Lake Simcoe Watershed Climate Change Vulnerability Assessment – Ecosystems

The potential of insects for tracking changes in biodiversity in response to changing climate in the Lake Simcoe Watershed, Ontario, Canada

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Introduction

Insects and other arthropods are a potentially useful taxa for examining the direct and indirect effects of changes in climate over time. Unlike many other taxa, insects exist over a wide range of temporal and spatial scales. Insect populations can respond rapidly, allowing researchers to identify study foci from ongoing monitoring. In plain words, insects live short lives, are everywhere, and respond quickly to subtle changes in habitat. This quick response makes insects particularly suitable as candidate species for monitoring changing environments. In addition, monitoring insect populations is generally inexpensive, and often requires a minimal investment in equipment and training. For these reasons, insects are potentially an important source of sentinel information for climatic effects on other higher order taxa.

Insects are poikilotherms, consequently their life history parameters are directly linked to temperature (Figs. 1 and 2) (Beresford and Sutcliffe 2009a, Allen 1976, Baskerville and Emin 1969). Insects have optimal temperatures for maximal survival and population growth, a variety of different life history responses to sub-optimal temperatures, and temperature minima and maxima beyond which insects either enter developmental stasis or die. Because of this, insect populations, physiological growth, and other life history parameters are measured in accumulated degree days above (and below) developmental temperature thresholds, symbolized as $ADD_{\text{lower threshold}}$, and commonly standardized against 0, 5 or 10 ^{o}C thresholds (Pruess 1983). This direct linkage between growth and temperature makes insects and other arthropods powerful tools for assessing climatic effects on a region's habitat and diversity.

Major sectors affect by changes in climate include ecologically sensitive regions, and economically important habitats, e.g. agricultural land. Expected effects of a changing climate are increased numbers of extant species, the appearance of new species in northern areas, more common appearance of species that are presently only seen after mild winters, and the disappearance of poor competitors that specialize in northern habitat with short growing seasons.

Pest species

An important indirect effect of a warming trend concerns late season agricultural pests. These currently require pesticide applications to control their numbers after reaching economic injury levels, usually in mid summer after populations increase over several generations. Under warming temperatures such pests may require spraying earlier in the summer, adding an additional burden of increased pesticide to the environment. It is not known what impact this might have on non-target organisms, but it could be significant.

Objectives

This assessment begins the process of describing the potential of insects as a sentinel group for monitoring climatic effects both ecological and economically important habitats within the Lake Simcoe Watershed. The objectives of this report are to:

1. identify several species that are ecologically and economically important, and are easy to monitor.
2. identify criteria for choosing what groups or species to monitor for various habitats
3. identify strategies needed for long term research
4. categorize different population level responses to changes in climates
5. develop hypotheses and subsequent predictions for distinguishing between changes in climate from regional or "normal" local climatic variability.

Methods and Materials

Projected changes were determined from the Canadian Climate Model Version 2, A2 contained in the Climate Change Research Report CCRR-16, for the Lake Simcoe watershed, under two levels of change severity, for time periods of 2011-2040, 2041-2070 and 2071-2100.

Insect development is tied to available heat energy for individual growth and population growth rates. Mean temperatures and similar data are not much use for entomological work directly. The appropriate metric for predicting the effects of changing climate on insect populations is accumulated degree days. These data were not available for the watershed for this report. To get some idea of changes in degree days, I assumed that the Lake Simcoe watershed would have climatic conditions midway between Algonquin Park and Bruce Peninsula National Park, and used the degree days for these listed in the CCRR-16 report Appendix 3.

A literature survey was used to identify potential insect orders for various habitat types. I searched Scholar's Portal for the words "climate change" and the order name occurring in the title, between 1991 and 2010. I then searched for the same words appearing in either the title, keywords, or abstract of the ESA (Entomological Society of America) journals.

Orders having a relevant literature were assessed across criteria based on their potential use for regional scale monitoring in the Lake Simcoe Watershed. It was assumed that ongoing monitoring may include the help of groups normally involved in such projects, e.g. Conservation Authorities, OFAH, high school projects, student volunteers, and similar organizations. For insect monitoring to be effective, sampling methods must be easily implemented, and be based on skill sets that are easily achieved and standardized. The five criteria were scored, as either high potential (4), moderate potential (3), limited potential (2), or useless (1), based on projected changes. The categories used were:

1) vulnerability to climatic change, with a score of 4 being highly vulnerable and 1 being unaffected by projected changes;

2) response potential to climatic change, 4 being rapid and 1 being a slow response;

3) importance and/or public profile, 4 being high profile or economically important and 1 being low profile or unimportant;

4) difficulty of identification, 4 easy to identity or acquire the skills needed and 1 being difficult either due to either a lack of suitable keys or the need of a specialized skill set;

5) difficulty of sampling, and again 4 being easy and/or inexpensive and 1 being difficult and/or costly.

From these, potential taxa for the Lake Simcoe watershed were identified, and hypotheses and predictions generated and associated response variables proposed.

To get an idea of the year-to-year variability with respect to the number of degree days available for development in the watershed, the daily maximum and minimum temperatures from 1973 to 2010 for Shanty Bay (44.4 North and 79.6 West, elevation 250 metres) were obtained from the Environment Canada Weather Office (http://www.weatheroffice.gc.ca/canada_e.html) (http://www.climate.weatheroffice.gc.ca/advanceSearch/searchHistoricData_e.html). These were used to calculate the daily degree days and accumulated degree days for each year above developmental thresholds of 0, 5, and 10 ^{o}C (Allen 1976, Baskerville and Emin 1969).

Results

The climate simulations are summarized in Table 1. Based on these, there is a minimal expected increase in temperature, about 2 ^{o}C for each period, with a slight increase in the length of the growing season in terms of days. But what is not apparent using temperature as the metric, is the large increase in the growing period in terms of accumulated degree days. These are expected to increase from 1500 at present to 1735 between 2011-2040, 1990 between 2041-2070, and 2400 between 2071-2100. These values correspond to growing periods (ADD_0) of 2600-2800, 3000-3300, and 3700-4000 for the Lake Simcoe region (upper and lower parts of the watershed, based on the map in OMAF Publication 296, their Corn Heat Zones map, reproduced in Dale et al. 1992). To put this in perspective, the region of London Ont. is between at 2700-2900, the north shore of Lake Ontario and Lake Erie is around 3000-3100, and the area around Windsor is from 3500-3700.

Based on the Shanty Bay historic climate data, there was a great deal of variability over the 38 years between 1973 and 2010. The greatest variability is between the minimum and maximum ADD_{10}. (e.g. the highest max/min ratio, Table 2). Any insects with a developmental threshold near this temperature would experience the greatest year to year fluctuation in available development times (Table 2).

From the literature survey (Table 3), while much has been published on general trends, little direct work has been produced on the effect of climate shifts on specific insects. The most promising candidate orders appear to be Diptera and Coleoptera, in terms of published material. Ticks, an important group, also appear in the literature. These groups also scored high in terms of monitoring potential (Table 4).

Test criteria were developed and are summarized in Table 5. Again, Diptera, specifically *Stomoxys calcitrans* and the Tabanidae, and Coleoptera seem to be good candidate groups for monitoring. While bees and other pollinators are important insects, and these would certainly be beneficial to monitor, their low score in Table 5 is based solely on the difficulty of identifying bees to species.

