

Lake Simcoe Climate Change Adaptation Strategy: The vulnerabilities of wildlife

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SUMMARY

We used wildlife indicators to assess the ecological conditions of the Lake Simcoe watershed and to identify vulnerabilities within the watershed. We measured avian guild richness, amphibian calling and breeding phenology, mammal species richness, and landscape fragmentation. All avian guilds experienced an increase in richness of species since 1985, with the exception of aerial foragers. The increase in avian richness was heterogeneous across the landscape. Several systems including: Georgina Creeks, Hawkestone Creeks, Oro Creeks South, and Ramara Creeks consistently contained the fewest species of each avian guild and thus may represent vulnerabilities in the watershed. Ultimately, however, we expect overall avian species richness to increase in response to changes in summer and winter temperature and precipitation throughout the next century. Reproduction in amphibians is also likely to be affected by climate change. Anuran calling date was negatively correlated with spring temperatures. The CGCM2-A2 climate model suggests that spring breeding amphibians may call 10 days earlier by 2100, consequently lengthening the breeding period for these species. Mammal species richness is positively related to mean annual temperatures. Thus, we expect that mammal species richness will increase 20% by 2100. We modelled range expansion by Virginia opossum (*Didelphis virginiana*) and demonstrated that its range may fully engulf the Lake Simcoe watershed within the next 30 years. Finally, we quantified landscape fragmentation throughout the watershed and found that Lake Simcoe ranked poorly compared to other measured watersheds in North America. Climate change in the Lake Simcoe watershed will likely be characterized by shifts in animal distributions and changes in reproductive phenology. The fragmented nature of the watershed, however, may impede distribution shifts and thus hinder the ability of species to respond to a changing climate.

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INTRODUCTION

Ecological integrity refers to the ability of an ecosystem to maintain a functional and adaptive community of organisms at a state comparable to historical conditions or to other similar ecosystems that have not been degraded by human activities (Carignan and Villard 2002, but see Stoddard et al. 2006). Vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, adverse effects of environmental change, including climate variability and extremes (IPCC 2007). It follows then, that vulnerabilities in a system are areas with poor ecological integrity that are incapable of maintaining natural processes under the influence of environmental change.

There are practical difficulties in measuring ecological integrity of wildlife, so we have taken the approach of measuring contemporary ecological condition, and then carrying out scenarios of future departures from these contemporary conditions to assess wildlife vulnerabilities. Thus, we have identified indicators of wildlife richness and ecological processes in the Lake Simcoe watershed. We assessed how these measures would respond to future climate change scenarios according to projections from the Coupled Global Climate Model (CGCM2) under emissions scenario A2 (Canadian Climate Change Scenarios Network [2010]). Four wildlife indicators were selected including: avian guild richness, anuran calling and breeding phenology, mammal species richness, and landscape fragmentation. These measures were chosen because they describe local biodiversity, community and range boundary dynamics, population size and landscape connectivity, all of which are potentially susceptible to human land-use practices and climate change. Thus, understanding the potential for changes in these measures will reveal vulnerabilities in the Lake Simcoe watershed.

METHODS

Avian guild richness

We assumed that subwatersheds with low avian guild richness reflected poor ecological conditions (and therefore vulnerabilities) whereas subwatersheds with high avian guild richness had relatively good ecological conditions. We selected species from four functional guilds to assess the integrity of the Lake Simcoe ecosystem including: forest interior species, cavity nesting species, aerial foraging species, and wetland obligate species based on Ontario Breeding Bird Atlas surveys conducted in 1981-85 and 2001-05 (Bird Studies Canada; www.bsc-eoc.org). Further, we examined shifts in the occurrence of species detected between the two surveys to qualitatively explore patterns and shifts in species composition. Finally, we discuss how future climate change may alter avian guild richness based on species-energy relationships (Currie 2001, Evans et al. 2005).

Anuran calling and breeding phenology

Amphibian populations are experiencing global declines in response to a variety of factors including habitat destruction and alteration, disease, invasive species, environmental contaminants, high levels of ultraviolet irradiation, and global environmental change (Wake 1991). Research has demonstrated that several common North American species have begun calling earlier in a fashion consistent with observed increases in spring temperatures over the past century (Gibbs et al. 2001). We explored

temporal trends in calling behaviour of seven common anuran species (Table 1) in the Lake Simcoe region between 1995 and 2008 (Amphibian marsh monitoring program data; Bird Studies Canada, www.bsc-eoc.org) in relation to current climate to understand the effects of changing climate on reproductive phenology. Based on contemporary relationships between calling behaviour (peak calling date) and climate variables (average spring temperatures), we made predictions of future climate change impacts on the breeding behaviour of wood frog populations in the region based on the regression model, Peak calling date = $155.9819 - 2.1052 \times (\text{mean April temperature in } ^\circ\text{C})$ derived from relationship between calling and temperature from 1995 to 2008.

