Determining potential impacts of climate change on anuran calling phenology in the Great Lakes Basin

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Foreword

The environment in which we live is one that is changing rapidly. Climate change is now a scientific consensus, and global temperatures are rising quickly. Many argue that the Earth has undergone various periods of climate change in its history, citing eras of glaciation and subsequent melting as evidence of the cyclical nature of our planet's climate. Though this is true, current climate change is very different. Historical episodes of global warming were the result of primarily natural forces, and did not include any significant anthropogenic effects (Hoegh-Guldberg, 2010). Also, historic levels of atmospheric carbon dioxide (CO_2), one of the key players in the greenhouse gas effect, never reached levels higher than 300 parts per million (NOAA, 2014). When looking at current data, atmospheric levels of CO_2 are significantly above 300 ppm, and have been climbing since the Industrial Revolution (NOAA, 2014). This is due to widespread anthropogenic carbon emissions, and is something our Earth has not experienced before.

Climate change affects many different ecosystems differently, and I will be focusing on the Great Lakes Marshlands in my major paper, more specifically the impacts on anuran calling phenology in the Great Lakes basin. Phenology is defined as the study of cyclic and seasonal natural phenomena, especially in relation to climate, plant, and animal life (Blaustein, 2001). My paper will be investigating the seasonal nature of anuran mating calls, which have historically been used to track potential impacts of climate change on sensitive ecosystems. It has been shown in studies worldwide that warming temperatures tend to result in earlier calling periods (Gibbs, 2000), however the impacts of these shifts in calling times are still being investigated (Corn, 2005). As anurans are so sensitive to ecosystem change, any impacts seen affecting them directly are thought to be a type of early warning system for the ecosystem as a whole (Klaus, 2013).

My major paper fulfills the requirements of my plan of study as my learning objectives are related to understanding environmental change, the impacts of said change on wildlife, and the conservation strategies for at-risk wildlife. My major paper has explored the changing climate of the Great Lakes Basin, its impact on six different anuran species, and explored the conservation strategies for the impacted species, not only through the writing of the paper itself, but also the extensive literature reviews undertaken to become familiar with the currents of thought and practice relating to similar studies.

In my plan of study, I outlined that I would like to: gain a reading knowledge of climate change and its impacts on coastal ecosystems, determine the primary behavioural, physiological, and ecological effects of climate change on target species, develop a thorough knowledge of quantitative methods, model effects of climate change using field study data, and engage with current conservation biology literature to form an educated opinion on various conservation strategies for at-risk wildlife. All of these objectives have been achieved through the preparation, analysis and writing of my major paper, which is structured as a stand-alone manuscript that will be submitted to the Journal of Great Lakes Research.

To become more comfortable with statistical software I also was able to take the Introduction to R short course with Dr. Robert Cribbie, and gained my own field experience through the York International Internship I was lucky enough to receive for 13 weeks to Costa Rica, during the Summer 2015 term. Both of these experiences allowed me to further my learning objectives alongside of the writing of my major paper. This paper is authored by myself, Dr. Gail Fraser, and Dr. Doug Tozer, as the data I analyzed came from Bird Studies

Canada through my supervisor, Dr. Fraser, with the permission of Dr. Tozer, the Ontario Program Scientist for Bird Studies Canada.

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Abstract

This study investigated how climate change affects the mating behaviour of anurans in the Great Lakes Basin. We examined temporal trends in spring and summer temperatures across the basin and were interested in quantifying how changing climate was related to the reproductive behaviour of six (6) different anuran species. Spring temperatures increased in some areas of the basin, but not others, and an interspecific variation in first calling date trends from 2006-2014 in response to spring temperatures was observed. Early breeding species, such as the spring peeper, (*Pseudacris crucifer*) and the American toad (*Bufo americanus*), have the propensity to be affected more extremely, as spring temperatures were more strongly correlated to shifts in first calling date in April and May. Our results demonstrate the irregular impacts of climate change amongst anuran species, and suggest how these impacts may disturb the reproductive processes of specific communities.