Twenty-eight groups were assessed for distribution based on distribution maps in published taxonomic keys. These are listed, in rank order from highest to lowest proportion south of the watershed in Figure 3. Based on the groups assessed, an average (+- 1 SD) of 32% (25.2) of all species are found in the region just south of the watershed, 56% (21.9) within the watershed, and 11.5% (14.3) north of the watershed.

The hypotheses and associated metrics for colonizing species are explained in detail in figures 4 to 8. Essentially, figures 4 and 5 show the nature of year to year variability in a colonizing species. Figure 6 was using a model, in which the year to year variability is drawn from a normal distribution or varying spread (the standard deviations). Increasing the yearly variability was able to confound the detection of climate shifts (SD 2.5 and 5 in the models). If we relax the assumption of a normal distribution of yearly variability, and allow these to be skewed, the difficulty of identifying climate effect becomes even more pronounced (Fig. 7).

Figures 8 and 9 identify the response variable for a seasonal colonizer, such as *Stomoxys calcitrans*. From these, monitoring should concentrate on finding the proportion of successful overwintering sites, rather than numbers. Fig. 9 makes this point, and includes an effect of drier summer predicted by the climate model.

Discussion

The temperature values from Table 1 are across the range of overwintering ability of stable flies, *Stomoxys calcitrans*. Stable fly populations were observed to range between 0 and 50% overwintering on dairy farms from the 2500 to 3000 heat-units range (Beresford and Sutcliffe 2010, Beresford and Sutcliffe 2009b). This makes stable flies a strong candidate for monitoring studies based on time series data. These regions also correspond to the current distribution of several species of Tabanidae (Table 6) (Teskey 1990), making tabanids a potentially important monitoring taxa based on changes in their diversity (Beresford et al. 2010). The ease of sampling these species and the incentive for sampling them as economically important pest species make these good candidates for ongoing monitoring.

Vulnerabilities

Because each species has locally adapted efficiencies in terms of the energetic requirements and optimal temporaries, these may be vulnerable due to increased mortality and/or lower fecundity. At the population level, large populations may fragment into metapopulations with the concomitant increased shift in dispersal toward colonization vs gene flow. This response to fragmentation may increase the potential for pest species to infest, and allow some species to persist in spite of an apparent low dispersal potential.

The data summarized in Table 2 indicates that there is a large variation in the number of days available for development each spring. For example, there were between 54 and 88 days with temperatures above 10 ^{o}C from 1973 to 2010. This variability argues that many insect species are unlikely to be vulnerable to phenological shifts due to the high level of year to year variability experienced. In simple terms, there is a great deal of sloppiness about when insects appear each spring so that any climate induced shift in the optimal emergence timing (e.g. pollinators, etc) would be likely be tracked by insect populations.

Selection of suitable metric for monitoring

A difficulty for predicting climatic effects is to separate normal levels of variability from climatic shifts. Statistics such as mean growing season temperature, (max, min, daily etc) do not reveal the potential impact of climate change on insect populations. For example, based on their coefficient of variation, the temperature data from a beef farm in the Peterborough area had similar maximum (CV = 3.4), mean (CV = 3.8), and minimum (CV = 2.9) temperatures for the summers of 1997 to 2001. The summer ADD_{15} had a mean of 505 from 1997 to 2001, but with a range from 446 in 2000 to 553 the previous year (CV = 9.1), almost 50% difference (Appendix 1, weather data from Trent University Geography Department Weather Station). Far more useful for insect work would be a probability distribution of ADDs so that rare events can be predicted, coupled with a function showing how the tails of this distribution are expected to change over time under different model scenarios.

Sampling recommendations

Insect species for monitoring should be easy to sample, identify, and of sufficient inherent interest outside of climate considerations to ensure that long term monitoring is maintained. Agricultural pests such as *Stomoxys calcitrans*, the Tabanidae, to a lesser degree Culicidae and the Acrididae (Orthoptera) satisfy these requirements. These are economically important, and producing time series data for these insects will have benefits beyond climate change assessment. this is an important consideration to ensure the sustainability of monitoring efforts. Similarly, forensically relevant taxa such as Calliphoridae and Silphidae also have potential as monitoring taxa. Sampling methods such as sticky traps (Beresford and Sutcliffe 2006, 2008a and b, Cilek 2000), pitfalls, baited traps (LeGros and Beresford 2010), and sweep netting are inexpensive, specimens are easy to preserve and house.

Not monitoring insects such as the *Stomoxys* and Tabanidae, would be a gross oversight for the data collection costs are minimal compared to other systems (see Beresford and Sutcliffe 2006, Beresford et al. 2010, and Legros and Beresford 2010, for descriptions of relevant and inexpensive sampling methods).

Predictions of response variables (abundance, presence absence, timing, growth rates, mortality and fecundity rates, changes in species diversity) need to be developed for each insect species or group being monitored in order to falsify relevant hypotheses. Without this prior development, important time series may be missed, and data generated of limited utility for the questions at hand.

In addition, environmental data needs to be monitored and made available to researchers in entomology, barometric pressure, daily min and max temperatures, precipitation, and relative humidity data from a wide variety of habitats.

Mitigation measures

Insects differ from larger taxa in that their generation times are normally one year or less, meaning that they have a tremendous capacity to adapt to climatic shifts. Indeed, their long evolutionary history is evidence of this ability to persist over a range of climatic conditions.

Insects are vulnerable, however, to land use changes and the loss of habitat. Typically, pest species benefit from large scale land use patterns, whereas insect predators, prey species for vertebrates, insect pollinators, and other longer lived insect species of conservation interest benefit from a diversity of habitats associated with variable land uses. For example, small scale agriculture, mixed farming, and other similar land uses. Typically habitats include artificial and/or seasonal ponds, ditches, waste placed, overgrown fence rows, mature pasture, small woodlots, and agriculturally marginal land. These areas are under increasing pressure from both urban, suburban, and agricultural development.

Mitigation measures should include such incentives that maximize individual initiatives and incentives for creating or maintaining diverse habitats on private and public land. Such incentives could include lower tax rates on marginal land and land taken up by fence rows. Preserving existing woodlots could be encouraged by giving tax incentives for using wood heat (a carbon neutral source of energy), and encouraging the use of wood as fuel, and tax incentives for land used in the production of maple syrup and other small scale forestry products.

The goal would be to create economic benefits for maintaining or planting woodlots as a source of farm product and income. In the same way, small scale agricultural economies such as backyard poultry production and/or community gardens would add to the amount of diverse habitats needed by insects such as native pollinators and other groups that might come under threat. Even such seemingly insignificant places as suburban lots with natural planting and windbreaks can act as important stepping stones for maintaining insect diversity, and the concomitant diversity of higher order taxa that depend on the insects.

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Glossary of Terms

Accumulated Degree Days. A single degree days is defined as one degree Celsius over a 24 hour period. The ADD is calculated as the area beneath a temperature vs time plot above some minimum threshold value, usually 0 ^oC, and standardized by increments of 5 ^oC (Pruess 1983). A room at constant temperature of 18 ^oC for 4 days would have 64 ADD_0, 52 ADD_5, 32 ADD_{10}, and 12ADD_{15}. The available ADD for a region is based on maximum and minimum daily temperatures, and integrating the area beneath this based on assuming that daily max and min temperatures define the amplitude of a sine curve (Allen 1976, Baskerville and Emin. 1969).