Mammal species richness

Species at their northern range boundary that are limited by climate are poised to benefit from a changing climate due to changes in the quality of their habitat from increasing annual temperatures (Myers et al. 2009). Populations at their southern range edge, however, are more likely to contract their range due to pressure from their southern counterparts (MacArthur 1972). Several species have already demonstrated significant northerly shifts in distributions in response to climate change (Brocke 1970, Bowman et al. 2005, Moritz et al. 2008).

Mean annual temperature has shown to be a strong predictor of regional mammal species richness in Canada (Kerr and Packer 1998). We assessed potential changes in mammal species richness in the Lake Simcoe watershed to the year 2100 based on current temperature and future mean annual temperature according to the CGCM2-A2 climate scenario. We forecasted mammal species richness based on the species – energy model developed by Kerr and Packer (1998):

$$\text{Mammal species richness} = 1.960 \times (\text{Mean annual temperature in } ^\circ\text{C}) + 38.1 + \varepsilon,$$

where temperature is recorded in Celsius and ε is the residual variance. Finally, as an instructive example of changing mammal richness, we used climate envelope modeling to explore the range expansion of the Virginia opossum (*Didelphis virginiana*) in northeastern North America (Wiseman & Hendrickson 1950, Brocke 1970, Tyndale-Biscoe 1976).

Landscape fragmentation

Landscape fragmentation results in smaller and more isolated habitat patches and consequently smaller and more isolated populations of wildlife that suffer an increased risk of localized extinction (Fahrig 2002). Species occupying fragmented landscapes will be less able to shift their distributions to compensate for altered habitat quality resulting from changing climatic conditions. Thus, there is a synergy between climate change and habitat fragmentation that may lead to a deficit in biodiversity compared to what is predicted by energy models (Varrin et al. 2007). We quantified fragmentation based on natural and anthropogenic land cover types aggregated from the Southern Ontario Land Resource and Information System (SOLRIS; Ontario Ministry of Natural Resources 2002) database to identify highly fragmented subwatersheds and thus vulnerabilities for wildlife populations in the Lake Simcoe watershed. We measured landscape fragmentation with effective mesh size (Jaeger 2000) to identify subwatersheds

vulnerable to climate change. Effective mesh size is a metric of fragmentation that can be interpreted generally as the average size of the habitat patch in the watershed (km^2) or the probability that two random animals will occur in the same patch of habitat and therefore be connected (Table 1). This metric is an appropriate means of assessing how the structural landscape will affect wildlife populations and thus identifies which systems would be more vulnerable to climate change.

RESULTS

Avian guild richness

Our results suggest that all avian guilds have experienced an increase in species richness since 1985 with the exception of the aerial foragers. We detected no relationship between guild richness and our measures of fragmentation or the size of the watershed (km^2 ; all $r < 0.19$, $n = 23$, $p > 0.35$). The Georgina Creeks, Hawkestone Creeks, Oro Creeks South, and Ramara Creeks subwatersheds consistently ranked the lowest for species richness in each of the four guilds (Table 1). Conversely, Innisfill Creeks, Upper Talbot River and Hewitts Creeks ranked among the highest for species richness in each guild (Table 1). A paucity of species from representative guilds suggests a degradation of the characteristics of habitat supporting that guild in the system. For example, few interior forest bird species in the Georgina Creeks subwatershed suggests that forest cover in that system lacks a suitable interior forest habitat necessary to sustain a relatively healthy assemblage of interior forest species. Systems with low guild species richness reflect poor ecological conditions sustaining the guild and likely a reduced ability of the system to cope with changing environmental conditions. Thus we expect that low guild richness identifies vulnerabilities in the watershed.

Several species at the northern extent of their geographic distributions are newly occurring or have expanded their range in the watershed since 1985. For the recently occurring hooded warblers (*Wilsonia citrina*; Melles et al. 2010), blue-winged warblers (*Vermivora cyanoptera*; Dabrowski et al. 2005), and Acadian flycatchers (*Empidonax virescens*; Emlen et al. 1986), their expansion into the watershed is likely attributable to changing climatic conditions.

Anuran calling and breeding phenology

Since 1995, spring breeding frogs and toads have begun calling earlier in the year (Figure 1). Nearly all species demonstrated a negative trend in peak calling date between 1995 and 2008 (Table 2). Regression slopes (coefficients) were positively related to the intercept (Figure 2), suggesting that early breeders are experiencing a stronger decline in peak calling dates than late breeding species.

Trends in anuran calling are consistent with an observed significant increase in spring temperatures since 1995. Spring temperatures in April and fall temperatures in November have increased ($r=0.56$, $n=11$, $p=0.039$ and $r=0.64$, $n=11$, $p=0.025$, respectively) and mid-summer July temperatures show a strong increasing trend in temperature ($r=0.60$, $n=11$, $p=0.050$).

