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Amphibian and Bird Communities of Lake Ontario Coastal Wetlands: Disturbance Effects and Monitoring Efficiencies

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Amphibian and bird communities of Lake Ontario coastal wetlands: disturbance effects and monitoring efficiencies

By

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Abstract

Anthropogenic disturbance has become a major topic of study in recent years. As human populations and development have increased, anthropogenic disturbance has led to the loss or conversion of many habitat types, including forests, wetlands, prairies, and grasslands. One major ecosystem negatively affected by anthropogenic disturbance is wetlands. Lake Ontario, within the Laurentian Great Lakes of North America, has seen major development of wetlands and wetland-associated landscapes. Development in wetlands and nearby areas can lead to habitat loss and population declines of wetland-dependent species. My two-part study examined 1) effects of anthropogenic disturbance surrounding Lake Ontario coastal wetlands on anuran and bird communities, and 2) effectiveness of the Great Lakes Coastal Wetlands Monitoring Program (GLCWMP) methods for monitoring birds and anurans in Lake Ontario wetlands.

In the first part of my study, I used six variables to represent anthropogenic disturbance and modelled the effects on species richness and abundance for birds and anurans. I found that wetland area was a significant predictor for increased bird species richness in wetlands, while increased levels of nitrogen, phosphorus, and chloride were significant predictors of decreased anuran species richness. This could be due to the permeability of anuran skin which allows for the increased movement of chemical compounds into organisms, causing mortality or decreased breeding success in many anurans. Further, increased agricultural land surrounding wetlands was a

significant predictor for increased anuran species richness, which could be due to some anuran species using upland habitats post-breeding.

In the second part of my study, I visited sites monitored for birds and anurans under the GLCWMP more frequently than the current methods require. I compared the richness counts between the two site visits required for bird monitoring and three site visits required for anuran monitoring under the GLCWMP with my more intensive surveys. I found that for both anurans and birds, species richness increased with the number of visits to a site. My first study supports the need for monitoring anuran species in Lake Ontario wetlands, due to disturbance. Increased nutrients from roadside runoff and agricultural land use is negatively affecting anurans. Bird species showed no negative effects from my disturbance variables, but several disturbance-tolerant species were observed in most counts. My second study supports increasing the number of visits to sites for better species richness estimates and individual species detections at individual wetlands.

General Introduction

The Laurentian Great Lakes contain 20 percent of the Earth's fresh water (Mitsch and Gosselink 2000). The wetlands associated with the Great Lakes provide habitat for many species of birds, mammals, amphibians, and plants (Mitsch and Gosselink 2000; Seilheimer *et al*. 2009; Schock *et al.* 2014). In the last 200 y, Great Lakes wetlands have been substantially altered by anthropogenic disturbance, or human actions, resulting in a major loss of wetlands (Mitsch and Wang 2001; Cvetkovic and Chow-Fraser 2011). Lake Ontario has experienced significant wetland loss from anthropogenic disturbance; more than 95 percent of wetlands surrounding western Ohio and Michigan have been lost in the last 200 y. As a result, many bird and amphibian species have been affected (Mitsch and Wang 2001; Cvetkovic and Chow-Fraser 2011).

Lake Ontario has seen an increase in the development and urbanization of lands adjacent to its shores, and wetlands have been negatively impacted. In the Rochester Area of Concern (AOC), elevated total phosphorus and turbidity have occurred as a result of increased nutrient runoff from surrounding tributaries (Makarewicz *et al.* 2012). Intensive agricultural activity in many counties adjacent to Lake Ontario further contributes to increased nutrient discharge in tributaries and wetlands. Both development and increased nutrient discharge contribute to habitat loss and decreased habitat quality for both wetland-dependent bird and anuran species (Houlahan and Findlay 2003; Deluca *et al.* 2004).

Both bird and amphibian species are affected by anthropogenic disturbances to wetlands because they depend on wetlands for at least part of their life cycle. Due to the permeability of their skin, amphibians have a direct association with water and also require water for reproduction (Hecnar 2004, Price *et al.* 2007). Similarly, wetland-dependent birds rely on wetlands for all stages of their life cycle. For example, the Pied-billed Grebe (*Podilymbus podiceps)* builds its nest among plants growing within wetlands and is very susceptible to wetland disturbances (Steen *et al.* 2006).

As a result of disturbances to Great Lakes coastal wetlands, monitoring programs were started to determine the health of these wetlands. In 1995, the Marsh Monitoring Program (MMP) was started as a joint program between the United States and Canada to monitor birds and amphibians in Great Lakes coastal wetlands. In addition, in 2011, the Great Lakes Restoration Initiative funded the Great Lakes Coastal Wetland Monitoring Program (GLCWMP), which uses a modified MMP protocol, but also samples vegetation, fish, macroinvertebrates, and water quality to determine overall impacts to wetlands (Uzarski *et al.* 2017). Researchers at the College at Brockport have contributed to this project for six years, monitoring wetlands adjacent to Lake Ontario.

Monitoring programs such as the MMP and GLCWMP are aimed at broader-scale data collection and basin-wide biodiversity trends for both bird and anuran species. However, these monitoring programs may not provide adequate population data for birds and anurans in individual wetlands. More accurate population analyses for individual wetlands can help researchers determine the quality of individual wetlands and better manage them for populations of bird and anuran species.

My thesis has two parts; one focuses on how anthropogenic disturbance affects the presence of birds and anurans in Lake Ontario coastal wetlands, while the second evaluates the effectiveness of the GLCWMP methods for monitoring birds and anurans at individual sites. The first part of my thesis uses data from five years of monitoring birds and anurans in Lake Ontario coastal wetlands as part of the GLCWMP. Other researchers and I contributed to the collection of these data. I used 64 sites and six variables to summarize anthropogenic disturbance in Lake Ontario coastal wetlands. I created models that show the effects of my six disturbance variables on richness, diversity, and abundance of bird and anuran species. The second part of my thesis involved more intensive sampling of 11 sites that were also monitored using the GLCWMP protocol. I chose to monitor sites more intensively so that I could compare richness between the two different monitoring protocols. This is important because large scale monitoring program methods may not be adequate for capturing true richness at individual wetland sites. When a research project's goal is to monitor birds or anurans on a smaller scale or at individual sites, a different monitoring program might be more effective than one such as the GLCWMP.

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Part One: Anthropogenic Disturbance Effects on Anuran and Bird Populations in Lake Ontario Coastal Wetlands

Introduction

Land use and human development can significantly affect wetland bird and anuran species. Development decreases the available habitat for birds and anurans, and many species may avoid unfavorable sites (Forman and Deblinger 2000; Forman *et al.* 2002). Due to the dynamic nature of wetland ecosystems, a disruption to one system often causes cascading affects for other parts of the system (Kovalenko *et al.* 2014). For example, nutrient discharge and sedimentation increase as a result of development and, in turn, negatively affect both wetland-dependent bird and anuran species (Kovalenko *et al.* 2014).

The Laurentian Great Lakes have experienced many negative effects from anthropogenic disturbances such as urbanization. One effect of urbanization is increased road density. Roads represent urbanization at the highest level; they are used for transportation from less urbanized to more urbanized areas and may cross vital habitat for wetland-dependent bird and amphibian species (Andrews *et al.* 2008). Additionally, roads disrupt migration of species and other ecological processes, and the impacts often extend far beyond the edge of the road (Forman and Deblinger 2000; Trombulak and Frissell 2000; Andrews *et al.* 2008). Roads are a major source of amphibian mortality when they bisect wetland and upland habitats, as many anuran species move between these habitats during their life cycles (Ashley and Robinson 1996; Forman and Alexander 1998, Hels and Buchwald 2001). Roads affect birds as well, with species avoiding sites with high levels of road noise, which interferes with communication between mates (Forman and Deblinger 2000). Furthermore, chronic anthropogenic noise has been shown to decrease the timing of territorial responses by individual birds in New Mexico (Kleist *et al.* 2016). In addition, increased road density and decreased distance from road to wetland habitat can affect the presence of bird species (Forman *et al.* 2002). Roads also contribute to nutrient and chemical loading of wetlands. In North America, 14 million tons of road salt are used annually (Sanzo and Hecnar 2006, Collins and Russell 2009); within the Great Lakes region several states and the province of Ontario use deicing agents in the winter. These deicing agents are harmful to amphibians due to the permeability of their skin, and they can become a major source of chloride for wetlands that are close to roads. Major effects of deicing agents on amphibians can include mortality and decreased breeding success (Sanzo and Hecnar 2006; Karraker *et al.* 2008; Collins and Russell 2009; Meter *et al.* 2011).

Agricultural land use is another anthropogenic disturbance that has significantly affected Lake Ontario wetlands (Schock *et al.* 2014). Some watershed catchments surrounding Lake Ontario have greater than 50 percent agricultural land use in the surrounding landscape (Makarewicz *et al.* 2007). Agricultural land use may affect wetland birds by decreasing wetland connectivity, decreasing prey availability, and increasing the chance of pollution (Whited *et al.* 2000; Tozer *et al.* 2010). Anurans are also affected by agricultural land use, as many agricultural lands are upstream from wetlands, and drainage from agricultural lands often contains increased nutrients, pesticides, and sediments. Watershed catchments that contain increased agricultural land use contribute to elevated nutrient levels in tributaries (Makarewicz *et al.* 2007), and these nutrients are potentially harmful to anuran species that inhabit wetlands (Price *et al.* 2007). Agricultural land use can also affect post-breeding habitat of some anuran species (Schock *et al.* 2014).

In addition to agricultural land use, Lake Ontario has been negatively impacted by water-level regulation. Historically, Lake Ontario water levels likely followed a 20-35 y cycle of climatic variation (Desgranges *et al.* 2006). The construction of power dams along the Lake Ontario-St. Lawrence Seaway disrupted water-level fluctuations and changed the type of wetlands found in watersheds on the St. Lawrence River and Lake Ontario, ultimately affecting native breeding birds (Desgranges *et al.* 2006). Water-level regulation has also negatively affected plant communities in Lake Ontario coastal wetlands (Wilcox *et al.* 2005, Wilcox *et al.* 2008), leading to dense monotypic stands of cattail (*Typha* spp.) and a loss of sedge-grass meadow areas, which has impacted many wetland-dependent bird species more significantly than natural fluctuations would (Riffell *et al.* 2001; Steen *et al.* 2006).

Given the potential negative effects from anthropogenic disturbance on birds and anurans in Lake Ontario wetlands, the goal of my project was to characterize the response of breeding birds and anurans to anthropogenic disturbances in Lake Ontario coastal wetlands. Hopefully, this will help managers determine causes of population declines in birds and anurans within Lake Ontario coastal wetlands and prevent future declines. To achieve this goal, I used 5 yr of monitoring data collected by Great Lakes Restoration Initiative (Uzarski *et al.*2017) researchers at The College at Brockport, as well as data that I collected on my own, to address three main objectives: 1) determine types of anthropogenic disturbances affecting birds and anurans in wetlands adjacent to Lake Ontario; 2) use a geographic information system, data from vegetation surveys, and water quality samples to develop a set of predictor variables that summarize land use and cover, water quality, and vegetation data in Lake Ontario coastal wetlands; and 3) model the effects of my disturbance-related predictor variables on bird and anuran diversity and abundance across a series of Lake Ontario coastal wetlands. I have two hypotheses for my study: 1) birds and anurans will be negatively affected by increasing nitrogen, phosphorus, chloride, pH, cattail cover, road-use, and agricultural land-use and, 2) bird species richness and abundance will increase with increasing wetland area.

Methods

Study Area

My study area included coastal wetlands along Lake Ontario. Lake Ontario is the smallest Laurentian Great Lake and consists of four basins: Niagara, Mississauga, Rochester, and Kingston. Water from the four upper Great Lakes reaches Lake Ontario through the Niagara River (Busch and Lary 1996). Lake sediments range from sand and gravel in near-shore areas to silt and clay in deeper parts of the basins. The maximum recorded depth is 245 m, and mean depth is 84 m (Busch and Larry 1996).

The data I used for response and predictor variables were collected between 2011 and 2015 by researchers at The College at Brockport as part of the Great Lakes Coastal Wetland Monitoring Program (GLCWMP), as well as from spatial statistics tools in ArcMap 10.2.2 (ESRI 2014). Sites included in the GLCWMP study were selected using a stratified random design based on different wetland types, (riverine, lacustrine, barrier protected, etc.), region (northern and southern, including political boundaries), and each Great Lake. This design allowed for clusters of sites on each lake based on wetland type and region (Uzarski *et al.* 2017). I used 64 GLCWMP sites for my analyses (Appendix 1). In my study, I did not include wetland type as a variable due to large differences between the number of the three types, which could have affected my statistical analyses.