The linear assumption of insect growth rate is based on assuming that the ADD for any species is a more or less fixed commodity. This simplification produces more accurate predictions than models which try to account for minor differences in ADD based on actual temperatures. Insect growth rate is correctly based on ADD rather than min, max, or mean temperatures (Beresford and Sutcliffe 2009).

Figures

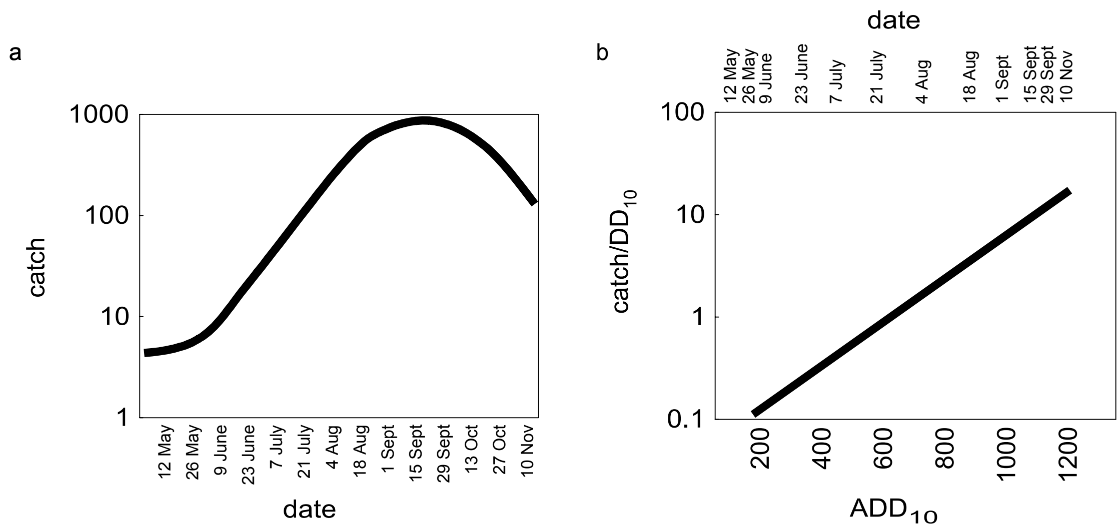
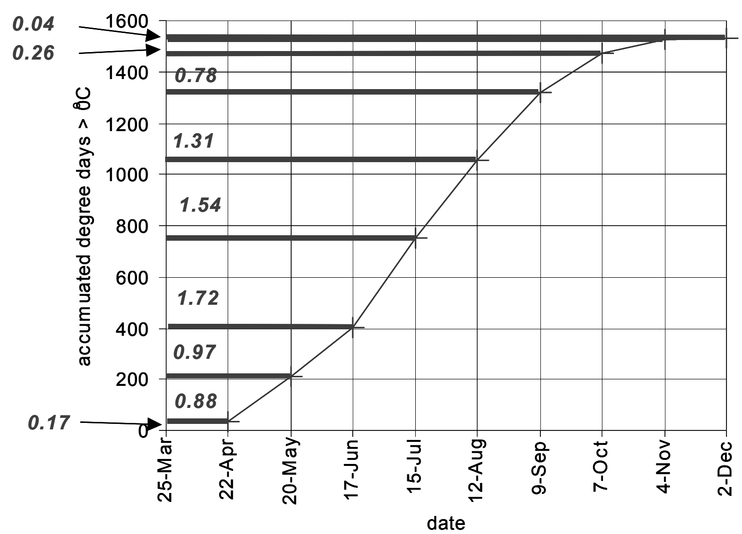


Fig. 1. Populations growth of *Stomoxys calcitrans* (typical), showing the pattern when catch data are plotted against time (a) and corrected for sample period and plotted against an ADD scale (b). The exponential growth is revealed by the degree days scale. Because of this, seasonal surveys of insect populations are all effectively on an irregular scale, and must be corrected (See Beresford and Sutcliffe 2009 for a detailed discussion of this argument). Figure from Beresford and Sutcliffe 2010.

Fig 2. Typical pattern of the variable number of degree days > 10 ^{o}C in each 4 week period. The italicized numbers are number of generations every 4 weeks for an insect with a generation time of 100 ADD_{10} (Peterborough, 1998 data). Spring and fall generations are oversampled compared to summer using standard weekly traps. Trap data needs to be corrected to be per sample period in terms of degree days.