We detected significant negative correlations between the peak calling date of early breeding anurans and mean monthly temperatures in March (SPPE: $r=-0.64$, $p=0.034$; GRTR: -0.62 , $p=0.044$), April (AMTO: $r=-0.65$, $p=0.032$; SPPE: $r=-0.61$, $p=0.048$; WOFR: -0.72 , $p=0.012$), and May (AMTO: $r=-0.66$, $p=0.027$). All other

species (except BULL) demonstrated negative but non-significant correlations between peak calling and mean monthly temperatures for February through May across the years examined (1995-2008). Based on these relationships, CGCM2-A2 suggests that peak calling date for wood frog (*Rana sylvatica*) in the Lake Simcoe watershed will occur approximately 10 days earlier by the year 2100.

Mammal Richness

Species-energy relationships predict that mammal species richness will increase 20% by the year 2100 in a linear response to changes in annual temperature according to CGCM2-A2. Current climate conditions support a richness of >50 species with consecutive increases of 3-4 species between each scenario (2011-40, 2041-2070, and 2071-2100) and up to a richness of 60 species by 2100 (Figure 3).

Virginia opossums currently range slightly south of the Lake Simcoe watershed. The species' northern range boundary has been found to coincide with the -7°C mean January isotherm (South America; Tyndale-Biscoe 1976) and it is seldom active at temperatures less than -7°C, not active below -12°C (Iowa; Wiseman & Hendrickson 1950) and it was found to not leave the den at temperatures less than -15°C. In Southern Ontario, the -12°C January minimum temperature isotherm (averaged from 1970-1993) coincides with their northern range boundary (1970-1993; Ontario Atlas of Mammals). Thus, we used the -12°C minimum January isotherm from the CGCM2-A2 climate model to assess potential future northern range boundaries of opossums in Ontario during 2011-2040, 2041-2070, and 2071-2100. The range of opossums will fully encompass the Lake Simcoe watershed by the 2011-2040 scenario (Figure 4). The distribution of other species, such as the Common grey fox (*Urocyon cinereoargenteus*) and eastern fox squirrel (*Sciurus niger*) have expanded substantially (Fritzell and Haroldson 1982 and De Vos 1964, respectively). The northern range boundary of these species currently reaches southern Ontario and is suspected to be limited by climate (Judge and Haviernick 2002, Moncrief et al. 2010) making those likely candidates for future expansion into the Lake Simcoe watershed.

Landscape Fragmentation

Based on our calculations of effective mesh size, the probability that two random animals will occur in the same habitat patch for the entire Lake Simcoe watershed is 0.11 (excluding islands). The Upper Talbot River, Hawkestone Creek, and Black River systems are the most well connected systems in the watershed (Table 1). The most fragmented systems include the Barrie Creeks, Hewitts Creek, Maskinonge River, West Holland, and Beaver River systems which represent the highest vulnerabilities in the watershed since wildlife populations inhabiting these systems would be comparatively small and isolated (Table 1).

DISCUSSION

Mean annual temperatures in the Lake Simcoe watershed are expected to rise 4.6 °C by 2100. This drastic change will ripple through the ecosystem with consequent changes to wildlife populations. We expect three of the four wildlife indicators we measured to be influenced by climate change. Rises in temperatures in the Lake Simcoe watershed are expected to lead to an increase in bird (Currie 2001, Evans et al. 2005) and

mammal (Kerr and Packer 1998) species richness (Figure 3) and accelerated reproduction in spring breeding anurans of as much as 10 days by 2100.

Increased richness of bird and mammal species is likely to be characterized by a shift in composition as species expand into and others recede out of the watershed (Myers et al. 2009). Since many of the species subject to these range shifts are commonly occurring and abundant, the impacts of a community shift on local systems has the potential to be substantial and complex as these changes will affect all trophic levels (Myers et al. 2009). Shifting ranges make local populations vulnerable to introduced pathogens, invasive species, or interspecific hybridization (Bowman et al. 2005, Brook et al. 2008, Garroway et al. 2010), and ultimately can cause rarity or extinction of northern species. Already, we are observing northerly range expansions of southern birds and mammals into the watershed in response to climate change (Brocke 1970, Myers et al. 2009, Melles et al. 2010). These trends in bird and mammal richness point to two related processes leading to wildlife vulnerabilities in the Lake Simcoe watershed: introduction of southern competitors and pathogens, and increased extinction risk of northern, cold-adapted species (Table 3).

Landscape fragmentation will play a major role in the ability of these organisms to continue shifting their distributions in response to changing climates. We measured landscape fragmentation with effective mesh size and found that suitable habitat in the Lake Simcoe watershed was more fragmented than other measured watersheds in North American (Girvetz et al. 2008). Fragmented landscapes are less permeable to animal dispersal and may even act as barriers to movement. Disrupted dispersal resulting from fragmentation in the Lake Simcoe watershed may lead to a deficit in biodiversity compared to what is predicted by species – energy models (Varrin et al. 2007). Thus, habitat fragmentation may result in selection for species with good dispersal ability in fragmented landscapes and against species with poor dispersal ability (Table 3). To augment the resilience of all wildlife populations to the impacts of fragmentation under projected climate changes, land managers should attempt to increase landscape connectivity in the Lake Simcoe basin by promoting establishment of natural cover, with a focus on highly fragmented subwatersheds (Table 1).