Bird monitoring:

Other researchers and I performed bird point counts using GLCWMP methods, which follow a modified Marsh Monitoring Program (MMP) protocol (Uzarski *et al.* 2017). These counts occurred during the breeding season, beginning in mid-May and ending in early July. The counts were 15 min long with 5 min of passive listening, 5 min of broadcast calls of cryptic marsh bird species, and another 5 min of listening. We recorded species in three separate radii: 0-50 m, ≥ 50-100 m and ≥ 100 m (Uzarski *et al.* 2017). Two counts were performed for each wetland, one morning and one evening. Morning counts occurred from 0.5 h after sunrise until 4 h after sunrise. Evening counts occurred from 4 h prior to sunset until 0.5 h past sunset (Uzarski *et al.* 2017). There were at least 15 d between the first and second counts; surveys were conducted when wind speed was less than 4 on the Beaufort wind scale and there was little or no rain. We recorded individuals even if we were not able to completely identify them, (i.e., unidentified warbler) and the minute in which the individual was first observed. We also recorded behavior (i.e., singing). For focal species, we recorded every minute they were detected during the count (Uzarski *et al.* 2017). According to the GLCWMP, focal species are defined as wetland-dependent for all parts of their life cycle and are of conservation concern across the Great Lakes (Uzarski *et al.* 2017; Appendix 2). Focal species are cryptic, not easily detected from auditory surveys alone, and so were difficult to detect.

Anuran monitoring:

Other researchers and I monitored anurans according to the GLCWMP, which follows a modified MMP protocol (Uzarski *et al.* 2017). Three surveys were performed at each wetland. Surveys occurred from 0.5 h after sunset until 4.5 h after sunset (Uzarski *et al.* 2017). Each count was 3 min long, with species recorded in the same radii as bird surveys. We recorded species abundance using three different calling codes: 1, 2, and 3. Calling code 1 indicates few individuals with no overlapping calls. Calling code 2 indicates some individuals with overlapping calls but the number of individuals present can still be estimated. Calling code 3 indicates a full chorus in which individuals cannot be estimated (Timmermans and Craigie 2002; Uzarski *et al.* 2017). Surveys began when an overnight temperature of 5 °C was reached for the first survey, 10 °C for the second, and 17 °C for the third, with 15 d between samples, in similar weather conditions to the protocol for bird surveys (Timmermans and Craigie 2002; Uzarski *et al.*2017). Researchers visited the same sites for the anuran and bird surveys.

Stress variables / geographical information system

I chose to use water-quality, land-use, and land-cover data because they have been used to assess human disturbance in similar studies (Danz *et al.* 2005; Danz *et al.* 2007). I obtained United States land-use/land-cover data from the National Land Cover Database (NLCD; Danz *et al.* 2007) and road data from the U. S. Census Bureau TIGER line files (Danz *et al.* 2005; U.S. Census Bureau 2017). I obtained Canadian land-use and road data from the Ontario Ministry of Natural Resources (OMNR 2007). I spatially transformed the data using ArcMap 10.2.2 and calculated three different buffer sizes (100 m, 500 m, and 1,000 m) around each wetland. I created binary rasters for cultivated crop and hay pasture land-use data and clipped these data to my wetland polygons. I also clipped road vectors to each wetland polygon. I then used the zonal statistics tool in ArcMap to calculate the amount of land use/road within each buffer. Road length was calculated on a per unit area basis so that one value for road length per unit area was obtained, while agricultural land use was calculated as a percent of each type of agricultural land within each buffer for each wetland. Percent agriculture (row cropping and hay pasture) and road length per unit area calculations at the watershed scale were obtained from Sumrel calculations following the methods of Host *et al.* (2011). I also measured wetland area, which I used in models as a non-disturbance-based predictor variable.

Water quality variables

Water quality data were collected by researchers from The College at Brockport State University of New York between 2011 and 2015. Two L of water were collected from the midpoint of the water column in three zone replicates and held on ice in a carboy. Nitrogen, phosphorus, and chloride samples were analyzed following Uzarksi *et al.* (2017). For each wetland, I calculated average nitrogen, phosphorous, and chloride content, as well as pH, converted to hydrogen ion concentration to average, by averaging values across all zones sampled per site. Temperature, dissolved oxygen, and specific conductance were measured using a YSI pro plus meter (YSI Inc. 2017)**.** One measurement of specific conductance was taken at each wetland.

Vegetation variables

Researchers at the College at Brockport collected vegetation data for all 64 sites used in my analysis. Three transects were sampled at each wetland when feasible. Five 1 m^2 quadrats were taken per habitat type of up to three habitat types: submersed aquatic vegetation (SAV), meadow marsh (MM), and emergent (E), for a possible 15 total quadrats. Percent cover was estimated for all species within each quadrat.

Statistical analyses

I calculated species richness for birds and anurans separately and the Shannon-Wiener species diversity index for birds in each wetland, as well as maximum call code for green frog (*Lithobates clamitans*), northern leopard frog (*Lithobates pipiens*), spring peeper (*Psuedacris crucifer*), and American bullfrog (*Lithobates catesbeianus*) at each wetland. No other species was abundant enough for maximum call-code analyses. I calculated percent invasive cattail cover for each wetland using percent cover data. Data that failed normality tests and were moderately positively skewed were transformed using the square root transformation, and data that were more substantially positively skewed were transformed using the log10 transformation. All of my predictor variables were standardized (Z score) to account for scale effects, and I used a correlation matrix to remove highly correlated variables ($r < 0.80$) (Danz *et al.* 2007). I used a linear regression to test for univariate statistical relationships between bird species richness, diversity, and anuran species maximum call code with wetland area, pH, and invasive cattail cover. I also examined univariate relationships between my agricultural variables and total nitrogen, phosphorus, and chloride content.

I used IBM SPSS version 23.0 to run three principal component analyses (PCA) to reduce the number of land-cover/land-use predictor variables (Danz *et al.* 2007). Each PCA created three new synthetic predictor variables for each category: agriculture land use, roads, and water quality excluding pH (Table 1). I excluded pH from the PCAs because it did not have a high correlation with other predictor variables and had more effect on species individually than as part of a synthetic predictor variable. I chose to use the first synthetic variable from each category for my modelling because greater than 50 percent of the original variance was explained by the first variable in each category and doing so reduced the number of variables used in my models. This resulted in six predictor variables used for modelling bird and anuran response variables: pH, wetland area, cattail cover, road length pc, agriculture pc, and water quality pc. I combined agricultural land use (row cropping and hay/pasture) into one category due to differences in characterization of agricultural land use between the United States and Canada and to reduce the number of predictor variables in my models.

I used backward model selection of Generalized Linear Models (GLMZ) in IBM SPSS 23.0 to create disturbance models for each response variable (Morrice *et al.* 2008). I used second-order Akaike's Information Criteria (AIC_c) to select the best model and reported all models with a Δ $AIC_c < 2.0$ (Anderson and Burnham 2002).

Results

I found no significant univariate relationships linking the amount of agricultural land use to nitrogen, phosphorus, or total chloride content within each wetland. Shannon-Wiener diversity indices for bird species ranged from 1.62 to 3.18 across all sites, and bird species richness ranged from 13 to 45 species per site. A total of 6119 individuals and 100 different bird species were observed. The three most commonly detected wetland species were Red-winged Blackbird (*Agelaius phoeniceus*), Swamp Sparrow (*Melospiza georgiana*), and Yellow Warbler (*Setophaga petechia*). Red-winged Blackbird was the most abundant species at most sites; one site had over 100 individuals of Red-winged Blackbirds observed in two separate counts in one year. Five focal species were observed, and one New York State endangered species, Black Tern (*Chlidonias niger*), was observed (NYSDEC, 2017). Least Bittern (*Ixobrychus exilis*) was the most-observed focal species.

Anuran species richness ranged from one to seven species across sites. The most commonly detected species was green frog (*Lithobates clamitans*), and the least commonly detected species was wood frog (*Lithobates sylvaticus*). There was no significant univariate relationship between anuran species richness and wetland area or pH.

PCA results

I retained one principal component from each of the three principal component analyses (Table 1). One principal component (wq pc) best summarized water quality data (total phosphorus, chloride content, and average total nitrogen), with 59.7 percent of the variance retained. Increased levels of nitrogen, phosphorus, and chloride were associated with positive eigenvalues, while decreased levels were associated with negative eigenvalues. Additionally, one pc (road pc) best summarized road-length data (road length per unit area at 100m, road length per unit area at 1000m, and road length per unit area at the watershed) with 53.0 percent of the variance explained; increased road length was associated with positive eigenvalues and decreased road length was associated with negative eigenvalues. Lastly, agricultural data (ag pc) (amount of hay pasture at 1000m, percent agriculture overall, and percent cultivated crops at 1000m) were best summarized by one pc with 58.2 percent of the variance explained; increased agricultural land-use was indicated by positive eigenvalues, and decreased agricultural land use was associated with negative eigenvalues (Table 1).

Bird species models

The best model for bird species richness showed a positive relationship with increasing wetland area, while the second-best model also showed a positive relationship with increased values on the water quality pc (Table 2). In the best model for total bird abundance, larger wetlands with increased cattail cover and increased values of nitrogen, phosphorus, and chloride supported a greater number of birds (Table 3). Bird species Shannon-Wiener Diversity scores showed no significant effects from any of the predictor variables included in my analyses.

Anuran species models

The best model for frog species richness suggested a negative relationship with increased values of nitrogen, phosphorus, and chloride, and a positive relationship with increased agricultural land use (Table 4). The second-best model also indicated a negative relationship with increasing invasive cattail cover (Table 4). The best model for bullfrog max call-code indicated a negative relationship with increasing wetland area and increasing road length, and a positive relationship with increasing pH. The second-best model indicated a positive relationship with increased agricultural land use. A third model indicated a negative relationship with increased values of nitrogen, phosphorus, and total chloride (Table 5). The best model for spring peeper max call-code suggested a positive relationship with increased agricultural land use and wetland area but a negative relationship with increasing pH. The second-best model included a positive relationship with increased levels of nitrogen, phosphorus, and total chloride (Table 6). Green frog max call-code and northern leopard frog max call-code were not significantly affected by any of the predictor variables.

A comparison of site-specific conditions at several wetlands demonstrates the effects of some important predictor variables identified in my models. For example, wetland 5088, located in Prince Edward Ontario, can be considered a “good” wetland for birds and anurans. A lacustrine wetland approximately 687 ha in size with a low density of roads and low values of nitrogen, phosphorus and chloride, wetland 5088 supported 42 bird species including three focal species, Least Bittern, Common Moorhen (*Gallinula chloropus*) and American Bittern (*Botaurus lentiginosus*), and seven anuran species (Table 7). In contrast, wetland 53, located in Greece NY, can be considered a “poor “wetland for birds and anurans. A riverine wetland approximately 9 ha in size with a high density of roads and increased values of nitrogen phosphorus and chloride, and low amounts of surrounding agricultural land, wetland 53 supported 14 bird species and two anuran species. Site 7052, also located in Greece NY, demonstrates how larger wetlands with increased cattail cover support a higher abundance of birds. A riverine wetland approximately 114-ha in size with 48 % cattail cover,569 birds were counted in wetland 7052 , as compared to only 43 in wetland 53 (Table 7).

Discussion

Bird Species Effects

My results indicate that bird species richness was positively affected by increasing wetland area, which supports my hypothesis. Additionally, bird abundance was positively affected by increasing wetland area, increasing nitrogen, phosphorus, and total chloride and increasing invasive cattail cover—results that do not support my hypothesis. There were no significant univariate or multivariate models showing a relationship between Shannon-Wiener bird species diversity indices and anthropogenic disturbance. The positive relationship between bird species richness and bird species abundance and wetland area is supported by several studies within

Great Lakes wetlands (Riffel *et al.* 2001; Brazner *et al.* 2007; Tozer *et al.* 2010). In all three studies, the researchers found that increasing wetland area led to an increase in the number of species and number of individuals of wetland birds.