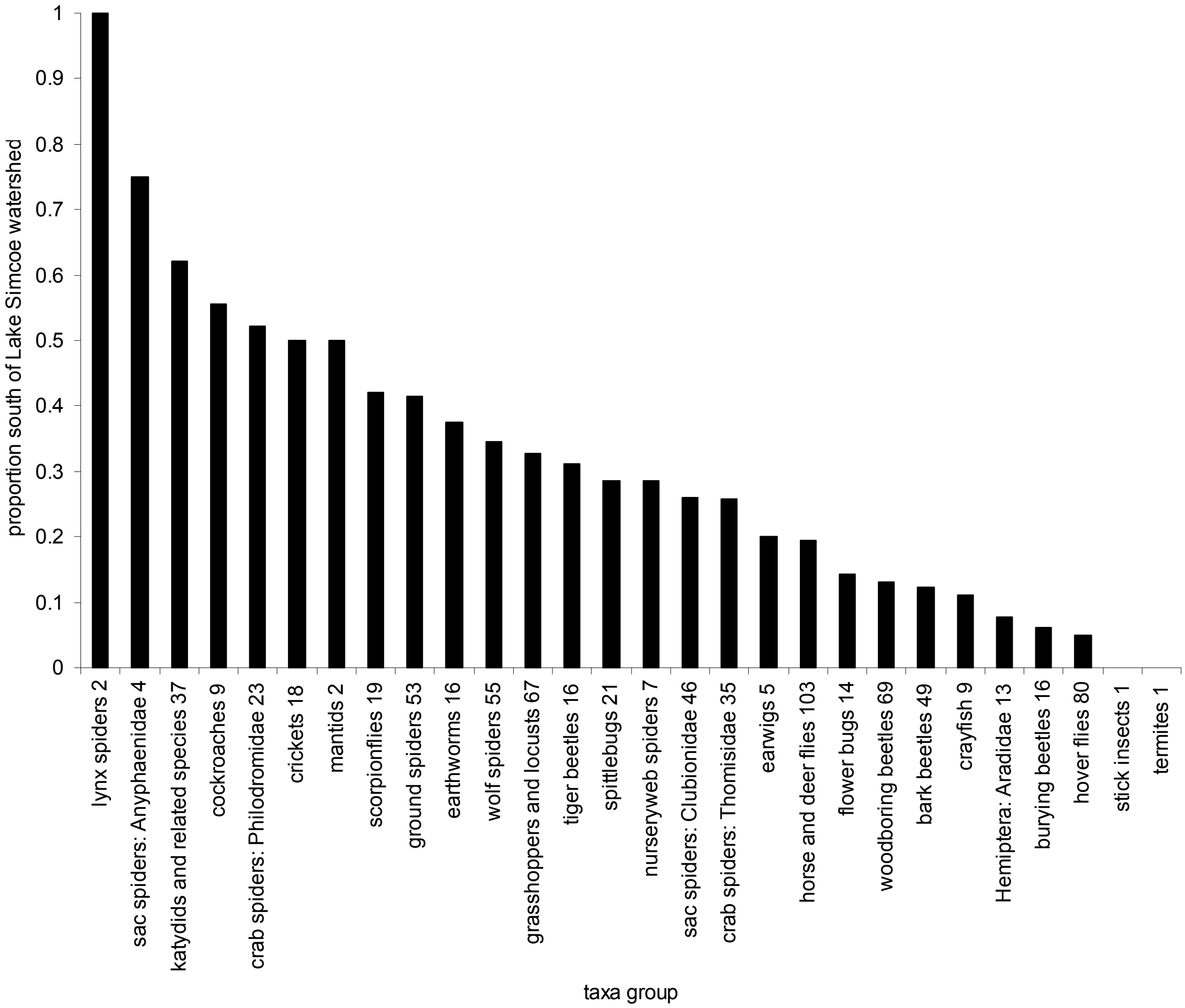


Fig. 3. The proportion of species in each group that are currently found in the region immediately south of Lake Simcoe watershed. These species might potentially be able to move into the watershed in response to increased annual temperatures. The number after the family or order name is the total number of species of that group in southern Ontario. Data based on published maps found in the various taxonomic keys (see Literature Cited). Note that the largest group is Tabanidae, with 103 species. Note the inclusion of crayfish and earthworm distributions in this figure.

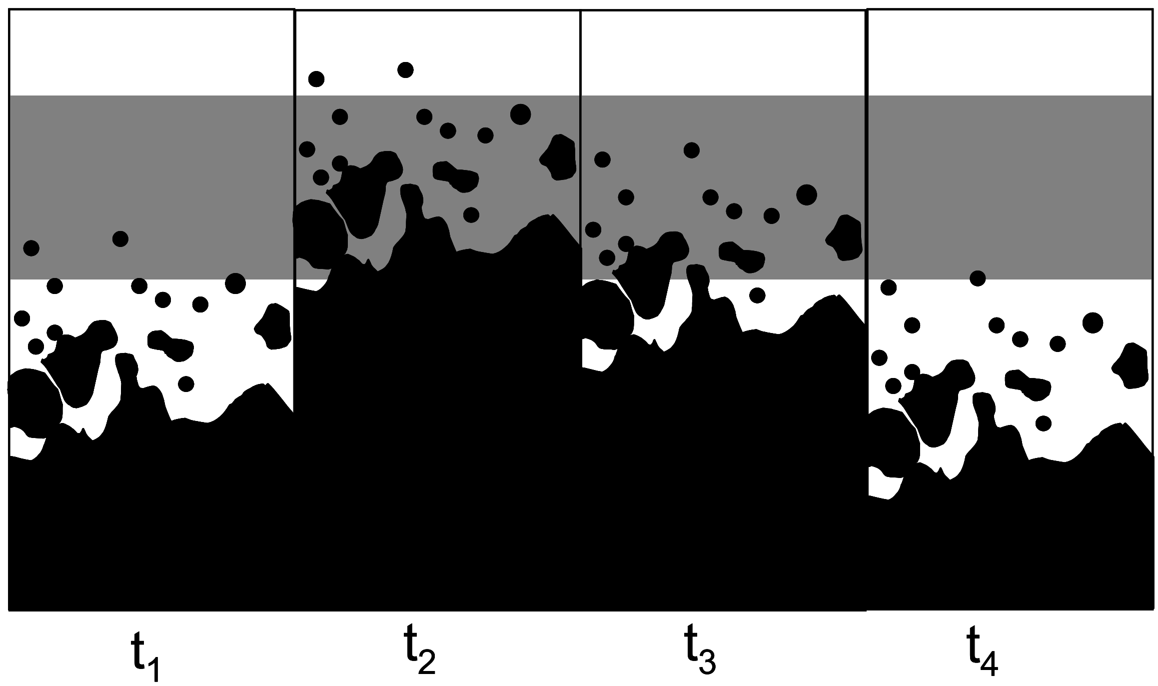


Fig. 4. Stereotyped diagram of the spatial distribution of a metapopulation of some insect species at the edge of its range during the summer. The individual populations vary from year to year, mild years allowing many populations to successfully overwinter (t2), and harsh years causing local extinctions (t4). The grey area represents the sampled region.

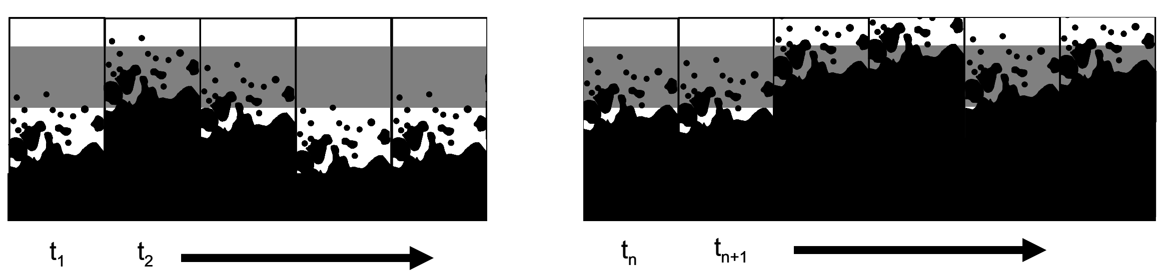
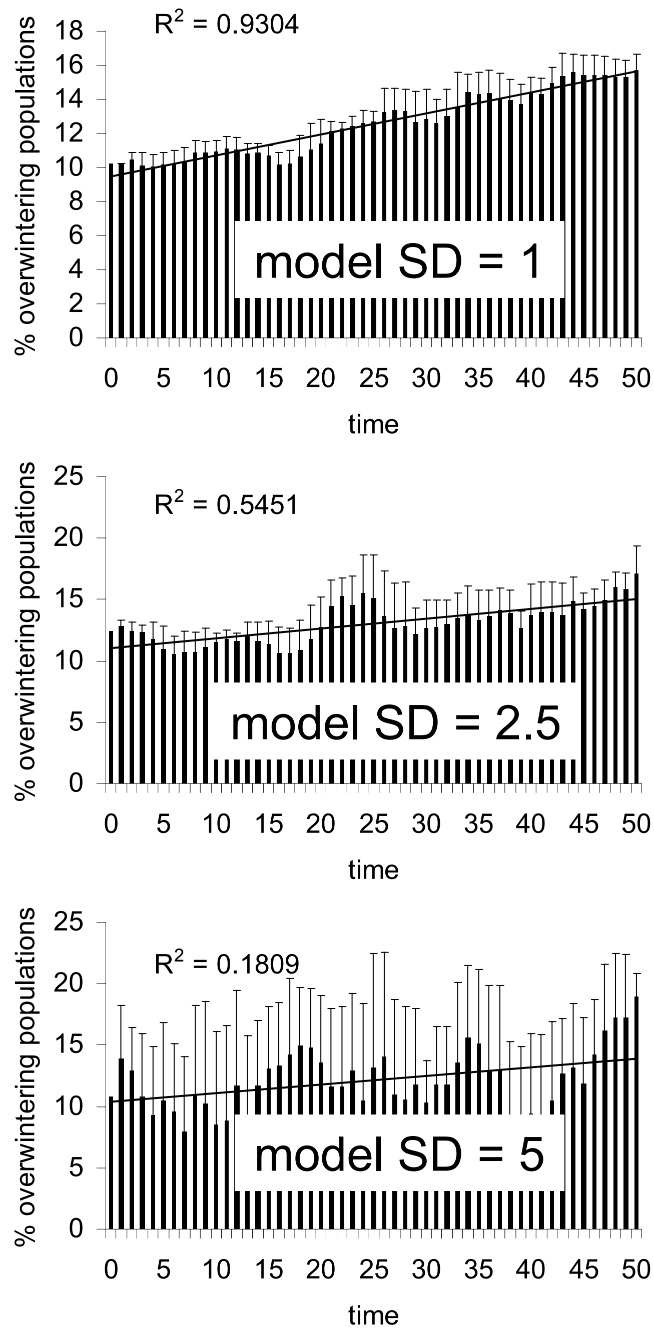