Key Words. – anuran; calling; climate change; community; phenology; temperature

Introduction

Climate is known to be a major driver for a number of biological processes such as sex determination in reptiles (Chaloupka, 2008), changes in phenology such as emergence dates for a variety of insects, including vital pollinators, (Scaven, 2013), and the flowering and leaf turn out of plants (Forrest, 2011). Since the onset of many biological processes is driven by ambient climate, anthropogenic changes in climate (e.g., NOAA, 2010) have the potential to disrupt biological process for many different species. One particularly vulnerable group are amphibians, due to their dual aquatic and terrestrial life histories and ectothermic temperature regulation strategies (Foden, 2013). As amphibians, particularly anurans, are so sensitive to ecosystem change, any impacts seen affecting them directly are thought to be a type of early warning system for ecosystems as a whole (Klaus, 2013).

Many studies have investigated the impacts of climate change on anuran phenology (Blaustein 2001, Todd 2010, Walpole 2012). Blaustein (2001) found earlier breeding periods correlating to increasing spring temperatures (Blaustein, 2001) and reproductive periods of fall breeding anurans were extended as a result of warming fall temperatures (Todd, 2010). Changes in phenology and reproductive behaviour have the capacity to alter ecosystem dynamics, such as influencing timing of offspring hatching, and thus food availability for predator species, and could also result in asynchronisity in anuran populations (Walpole et al. 2012). Walpole et al. (2012) observed such changes in areas of the Great Lakes Basin, in the Simcoe watershed in Ontario, Canada; with increasing mean monthly temperatures in April resulted in significant declining trends in calling dates for three species of anurans; the wood frog (*Lithobates sylvaticus),* northern leopard frog (*L. pipiens),* and spring peeper (*Pseudacris crucifer).* Non-significant declining trends in calling date were seen for the American toad

(*Anaxyrus americanus*) and the gray tree frog (*Hyla versicolor*), and the green frog (*L. clamitans*) and American bullfrog (*L. catesbeianus*) exhibited non-significant positive trends for calling date.

In this study we sought to determine if changes in mating call phenology with respect to trends in spring and summer temperatures could be observed in six anuran species present in a wider area of the Great Lakes Basin for an eight year period. Building off Walpole et al.'s (2012) work we predicted that the annual timing of mating calls would advance with warming spring and summer temperatures, predominantly in early-breeding species, and initial calling dates would advance significantly with changes in ambient climate across geographic and species boundaries.

Materials and Methods

We used Bird Studies Canada Great Lakes Marsh Monitoring Program (MMP: http://www.bsc-eoc.org/volunteer/glmmp/index.jsp?lang=EN [Accessed September 2015]) anuran call data. Amphibian populations were surveyed three times (early, mid, and late) each year in the anuran breeding season at fixed stations in wetlands across the Great Lakes Basin. The timing of surveys were linked to nighttime temperatures: early 5°C, mid 10°C and late 3 17°C, which generally corresponded to April 15 to 30, May 15 and 31, and June 15 to July 15, respectively. The standardized surveys were conducted by volunteer marsh monitors recording the relative abundance of individuals calling during each visit for a 3-5-minute listening period, as well as recording local temperatures at the time of survey (Marsh Monitoring Program, 2008).

There were fifteen (15) sites used in this analysis; three northerly, easterly, southerly, westerly, and centrally located respectively grouped by cardinal direction for an even spread of the Great Lakes Basin. (Table 1). Sites needed to have a minimum of eight consecutive monitoring years, from 2006 to 2014, and three survey visits per year to be included in the analysis. All anuran species detecting during monitoring at these fifteen sites were used in this analysis (Table 2).