In my study, the best model for bird species richness showed that wetland area was by far the most important factor. Brazner *et al.* (2007) performed a similar study over the entire Laurentian Great Lakes basin and found that bird species richness was less affected by disturbance variables than non-disturbance variables like wetland area. However, bird species richness appeared to increase with increasing concentrations of nitrogen and phosphorus, as shown by the second-best model (Table 2). This is a positive response to what I defined as a human disturbance; a similar relationship was found by Brazner *et al.* (2007), although they did not provide an explanation as to why this relationship was found. In a similar study performed across the Laurentian Great Lakes, Uzarski *et al.* (2017) found that birds responded negatively to increased concentrations of variables such as nitrogen and phosphorus. The results of Uzarski *et al.* (2017), as well as those of Hanowski *et al.* (2007), contradict my findings. Hanowski *et al.* (2007) found that the amount of developed land within 1 km of the wetland had a negative effect on bird abundance when using bird species guilds as response variables. Furthermore, another study within the Great Lakes basin also found a negative response by wetland birds to increased levels of water quality variables like nitrogen, phosphorus and total chloride (Danz *et al.* 2007).

One possible reason that I found a positive response to increased nitrogen and phosphorus is the prevalence of disturbance-tolerant species. Using Bryce *et al.* (2002) as a basis, I found that ten of the species they listed as disturbance-tolerant were present during my study. Bryce *et al.* (2002) showed that species richness for birds tolerant of disturbance increased with increasing disturbance values for variables such as agricultural land in the Willamette River Valley, Oregon. One disturbance-tolerant species was the Red-winged Blackbird, which were very abundant at most of my sites. A similar relationship was found by Danz *et al.* (2007) within Great Lakes wetlands. Danz *et al.* (2007) showed that species that prefer edge or urban habitats such as Red-winged Blackbird or House Sparrow (*Passer domesticus*) had a positive relationship with increasing human stress values. Many of my wetland points were located adjacent to disturbed/urban habitat that could facilitate the presence of more edge/urban species in areas surrounding my study wetlands. Also, due to use of a full circle point count by the GLCWMP project, many species that inhabited these edge/urban habitats adjacent to study wetlands were included in counts

Further, Steen *et al.* (2006) assessed the risk of habitat loss for wetland-dependent bird species found in Lake Ontario coastal wetlands due to the effects of human disturbance, such as invasive cattail cover due to human-controlled water-level regulation. As many Lake Ontario wetlands have become dense monotypic stands of *Typha*, wetland-bird species that prefer more dense vegetation are increasing (Steen *et al.* 2006). Two low risk species identified by Steen *et al.* (2006)

were Swamp Sparrow and Red-winged Blackbird, which have affinities for increased vegetative cover by species like *Typha*. Both Swamp Sparrow and Red-winged Blackbird were commonly detected in my studies, which may explain why I found a positive relationship between bird total individuals and increased invasive cattail cover.

In addition to species responses to development in the surrounding landscape, Hanowski *et al.* (2007) also found that bird communities tended to differ based on wetland geomorphology and which Great Lake they occupy. Wetland type was an important factor when developing an index of biotic integrity for marsh-bird species to model effects of disturbance (Hanowski *et al.* 2007). However, in my study, I did not have an even distribution of wetland hydrogeomorphic types and could not use this variable in my analyses. Also many species have different habitat requirements and respond differently to wetland characteristics. Some species respond more to changes in individual vegetative characteristics of a wetland, while other species respond more to surrounding landscape changes (Naugle *et al.* 2000). This makes it difficult to assess the effects of "disturbance" on overall bird species richness. Furthermore, the scales at which variables are measured are important in species responses (Brazner *et al.* 2007). I combined variables such as agricultural land use and road length into synthetic predictor variables instead of having multiple scales for each variable type, which made it more difficult to interpret the effects on species and to determine which scale is the most important. Additionally, I focused on avian community attributes and did not use any of the more commonly detected species as response variables, which also limits my ability to interpret species-specific effects.

Anuran Species Effects

In contrast to my results for modeling wetland bird/habitat relationships, anuran species richness was negatively affected by increasing levels of nitrogen, phosphorus, and total chloride, which supports my hypothesis. The negative relationship between frog species richness and increased levels of nitrogen, phosphorus, and chloride content has been previously supported in other Great Lakes wetland studies (Houlahan and Findlay 2003; Price *et al.* 2007). Elevated levels of nutrients such as nitrogen can lead to increased mortality in amphibians (Houlahan and Findlay 2003), while increased chloride content in wetlands near the road edge can decrease breeding success and lead to mortality of amphibians (Sanzo and Hecnar 2006; Karraker *et al.* 2008; Collins and Russell 2009; Meter *et al.* 2011).

However, in contrast to the negative relationship between anuran species richness and increased levels of nitrogen, phosphorus, and chloride, anuran species richness showed a positive relationship with increased agricultural land, which does not support my hypothesis. Great Lakes research suggests that increasing agricultural land area should decrease frog species richness, as an increase in agricultural land use surrounding wetlands can lead to an increase in concentrations of nitrogen and phosphorus in these wetlands (Mackarewicz *et al.* 2007; Price *et al.* 2007; Schock *et al.* 2014). However, in my analyses, I found no significant relationship between nitrogen, phosphorus, or chloride content and agricultural land use, which suggests that agricultural land use and my water quality variables may affect anuran species independently of one another. Furthermore, there may be an ecological explanation for the increased frog species richness associated with increased agricultural land use. Many frog species migrate to upland areas after breeding in wetlands (Guerry and Hunter 2002; Babbit *et al*. 2009). Increased agricultural land in the surrounding landscape could provide adequate post-breeding habitat for species that prefer more open habitats, such as the northern leopard frog and American toad (Guerry and Hunter Jr. 2002). Thus, hay pastures in the landscape adjacent to wetlands could provide habitat for northern leopard frogs and American toads and explain the increase of species richness with increasing agricultural area. Bullfrog and spring peeper also showed positive responses to increased agricultural land in the surrounding landscape, despite preferences for wetlands and woodlands, respectively, for post-breeding habitat (Conant and Collings 1998).

However, condensing all of my measures of agricultural land use into one synthetic predictor variable also may have reduced my ability to explain the effects of agricultural land use on anuran species richness. Koumaris and Fahrig (2016) showed that different species of anurans respond differently to agricultural intensity and other measured values, such as nitrate content in wetlands. Price *et al.* (2004) also found that anuran species responded in different ways to the amount of herbaceous or cultivated land in Lake Michigan. These two studies suggest that analyzing the effects of total species richness from agricultural land use might not explain effects on individual species, as their responses can differ. Further, Price *et al.* (2007) suggest that amphibian species richness is not useful in estimating ecological condition of wetlands, given the varying response of different species.

At the species level, I detected two specific responses to disturbance. The best models suggested that bullfrog abundance responded negatively to increased road length and positively to increased pH, while spring peeper abundance responded positively to increased agricultural land use and negatively to increased pH. These results suggest that roads may decrease anuran abundance, which could be due to roads cutting through vital habitat for frogs, resulting in many frogs being killed attempting to cross roads to migrate to different habitats (Ashley and Robinson 1996). This is further supported by a study within an agricultural prairie pothole landscape showing that fragmentation, such as roads, significantly decreased the number of anuran species found in prairie potholes because roads can lead to decreased connectivity and increased fragmentation of amphibian habitat (Lehtinen *et al.*1999). Roads can also contribute to high chloride content of wetlands from nearby road run-off (Sanzo and Hecnar 2006; Karraker *et al.*2008; Collins and Russell 2009; Meter *et al.*2011).

The positive response to increased pH by bullfrogs was unexpected. One study from Quebec suggests that bullfrog are more susceptible to negative effects from water pollution than more terrestrial species such as spring peeper because bullfrogs are fully aquatic (Spear *et al.* 2009). However, a study from Ontario also found positive responses to pH and agricultural land use that conflicts with accepted adult habit requirements of bullfrog, and stated that the species response to different variables was “confusing,” due to models also showing a negative relationship with wetland cover (Koumaris and Fahrig 2016). In addition, pH and agricultural land use showed no correlation with one another, which suggests that these two variables are not co-dependent. Therefore, a species could have a positive response to both agricultural land use and pH for different reasons and, likewise, a positive response to agricultural land use, but a negative response to pH . Further, there were no correlations between pH and either spring peeper max call-code or bullfrog max call-code. This suggests that the differing responses to pH of bullfrog and spring peeper in my study were likely due to another reason that I was not able to evaluate.

In contrast to my results for the bullfrog, spring peepers’ negative response to pH and roads are supported by Price *et al.* (2007), who found that the spring peeper was the most responsive among 14 observed anuran species to disturbance variables, which included two different point source pollution variables. However, no explanation as to why spring peeper was the most responsive to disturbance variables was given. These results suggest that spring peeper are a good study organism to use for monitoring ecosystem health.

Alternatives to my approach to modelling

In my study, I found several relationships that I did not expect, including a positive relationship between anuran species richness and increasing agricultural land use, a positive relationship between bird species richness and increasing invasive cattail cover, and a positive relationship between bird species richness and increasing nitrogen, phosphorus, and chloride concentrations. This may be due to my modelling approach. In future studies, it may be useful to separate bird species into guilds based on their habitat preferences (Hanowski *et al.* 2007). This may have helped discern more relationships relative to wetland-dependent birds. Additionally, accounting for different habitat characteristics, such as amount of open water, and including them within my models may have made my results more interpretable. As Hanowski *et al.* (2007) showed, certain habitat characteristics, such as hydro-geomorphology, are important factors when considering wetland use by bird species. However, I could not use these variables in my study due to the uneven distribution of each type. Additionally, many habitat factors, such as the amount of open water and density of vegetation, were not used in my study due to data not being collected through the GLCWMP.

Conclusions

My study showed that both birds and anurans in Lake Ontario wetlands are affected by anthropogenic disturbance. Birds showed positive responses to increased wetland area and increased invasive cattail cover, while anurans showed both positive and negative responses to agricultural land use and pH. Many of the responses to the variables are supported by other literature from the Great Lakes, but some were not. Overall, for my analyses, the effects of human disturbance are much clearer for anurans than for birds.

The best model for bird species richness indicated how important wetland area is to the number of bird species. Bird habitat-area relationships have been supported in several Great Lakes wetland studies (Riffel *et al.*2001; Brazner *et al.*2007; Tozer *et* *al.* 2010)**.** Furthermore, the number of individuals also showed a positive response to wetland area. The positive response from both bird species richness and abundance supports the importance of wetland area in bird conservation. Additionally, birds showed a positive response to increased values of nitrogen, phosphorus, and chloride as well as invasive cattail cover, which was surprising; however, this could be due to Red-winged Blackbird observed in abundance at many sites.

In my study, anurans had a mix of positive and negative responses to the disturbance variables used in my modelling. Anuran species richness showed a positive relationship to agricultural land use and a negative response to roads. The negative effects of roads on anurans is also supported by many other studies of how roads fragment vital amphibian habitat (Ashley and Robinson 1996; Forman and Alexander 1998; Forman and Deblinger 2000; Trombulak and Frissell 2000; Hels and Buchwald 2001; Andrews *et al.*2008). Spring peeper and bullfrog both showed negative responses to increased road length but differing responses to pH. The different response of each species to pH highlights the difficulties in using overall species richness as an indicator when each species may respond differently to certain variables. Using specific anuran species responses may be more useful than overall species richness when trying to determine impacts from anthropogenic disturbances in Lake Ontario wetlands.

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Tables

Table 1. Principal Component score values for each variable used in three PCAs. AG 1, AG 2, and AG 3 refer to each of the three synthetic principal components created from the principal component analysis. AG =Agriculture, RD = Roads, and WQ = Water Quality. Negative values indicate a negative relationship with increasing values of each principal component and positive values indicate positive relationships.

