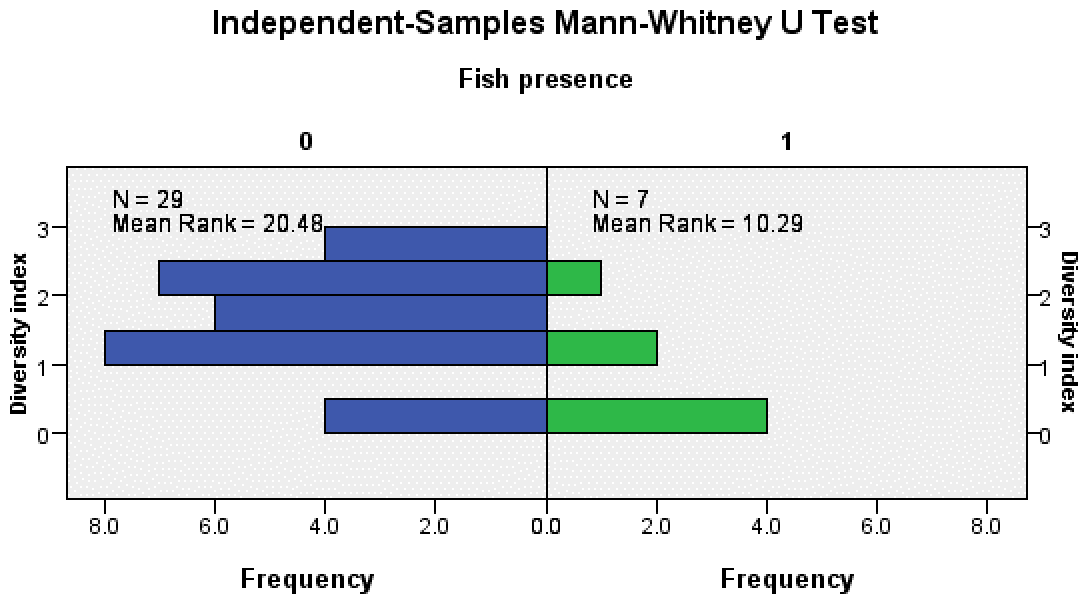

Figure 16a: Results of Mann-Whitney U test comparing amphibian species richness in 2011 to presence of fish within stormwater ponds. Sites where fish were not detected are represented by "0", while "1" is used for sites with fish.

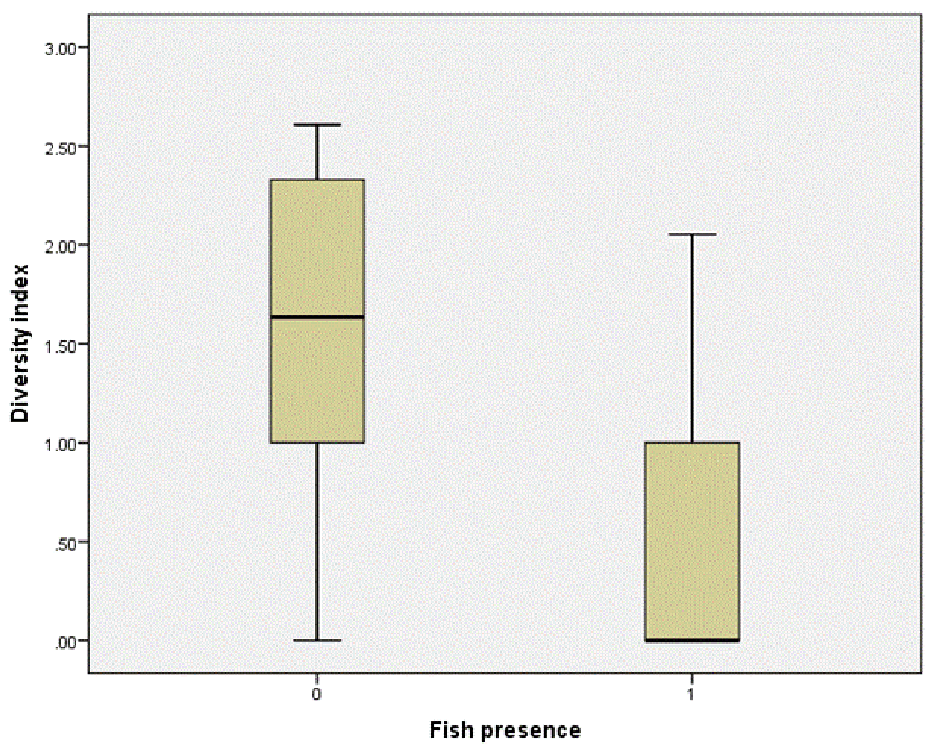

Figure 16b. Boxplot comparing amphibian species diversity to fish presence during 2012 at 38 stormwater ponds within Monroe County, NY. Sites where fish were not detected are represented by "0", while "1" is used for sites with fish.