Table 1: Survey sites across the Great Lakes Basin as chosen from Bird Studies Canada Great Lakes Marsh Monitoring Program (MMP). MMP station identification code, as well as latitude and longitude (both in decimal units) are provided, along with cardinal direction for reference. Stations cover Ontario (ON), Canada, Indiana (IN), USA, Wisconsin (WI), USA, and Ohio (OH), USA.

Cardinal Direction	MMP Station ID	Latitude (decimal units)	Longitude (decimal units)	Associated Great Lake
North	ON 692	46.2008	-83.8036	Huron
North	ON 379	46.6955	-84.4262	Superior
North	ON 757	46.302219	-79.442925	Huron
East	ON 663	45.09369	-74.52015	Ontario
East	ON 729	45.300833	-74.641944	Ontario
East	ON 050	45.12297	-75.87431	Ontario
South	OH 049	41.45887	-81.60614	Erie
South	IN 018	41.61354	-87.43994	Michigan
South	OH 034	41.52486	-83.0012	Erie
West	WI 026	46.72833	-90.90556	Superior
West	WI 016	44.669347	-87.99889	Michigan

West	WI 035	44.8474	-87.5512	Michigan
Central	ON 099	43.6302	-81.4652	Huron
Central	ON 549	43.8848889	-78.679722	Ontario
Central	ON 343	43.10149	-79.303039	Ontario

Statistical Analysis

Spring and summer temperatures across the Great Lakes Basin were obtained from site visit recordings (see Stations below) from 2006 to 2014, and used to calculate both mean survey temperatures and mean monthly temperature averages across the eight-year study period. Trends from 2006 to 2014 for the months of April to June were linearly regressed at $\alpha = 0.05$ and significant trends were examined for mean monthly and total survey length (April to June/July) temperatures for all fifteen study sites.

The initial calling date (Julian calendar) for each species was linearly regressed ($\alpha = 0.05$) against the average survey temperature for the given study year, as well as the mean monthly temperature for the specific study site. Pearson correlations were used to test the correlation between first calling date to both mean yearly and monthly temperature for each species, at each of the study sites. All statistical analysis was performed with R Statistical Software.

Table 2: Anuran Species listed by both Latin and Common name, with ID codes used by Bird Studies Canada, and type of breeder (early or late in season) listed.

Anuran Species (Latin name/Common name)	ID Code	Type of breeder
Bufo americanus / American toad	AMTO	Early

Rana pipiens / northern leopard frog	NLFR	Early
Pseudacris crucifer / spring peeper	SPPE	Early
Rana catesbeiana / American bullfrog	BULL	Late
Rana clamitans melanota / green frog	GRFR	Late
Hyla versicolor / gray (tetraploid) treefrog	GRTR	Late

Results

Mean survey temperatures across the survey time period (March/April to June/July) did not increase significantly in any of the individual selected routes. There were non-significant increasing trends observed in ten (10) of the selected routes, with the northern route ON 692 approaching significance ($R^2 = 0.343$, DF = 5, p=0.098). For ON 692 an increasing trend of 1.275°C per year was observed. For the ten (10) routes that showed non-significant increasing trends, a mean increase of 0.314°C was observed.

Mean temperatures across the survey time period did decrease significantly in one (1) selected western route, WI 016 ($R^2 = 0.423$, DF = 7, $p = 0.034$). This represents an annual decrease of 0.663°C (Figure 1). There were non-significant decreasing trends observed in four (4) of the selected routes, with the central route ON 343 approaching significance ($R^2 = 0.343$, DF = 5, $p = 0.098$), which represents an annual decrease in temperature of 0.470°C at this route. For the four (4) routes that showed non-significant decreasing trends, a mean decrease of 0.255°C was observed.