Fig. 5. Predicted effect of a warm shift in climate on the pattern of spatial distribution. While the individual populations still vary from year to year, the general trend is for residency. The grey area is the sampled region. The level of between-year variability would differ between species.

Fig. 6. Overwintering population metric for finding evidence of climatic change effects. Predictions of % overwintering population over 50 years. Model parameters are a normal distribution of means, with starting mean at 10% overwintering increasing by 1% per year, with different SD values used on the model. The SD values represent expected variability based on normal climatic variation for the modelled region. The bars and error lines are 5 year averages. The more year to year variability, the longer the time series needed to find an effect of climate changes.



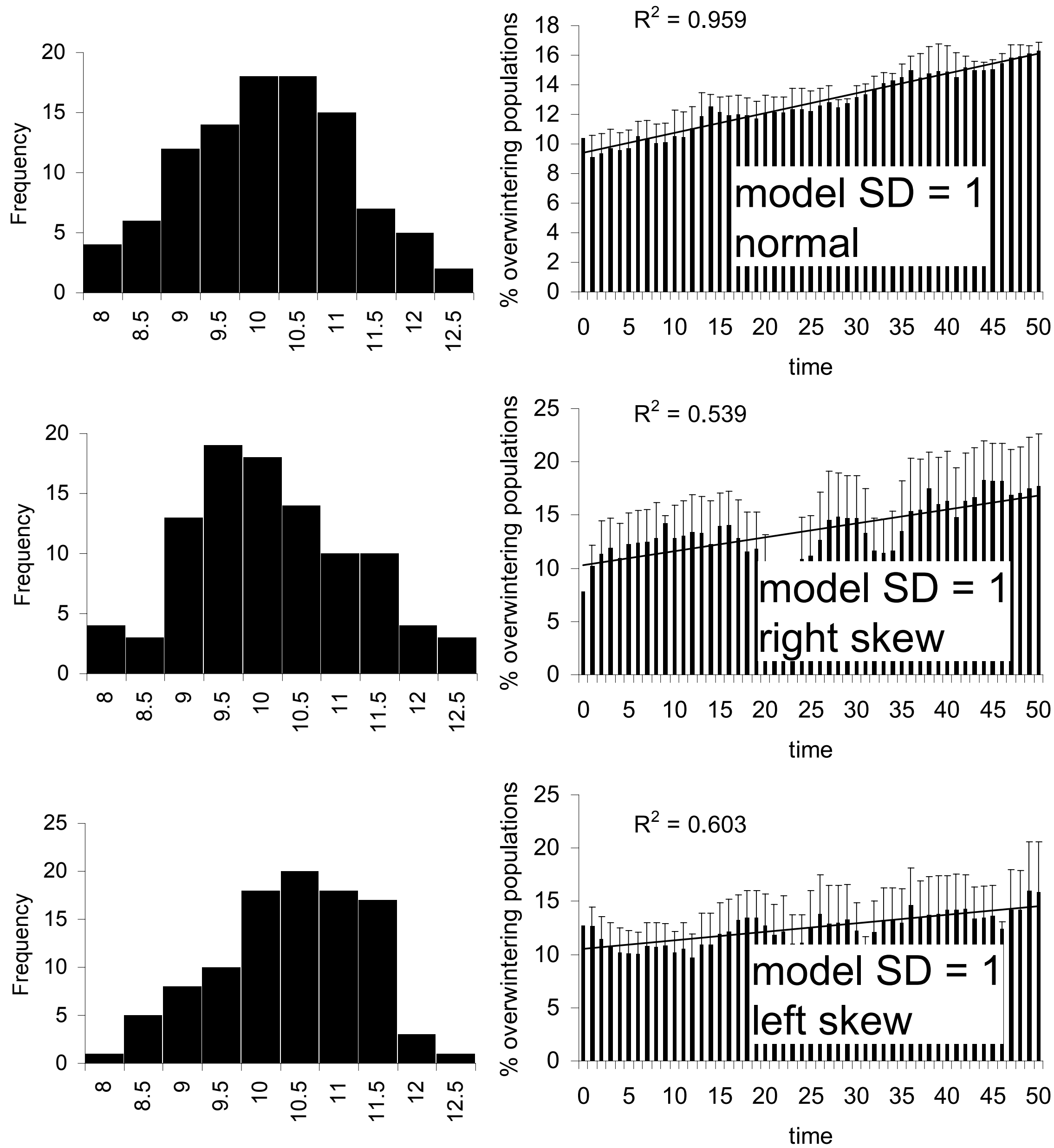


Fig. 7. Overwintering population metric for finding evidence of climatic change effects. Same model parameters as Fig. 5. These projections compare the effect of normal and skewed distributions of between-year variability on % of overwintering populations. The skewed distribution makes it harder to sort out the effect of the warming climate that increases % of overwintering populations. Typical of the distributions that were drawn from are shown on the left.