Early breeding anurans have begun calling and thus breeding earlier in the year in response to a warming climate (Figure 1). Increased temperatures predicted by climate models are expected to accelerate reproduction in spring breeding anurans, ultimately lengthening their breeding season. Although these projections may ignore other factors such as environmental pollutants, ultra-violet radiation, non-native invasive species, habitat destruction, and disease (Blaustein et al. 2004), temperature appears to be a major factor influencing amphibian populations. Continued monitoring of amphibians is necessary to understand how populations will respond to these multiple and possibly interacting factors. Trends in spring calling by amphibians point to two key processes leading to system vulnerabilities (Table 3). Early breeders may have a selective advantage over late breeders, which demonstrates the asymmetric effects of rapid climate change on timing of breeding. Any change in breeding dates would have to be matched however, by a change in the availability of food (e.g., insects), which demonstrates the potential for climate change to create asynchronies in ecological systems.

Finally, caution should be used when interpreting the response of indicators to anthropogenic land-use and disturbance because other factors may contribute to the

observed patterns of the wildlife indicators. We have presented a starting point that will require further monitoring and investigation to identify potential confounding and unaccounted factors that might also influence the state of the wildlife indicators (Carignan and Villard 2002).

RECOMMENDATIONS

We noticed that several subwatersheds sustain relatively few species of aerial foragers compared to elsewhere in the Lake Simcoe system. The guild of aerial foragers has undergone drastic population declines and range contractions throughout North America (Nebel et al. 2010). Declines in populations of flying insects are the primary suspected causes of declines observed in aerial foraging birds. Currently, however, there is no program in place for monitoring population trends of flying insects in Ontario. Importantly, several studies have demonstrated that insects are sensitive to changes in temperature (Bale et al. 2002, Reynolds et al. 2007, Richter et al. 2008). Fluctuations in insect abundance may have significant impacts on organisms that depend on them for food and the plants that depend on them for pollination (Memmott et al. 2007). Therefore, we recommend the implementation of a monitoring program to develop a better understanding of flying insect population trends in the Lake Simcoe watershed.

Our research noted a scarcity of spatial and temporal information on reptile occurrence, abundance and reproduction in Ontario. Reptiles may be particularly susceptible to the impacts of climate change because temperature dictates the sex ratio of offspring. Indeed, the development of painted turtle (*Chrysemys picta*) offspring was found to respond to moderate fluctuations in July temperatures (less than 2°C) and an increase of 4°C would virtually halt development of male offspring (Janzen 1994). Thus, reptiles with temperature-dependent sex determination are ideal candidates as indicators of climate change. We recommend the development of a standard sampling protocol for reporting the occurrence, demography and population trends of reptiles in the watershed.

More frequent and higher resolution sampling for mammalian species is also required in the watershed. Currently, we are aware of no database that sufficiently documents the occurrence or absence of all mammalian species potentially occurring within the Lake Simcoe watershed. These data should be collected repeatedly over time (e.g., every 5 or 10 years) with similar techniques and cover the extent of the watershed to permit a comprehensive analysis of the impacts of climate change or land-use on the mammalian community. Finally, other climatic factors such as snow depth, and annual duration of snow cover, are known to influence the distribution of wildlife in the landscape (Hansson 2002) and should be incorporated into projections of future climate.

In summary, we detected gaps in information on population trends of flying insects, reptiles and mammals in the Lake Simcoe region and thus we recommend the development of monitoring programs for these taxa. While our models generally predict increases in species richness, the highly fragmented state of natural cover in the watershed may interfere with population level processes and thus threaten species persistence under current prediction of future climate change. Thus, we recommend an initiative to increase landscape connectivity and the amount of natural cover in the region, with a particular focus on highly fragmented subwatersheds.

REFERENCES

Bale, J.S., G.J. Masters, I.D. Hodgkinson, C. Awmack, T.M. Bezemer, V.K. Brown, J. Butterfield, A. Buse, J.C. Coulson, J. Farrar, J.E.G. Good, R. Harrington, S. Hartley, T.H. Jones, R.L. Lindroth, M.C. Press, I. Symrnioudis, A.D. Watt, and J.B. Whittaker. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology* 8: 1-16.

Bishop, J.A. and W.L. Myers. 2005. Associations between avian functional guild response and regional landscape properties for conservation planning. *Ecological Indicators* 5: 33-48.

Blaustein, A.R. and J.M. Kiesecker. 2002. Complexity in conservation: lessons from the global decline of amphibian populations. *Ecology Letters* 5: 597-608.

Bowman, J. G.L. Holloway, J.R. Malcom, K.R. Middel, and P.J. Wilson. 2005. Northern range boundary dynamics of southern flying squirrels: evidence of an energetic bottleneck. *Canadian Journal of Zoology* 83: 1486-1494.