	AG 1	AG 2	AG 3
Eigenvalue	1.745	0.785	0.47
Percent of total variance explained	58.168	26.168	15.664
Cumlative variance	58.168	84.336	100
Variable			
Hay pasture (1000m) z score	0.720	-0.614	0.324
Agriculture Z score	0.852	-0.012	-0.524
Cultivated crops Z score	0.708	0.639	0.301
	RD 1	**RD 2**	**RD 3**
Eigenvalue	1.590	0.852	0.558
Percent of total variance explained	52.996	28.414	18.590
Cumlative variance	52.996	81.410	100.000
Variable			
Road length per unit area_100m Z score	0.626	0.738	0.254
Road length per unit area_1000m Z score	0.823	-0.079	-0.562
Road length per unit area watershed Z score	0.721	-0.550	0.421
	WQ 1	**WQ 2**	**WQ 3**
Eigenvalue	1.792	0.670	0.538
percent of total variance explained	59.725	22.338	17.937
Cumlative variance	59.725	82.063	100.000
Variable			
Total phospohorus Z score	0.799	-0.279	-0.533
Chloride content Z score	0.726	0.686	0.039
Average total nitrogen	0.791	-0.349	0.502

Table 2. Best disturbance models (ΔAICc <2) for bird species richness. AIC_c refers to the second order Akaike's Information Criteria, B refers to the slope of the effect (logistic coefficient), and w_i is the weight of each individual variable in the model. Variable definitions are given in the appendix.

bird species richness					
Rank	AIC_c	ΔAIC_c	w_i	Variable (s)	B
1	429.04	0	0.51	Wet-area	1.722
2	429.908	0.868	0.33	Wet-area	0.98
				Water-qual pc	1.79

Table 3. Best disturbance models (ΔAICc <2) for bird total individuals. AIC_c refers to the second order Akaike's Information Criteria, B refers to the slope of the effect (logistic coefficient), and w_i is the weight of each individual variable in the model. Variable definitions are given in the text.

bird total individuals					
Rank	AIC_c	ΔAIC_c	w_i	Variable (s)	B
1	767.541	0	0.35482	Water- qual pc	18.704
				Inv-cattail	15.610
				Wet-area	22.690
2	767.789	0.248	0.312964	Inv-cattail	19.141
				Wet-area	21.785
3	768.978	1.437	0.172706	Inv-cattail	16.795

Table 4. Best disturbance models (ΔAICc <2) for anuran species richness. AIC_c refers to the second order Akaike's Information Criteria, B refers to the slope of the effect (logistic coefficient), and w_i is the weight of each individual variable in the model. Variable definitions are given in the text.

frog species richness					
Rank	AIC_c	ΔAIC_c	w_i	Variable (s)	B
1	199.159	0	0.51	Water-qual pc	-.300
				Ag pc	.470
2	200.173	1.014	0.31	Water-qual pc	-.267
				Ag pc	.506
				Inv-cattail	-.163

Table 5. Best disturbance models (ΔAICc <2) for bullfrog abundance using max-call-code. AIC_c refers to the second order Akaike's Information Criteria, B refers to the slope of the effect (logistic coefficient), and w_i is the weight of each individual variable in the model. Variable definitions are given in the text.

bullfrog max call-code					
Rank	AIC_c	ΔAIC_c	w_i	Variable (s)	B
1	143.673	0	0.42	Wet-area	-.236
				Road pc	-.302
				pH	.208
2	144.487	0.814	0.28	Wet-area	-.198
				Road pc	-.276
				pH	.175
				Ag pc	.122
3	144.885	1.212		Wet-area	-.199
				Road pc	-.207
				pH	.155
				Ag pc	.136
				Rd pc	-.207

Table 6. Best disturbance models (ΔAICc <2) for spring peeper abundance using max-call-code. AIC_c refers to the second order Akaike's Information Criteria, B refers to the slope of the effect (logistic coefficient), and w_i is the weight of each individual variable in the model. Variable definitions are given in the text.

Spring peeper max call-code					
Rank	AIC_c	ΔAIC_c	w_i	Variable (s)	B
1	162.692	0	0.40	Ag pc	.232
				pH	-.266
				Wet- area	.264
2	163.176	0.484	0.31	Ag pc	.236
				pH	-.249
				Wet- area	.273
				Water qual pc	.140

Table 7. Data from three sites demonstrating important relationships I found between my variables and bird and anuran species metrics. Water pc refers to my water quality principal component, road pc refers to my road length principal component and ag pc refers to my agricultural land use pc. Values for water pc, road pc, and ag pc, are z scores.

site	water pc	road pc	ag pc	pH	cattail cover (%)	wetland area (ha)	bullfrog max call-code	spring peeper max call-code	bird richness	bird abundance	anuran richness
5088	-0.94	-1.25	0.31	7.98	16.33	687.3	1	3	42	307	7
7052	0.37	0.15	0.13	7.9	48.6	113.5	1	3	39	569	5
53	1.5	3.51	-2.27	8.19	44.67	9.2	0	0	14	43	2

Part Two: Assessing the Effectiveness of the Great Lakes Coastal Wetland Monitoring Program Methods for Monitoring Breeding Birds and Anurans at Individual Sites

Introduction

Over the last two centuries, Great Lakes Coastal wetlands have been degraded or lost as a result of human activities, and less than 30 percent of pre-European wetlands still exist as viable habitat for native wildlife species (Cvetkovic and Fraser 2011). Much of this wetland loss is due to urban and agricultural development in watersheds adjacent to the Great Lakes (Cvetkovic and Fraser 2011). Both birds and anurans are greatly affected by habitat loss, as many species depend on wetlands for at least part of their life cycle. Increased degradation and loss of wetland habitat has led to an increase in programs designed to monitor wetland-dependent species.

One program started as a result of increased degradation is the Marsh Monitoring Program (MMP). The MMP began in 1995 as a joint effort between the United States and Canada to monitor birds and anurans in wetland habitats in the Great Lakes Basin (Timmermans and Craigie 2002). The MMP was originally designed as a volunteer program that could be conducted over large areas, allowing researchers to increase their data-collection capabilities; volunteers are trained to identify birds and anurans by sight and sound. The program requires three site visits to sample anurans and two visits for birds, with playback recordings of cryptic marsh birds during bird surveys (Timmermans and Craigie 2002). These methods are used by many researchers working with wetland-dependent birds and anurans.

In 2011, another joint monitoring effort between Canada and the United States was developed, with funding of the Great Lakes Coastal Wetland Monitoring Program (GLCWMP) by the Great Lakes Restoration Initiative. The GLCWMP uses a modified MMP protocol for sampling birds and amphibians and also samples water quality, vegetation, aquatic macroinvertebrates, and fish (Uzarski *et al.* 2017). Since 2011, MMP volunteers and paid technicians participating in the GLCWMP from several institutions in the United States and Canada have collected data at hundreds of wetlands on each Great Lake. The main goal of the GLCWMP is to understand threats to wetland ecosystems over the entire Great Lakes Basin and large-scale temporal and spatial biodiversity patterns within Great Lakes coastal wetlands.

Given the goal of the GLCWMP for estimating species abundance over a large scale, it is important to understand the scale at which data on various anthropogenic disturbances should be interpreted. Many disturbances can have different effects, depending upon the scale at which they are acting (Brazner *et al.* 2007). Species groups can respond to disturbances at different scales within a landscape, with larger vertebrates more affected by large-scale disturbances, and smaller vertebrates, such as amphibians, affected more by multiple or local scale disturbances (Price *et al.* 2004; Brazner *et al.* 2007).

Detectability of individual species may also cause observers to miss species during surveys. Detectability affects an observer's ability to describe the community present at a wetland adequately, regardless of any disturbance to the wetland. A species not recorded during a survey should not be counted as absent unless the observer has already accounted for detection probabilities, which describe the likelihood of detecting each species present (MacKenzie *et al.* 2002). For example, cryptic marsh bird species may not always respond to playback audio or actively call during a survey (Bogner and Baldassare 2002). Although Least Bitterns (*Ixobrychus exilis*) will respond to playback calls similar to the recordings used by the MMP, one study demonstrated that three or more minutes of playback are necessary to elicit vocalizations (Bogner and Baldassare 2002), while the methods used by the MMP play vocalizations of five species for 30 s each. Another study documented the effects of survey length on detectability of anuran species and found that most species were detected during the first 3 min of surveys, but to some degree, detection rates depended on species-specific temporal breeding patterns. Accounting for breeding patterns of anuran species may ultimately affect the length, number, and temporal distribution of surveys depending upon how accurate estimates of species richness, abundance, and presence/absence need to be (Gooch *et al.* 2006).

Considering problems associated with detectability and how different species respond to various types of disturbance, methods used in a basin-wide monitoring program may not be effective for representing species richness or diversity or detecting change on a site-by-site basis. Studies are needed to evaluate if data from programs such as the GLCWMP and MMP are useful to answer questions on a local scale, where the goal may be for a more accurate species richness count, abundance count, or species presence/absence. Thus, the main goal of my project was to evaluate the effectiveness of the number of visits mandated by the MMP protocol in adequately representing marsh bird and calling anuran species richness and presence in individual wetlands. I sampled 11 wetlands adjacent to Lake Ontario to compare richness counts at individual sites using MMP methods and more intensive sampling at intervals of c. one week. My main study objectives were to 1) compare bird and anuran species richness estimates obtained by a more intensive sampling protocol with those obtained by MMP methods and 2) provide sampling efficiency data to compare how well consecutive weekly surveys portrayed total expected species richness. Results of my study are useful for determining if the MMP/GLCWMP monitoring methods are adequate for restoration projects on a local scale. I have two hypotheses for my study 1) weekly surveys will result in increased species richness for both birds and anurans, and 2) there will be a statistically significant difference in richness counts between methods.

Methods

Study area

I intensively sampled 11 sites in 2015. Of the 11 sites sampled, six were also sampled in 2016, plus five additional sites. All sites were located along the southern shore of Lake Ontario (Appendix 1). These sites included eight in the Rochester Embayment, which is listed as an Area of Concern within the Great Lakes, meaning that it has not met environmental standards set forth by the Great Lakes Water Quality Agreement (International Joint Commission 1985). Additionally, all sites in my study were sampled at least once using the GLCWMP protocol between 2011 and 2015.

Bird monitoring

I performed bird point counts using GLCWMP methods, which follow a modified Marsh Monitoring Program (MMP) protocol (Uzarski *et al.* 2017). These counts occurred during the breeding season, beginning in mid-May and ending in early July. The counts were 15 min long, with 5 min of passive listening, 5 min of recordings of cryptic marsh bird species, and another 5 min of listening. I recorded species in three separate radii: 0-50 m, ≥ 50-100 m and ≥ 100 m (Uzarski *et al.* 2017). I intensively sampled 11 wetlands once per week during the breeding seasons of 2015 and 2016 to determine if there was a difference in bird species richness found using the GLCWMP protocol and my weekly sampling efforts. Due to scheduling conflicts and inclement weather, the total number of visits to each wetland ranged from four to six in 2015, while I was able to visit each site five times in 2016. I alternated bird counts weekly between morning and evening when feasible to avoid bias between morning and evening counts. Morning counts occurred between 0.5 h after sunrise until 4 h after sunrise. Evening counts occurred between 4 h prior to sunset until 0.5 h past sunset (Uzarski *et al.* 2017). All surveys were conducted when wind speed was less than 4 on the Beaufort Scale, and there was little to no rain. I recorded individuals even if I was not able to completely identify them, (i.e., “unidentified warbler”), and the minute in which the individual was first observed. I also recorded behavior (i.e., singing). For focal species, I recorded every minute interval in which they were detected during the count (Uzarski *et al.* 2017). According to the GLCWMP, focal species depend on wetland habitats for all parts of their life cycle and are of conservation concern across the Great Lakes; these species are cryptic and not easily detected by auditory surveys alone, and so were difficult to detect. (Uzarski *et al.* 2017; Appendix 2).

Anuran monitoring

I performed calling anuran point counts according to the GLCWMP, which follow a modified MMP protocol (Uzarski *et al.* 2017). Anuran surveys began when an overnight temperature of 5° C was reached. Each survey was 3 min long and occurred between 0.5 h after sunset until 4.5 h after sunset (Uzarski *et al.* 2017). Species were recorded in the same three radii as bird surveys. I recorded species abundance using three different calling codes: 1, 2, and 3. Calling code 1 indicated few individuals with no overlapping calls. Calling code two indicated some individuals with overlapping calls but the number of individuals present could still be estimated. Calling code 3 indicated a full chorus in which individuals were not estimated (Timmermans and Craigie 2002; Uzarski *et al.* 2017). I intensively sampled 11 wetlands once per week during the breeding seasons of 2015 and 2016 to determine if there was a difference in species found using the GLCWMP protocol and my weekly sampling efforts at each individual wetland. Due to scheduling conflicts and inclement weather, the number of visits to each site ranged from nine to ten visits in 2015, while I was able to visit each site nine times in 2016. Anuran surveys were conducted in similar weather conditions as bird surveys.

Statistical Analyses

I created presence-absence matrices for each site with the number of samples performed and all species detected. I used EstimateS version 9.1 (Colwell 2013) to calculate an analytical richness for bird data, the expected number of species given a reference sample, as well as the Chao 2 species richness estimator (Chao 1987). The Chao 2 estimator uses species present in only one sample (uniques) and species present in two or more samples (duplicates) to determine the estimated true richness based on the presence absence matrix that I provided. I compared the Chao 2 estimator of bird species richness to the analytical bird species richness from my samples and created species richness rarefaction curves using the analytical species richness estimate. I calculated the percent sample efficiency for each site using the equation $\frac{S\ est(analytical)}{Chao\ 2\ estimate} * 100$. I did not evaluate the frog data using EstimateS because the program calculated a higher richness than the total possible species I could have detected in Great Lakes wetlands of 13. This is due to the inability to specify a maximum total richness possible at a site within the EstimateS program.