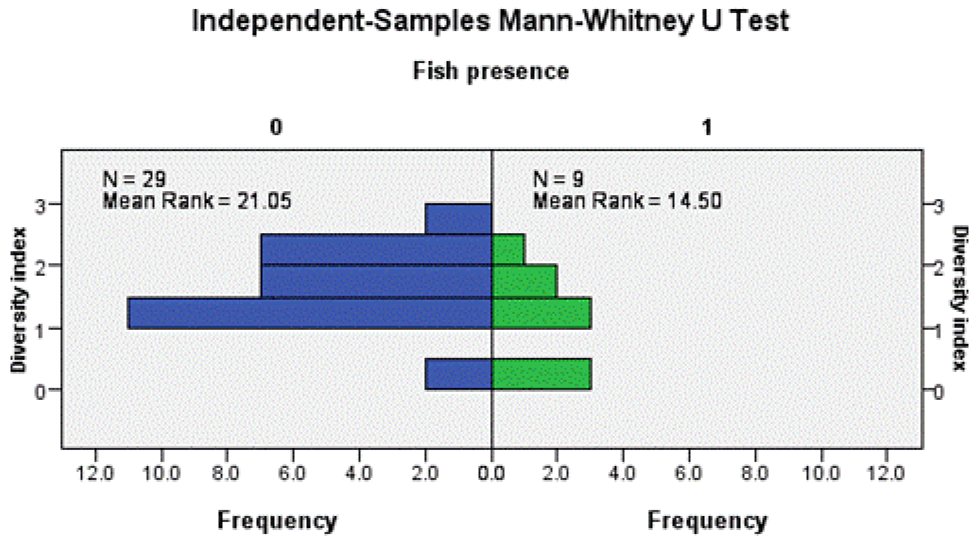

Figure 17: Results of Mann-Whitney U test comparing amphibian species richness in 2012 to presence of fish within stormwater ponds. Sites where fish were not detected are represented by “0”, while “1” is used for sites with fish.

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Appendices:

Pond name	Pond site	Latitude (DMS)	Longitude (DMS)
Spurr East	Brockport Wal-Mart	43^o 11' 47"	77^o 56' 02"
Spurr West	Brockport Wal-Mart	43^o 11' 49"	77^o 56' 07"
Wal-mart Entrance	Brockport Wal-Mart	43^o 11' 52"	77^o 55' 49"
Car Wash	Brockport Wal-Mart	43^o 11' 52"	77^o 55' 51"
Wal-mart Back	Brockport Wal-Mart	43^o 11' 52"	77^o 55' 35"
Maurice's	Brockport Wal-Mart	43^o 11' 44"	77^o 55' 45"
Pawn King	Brockport Wal-Mart	43^o 11' 44"	77^o 55' 50"
Goodwill	Brockport Wal-Mart	43^o 11' 45"	77^o 55' 53"
Wal-mart Lot	Brockport Wal-Mart	43^o 11' 45"	77^o 55' 46"
College Suites West	College Suites	43^o 12' 38"	77^o 58' 21"
College Suites East	College Suites	43^o 12' 38"	77^o 58' 13"
Post Office W	Latta Road Wegmans	43^o 15' 05"	77^o 42' 09"
Post Office E	Latta Road Wegmans	43^o 15' 09"	77^o 42' 04"
Latta UPS	Latta Road Wegmans	43^o 15' 09"	77^o 41' 58"
McDonald's	Latta Road Wegmans	43^o 15' 02"	77^o 41' 49"
Chase	Latta Road Wegmans	43^o 15' 07"	77^o 41' 48"
First Niagara	Latta Road Wegmans	43^o 15' 09"	77^o 41' 53"
MCC Townhomes	Monroe Community College	43^o 06' 17"	77^o 36' 27"
M Lot	Monroe Community College	43^o 06' 12"	77^o 36' 26"
ESL E	Monroe Community College	43^o 05' 51"	77^o 36' 13"
ESL W	Monroe Community College	43^o 05' 51"	77^o 36' 14"
MCC 390	Monroe Community College	43^o 06' 06"	77^o 36' 08"
V-1 South	The College at Brockport	43^o 12' 29"	77^o 57' 19"
Redman Road	The College at Brockport	43^o 12' 36"	77^o 57' 57"
V-1 North	The College at Brockport	43^o 12' 32"	77^o 57' 19"
V Lot	The College at Brockport	43^o 12' 32"	77^o 57' 14"
Townhomes S	The College at Brockport	43^o 12' 35"	77^o 57' 15"
Townhomes N	The College at Brockport	43^o 12' 37"	77^o 57' 15"
D-1	The College at Brockport	43^o 12' 50"	77^o 57' 05"
UR Ortho S	UR Orthopedic Office	43^o 10' 48"	77^o 42' 07"
UR Ortho W	UR Orthopedic Office	43^o 10' 49"	77^o 42' 12"
UR Ortho N	UR Orthopedic Office	43^o 10' 49"	77^o 42' 07"
Brooks East	Wegmans Brooks Ave	43^o 07' 51"	77^o 40' 43"
Brooks West	Wegmans Brooks Ave	43^o 07' 51"	77^o 40' 47"
WMS 200 N	Wegmans Market Street	43^o 07' 16"	77^o 41' 37"
WMS 200 S	Wegmans Market Street	43^o 07' 16"	77^o 41' 36"
Jet View	Wegmans Market Street	43^o 07' 01"	77^o 41' 58"
WMS 300	Wegmans Market Street	43^o 07' 21"	77^o 41' 58"