Brocke, R. H. 1970. The winter ecology and bioenergetics of the opossum, *Didelphis marsupialis*, as distributional factors in Michigan. Ph.D. Thesis. Michigan State University.

Brook, B.W., N.S. Sodhi, and C.J.A. Bradshaw. 2008. Synergies among extinction drivers under global change. *Trends in Ecology and Evolution* 23: 453-460.

Carignan, V. and M. Villard 2002. Selecting indicator species to monitor ecological integrity: a review. *Environmental Monitoring and Assessment* 78: 45-61.

Currie, D.J. 2001. Projected effects of climate change on patterns of vertebrate and tree species richness in the conterminous United States. *Ecosystems* 4: 216-225.

Dabrowski, A., R. Fraser, J.L. Confer, and I.J. Lovette. 2005. Geographic variability in mitochondrial introgression among hybridizing populations of Golden-winged (*Vermivora chrysoptera*) and Blue-winged (*V. pinus*) Warblers. *Conservation Genetics* 6: 843-853.

de Vos, A. 1964. Range changes of mammals in the Great Lakes Region. *American Midland Naturalist* 71: 210-231.

Emlen, J.T., M.J. DeJong, M.J. Jaeger, T.C. Moermond, K.A. Rusterholz, and R.P. White. 1986. Density trends and range boundary constraints of forest birds along a latitudinal gradient. *The Auk* 103: 791-803.

Evans, K.L., Greenwood, J.J.D., and Gaston, K.J. 2005. Dissecting the species-energy relationship. *Proceedings of the Royal Society, B* 272:2155-2163.

- Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: a synthesis. *Ecological Applications* 12: 346-353.
- Fritzell, E.K. and K.J. Haroldson 1982. *Urocyon cinereoargenteus*. *Mammalian Species* 189: 1-8.
- Garroway, C. J., J. Bowman, G. L. Holloway, C. G. Mahan, J. R. Malcolm, T. J. Cascaden, M. A. Steele, G. Turner, and P. J. Wilson. 2010. Climate change induced hybridization in flying squirrels. *Global Change Biology* 16: 113-121.
- Gibbs, J.P. and Breisch, A.R. 2001. Climate warming and calling phenology of frogs near Ithaca, New York, 1900-1999. *Conservation Biology* 15: 1175-1178.
- Girvetz, E.H., J.H. Thorne, A.M. Berry, J.A.G. Jaeger. 2008. Integration of landscape fragmentation analysis into regional planning: a statewide multi-scale case study from California, USA. *Landscape and Urban Planning* 86:205-218.
- Hansson, L. 2002. Dynamics and trophic interactions of small rodents: landscape or regional effects on spatial variation? *Oecologia* 130: 259-266.
- IPCC. 2007. Fourth Assessment Report, Working Group 2: Impacts, Adaptation and Vulnerability, Geneva, Switzerland.
- Jaeger, J. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* 15: 115-130.
- Jaeger, J., Bertiller, and R., Schwick, C. 2007. Degree of landscape fragmentation in Switzerland: quantitative analysis 1885–2002 and implications for traffic planning and regional planning. Condensed version. Federal Statistical Office, Neuchâtel, 36 pages.
- Janzen, F.J. 1994. Climate change and temperature-dependent sex determination in reptiles. *Proceedings of the National Academy of Sciences* 91:7487-7490.
- Judge, K.A. and M. Haviernick. 2002. Update COSEWIC status report on the grey fox *Urocyon cinereoargenteus* in Canada, in COSEWIC assessment and update status report on the grey fox *Urocyon cinereoargenteus* interior in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-32 pp.
- Kerr, J. and Packer, L. 1998. The impact of climate change on mammal diversity in Canada. *Environmental Monitoring and Assessment* 49: 263-270.
- MacArthur, R.H. 1972. *Geographical ecology: patterns in the distribution of species*. Harper and Row, New York.
- Melles, S.J., M.-J. Fortin, K. Lindsay, and D. Badzinski. 2010. Expanding northward: influence of climate change forest connectivity, and population processes on a threatened species' range shift. *Global Change Biology*. In press.