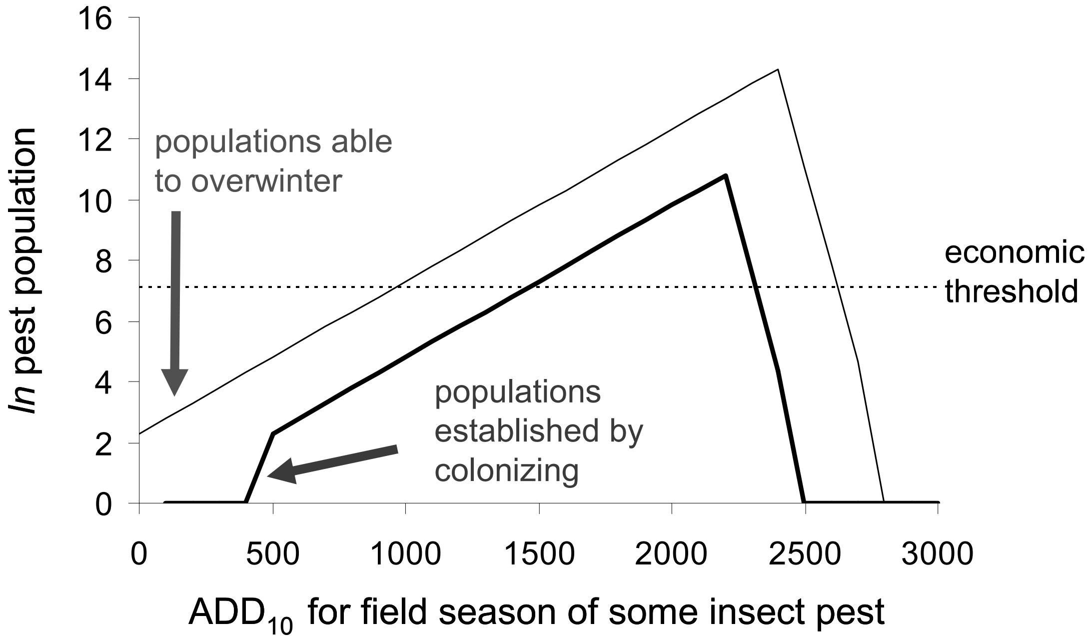
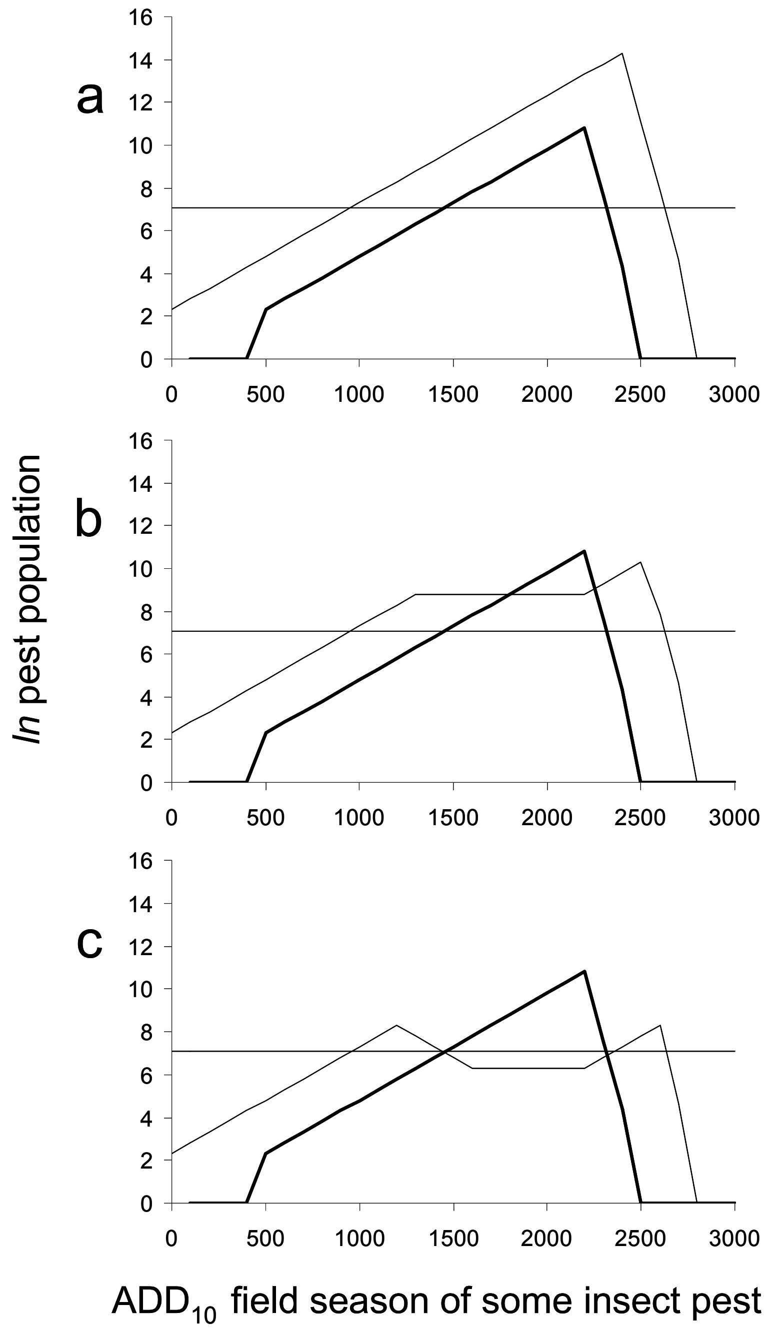


Fig. 8. Exponential growth of a pest species which is able to maintain populations due to warming conditions. Economic injury occurs earlier due to eliminating the lag time of colonization, and continues longer due to the increased growing season. Note the broken stick shape of the colonizing population just prior to 500 ADD_{10}. This is characteristic of the immigrant stage of a colonizing species before natal populations are established.

Fig. 9. The predicted effect of a reduced summer rainfall and warmer temperatures on an insect population, ranging from no effect (a), to a strong effect (c). In all cases, warm temperatures allow the new population to overwinter and begin growing earlier in spring, but numbers decline over summer due to drier habitat. The bimodal pattern of c is seen south of Ontario in *Stomoxys calcitrans* populations that are able to overwinter.



Tables

Table 1. Projected temperature increase, and associated increase in degree days (ADD_5) for Lake Simcoe Watershed. Data for the ADD_5 projections are from CCRR-16 report for Algonquin and Bruce Peninsula, the Lake Simcoe projections are based on the mean of these two.

	Watershed 02EC - Black R./L. Simcoe A2 scenario			
	current	2011-2040	2041-2070	2071-2100
winter diff. in mean temp.	-13	1-2	3-4	4-5
	growing season* ADD_5			
	1971-2000	2011-2040	2041-2070	2071-2100
Algonquin mean summer temp	13.3	14.3	14.9	16.1
Algonquin ADD_5	1447.4	1655	1892.1	2284
Algonquin growing season days	183.5	187.6	199.8	215.7
Bruce Peninsula mean summer temp	12.7	13.7	14.6	15.9
Bruce Peninsula ADD_5	1559.3	1815	2085	2530.5
Bruce Peninsula growing season	211.5	219.1	228.3	242.3
mean of the two mean summer temp	13	14	14.8	16
ADD_5	1503.4	1735.0	1988.6	2407.3
growing season days	197.5	203.4	214.1	229.0

From CCRR-16, Appendix 3

Table 2. Climate data for Shanty Bay, from 1973 to 2010. Part A is based on the accumulated degree days (ADD) above the indicated temperature threshold for the given date. Part B reports the number of days (date inclusive) with degree days (DD) above the indicated threshold temperatures (0, 5 and 10 ^{o}C). The CV is the coefficient of variation (SD/mean) in order to compare the relative spread of different data sets.