Appendix A: Approximate coordinates of 38 stormwater ponds used in study

Variable	Definition
Agriculture	Land used for growing crops
Building	Land made up of non-residential buildings
Creek	Natural stream of water smaller than a river
Drain run	Inlet to or outlet from a stormwater pond that feeds or drains rainwater
Fallow	Non-mowed or seasonally mowed fields
Highway	Inter- or intrastate expressway
Impervious	Non-residential asphalt and concrete surface
Lawn	Non-residential maintained grass
Pond	Permanent and/or ephemeral pools identified from aerial photography
Residential	Percentage of land use within 300 m of stormwater pond comprised Residential neighborhood, including lawns, driveways, homes, and sidewalks, but excluding roads
Road	local and county maintained roads, excluding highways
Stone	Land covred by a stone surface
Stormwater pond	Retention basin used to manage stormwater runoff
Woodlot	Area covered by trees

Appendix B. Definitions of land uses used in aerial photointerpretation.

Variable	Definition
Building	Percentage of land use within 300 m of stormwater pond comprised of non-residential buildings
Fallow	Percentage of land use within 300 m of stormwater pond comprised of non-mowed or seasonally mowed fields
Impervious	Percentage of land use within 300 m of stormwater pond comprised of non-residential asphalt and concrete surface
Impervious total	Sum of building, impervious, and road percentages within 300 m of stormwater pond
Lawn	Percentage of land use within 300 m of stormwater pond comprised of non-residential maintained grass
Pond count	Number of ponds within 300 m of stormwater pond of interest.
Residential	Percentage of land use within 300 m of stormwater pond comprised of residential neighborhood, excluding roads
Road	Percentage of land use within 300 m of stormwater pond comprised of roads
Stone	Percentage of land use within 300 m of stormwater pond comprised of stone surface
Stormwater pond	Percentage of land use within 300 m of stormwater pond comprised of stormwater pond surface area
Woodlot	Percentage of land use within 300 m of stormwater pond comprised of wooded area

Appendix C: Definitions of land use variables included in Principal Component Analysis.

Natural history observations of possible significance
Gray treefrogs and woodfrogs were heard calling from ephmemeral pools in adjacent woodlots on several occasions during my study. While wood frogs were not detected during point counts, gray treefrogs were, especially in ponds close to the woodlot edge.
There seems to be a negative correlation between distance from woodlot and gray treefrog calling intensity, the latter being further influenced by emergent vegetation. Ponds close to forest edges were often full of gray treefrogs, and as I moved to ponds further away I found less. Gray treefrogs also seem to skip over larger, permanent ponds and call from shallow, well-vegetated ponds.
Lack of migratory species was evident at many of my sites. I feel the lack of detections of these species made my models less predictable. It could be that I missed their optimal calling period, or that they are not there in prominent numbers. Presence of predators, whether fish, birds, or egg predators, may be masking the importance of variables not included in the best model, including chloride concentration.
I've read where green frogs can be heavily predated by bullfrogs, yet I found no difference of green frog presence in ponds also occupied by bullfrogs. I'm curious if green frogs are able to exploit stormwater ponds and bullfrogs are not eating enough of them, or if they seek refuge in adjacent ponds.

Appendix D: Natural history observations made during 2011 and 2012.

Items	Rotated component matrix			
	Rotated component coefficients			
	Component 1	**Component 2**	**Component 3**	**Communalities**
Impervious total	**0.953**	-0.142	0.141	0.948
Impervious	**0.941**	-0.008	0.126	0.902
Building	**0.869**	-0.215	-0.009	0.801
Fallow	**-0.655**	-0.026	0.349	0.552
Lawn	**0.614**	0.197	-0.514	0.679
Stormwater pond	-0.082	**0.771**	0.338	0.715
Woodlot	-0.485	**0.651**	-0.025	0.659
Residential	-0.527	**-0.621**	**0.351**	0.787
Stone	0.447	**0.592**	0.336	0.662
Pond count	0.291	0.237	**0.808**	0.793
Road	0.189	-0.475	**0.605**	0.628

Appendix E. Major loadings of land use variables onto component axes without Varimax rotation.

Variable	Definition
pH	Percent hydronium ion concentration in stormwater pond measured during point count
Conductivity	Specific conductance (µS/cm) in stormwater pond measured during point count
Decible level	Maximum decible level recorded adjacent to stormwater pond during point count
Permanence	Measurement of whether there was standing water in a stormwater pond during point count
Fish presence	Fish were either caught with dip nets or observed in stormwater pond
Emergent vegetation	Midpoint value of 10% class interval of emergent vegetation within the stormwater pond
Chloride	Chloride ion concentration (mg/L) measured from water sample taken during point count
Pond size	Extent of stormwater pond surface area determined from 2012 orthoimagery
Cost	Relative score asssigned to a pond that reflects available upland habitat and the cost associated with migration

Appendix F. Definitions of variables excluded from Principal Component Analysis.