- Memmott, J., P.J. Graze, N.M. Waser, and M.V. Price. 2007. Global warming and the disruption of plant – pollinator interactions. *Ecology Letters* 10: 710-717.
- Moncrief, N.D., J.B. Lack, and R.A. Van Den Bussche. 2010. Eastern fox squirrel (*Sciurus niger*) lacks phylogeographic structure: recent range expansion and phenotypic differentiation. *Journal of Mammalogy* 91: 112-1123.
- Myers, P., B.L. Lundrigan, S.M.G. Hoffman, A.P.Haraminac, and S.H. Seto. 2009. Climate-induced changes in the small mammal communities of the Northern Great Lakes Region. *Global Change Biology* 15: 1434-1445.
- Nebel, S., A. Mills, J.D. McCracken, P.D. Taylor. 2010. Declines of aerial insectivores in North America follow a geographic gradient. *Avian Conservation and Ecology* 5(2): 1-14.
- Reynolds, L.V., M.P. Ayres, T.G. Siccama, and R.T. Holmes. 2007. Climate effects on caterpillar fluctuations in northern hardwood forests. *Canadian Journal of Forest Research* 37: 481-491.
- Richter, O., F. Suhling, O. Muller, and D. Kern. 2008. A model for predicting the emergence of dragonflies in a changing climate. *Freshwater Biology* 53:1868-1880.
- Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting expectations for the ecological condition of streams: the concept of a reference condition. *Ecological Applications* 16: 1267-1276.
- Tyndale-Biscoe, C.H. and R.B. MacKenzie. 1976. Reproduction in *Didelphis marsupialis* and *D. albiventris* in Columbia. *Journal of Mammalogy* 57: 249-265.
- Varrin, R., J. Bowman, and P.A. Gray. 2007. The known and potential effects of climate change on biodiversity in Ontario's Terrestrial ecosystems: Case studies and recommendations for adaptation. Ontario Ministry of Natural Resources, Applied Research and Development Section, Sault Ste. Marie, Ontario. Climate Change Research Report CCRR-09. 47 p.
- Wake, D.B. 1991. Declining amphibian populations. *Science* 253: 860.
- Wiseman, G.L. and G.O. Hendrickson. 1950. Notes on the life history and ecology of the opossum in southeast Iowa. *Journal of Mammalogy* 31(3): 331-337.

Table 1. Land cover characteristics and estimated richness of species in each guild group in subwatersheds constituting the Lake Simcoe watershed. Richness estimates are based on area weighted averages in each subwatershed from Ontario Breeding Bird Atlas squares (10 km x 10 km). Effective mesh size represents the average size of meshed habitat patches (km²) and the probability that two patches in the subwatershed will be connected.

Subwatershed	Forest Interior	Aerial Forager	Cavity Nester	Wetland Obligates	Subwatershed Area (km²)	Effective mesh size (km²)	Effective mesh size (probability)
Pefferlaw Brook	48.3	22.0	29.2	12.1	446.2	67.92	0.15
Black River	67.4	31.1	42.3	22.7	375.4	75.76	0.2
West Holland	46.6	25.2	29.4	17.6	351.9	22.1	0.06
Beaver River	21.4	18.8	17.1	15.8	327.3	24.28	0.07
Upper Talbot River	62.6	43.2	39.8	29.6	294.0	71.99	0.24
East Holland	40.8	25.9	36.3	19.0	247.1	19.04	0.08
Ramara Creeks	22.3	14.8	14.5	11.0	137.2	14.12	0.1
Innisfil Creeks	56.6	31.6	42.9	34.5	107.2	8.88	0.08
Whites Creek	31.4	23.1	20.2	12.2	105.4	9.09	0.09
Oro Creeks North	37.9	16.9	21.0	12.7	75.3	10.94	0.15
Upper Talbot River	32.5	26.0	21.1	20.9	70.2	6.4	0.09
Maskinonge River	20.5	17.6	16.6	9.9	63.5	2.24	0.04
Lovers Creek	52.2	35.0	38.7	18.3	59.9	4.86	0.08
Oro Creeks South	22.6	14.0	19.7	4.3	57.4	8.82	0.15
Georgina Creeks	17.9	14.7	20.4	6.4	49.3	6.45	0.13
Hawkestone Creek	36.2	15.8	19.1	7.9	47.8	10.67	0.22
Barrie Creeks	51.9	33.9	43.8	23.9	37.5	0.75	0.02
Hewitts Creek	54.9	28.0	41.4	25.2	17.5	0.61	0.03

Table 2. Linear regression results of changes in peak calling dates of Anurans in the Lake Simcoe region over time (1995-2008).

Common name	Species Code	Intercept	Coefficient	SE of slope	t-statistic	p-value	-95% CI	+95% CI
Green Frog	GRFR	199.94	-0.18	0.36	-0.49	0.630	-0.96	0.60
Bull Frog	BULL	198.97	0.46	1.08	0.42	0.678	-1.89	2.81
Gray Tree Frog	GRTR	193.19	-0.28	0.29	-0.95	0.359	-0.91	0.36
American Toad	AMTO	176.82	-0.27	0.29	-0.95	0.360	-0.90	0.35
Northern Leopard Frog	NLFR	169.72	-0.69	0.61	-1.13	0.279	-2.01	0.63
Spring Peeper	SPPE	164.64	-0.52	0.37	-1.40	0.187	-1.33	0.29
Wood Frog	WOFR	152.87	-1.18	0.28	-4.22	0.002	-1.80	-0.57

Table 3. Some processes leading to wildlife vulnerabilities to climate change in the Lake Simcoe watershed.