For 2016 bird data, I compared richness between weekly counts and GLCWMP counts of bird species richness using a paired t test; for the 2015 bird data, I used a paired Mann-Whitney U test as the data were not normally distributed. Both 2015 and 2016 frog species comparisons between weekly counts and the GLCWMP counts were analyzed with a paired Mann-Whitney U test because the data were not normally distributed.

Results

Bird Point Counts

I visited seven sites six times each, three sites five times each, and one site four times in 2015. I identified 70 species and observed 1935 individuals, of which 41 were not positively identified. The most abundant species was the Red-winged

Blackbird (*Agelaius phoeniceus*), with 513 individuals observed. There were several species detected only once. I visited all eleven sites five times each in 2016. I identified 67 species and 2312 individuals across all sites, with 34 unidentified individuals. As in 2015, the most abundant species was the Red-winged Blackbird with 481 individuals counted, while several species were only detected once.

In 2015, I identified four focal marsh bird species, as defined by the GLCWMP (Uzarski *et al.* 2017): American Bittern (*Botaurus lentiginosus*), Least Bittern, American Coot (*Fulica americana*), and Virginia Rail (*Rallus limicola*). Virginia Rail was detected at two sites, while American Bittern, American Coot, and Least Bittern were only detected at one site each. I identified three focal marsh bird species in 2016: American Bittern, Common Moorhen (*Gallinula galeata*), and Virginia Rail. American Bittern was detected at three sites while Common Moorhen and Virginia Rail were only detected at one site each.

EstimateS software indicated that, in 2015, two sites reached an expected asymptote of species richness within five point counts, while nine sites did not reach an asymptote (Figure 1). When the analytical species richness was compared to the Chao 2 estimator, there was a wide range of sampling efficiencies, from 42.5 to 88.9 percent (Table 1). In 2016, two sites reached an expected asymptote of species richness within five point counts, while nine sites did not reach an asymptote (Figure 2). When comparing analytical richness to the Chao 2 estimator, the 2016 sampling was more efficient than in 2015, with efficiencies ranging from 65 to 88.3 percent (Table 2). Bird species richness was significantly higher in 2015 and 2016 for weekly counts, as compared to values obtained from only three visits (2015, paired t-test; t= -10.99, p=0.00); 2016,W= 76, P=0.001) (Figure 3). There was no significant difference between sampling efficiencies between years (paired t-test; t=-1.57, P=0.146).

Anuran Point Counts

I visited four sites ten times, six sites nine times, and one site eight times in 2015 and identified eight anuran species across all sites. Spring peeper was recorded at all 11 sites, while wood frog (*Lithobates sylvaticus*) was heard at only one site. In 2015, species richness detected by weekly visits was significantly higher than species richness detected by three visits at each site (W=162.5, p=0.0197; Figure 4). In 2016, I visited all 11 sites nine times and identified six species across all sites. Western chorus frog and wood frog were not observed in 2016. Spring peeper, green frog, and northern leopard frog were the most frequently detected species and were found at all eleven sites, while American bullfrog (*Lithobates catesbeianus*) was detected less frequently, at only 6 sites. In 2016, there was no significant difference between richness for three visits, as compared to weekly visits, for each site (W=140.5, p=0.35; Figure 4).

Discussion

My results show that two site visits for bird surveys were insufficient to detect the expected total species richness at a Lake Ontario coastal wetland, as estimated by the Chao 2 species richness estimator, which supports my hypothesis. At many sites, even a series of up to six weekly visits failed to represent expected species richness adequately, as based on the Chao 2 estimate. My data indicate that more site visits will increase the number of bird species observed at a site, which also supports my hypothesis. Several studies have also found that more than two visits are necessary to increase richness. Gibbs and Melvin (1993) found that three surveys detected 90 percent of breeding marsh bird species present in wetlands in Maine. Additionally, a standardized protocol for sampling wetland breeding birds calls for three surveys to be performed over a 44-day period to account for variation in the breeding chronology of species (Conway 2005). However, Rehm and Baldassare (2007) found that even the standardized protocol for three surveys in the 44-day period could miss several marsh bird species due to differences in breeding chronology.

Weekly visits also more accurately captured anuran species richness at sites in 2015, but not in 2016, based on species known to occupy Great Lakes coastal wetlands, which partially supports my hypothesis. However, with either method, some potentially occurring frog species could remain undetected. Wood frog is an example of one species that may go undetected. Due to their explosive breeding pattern and narrow temporal window many surveys can fail to detect wood frog (Crouch and Paton 2002). In my study I only detected wood frog at one site. Further, different habitat requirements of each species, breeding chronology, or proximity to other land types in the surrounding matrix, such as open grassland areas or forests may affect presence/absence of species. Many anuran species rely on wetland habitat for reproduction but upland forest for foraging or hibernating (Guerry and Hunter 2002). Further, Pope et al. (2000) demonstrated that to determine site occupancy for northern leopard frogs, the full landscape structure should be considered, including breeding habitat and complementary habitat such as grassy meadows used during the summer.

These results suggest that if a research project's goals are focused on describing true bird or anuran species richness at a single site or small group of coastal wetland sites, more visits than used in the GLCWMP methods will be necessary. However, the goal of the GLCWMP is not to collect data on true species richness at individual sites. Rather, the goal of the GLCWMP is to use a standardized methodology that can be used by multiple organizations across many sites to efficiently collect data that address large-scale spatial and temporal questions about wetland ecosystem condition throughout the Great Lakes (Uzarski *et al.* 2017).

It is generally understood that increasing sampling effort, such as more site visits, will increase observed species richness for birds and anurans (Gibbs and Melvin 1993, Swift *et al.* 1988, Walther and Martin 2001). When graphed, this increase in species richness with sampling effort will continue until an asymptote is reached—the total richness of a site (Walther and Martin 2001). According to my data, in each year, only two sites reached an asymptote for bird species richness. I was unable to graph anuran species richness data using the EstimateS software because the software calculated too high of a species richness possible in Great Lakes coastal wetlands. These results indicate that more visits will be needed if the goal of a project is to describe the total species richness at a site.

One reason I chose to evaluate the MMP/GLCWMP methods is because many cryptic marsh bird species have low detectability. Often, longer surveys may be required to detect cryptic species such as the Least Bittern (Bogner and Baldassare 2002). Furthermore, breeding chronology is often different for many species, which affects when and how many surveys should be performed throughout the season; Conway (2011) recommends three or more surveys using the Standardized North American Marsh Bird Monitoring Protocol. Furthermore, researchers found that at least three surveys were necessary to detect the presence of cryptic marsh bird species in New York and Maine wetlands adequately, in addition to using playback recordings (Swift *et al.* 1988; Gibbs and Melvin 1993). However, one potential problem with using playback recordings is the presence of surveyors and auditory equipment, which can affect detection rates; birds within 5m of the speakers are less likely to respond and may go undetected (Gibbs and Melvin 1993).

Detectability also may be an issue when sampling anuran species. Some species are more vocal than others and can be detected at farther ranges than other species. Crouch and Patton (2002) found that in Rhode Island, spring peepers call much more intensively, often choruses of calling code 3, than do green frogs and American toads. This makes detecting species such as green frogs or American toads harder when fewer individuals are present or if the wetland is larger. These findings agree with my findings. I detected spring peepers much more consistently and in higher abundances than other species. The maximum call-code for spring peepers detected was 3 for all eleven sites in 2015 and 2016, while the maximum call code for green frog at all sites where it was detected was 2 in 2015 and 2016. Furthermore, Gooch *et al.* (2006) found that more time spent listening led to increased detection probabilities of anurans in North Carolina.

In addition to the number of surveys, other factors affect detection rates of both bird and anuran species. Gibbs and Melvin (1993) found that early morning surveys were more likely to detect American bittern, while other cryptic species were more vocal and adequately sampled later in the morning survey period, leading to increased detections. Moreover, although the current MMP methods require one morning and one evening survey for birds, Hanowski *et al.* (2007) showed that two morning counts recorded more individuals and species than one morning and one evening count, with more wetland-dependent bird species recorded in morning surveys in Lake Michigan and Lake Superior wetlands. In anuran species sampling, the timing of nocturnal surveys can affect the number or abundance of species detected. A study done with breeding anuran species in Florida (Bridges and Dorcas 2000) found that many of the surveyed ranid species, such as green frog and American bullfrog, called more frequently between midnight and pre-dawn hours, after survey periods had ended.

Wetland factors such as hydrogeomorphic type can also affect detection of bird species. Hanowski *et al.* (2007) showed that bird community composition was different across the Great Lakes and varied with hydrogeomorphic type. For example, lacustrine wetlands had ten species with high importance values and significant affinities, while only two species had specific affinities for riverine wetlands

(Hanowski *et al*. 2007). This demonstrates difficulties using methods developed for large-scale monitoring to describe bird species communities in individual wetlands or to detect smaller-scale spatial or temporal patterns in these communities. In addition, species have limited ranges or are more common in certain regions of the Great Lakes, leading to problems interpreting effects over large spatial scales (Hanowski *et al.* 2007b).

There are also inherent difficulties with interpreting negative effects of anthropogenic disturbance on anuran species because species may not call for reasons other than anthropogenic disturbance. For example, even slight temperature drops or weather changes can affect calling rates during surveys, and each species may be affected differently (Shirose *et al.* 1997). Changes in weather throughout a survey night can interrupt breeding activity, potentially decreasing the calling rate. During my study, there were different weather patterns during the two sampling seasons. In 2015, it was very wet, which could have led to increased detection of anuran species, but in 2016, it was more dry, which could have decreased detection probability (NOAA 2018). My data support this assertion, as I detected two more species in 2015 than 2016, and I found a significant difference between the count methods in 2015 but not in 2016. In addition, differing weather patterns can lead to difficulties with obtaining reliable data across years during long-term monitoring programs.

To help avoid weather-related sampling issues, increasing the frequency of surveys can help to offset detection problems as time constraints and funding can make it difficult to increase survey length (Pierce and Gutzwiller 2004). Shirose *et al.*

(1997) and Pierce and Gutzwiller (2004) both found that there was little difference in anuran species detections between 3-and 5-min surveys, while surveys that continued for up to 60 min did not guarantee detection of all species present (Shirose *et al.* 1997). Additionally, Tozer *et al.* (2017) found minimal loss in detection probability of marsh bird species when reducing surveys from 15 min to 10 min. A reduction in the amount of time spent sampling at one site can lead to increased sites surveyed, ultimately increasing the statistical power of analyses; however, considerations must be made for time spent traveling between sites and from home to sites during limited survey times. Furthermore, decreasing survey length can lead to measurable decreases in costs associated with monitoring programs like the MMP (Tozer *et al.* 2016).

Weather also affected my ability to sample more intensively for bird species. The MMP methods do not allow surveys to be conducted when raining, which did not always allow me to sample each wetland on a "weekly" basis (i.e., every seven days). This did not seem to affect the results, however, as there were no significant differences between sampling efficiencies between years, and in both years, my intensive surveys had higher richness counts than the GLCWMP sampling method. Thus, my findings, as well as those of others (Walther and Martin 2001; Conway 2011), indicate that more than two surveys are necessary to measure bird species richness at individual wetland sites adequately.

Conclusions

My data, as well as those from many other studies, show that for increased detection of bird and anuran species, more site visits than currently used by the

GLCWMP are necessary. The data I present show that for both Great Lakes coastal wetland birds and anurans, more site visits will lead to increased species richness counts and increased detection rates, which will allow researchers to increase understanding and provide more reliable long-term data on species population trends. My methodology will be useful for project managers designing a program to sample total species richness at selected sites. To refine the methods used for monitoring bird and anuran species further, future studies should focus on detection rates of individual species using longer surveys or increased frequency of surveys to determine if a more species-specific sampling protocol may need to be developed. Additionally, studies that look to determine the cost of increased visits in terms of volunteer time or funding, as opposed to increased detection rates, would be useful in designing future protocols

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Tables and Figures

Table 1. Number of samples for bird species richness at eleven Great Lakes coastal wetlands in 2015. Both analytical (S(est)) and Chao 2 species richness estimates along with sampling efficiency are shown. S(est) is also the number of species I detected in total. Efficiency was calculated by dividing the S(est) by the Chao 2 richness estimate.