A		accumulated degree days above 0 ^{o}C				
before date	mean	SD	max	min	skew	max/min ratio
1 Mar	25.7	14.1	62.5	2.1	0.60	
20 Mar	50.1	25.5	116.4	8.2	1.08	
1 Apr	86.9	36.7	185.2	20.9	0.55	
1 May	278.9	67.2	442.4	116.4	-0.04	
1 Jun	664.3	98.1	907.5	495.0	0.69	
21 Jun	1000.4	101.6	1245.7	834.2	0.63	
year end	3222.2	186.7	3591.4	2808.7	0.11	1.28
		accumulated degree days above 5 ^{o}C				
1 Mar	3.4	2.9	13.6	0	1.34	
20 Mar	10.1	9.5	39.5	0	1.95	
1 Apr	22.9	16.1	65.2	2.0	0.98	
1 May	112.3	40.4	214.6	33.6	0.35	
1 Jun	348.2	76.0	530.1	220.6	0.65	
21 Jun	584.3	78.2	768.3	468.4	0.67	
year end	2075.7	154.4	2370.2	1721.7	0.20	1.38
		accumulated degree days above 10 ^{o}C				
1 Mar	0.2	0.3	1.3	0	1.88	
20 Mar	1.8	3.2	11.5	0	2.36	
1 Apr	5.5	6.5	24.1	0	1.71	
1 May	40.3	21.3	87.9	8.8	0.51	
1 Jun	157.4	50.6	275.3	70.7	0.66	
21 Jun	296.9	54.3	429.6	200.2	0.63	
year end	1183.9	125.1	1451.7	896.4	0.28	1.62

B	number of days with temperatures above 0 ^{o}C					
	mean	SD	max	min	skew	CV
total days	292.2	12.1	321	270	0.50	0.04
before June 21	120.7	8.8	141	100	0.29	0.07
after Sept 21	80.5	7.2	94	65	-0.36	0.09
	number of days with temperatures above 5 ^{o}C					
total days	238.3	10.9	259	215	-0.05	0.05
before June 21	90.0	7.6	104	68	-0.74	0.08
after Sept 21	57.3	7.1	71	42	0.16	0.12
	number of days with temperatures above 10 ^{o}C					
total days	197.2	10.4	219	180	0.05	0.05
before June 21	69.5	7.0	88	54	0.32	0.10
after Sept 21	36.8	7.1	50	22	0.01	0.19
number of days from Jan 1 to June 21 with temperatures below indicated threshold						
0 ^{o}C	52.3	8.8	73	32	-0.29	0.17
5 ^{o}C	83.0	7.6	105	69	0.74	0.09
10 ^{o}C	103.5	7.0	119	85	-0.32	0.07

Table 3. Literature survey of publications on climate change and insects by major order. Upper table, Scholars Portal search (includes Cambridge Abstracts) of "climate change" and order name in the article title. While there is an extensive literature on the general theme of climate change, little direct work is published on species responses. Lower table, search of Entomological Society of America (ESA) journals for "climate change" and order name in title, keywords, or abstract. The ESA journals are: Annals of the ESA, Environmental Entomology, Journal of Economic Entomology, Journal of Medical Entomology, Journal of Integrated Pest Management, American Entomologist, Arthropod Management Tests.

year	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	total
Insects	3	7	3	2							3				2				1	2	23
Lepidoptera	1	2		4		2								4							13
Diptera			5											1							6
Coleoptera		2													2						4
Hemiptera		1				3															4
Plecoptera	1																				1
Odonata										1											1
Homoptera													1								1
Ephemeroptera																					0
total	5	12	8	6	0	5	0	0	0	1	3	0	1	5	4	0	0	0	1	2	53
Diptera	1		1	1					1	2					1						7
Coleoptera	1	1	2	1								1								1	7
Ticks	1			1	1								1								4
Orthoptera	1	2	1																		4
Lepidoptera	2				1											1					4
Homoptera	1											1									2
Odonata		1																			1
Thysanoptera						1															1
Hymenoptera						1															1
Mantidea							1														1
total 7		4	4	3	2	2	1		1	2	0	2	1	0	1	1	0	0	0	1	32

Table 4. Score of insect taxa, by order (except ticks, by class) based on subjective criteria (see text). A high score indicates a high potential as a group for long term monitoring. Vulnerability is based on likelihood of some observable change in distribution, response is how quickly this will occur, importance is a combination of economic and public profile, ID is skill set required for species identification, sampling is the cost and labour of sampling for producing time series data.

order	vuln.	response	importance	ID	sampling	total	sampling method
Diptera	4	4	4	3	4	19	sticky traps, sweep netting, baited traps
Coleoptera	3	4	4	3	4	18	pitfalls, sweep netting
Ticks	3	4	4	3	2	16	drag sampling
Homoptera	3	4	3	2	3	15	sweep netting
Lepidoptera	2	3	4	3	2	14	direct netting adults and larvae, watching*
Odonata	2	2	4	3	2	13	direct netting adults and larvae, watching*
Hemiptera	2	4	3	2	2	13	sweep netting
Orthoptera	3	3	2	2	2	12	sweep netting
Hymenoptera	2	4	3	1	2	12	sweep netting, pan traps
Mantidea	2	2	2	4	1	11	sweep netting, egg case counts
Thysanoptera	?	4	2	2	1	9	sweep netting
Plecoptera	2	2	2	2	1	9	aquatic searches, dip net
Ephemeroptera	2	2	2	2	1	9	aquatic searches, dip net
Trichoptera	2	2	3	1	1	9	aquatic searches, dip net

The five criteria were scored, as either high potential (4), moderate potential (3) limited potential (2) or useless (1).

* good for common or easily identified species only.

Table 5. Population categories, with examples, showing characteristics, and potential for assessing a warm shift in climate over time.

population category		typical examples	characteristics	response to warming trends	response variable	response time
naturalized populations	metapopulation	**Carabidae**	exist as connected local populations	may lose habitat, increasingly fragment, highly dependent on land use	increased dispersal, dynamics become asynchronous	long, decadal
	panmictic	*Musca domestica,* (house fly)	exist throughout region as mixing population	none	none	none
windborne spring immigrants		*Ostrinia nubilalis,* (corn borer)	arrive in spring on weather systems	may lose habitat, highly dependent on land use	none	none
migratory populations		*Danaus plexippus*, (monarch)	arrive in spring, migrate northward	may lose habitat, highly dependent on land use	none	none
edge of range	northern edge, refuges	***Stomoxys calcitrans,* (stable fly)**	overwintering populations in the southern part of watershed	increased overwintering, overwintering possible at northern edge of watershed	increased proportion of overwintering populations, populations occur early in season, as soon as temperatures allow, number may or may not increase overall, depending on mid-summer drought	rapid, yearly
	southern edge refuges	Culicidae (varies by species)	same	same	same	same
	occasional	Culicidae (varies by species)	same	same	same	same
range location of re watershed	overlaps	**Tabanidae, Acrididae, Calliphoridae, Silphidae**	populations throughout region	fragment, shift north or south	diversity changes, change in species composition of extant taxa	rapid, yearly

south	**Tabanidae**	populations south of region	populations move into region	diversity changes, change in species composition of extant taxa	rapid, yearly
north	**Tabanidae**	populations north of region	occasional populations become more rare or disappear entirely from northern edge	diversity changes, change in species composition of extant taxa	rapid, yearly
habitat specific	**Carabidae, Trichoptera**	tied to specific habitats, eg alvar, old fields, wooded areas, aquatic systems, vernal pools, specialized stream locations	habitats disappear, corridors are lost	local populations go extinct, proportions of local extinctions increase over time, corridors disappear, re-colonization is slower	long, decadal
			habitats increase as new habitats become available, corridors emerge	local populations increase in number and persistence, corridors appear, re-colonization is faster	long, decadal
herbivores	Hemiptera, Homoptera	budding and ecclosion synchronous	ecclosion and budding become increasingly asynchronous	shift in timing of events	long, decadal