Process
Introduction of southern competitors and pathogens
Increased extinction risk of cold-adapted species
Increased interspecific hybridization
Selection for species able to rapidly move through fragmented landscapes
Selection for early breeding
Selection for high genetic variability for fitness related traits
Enhanced asynchrony in ecological systems

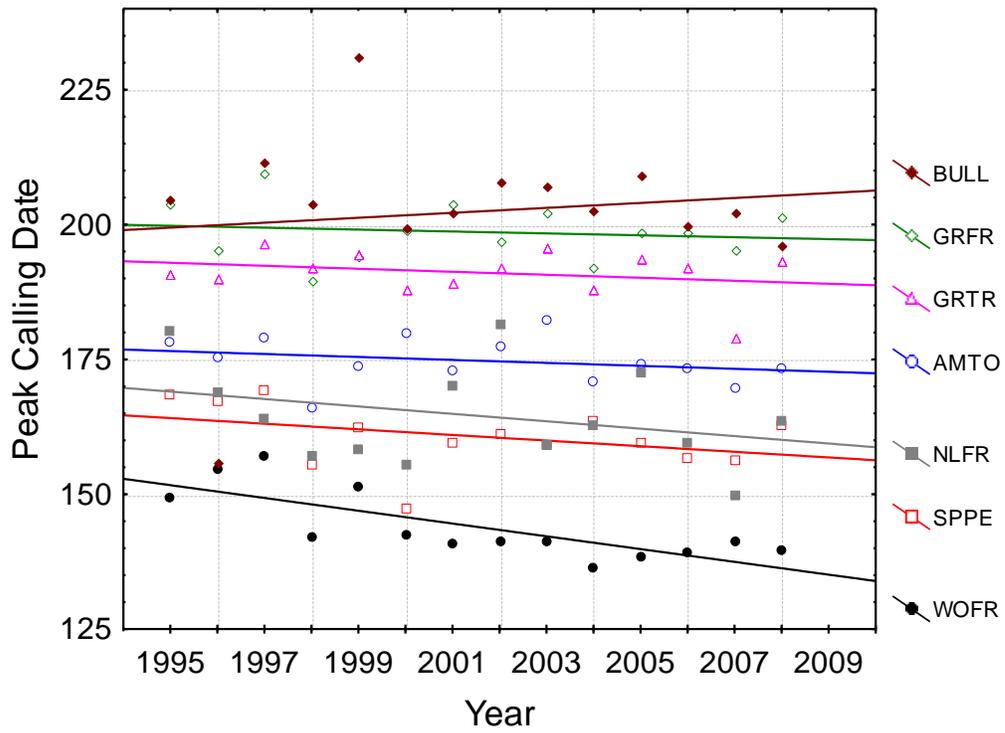


Figure 1. Trends in peak calling date for seven anurans occurring in the Lake Simcoe watershed between 1995 and 2008.

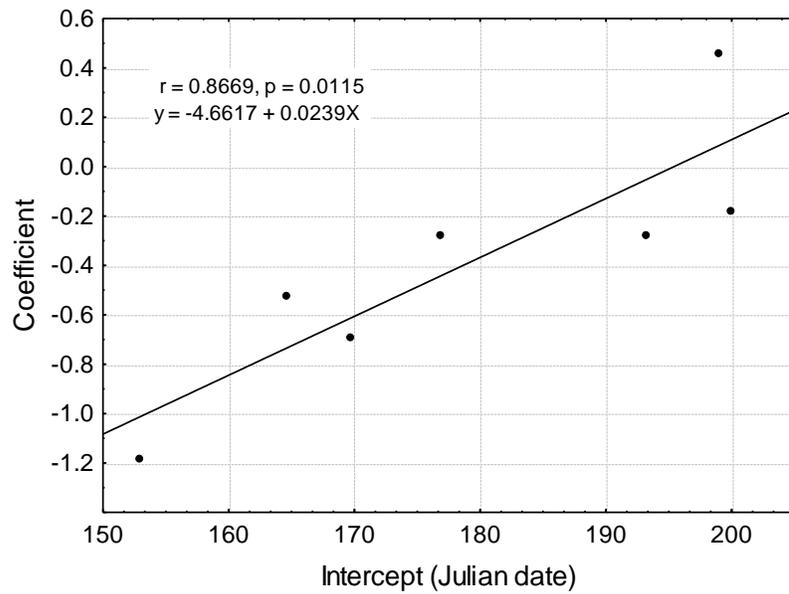


Figure 2. Relationship between traditional breeding Julian date (pre-1995) for each species and the magnitude of their shift in peak calling date over time. Greater coefficients indicated greater slope of response to increasing year (1995-2008).