Site	samples	S (est)	Chao 2	Efficiency (%)
Braddock Bay	5	29	32.73	88.6
Brush Creek	5	22	38.13	57.7
Buck Pond	4	42	63.43	66.2
Buttonwood Creek	5	36	46.4	77.6
Fourmile Creek	6	26	61.21	42.5
Hopkins Creek	6	28	63.21	44.3
Long Pond	6	38	51.38	74.0
Salmon Creek	6	41	57.88	70.8
Sixmile Creek	6	28	40	70.0
Tuscarora Bay	6	28	33.36	83.9
Twelvemile Creek	6	24	27	88.9

Table 2. Number of samples for bird species richness at eleven Great Lakes coastal wetlands in 2016. Both the analytical (S(est)) and Chao 2 species richness estimates along with sampling efficiency are shown. S(est) is also the number of species I detected in total. Efficiency was calculated by dividing the S(est) by the Chao 2 richness estimate.

Site	samples	S (est)	Chao 2	Efficiency(%)
Braddock Bay	5	56	71.2	78.7
Brush Creek	5	28	42	66.7
Buck Pond	5	35	43.8	79.9
Buttonwood Creek	5	40	45.28	88.3
Cranberry Pond	5	28	35.33	79.3
East Creek	5	31	36.28	85.4
Long Pond	5	27	31.4	86.0
Payne Beach	5	31	40.6	76.4
Round Pond	5	29	39.4	73.6
Salmon Creek	5	35	42.64	82.1
Sandy Creek	5	29	44.6	65.0

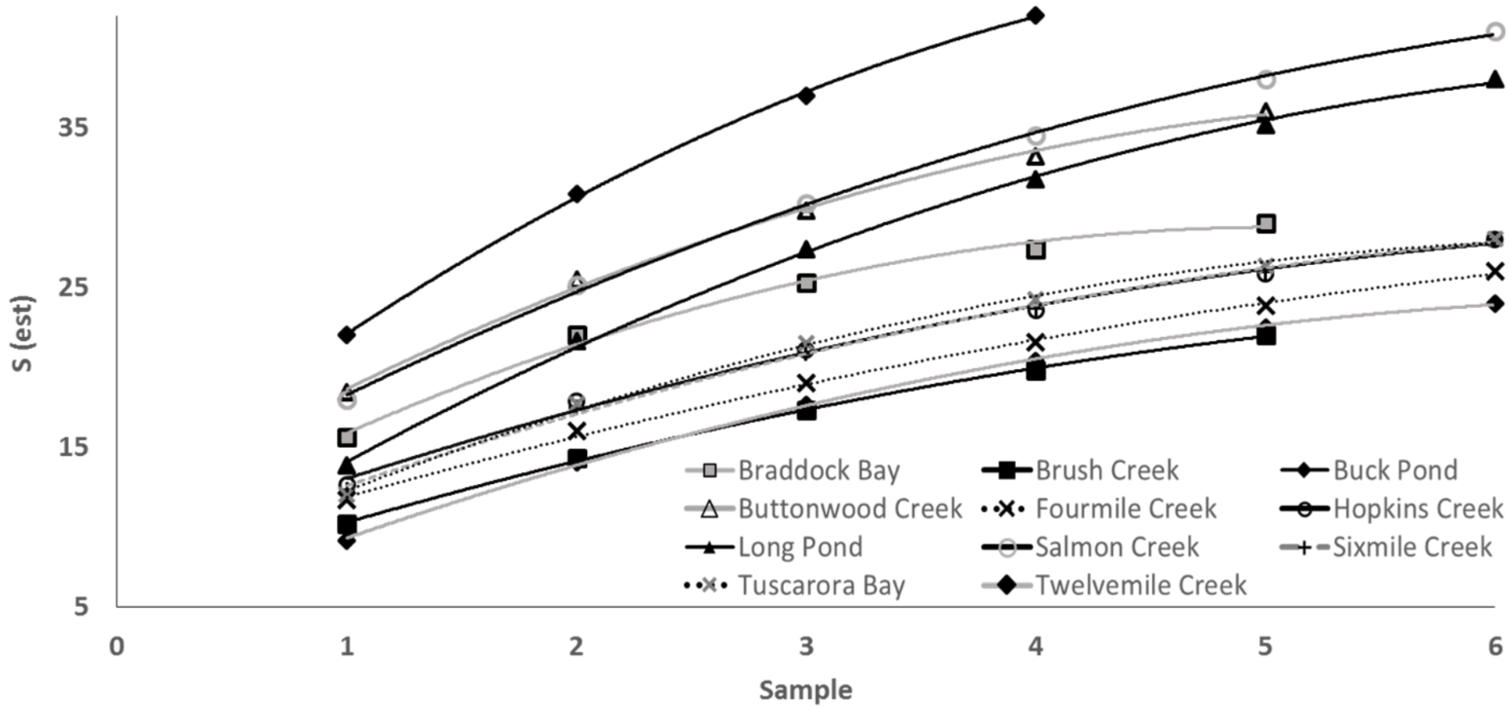

Figure 1. Species richness rarefaction curves for bird species richness at eleven Great Lakes coastal wetlands in 2015.

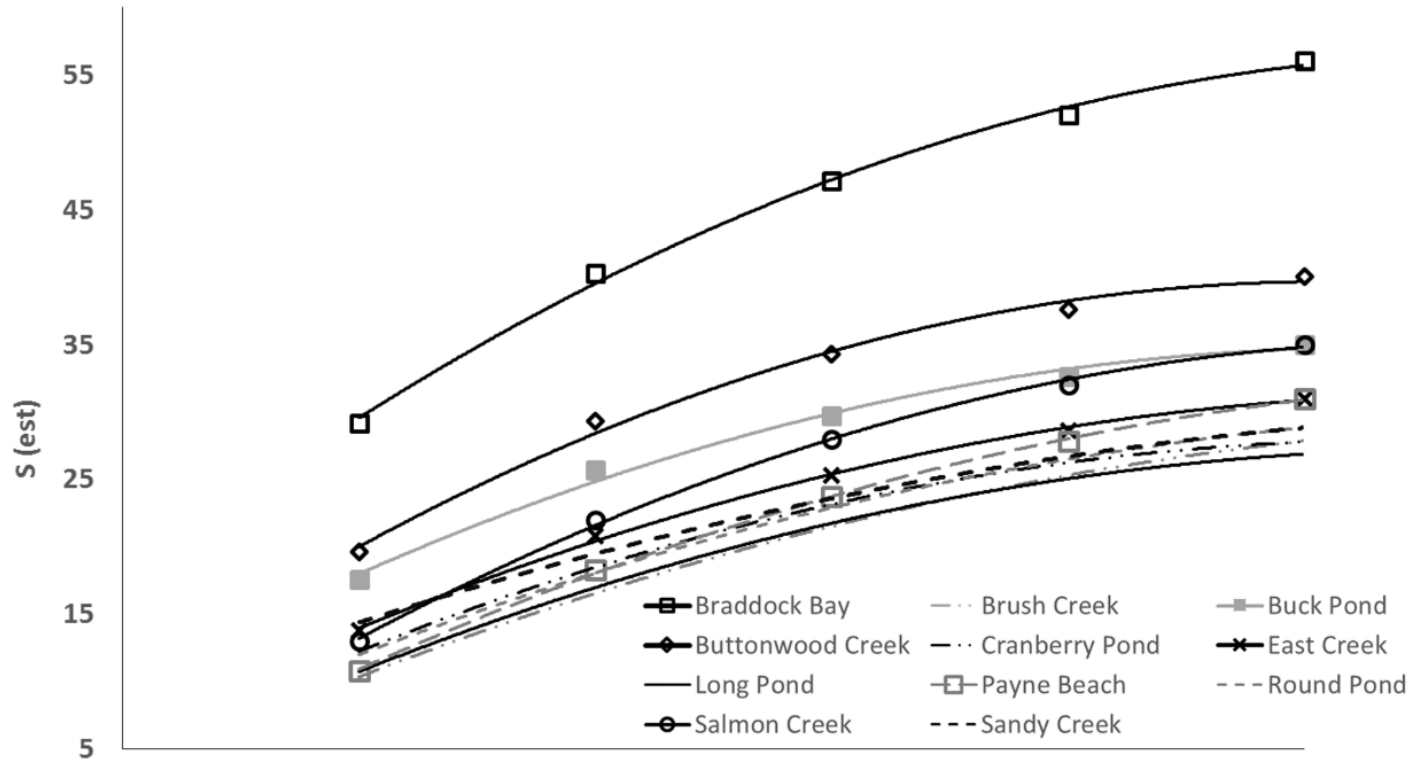

Figure 2. Species richness rarefaction curves for bird species richness at eleven Great Lakes coastal wetlands in 2016.

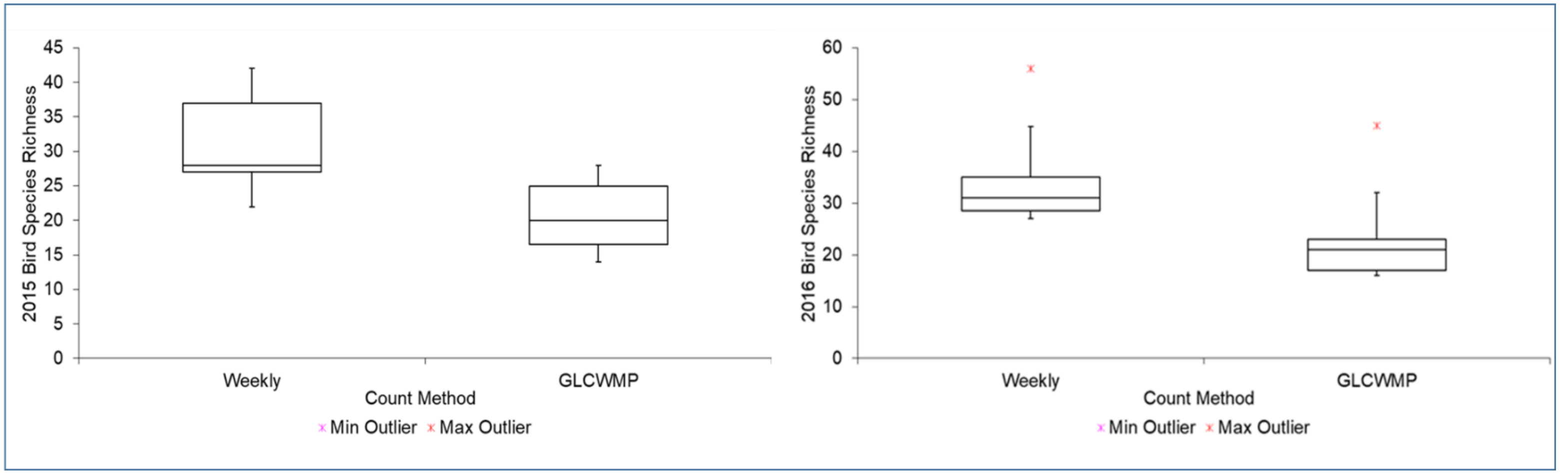

Figure 3. Comparison of richness counts between the GLCWMP methods and my more intensive sampling method for bird species richness in 2015 and 2016. The horizontal lines represent the 1st and 3rd quartile ranges as well as the median.

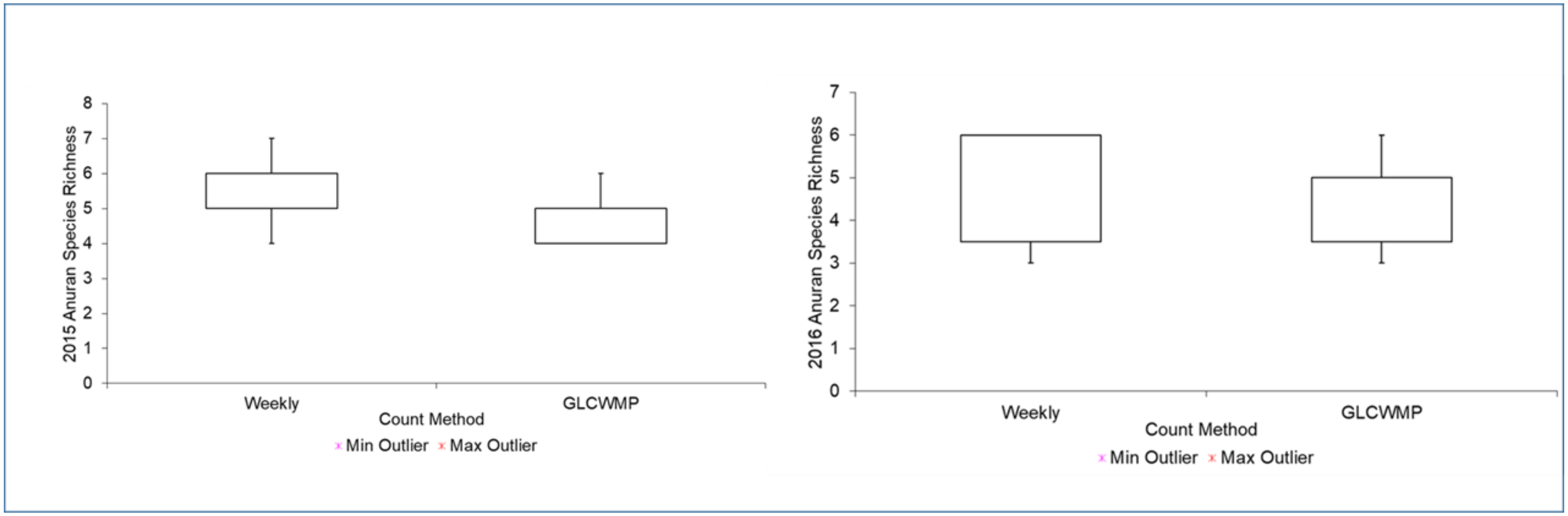

Figure 4. Comparison of richness counts between the GLCWMP methods and my more intensive sampling method for anuran species richness in 2015 and 2016. The horizontal lines represent the 1st and 3rd quartile ranges as well as the median.