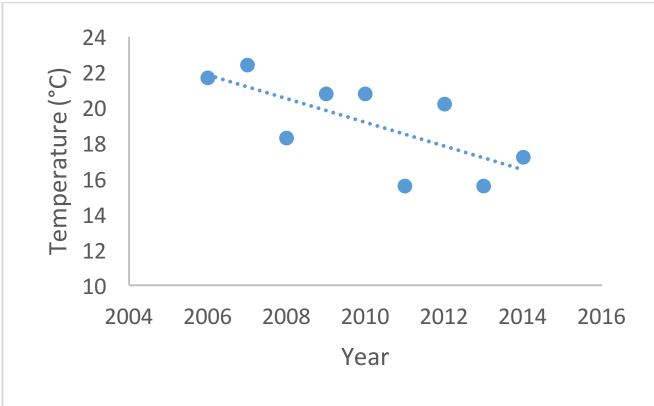

Figure 1: Average survey temperatures for western route WI 016. Average temperature calculated from April to June at location represented by (44.669347, -87.99889). Slope calculated as m=-0.663, representing a temperature decrease of 0.663°C per year surveyed. Linear regression α=0.05, R^2 = 0.423, DF = 7, p = 0.034.

Mean monthly temperatures for April showed a significant increase in one (1) selected route, ON 692 (R^2 = 0.665, DF = 5, p = 0.0157). This represents an average temperature increase in April of 1.821°C from 2006-2014 (Figure 2). Non-significant increases in April temperatures were seen in ten (10) of the selected routes, representing an average April temperature increase of 0.367°C per year.

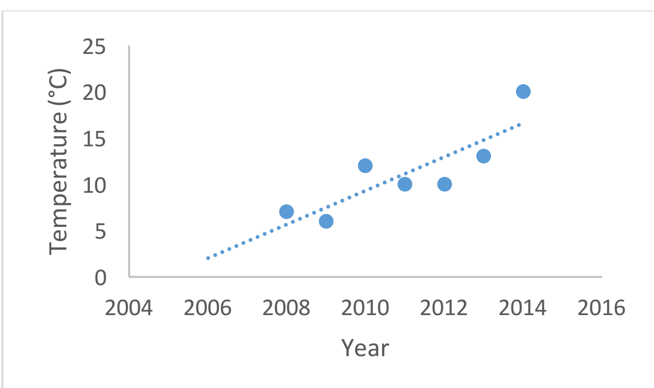

Figure 2: Average April temperatures for northern route ON 692. Average temperature calculated from 2006 – 2014. Slope calculated as m=1.821, representing a temperature increase of 1.821°C per year surveyed. Linear regression α=0.05, R^2 = 0.665, DF = 5, p = 0.0157.

Decreasing trends in April temperatures were seen in four (4) of the selected routes, all of which were non-significant. These routes represent a mean April temperature decrease of 0.318°C per year.

Mean monthly temperatures for May did not show any significant trends for increasing or decreasing temperatures. Non-significant increasing trends were seen for ten (10) of the selected routes, which represents an average increase of 0.291°C per year. Non-significant decreasing trends were seen for five (5) of the selected routes, which represents an average decrease of 0.472°C per year.

Mean monthly temperatures for June showed a significant increase in one (1) selected route, ON 663 (R^2 = 0.650, DF = 6, p = 0.0097). This represents an annual increase in June temperatures of 1.004°C (Figure 3).

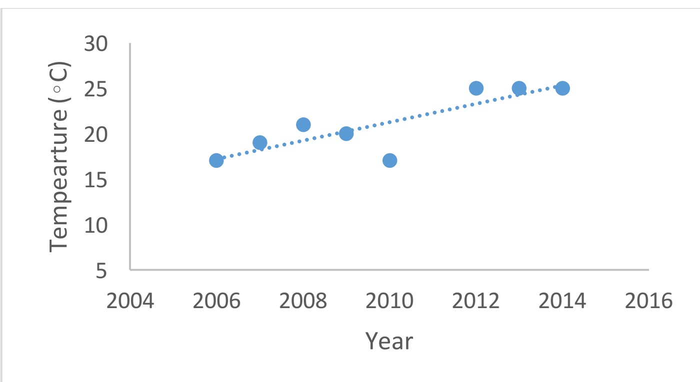

Figure 3: Average June temperatures for eastern route ON 663. Average temperature calculated from 2006 – 2014. Slope calculated as m=1.004, representing a temperature increase of 1.004°C per year surveyed. Linear regression α=0.05, R^2 = 0.650, DF = 6, p = 0.0097.