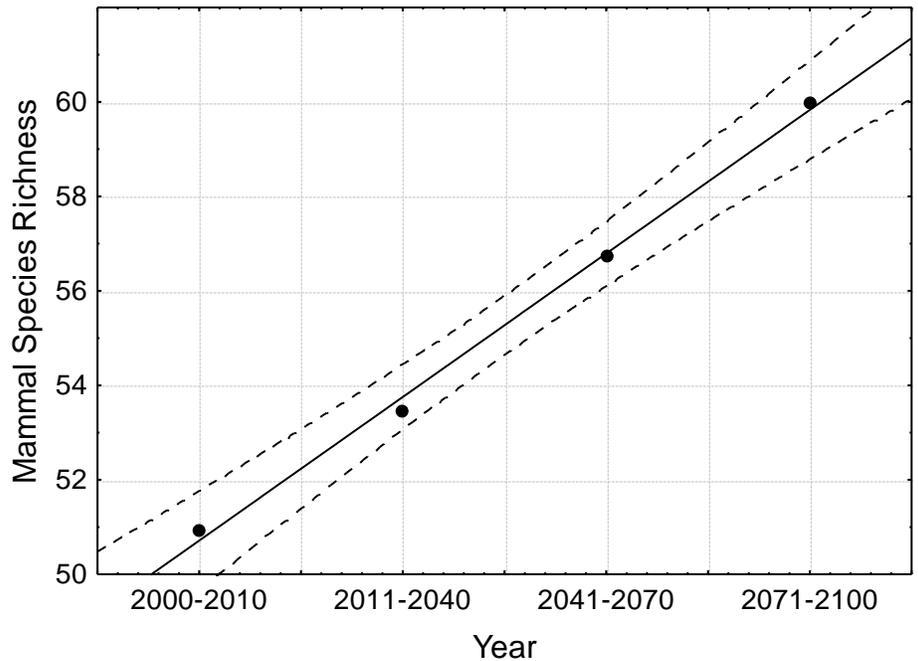


Figure 3. Projected changes in mammal species richness in the Lake Simcoe watershed in response to changing temperatures predicted by the Coupled Global Climate Model 2, Emissions Scenario A1. Mammal species richness response to temperature is based on a mammalian species-energy model (Kerr and Packer 1998).

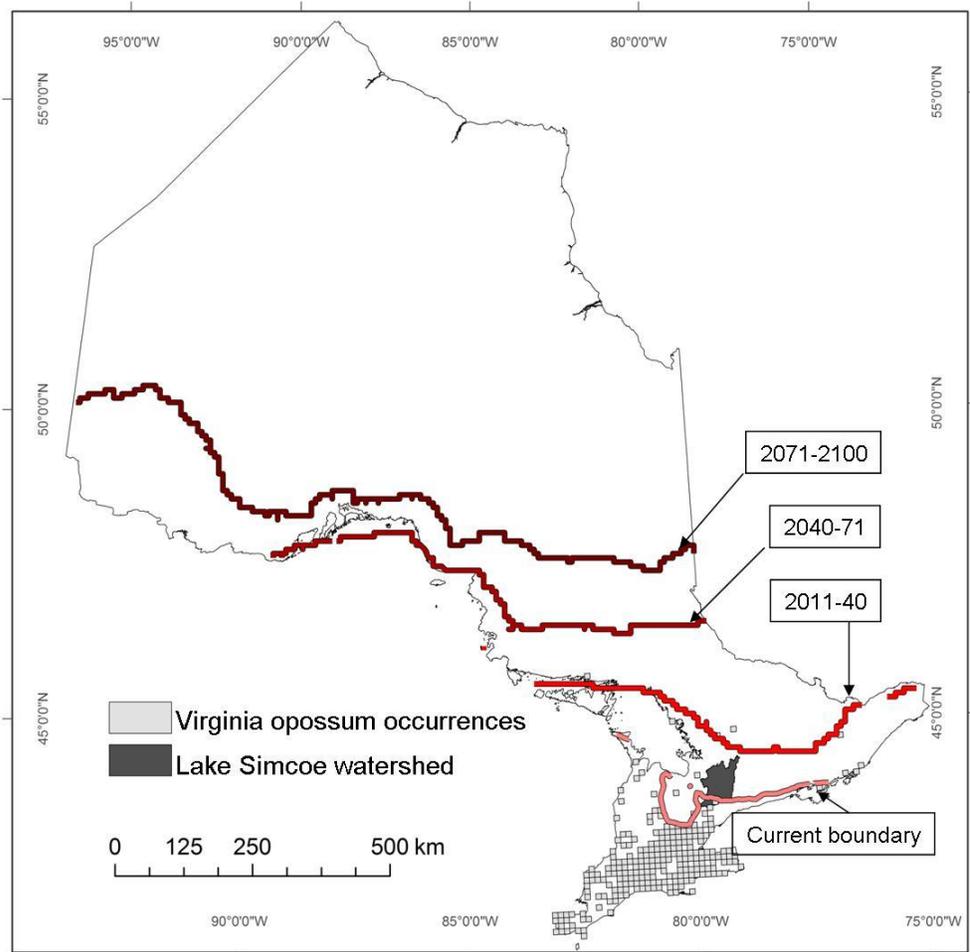


Figure 4. Future projections of the Virginia opossum northern range boundary in Ontario according to the -12°C mean minimum January isotherms for current and future climate scenarios predicted by climate models, CGCM2-A2. Virginia opossum occurrences area based on the 1970-1993 Ontario Atlas of Mammals data (OMNR).