Table 6: Distribution of Tabanidae (a typical group) relative to the Lake Simcoe watershed. Lower table lists the species by distribution. Ranges based on Teskey (1990), or [1]Thomas and Marshall (2009), * means range change updated from Teskey using Thomas and Marshal.

taxa		distribution		
common name	genera	within range	north of watershed	south of watershed
deer flies	*Chrysops*	25	7	9
	Goniops	1	0	0
	Mercycomyia	1	0	0
	Stonemyia	1	0	0
	total	28	7	9
horse flies	*Hybomitra*	18	8	0
	Tabanus	12	1	10
	Atylotus	8	1	1
	total	38	10	11

species list

within range	north of watershed	south of watershed
Chrysops aberrans	*Chrysops calvus* *	*Chrysops brunneus*
Chrysops aestuans	*Chrysops dawsoni*	*Chrysops celatus*[1]
Chrysops ater	*Chrysops nigripes*	*Chrysops flavidus*[1]
Chrysops callidus	*Chrysops shermani*	*Chrysops geminatus*
Chrysops calvus *	*Chrysops zinzalus*	*Chrysops impunctus*[1]
Chrysops carbonarius	*Chrysops furcatus*	*Chrysops luteopennis*[1]
Chrysops cincticornis	*Chrysops pudicus*	*Chrysops macquarti*
Chrysops cuclux	*Atylotus intermedius*	*Chrysops pikei*
Chrysops delicatulus	*Hybomitra brennani*	*Chrysops pudicus*
Chrysops excitans	*Hybomitra cridlei*	*Merycomyia whitneyi*[1]
Chrysops frigidus	*Hybomitra frosti*	*Stonemyia tranquilla*[1]
Chrysops geminatus[1]	*Hybomitra hearlie*	*Atylotus ohioensis*
Chrysops indus	*Hybomitra hinei*	*Tabanus americanus*
Chrysops lateralis	*Hybomitra itasca*	*Tabanus calens*
Chrysops macquarti[1]	*Hybomitra longiglossa*	*Tabanus fairchildi*
Chrysops mitis	*Hybomitra typhus*	*Tabanus limbatinevris*
Chrysops moechus	*Tabanus sequax*	*Tabanus sagax*
Chrysops montanus		*Tabanus stygius*
Chrysops niger		*Tabanus subniger*
Chrysops sackeni		*Tabanus sulcifrons*
Chrysops sordidus		*Tabanus superjumentarius*
Chrysops striatus		*Tabanus trimaculatus*
Chrysops univittatus		
Chrysops venus		
Chrysops vittatus		
Goniops chrysocoma[1]		
Mercycomyia whitneyi[1]		
Stonemyia rasa[1]		
Atylotus bicolor		
Atylotus duplex		

Atylotus hyalicosta
Atylotus palus
Atylotus sphagnicolus
Atylotus sublunaticornis
Atylotus thoracicus
Atylotus woodi
Hybomitra affinis
Hybomitra arpadi
Hybomitra astuta
Hybomitra aurilimba
Hybomitra cincta
Hybomitra epistales
Hybomitra frontalis
Hybomitra illota
Hybomitra lasiophthalma
Hybomitra liorhina
Hybomitra lurida
Hybomitra microcephala
Hybomitra miniscula
Hybomitra nitidifrons
Hybomitra pechumani
Hybomitra sodalis
Hybomitra trepida
Hybomitra zonalis
Tabanus atratus
Tabanus catenatus
Tabanus fulvicallus
Tabanus lineola
Tabanus marginalis
Tabanus nigripes
Tabanus novascotiae
Tabanus pumilus
Tabanus quniquevittatus
Tabanus reinwardtii
Tabanus similus
Tabanus vivax

Table 7: Distribution of Insects and spiders relative to the Lake Simcoe watershed. Categorized by current distribution rage (published maps).

category	reference	group	classification	south	within range	north
spiders	Dondale & Redner 1982	sac spiders	Clubionidae	12	26	8
		sac spiders	Anyphaenidae	3	1	0
	Dondale & Redner 1990	wolf spiders	Lycosidae	19	33	3
		nurseryweb spiders	Pisauridae	2	5	0
		lynx spiders	Oxyopidae	2	0	0
	Platnick & Dondale 1992	ground spiders	Gnaphosidae	22	23	8
	Dondale & Redner 1978	crab spiders	Philodromidae	12	7	4
		crab spiders	Thomisidae	9	18	8
bark beetles			Scolytidae	6	32	11
butterflies	Layberry et al. 1998		Lepidoptera	48	89	14
carrion beetles	Anderson and Peck 1985		Silphidae	1	12	3
flower bugs			Anthocaridae	2	5	7
frog hoppers	Hamilton 1982		Homoptera	6	15	0
Hemiptera			Aradidae	1	6	6
horse and deer flies	Teskey 1990		Tabanidae	20	66	17
hover flies			Syrphinae	4	57	19
orthopterans	Vickery & Kevin 1985	earwigs	Dermaptera	1	4	0
		stick insects	Cheleutoptera	0	1	0
		termites	Termitodea	0	1	0
		mantids	Manidea	1	1	0
		cockroaches	Blattodea	5	4	0
		katydids	Tettigoniodea	23	14	0
		crickets	Gryllodea	9	9	0
		grasshoppers	Orthoptera	22	41	4
scorpionflies and allies	Cheung et al. 2006		Mecoptera	8	9	2
tiger beetles	Pearson et al. 2006		Cicindelidae	5	11	0
woodboring beetles			Burpestidae	9	42	18

Appendices

Appendix 1. Table of temperature data from Beef farm, Warsaw Ontario, 1997 to 2001. The CV or coefficient of variation was calculated as CV = (SD x 100)/mean (Sokal and Rohlf 1995)

	1997	1998	1999	2000	2001	mean	SD	CV
				annual ADD_0				
ADD_0	3272.1	3882.2	3718.1	3485.8	3666.8	3605.0	233.7	6.5
ADD_{10}	1270.8	1568.5	1509.1	1322.3	1477.0	1429.5	127.1	8.9
ADD_{15}	625.9	794.2	795.9	626.8	746.2	717.8	85.8	12.0
				summer ADD_0				
ADD_0	1800.8	1886.5	1878.1	1764.1	1843.8	1834.7	51.9	2.8
ADD_{10}	879.5	965.6	963.3	847.9	926.7	916.6	51.9	5.7
ADD_{15}	468.3	540.2	553.1	446.4	517.0	505.0	46.1	9.1
				summer temperatures				
max	25.9	27.0	27.5	25.5	27.3	26.6	0.9	3.4
min	13.2	14.0	13.3	12.9	12.7	13.2	0.5	3.8
mean	19.6	20.5	20.4	19.2	20.0	19.9	0.6	2.9