Non-significant increasing trends were seen in five (5) of the selected routes, which represents a mean annual increase in June temperatures of 0.331°C. Mean monthly temperatures for June did not show any significant decreasing trends, but did show near-significant trends in two (2) of the selected routes; OH 049 (R^2 = 0.293, DF = 7, p = 0.077) and WI 035 (R^2 = 0.293, DF = 7, p =

0.077). In total nine (9) of the selected routes showed non-significant decreases in June temperatures, representing a mean decrease in June temperatures of 0.349°C.

Significant increasing trends in first calling date were seen at three (3) selected routes, ON 343 (R^2 = 0.998, p = 0.0008) and WI 016 (R^2 = 0.584, p = 0.017) both for the American toad, and ON 099 (R^2 = 0.648, p = 0.0330) for the American bullfrog. Near-significant trends were seen in two (2) other selected routes; IN 018 (R^2 = 0.446, p = 0.061) and ON 343 (R^2 = 0.372, p = 0.064) for the American toad and spring peeper, respectively (Figure 4).

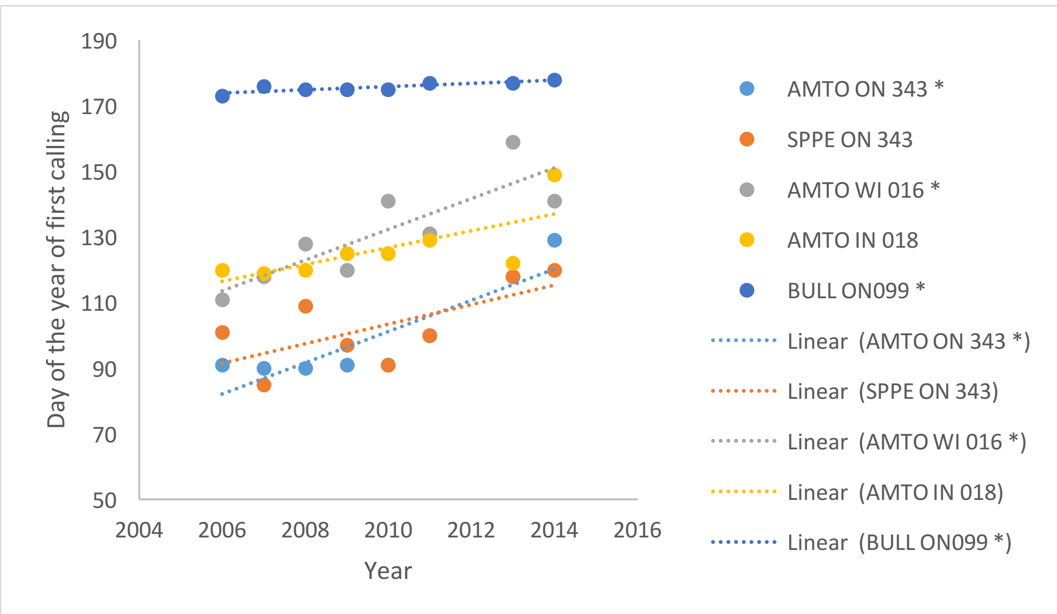

Figure 4: Increasing trends in day of year of first calling for three anuran species detected through calling surveys at stations location throughout the Great Lakes Basin, from 2006 to 2014. The dashed lines represent linear regression trend lines fitted to the average first calling dates for each species across the years studied. The species included are *Bufo americanus* (AMTO), *Pseudacris crucifer* (SPPE) and *Rana catesbeiana* (BULL) and routes ON 343, ON 099, IN 018 and WI 016. * denotes significance

No significant decreasing trends in first calling date were observed in the selected sites, but four (4) near-significant decreasing trends were observed; ON 663 (R^2 = 0.207, p = 0.170) for the American toad, and green frog (R^2 = 0.010, p = 0.212), OH 049 (R^2 = 0.115, p = 0.197) for the spring peeper, and IN 018 (R^2 = 0.176, p = 0.191) for the green frog (Figure 5).