Appendices

Four appendices are presented. The first is a list of all 64 sites sampled and coordinates. Second is a list of focal species designated by the GLCWMP. Third is a list of all bird species observed during my intensive monitoring of sites during 2015 and 2016. Fourth is a list of all anuran species detected during my intensive monitoring of sites in 2015 and 2016.

Appendix 1. List of all sites used in my disturbance analyses.

SITE ID	site name	Latitude	Longitude
1	Tuscarora Bay	43.31	-78.84
8	Golden Hill State Park Wetland	43.37	-78.48
10	Johnson Creek Wetland	43.37	-78.26
15	Yanty Marsh	43.36	-77.93
16	Sandy Harbor Wetland	43.35	-77.89
20	Cowsucker Creek Wetland #1	43.34	-77.84
22	Brush Creek Wetland	43.34	-77.81
23	East Creek Wetland	43.34	-77.80
27	Payne Beach Area Wetland	43.33	-77.73
28	Salmon Creek	43.31	-77.74
29	Long Pond Wetland	43.29	-77.70
50	Braddock Bay-Cranberry Pond Wetland	43.30	-77.70
51	Buck Pond	43.28	-77.67
53	Little Pond Wetland	43.26	-77.64
54	Genesee River Wetland	43.23	-77.62
56	Irondequoit Bay Wetland 2	43.17	-77.52
62	Maxwell Bay Wetland	43.27	-77.03
63	Third Creek	43.23	-76.96
66	East Bay Wetland	43.28	-76.90
70	Port Bay Wetland	43.28	-76.83
76	Red Creek Wetland	43.30	-76.79
82	Blind Sodus Bay Wetland	43.34	-76.73
86	Sterling Creek Wetland	43.34	-76.68
92	Eighteenmile Creek Wetland	43.41	-76.62
95	Rice Creek Marsh	43.44	-76.57
112	Little Salmon River Marsh	43.52	-76.25

SITE ID	site name	Latitude	Longitude
116	Ramona Beach Marsh	43.53	-76.22
118	Salmon River Marsh	43.57	-76.19
119	South Pond Wetland #1	43.62	-76.19
122	North Pond Area Wetland	43.66	-76.18
123	Little Sandy Creek Marsh	43.64	-76.16
124	Blind Creek Wetland	43.65	-76.15
126	Cranberry Pond Marsh	43.69	-76.19
130	Black Pond-Little Stony Creek Marsh	43.80	-76.22
157	Sherwin Bay Marsh	43.97	-76.17
161	Muskalonge Bay Wetland	43.98	-76.09
163	Perch River Wetland	44.00	-76.08
164	Guffin Bay Marsh	44.04	-76.13
167	Chaumont River Mouth Wetland	44.07	-76.15
181	Isthmus Marsh South	44.01	-76.28
186	Long Carry Marsh	44.05	-76.27
187	Fox Creek Marsh	44.06	-76.30
197	Mud Bay Marsh #1	44.08	-76.33
199	Mud Bay Marsh #2	44.08	-76.31
5088	Big Island Marsh	44.11	-77.23
5103	Blessington Creek Marsh 1	44.17	-77.32
5151	Carnachan Bay Wetland 2	44.08	-77.03
5152	Carnachan Bay Wetland 3	44.08	-77.02
5196	Collins Creek Wetlands 2	44.24	-76.61
5568	Lucas Point Wetland	44.18	-76.50
5635	Mill Point Wetland	44.19	-76.46
5855	Sand Bay 1	44.15	-76.50
7020	Lakeview Pond-Sandy Creek-Colwell Ponds Marsh	43.75	-76.20
7021	South Colwell	43.70	-76.19
7023	North Colwell	43.71	-76.19
7024	Floodwood Pond	43.73	-76.19
7025	Goose Pond	43.71	-76.19
7026	Buttonwood Creek	43.30	-77.73
7027	East Sodus	43.26	-76.94
7028	Second Creek	43.25	-76.98
7051	South Pond Wetland 2	43.58	-76.19
7052	Braddock Bay	43.31	-77.72
7053	Irondequoit Bay Wetland	43.17	-77.53
7054	Isthmus Marsh South	44.02	-76.29

Appendix 2. List of Focal species as designated by the GLCWMP.

Focal Species	
American Bittern	*Botaurus lentiginosus*
American Coot	*Fulica americana*
King Rail	*Rallus elegans*
Common Moorhen	*Gallinula chloropus*
Black Rail	*Laterallus jamaicensis*
Least Bittern	*Ixobrychus exilis*
Pied-billed Grebe	*Podilymbus podiceps*
Sora	*Porzana carolina*
Virginia Rail	*Rallus limicola*
Yellow Rail	*Coturnicops noveboracensis*

Appendix 3**.** List of all bird species observed during intensive surveys at each site in 2015 and 2016. The numbers for each species refers to the total count of individuals observed at each site.

	Species					
Site	Alder Flycatcher (*Empidonax alnorum*)	American Bittern (*Botaurus lentiginosus*)	American Coot (*Fulica americana*)	American Crow (*Corvus brachyrhynchos*)	American Goldfinch (*Spinus tristis*)	American Redstart (*Setophaga*
Braddock Bay						
2015				1	3	
2016	1	2		11	14	4
Brush Creek						
2015				1	3	
2016		1		2	3	1
Buck Pond						
2015					5	
2016					7	
Buttonwood Creek						
2015				8	12	
2016				7	10	
Cranberry Pond						
2016				2	6	
East Creek						
2016					1	
Four Mile Creek						
2015					1	
Hopkins Creek						
2015				2	4	5
Long Pond						
2015				1	4	
2016				1	3	
Payne Beach						
2016				3	4	1
Round Pond						
2016				1	5	3
Salmon Creek						
2015			1	4	14	
2016		1		2	9	
Sandy Creek						
2016					1	
Six Mile Creek						
2015		1			3	
Tuscarora Bay						
2015				1	4	
Twelve Mile Creek						
2015				5	2	

Site	American Robin (*Turdus migratorius*)	Bald Eagle (*Haliaeetus leucocephalus*)	Bank Swallow (*Riparia riparia*)	Baltimore Oriole (*Icterus galbula*)	Barn Swallow (*Hirundo rustica*)	Black-billed Cuckoo (*Coccyzus erythropthalmus*)
Braddock Bay						
2015	3				6	
2016	19	3		5	14	
Brush Creek						
2015	9			1	1	
2016	5			1	1	
Buck Pond						
2015	6		1	3	5	
2016	4			4	9	
Buttonwood Creek						
2015	8			1	8	
2016	10			5	10	
Cranberry Pond						
2016	5			1	1	1
East Creek						
2016	7			1	2	
Four Mile Creek						
2015	9				1	
Hopkins Creek						
2015	10			1		
Long Pond						
2015	12			1	2	
2016	7			3	2	
Payne Beach						
2016	3			1	1	
Round Pond						
2016	3				1	
Salmon Creek						
2015	4			1	6	
2016	1			1	2	
Sandy Creek						
2016	2		1		5	
Six Mile Creek						
2015	10			1		
Tuscarora Bay						
2015	12				3	
Twelve Mile Creek						
2015	8					

Site	Black-capped Chickadee (*Poecile atricapillus*)	Black-crowned Night-Heron (*Nycticorax nycticorax*)	Belted Kingfisher (*Megaceryle alcyon*)	Blue-gray Gnatcatcher (*Polioptila caerulea*)	Brown-headed Cowbird (*Molothrus ater*)
Braddock Bay					
2015					
2016			2	2	1
Brush Creek					
2015			1		
2016				1	
Buck Pond					
2015				1	
2016			1		
Buttonwood Creek					
2015			1		
2016	1				
Cranberry Pond					
2016	1				
East Creek					
2016					
Four Mile Creek					
2015	1				
Hopkins Creek					
2015			1		
Long Pond					
2015	2				
2016	3				
Payne Beach					
2016	1			1	1
Round Pond					
2016				1	
Salmon Creek					
2015	3				1
2016					
Sandy Creek					
2016					
Six Mile Creek					
2015	1				
Tuscarora Bay					
2015		1	4		
Twelve Mile Creek					
2015			3		

Site	Blue Jay (*Cyanocitta cristata*)	Bobolink (*Dolichonyx oryzivorus*)	Canada Goose (*Branta canadensis*)	Caspian Tern (*Hydroprogne caspia*)	Cedar Waxwing (*Bombycilla cedrorum*)	Chipping sparrow (*Spizella passerina*)
Braddock Bay						
2015	1		1		4	
2016	11	3	14	4	16	1
Brush Creek						
2015			1		3	
2016					4	
Buck Pond						
2015	1	1			7	
2016	2		2		11	
Buttonwood Creek						
2015	1		5		6	
2016	4		2		10	1
Cranberry Pond						
2016					5	
East Creek						
2016	2		1		4	
Four Mile Creek						
2015	1		1			
Hopkins Creek						
2015					1	
Long Pond						
2015	6		1		3	
2016	2				2	
Payne Beach						
2016	2		1		2	
Round Pond						
2016				1	4	
Salmon Creek						
2015	1	1	1		8	1
2016	2				5	
Sandy Creek						
2016	1		1		9	
Six Mile Creek						
2015	1				5	
Tuscarora Bay						
2015	3					
Twelve Mile Creek						
2015	8				1	

Site	Chimney Swift (*Chaetura pelagic* a)	Cliff Swallow (*Petrochelidon pyrrhonota*)	Common Grackle (*Quiscalus quiscula*)	Common Moorhen (*Gallinula chloropus*)	Common Nighthawk (*Chordeiles minor*)	Common Raven (*Corvus corax*)
Braddock Bay						
2015			3			
2016			35	1	1	
Brush Creek						
2015			4			
2016			3			
Buck Pond						
2015			14		2	
2016			20			1
Buttonwood Creek						
2015			5			
2016			13			
Cranberry Pond						
2016			13			
East Creek						
2016			13			
Four Mile Creek						
2015			11			
Hopkins Creek						
2015			1			
Long Pond						
2015			15			
2016			4			
Payne Beach						
2016			6		1	
Round Pond						
2016			7			
Salmon Creek						
2015			8			
2016			8	2		
Sandy Creek						
2016	1	4	4			
Six Mile Creek						
2015			10			
Tuscarora Bay						
2015			2			
Twelve Mile Creek						
2015			2			

Site	Common Tern (*Sterna hirundo*)	Common Yellowthroat (*Geothlypis trichas*)	Double-crested Cormorant (*Phalacrocorax auritus*)	Downy Woodpecker (*Picoides pubescens*)	Eastern Kingbird (*Tyrannus tyrannus*)	Eastern Meadowlark (*Sturnella magna*)
Braddock Bay						
2015	1	12	1		2	
2016		32	1		1	
Brush Creek						
2015		15				
2016		6				
Buck Pond						
2015		20			1	
2016		25				
Buttonwood Creek						
2015		24			4	
2016		23		2	5	
Cranberry Pond						
2016		6				
East Creek						
2016		4				
Four Mile Creek						
2015		7				
Hopkins Creek						
2015		4				
Long Pond						
2015		4			1	
2016		3		1		
Payne Beach						
2016		2		1		
Round Pond						
2016		10				
Salmon Creek						
2015		13			3	1
2016		2				
Sandy Creek						
2016	1	2				
Six Mile Creek						
2015		3				
Tuscarora Bay						
2015		1				
Twelve Mile Creek						
2015		1				