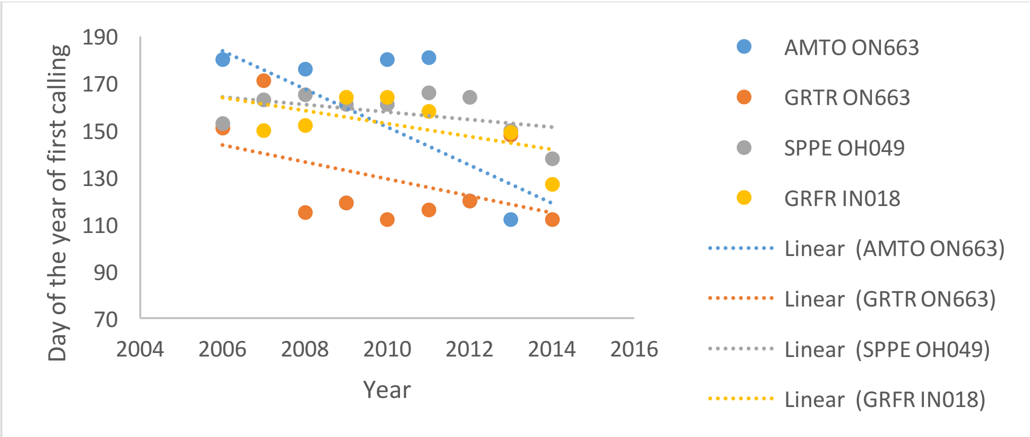

Figure 5: Decreasing trends in day of year of first calling for three anuran species detected through calling surveys at stations location throughout the Great Lakes Basin, from 2006 to 2014. The dashed lines represent linear regression trend lines fitted to the average first calling dates for each species across the years studied. The species included are *Bufo americanus* (AMTO), *Pseudacris crucifer* (SPPE), *Rana catesbeiana* (BULL), and *Rana clamitans melanota* (GRFR) and routes ON 663, IN 018 and OH 049.

Pearson correlations between first calling date and mean survey temperature yielded two (2) significant results for ON 099 (*p*= 0.012, cor = -0.788) for the American toad, and ON 549 (*p*=0.028, cor = 0.721) for the green frog. Four (4) near-significant results were seen for ON 343 (*p*=0.0752, cor=-0.767) and ON 692 (*p* = 0.063, cor = 0.730) both for the green frog, WI 016 (*p* = 0.061, cor = -0.643) for the spring peeper, and WI035 (p = 0.074, cor = 0.621) for the American toad (Table 3).

Table 3: Summary of Pearson Correlation results between anuran species and mean survey temperature. *denotes significance, and a negative Pearson Correlation coefficient represents an inversely proportional correlation.

Route ID	Cardinal Direction	Associated Great Lake	Species common name	p-value	Pearson Correlation
ON 099	Central	Huron	American toad	0.012*	-0.788
ON 549	Central	Ontario	Green frog	0.028*	0.721
ON 343	Central	Ontario	Green frog	0.075	-0.767

ON 692	North	Huron	Green frog	0.063	0.730
WI 016	West	Michigan	Spring pepper	0.061	-0.643
WI 035	West	Michigan	American toad	0.074	0.621

Pearson correlations between anuran species and mean monthly temperature yielded fourteen (14) significant results; six (6) from mean April temperatures, six (6) from mean May temperatures, and two (2) from mean June temperatures, and involving five (5) anuran species; the green frog, American toad, spring peeper, northern leopard frog, and American bullfrog (Table 4).

Table 4: Summary of Pearson Correlation results between anuran species and mean monthly temperatures. *denotes significance, and a negative Pearson Correlation coefficient represents an inversely proportional correlation.

Month	Route ID	Species ID	p-value	Pearson Correlation
April	OH 034	GRFR	0.043*	-0.683
April	OH 034	NLFR	0.036*	0.699
April	ON 549	GRFR	0.012*	0.788
April	ON 692	AMTO	0.023*	0.824
April	ON 692	NLFR	0.033*	0.795
April	ON 692	SPPE	0.033*	0.795
May	OH 034	GRFR	0.050*	0.660
May	ON 050	NLFR	0.021*	0.828
May	ON 050	BULL	0.025*	0.815
May	ON 050	GRFR	0.020*	0.834
May	ON 099	AMTO	0.033*	-0.709
May	WI 035	AMTO	0.046*	0.675
June	ON 549	GRFR	0.006*	0.830
June	ON 757	GRFR	0.023*	0.929

Discussion

Our study illustrates the relationship between the calling of spring breeding anurans and temperature using univariate statistical models. It is understood that a multivariate model would be more appropriate and this is being presently undertaken. We found that significant advancing calling trends were seen in three routes and involved the American toad and American bullfrog. Regressing calling trends were non-significant, but did include the American toad, spring peeper, American bullfrog, green frog, and grey treefrog at different routes. When first calling date was compared with mean monthly temperatures, we observed that April and May temperatures had more of an effect on shifts in first calling than June temperatures. Thus, the early breeding species, spring peeper and American toad, are likely to be more effected by changes in ambient climate, which is consistent with previous findings (Walpole et al. 2012, Gibbs and Breisch 2001; Todd et al. 2010). This suggests that life history characteristics are extremely important in determining whether anurans will be impacted by changing climate (Primack et al. 2009).

Pearson correlations showed that not only do anurans respond to changing climate by moving forward their first calling date, but also by moving it back. In our study both the grey treefrog and American bullfrog showed a negative correlation between first calling date and temperature, meaning that as temperatures increased, calling date regressed. However, the American bullfrog, spring peeper, and green frog all showed a positive correlation between these variables, indicating that when ambient temperatures increased, their first calling dates advanced. This asymmetric response has been seen in previous studies (Walpole et al. 2012, Donnelly and Crump, 1998) and it is suggested that these varying responses could ultimately alter the species composition of affected communities and their ecological processes if the climate continues to warm (Yang and Rudolf, 2010).

According to the climate model CGCM3.1-A2 (Walpole et al, 2012) mean air temperatures are expected to rise by as much as 4°C in the Great Lakes Basin by the year 2100. The results of our study suggest that there will be varying responses by anurans in the basin, with some anurans displaying a regressed first calling date, while others may continue to advance.

Due to these varying responses, the propensity for niche overlaps may increase, altering competitive and reproductive interactions alike (Walpole et.al 2012, Todd et al. 2010, Yang and Rudolf 2010, Winder and Schindler 2004). Asynchronicities between predator/prey systems may develop, along with increased competition for ecosystem resources (Thackeray et al. 2010).

Lastly, we detected shifts in first calling date of anurans over a relatively short period of time (eight years). Similar shifts in first calling date have been seen by Walpole et al. (2012), over a 14-year period, Todd et al. (2010) over a 30-year period, and Gibbs and Breisch (2001) over a 99-year period. Ecologically and evolutionarily, these are minute timescales and so suggest that changes in anuran communities may occur rapidly over a comparatively short period of time. This study also set out to determine if the results obtained from the Walpole et al. 2012 study could be replicated in a wider area of the Great Lakes Basin. Our study shows the same shifts in calling date and asynchronisity of interspecies results as Walpole et al. 2012. However, the full implications of these shifts remain unclear, as our climate continues to change at such a rapid rate.

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