Site	Eastern Phoebe (*Sayornis phoebe*)	Eastern Wood-Peewee (*Contopus virens*)	European Starling (*Sturnus vulgaris*)	Field Sparrow (*Spizella pusilla*)	Great blue Heron (*Ardea herodias*)	Great Crested Flycatcher (*Myiarchus crinitus*)
Braddock Bay						
2015			5		1	
2016			19		6	2
Brush Creek						
2015		1				
2016						
Buck Pond						
2015		2			1	
2016		3	1		2	1
Buttonwood Creek						
2015		1	2			1
2016			7		1	1
Cranberry Pond						
2016		1			4	4
East Creek						
2016		1	2			
Four Mile Creek						
2015		5	2			
Hopkins Creek						
2015	2	7		1		1
Long Pond						
2015		2	2			
2016	2	1	2			1
Payne Beach						
2016		2				
Round Pond						
2016					1	1
Salmon Creek						
2015			7		2	
2016			4		3	
Sandy Creek						
2016			6			2
Six Mile Creek						
2015			2		1	
Tuscarora Bay						
2015		1	3			2
Twelve Mile Creek						
2015		2				1

Site	Gray Catbird (*Dumetella carolinensis*)	Green Heron (Butorides virescens)	House Finch (*Haemorhous mexicanus*)	House Sparrow (*Passer domesticus*)	House Wren (*Troglodytes aedon*)	Indigo Bunting (*Passerina cyanea*)
Braddock Bay						
2015	5					
2016	18					
Brush Creek						
2015	1					
2016	2					
Buck Pond						
2015	8		1			
2016	5	4				
Buttonwood Creek						
2015	10	1				
2016	3	1				
Cranberry Pond						
2016	2	4				
East Creek						
2016	1	2				
Four Mile Creek						
2015	3					
Hopkins Creek						
2015	11					
Long Pond						
2015	2			1	1	
2016				1		
Payne Beach						
2016	5					
Round Pond						
2016	4					
Salmon Creek						
2015	6		1			1
2016	1	1	1			
Sandy Creek						
2016	3	1				
Six Mile Creek						
2015	6	1	1			
Tuscarora Bay						
2015	6					
Twelve Mile Creek						
2015	2	2				

Site	Killdeer (*Charadrius vociferus*)	Least Bittern (*Ixobrychus exilis*)	Least Flycatcher (*Empidonax minimus*)	Mallard (*Anas platyrhynchos*)	Marsh Wren (*Cistothorus palustris*)	Mourning Dove (*Zenaida macroura*)	Mute Swan (*Cygnus olor*)
Braddock Bay							
2015				3	28		
2016	6			10	59	6	8
Brush Creek							
2015				1		3	1
2016					7		
Buck Pond							
2015				3	16	2	2
2016	1			1	21	6	
Buttonwood Creek							
2015					16	4	
2016	2			2	25	5	
Cranberry Pond							
2016	1				1	2	
East Creek							
2016						6	2
Four Mile Creek							
2015						3	
Hopkins Creek							
2015						5	
Long Pond							
2015			1	2	3	8	
2016				1	1	3	
Payne Beach							
2016							
Round Pond							
2016						3	
Salmon Creek							
2015	1			2	28	2	1
2016					15	2	3
Sandy Creek							
2016					7	2	2
Six Mile Creek							
2015	1					6	
Tuscarora Bay							
2015				1		6	
Twelve Mile Creek							
2015		1				7	1

Site	Northern Cardinal (*Cardinalis cardinalis*)	Northern Flicker (*Colaptes auratus*)	Northern Harrier (*Circus cyaneus*)	Northern Mockingbird (*Mimus polyglottos*)	Northern Rough-winged Swallow (*Stelgidopteryx serripennis*)	Osprey (*Pandion haliaetus*)
Braddock Bay						
2015	3					
2016	23	3	2			1
Brush Creek						
2015	6	1				
2016	3	1				
Buck Pond						
2015	4	1		1		
2016	8					
Buttonwood Creek						
2015	9	2				1
2016	10	1				1
Cranberry Pond						
2016	3	2				
East Creek						
2016	6	1	1			1
Four Mile Creek						
2015	4	1			1	
Hopkins Creek						
2015	11	1				
Long Pond						
2015	3	1			1	
2016	5	5				
Payne Beach						
2016	2	1				
Round Pond						
2016	1	1				
Salmon Creek						
2015	11					2
2016	4					1
Sandy Creek						
2016	4					
Six Mile Creek						
2015	3	1				
Tuscarora Bay						
2015	7	2				
Twelve Mile Creek						
2015	5	2				

Site	Pileated Woodpecker (*Hylatomus pileatus*)	Purple Finch (*Haemorhous purpureus*)	Purple Martin (*Progne subis*)	Ring-billed Gull (*Larus delawarensis*)	Red-bellied Woodpecker (*Melanerpes carolinus*)	Red-eyed Vireo (*Vireo olivaceus*)
Braddock Bay						
2015				8	4	
2016			1	5	1	2
Brush Creek						
2015	1			2	3	
2016		1		1	2	1
Buck Pond						
2015	1			4		
2016				2		
Buttonwood Creek						
2015					1	1
2016				2		
Cranberry Pond						
2016					1	
East Creek						
2016				2	1	
Four Mile Creek						
2015				2	7	
Hopkins Creek						
2015	1			5	5	
Long Pond						
2015	1			1	2	
2016						
Payne Beach						
2016				3		1
Round Pond						
2016				2		1
Salmon Creek						
2015				4	3	
2016			3	3	1	
Sandy Creek						
2016			1	4		
Six Mile Creek						
2015				20	3	
Tuscarora Bay						
2015				3	1	
Twelve Mile Creek						
2015						

Site	Ring-necked Pheasant (*Phasianus colchicus*)	Ruby-throated Hummingbird (*Archilochus colubris*)	Red-winged Blackbird (*Agelaius phoeniceus*)	Song Sparrow (*Melospiza melodia*)	Spotted Sandpiper (*Actitis macularius*)
Braddock Bay					
2015		1	35	12	
2016			180	33	
Brush Creek					
2015			38	5	
2016			23	1	1
Buck Pond					
2015	1		61	16	
2016			59	15	
Buttonwood Creek					
2015			76	17	
2016			64	12	
Cranberry Pond					
2016			25	2	
East Creek					
2016			33	7	
Four Mile Creek					
2015			40	10	
Hopkins Creek					
2015			5	3	
Long Pond					
2015			31	4	
2016			21	6	
Payne Beach					
2016			21	3	
Round Pond					
2016			24	2	
Salmon Creek					
2015			64	19	
2016			34	6	
Sandy Creek					
2016			29	6	
Six Mile Creek					
2015			48	5	
Tuscarora Bay					
2015			43	6	
Twelve Mile Creek					
2015			40		

Site	Sharp-shinned Hawk (*Accipiter striatus*)	Swamp Sparrow (*Melospiza georgiana*)	Tree Swallow (*Tachycineta bicolor*)	Turkey Vulture (*Cathartes aura*)	Unidentifed Species	Virginia Rail (*Rallus limicola*)	Warbling Vireo (*Vireo gilvus*)
Braddock Bay							
2015		13	8		1		3
2016		56	26	5	9	2	12
Brush Creek							
2015		14			4		
2016		13			1		
Buck Pond							
2015		28	7		6	2	7
2016		23	8		9		16
Buttonwood Creek							
2015		29	3		3		5
2016		30	8		4	1	4
Cranberry Pond							
2016		9	3		1		
East Creek							
2016		9	2	2	1		3
Four Mile Creek							
2015		11			2		1
Hopkins Creek							
2015					4		5
Long Pond							
2015		3	1		5		2
2016		3	1				3
Payne Beach							
2016		2	2		2	2	1
Round Pond							
2016		11	1		4		3
Salmon Creek							
2015		11	8		2	1	1
2016	1	6	3	1	3		
Sandy Creek							
2016			4		1		5
Six Mile Creek							
2015					3		5
Tuscarora Bay							
2015			1		6		2
Twelve Mile Creek							
2015					5		

Site	White-breasted Nuthatch (*Sitta carolinensis*)	Willow Flycatcher (*Empidonax traillii*)	Wood Duck (*Aix sponsa*)	Wood Thrush (*Hylocichla mustelina*)	Yellow Warbler (*Setophaga petechia*)
Braddock Bay					
2015		3			18
2016		14	1	2	63
Brush Creek					
2015			1	1	14
2016		2	1	2	13
Buck Pond					
2015		9	1		23
2016		8		1	25
Buttonwood Creek					
2015		5	1	1	25
2016		3	3	2	25
Cranberry Pond					
2016		1			15
East Creek					
2016		1		2	7
Four Mile Creek					
2015	1			1	7
Hopkins Creek					
2015				1	11
Long Pond					
2015			1		1
2016					1
Payne Beach					
2016				2	17
Round Pond					
2016		5			8
Salmon Creek					
2015		2	2	1	26
2016		5	1		11
Sandy Creek					
2016				1	12
Six Mile Creek					
2015		1	1		7
Tuscarora Bay					
2015					8
Twelve Mile Creek					
2015			2		5

Site	White-breasted Nuthatch (*Sitta carolinensis*)	Willow Flycatcher (*Empidonax traillii*)	Wood Duck (*Aix sponsa*)	Wood Thrush (*Hylocichla mustelina*)	Yellow Warbler (*Setophaga petechia*)
Braddock Bay					
2015		3			18
2016		14	1	2	63
Brush Creek					
2015			1	1	14
2016		2	1	2	13
Buck Pond					
2015		9	1		23
2016		8		1	25
Buttonwood Creek					
2015		5	1	1	25
2016		3	3	2	25
Cranberry Pond					
2016		1			15
East Creek					
2016		1		2	7
Four Mile Creek					
2015	1			1	7
Hopkins Creek					
2015				1	11
Long Pond					
2015			1		1
2016					1
Payne Beach					
2016				2	17
Round Pond					
2016		5			8
Salmon Creek					
2015		2	2	1	26
2016		5	1		11
Sandy Creek					
2016				1	12
Six Mile Creek					
2015		1	1		7
Tuscarora Bay					
2015					8
Twelve Mile Creek					
2015			2		5

Appendix 4. List of all anuran species observed during intensive surveys in 2015 and 2016. The numbers for each species refers to the maximum callcode observed for that species at that site.

	Species				
Site	American toad (*Anaxyrus americanus*)	American bullfrog (*Lithobates catesbeianus*)	Western chorus frog (*Pseudacris triseriata*)	green frog (*Rana clamitans*)	gray treefrog (*Hyla versicolor*)
Braddock Bay					
2015	2	1			2
2016	1	1		2	1
Brush Creek					
2015	2	1		2	3
2016	1	1		2	1
Buck Pond					
2015	2			2	2
2016				2	
Buttonwood Creek					
2015	2			2	2
2016	2	1		2	2
Cranberry Pond					
2016				2	
East Creek					
2016	1	1		2	1
Four Mile Creek					
2015		2	2	1	1
Hopkins Creek					
2015	3	2		1	2
Long Pond					
2015	2			1	
2016	2			2	2
Payne Beach					
2016				2	
Round Pond					
2016	1			2	
Salmon Creek					
2015	2	2		2	3
2016	2	2		2	1
Sandy Creek					
2016	3	1		2	2
Six Mile Creek					
2015	1	2		1	3
Tuscarora Bay					
2015		2			2
Twelve Mile Creek					
2015	1	2		1	1

Species				
Site		northern leopard frog (*Lithobates pipiens*)	spring peeper (*Pseudacris crucifer*)	wood frog (*Lithobates sylvaticus*)
Braddock Bay				
	2015	2	3	
	2016	1	3	
Brush Creek				
	2015	2	3	
	2016	2	3	
Buck Pond				
	2015	1	3	
	2016	1	3	
Buttonwood Creek				
	2015	2	3	
	2016	2	3	
Cranberry Pond				
	2016	2	3	
East Creek				
	2016	2	3	
Four Mile Creek				
	2015	1	3	
Hopkins Creek				
	2015	1	3	
Long Pond				
	2015	1	3	
	2016	1	3	
Payne Beach				
	2016	2	3	
Round Pond				
	2016	1	3	
Salmon Creek				
	2015	3	3	
	2016	2	3	
Sandy Creek				
	2016	2	3	
Six Mile Creek				
	2015	2	3	1
Tuscarora Bay				
	2015	1	3	
Twelve Mile Creek				
	2015	3		