

# Dragonfly and Damselfly (Insecta, Odonata) Distributions in Ontario, Canada: Investigating the Influence of Climate Change

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## Abstract

We analysed temperature data and odonate distribution data collected in the province of Ontario, Canada, over approximately sixty years. Analysis of temperature data from 31 weather stations collected in the years 1945–2000 showed an overall significant increase in the minimum, maximum and mean monthly temperatures; these trends were not adjusted for changes in urbanisation. Comparison of county level presence/absence data for odonates from the 1950's and 2002 found a slight decrease in the northernmost distributions of some species, although no significant patterns were evident. Lower sampling coverage in the larger, more northerly counties in Ontario, as well as the assessment of distributions based on county records may limit the sensitivity of our approach in detecting changes in odonate species distributions over time. Future work should focus on increasing the coverage, uniformity and geographic detail of available datasets, as well as evaluating range change through testing predictions based on the ecology and biogeography of odonate species.

## Keywords

temperature, Odonata, climate change, range extension, Ontario

## Introduction

### Climate Change, Ecological Responses & Odonates

Compelling evidence for a global trend in environmental warming continues to accumulate (IPCC 2007, Karl and Trenberth 2003). Likewise, researchers have found ecological and evolutionary responses to the effects of climate change in a number of plant and animal groups (Huntley 1991, Hughes 2000), with a range of data specifically from arthropods (Parmesan et al. 1999, Warren et al. 2001). Further study of the ecological and evolutionary responses of a number of plant and animal groups is necessary to better understand and predict future climate change responses, and to potentially mitigate the detrimental effects of climate change.

Organisms can respond to climate change in a number of ways: by going extinct, by adaptation *in situ*, by range change or expansion (Coope 1995), and/or through plastic changes in life-history patterns (Butterfield and Coulson 1997, Hassall et al. 2007, Parmesan 2007). The type of response observed will likely be a function of both the type of organism involved (based on its ecology and life-history), as well as the home-range conditions of that organism. Dragonflies and damselflies (Insecta: Odonata), offer great potential as an indicator group for anthropogenic disturbances, such as habitat alteration, and climate change (Corbet 1999 Chapter 12 and sources therein). The majority of dragonfly species have an obligate aquatic larval stage, linking their ecological success to the distribution and quality of a range of aquatic habitat types throughout the landscape. As an aerial adult, odonates demonstrate a potential for dispersal and recolonization (Conrad et al. 1999), with some species migrating great distances in response to seasonal changes in weather and climate (Wikelski et al. 2006). As such, the possibility of range change and expansion is high in this group, if other ecological factors (such as the distribution of appropriate habitat for specialist species) allow for such responses.

Recent work has investigated the change in range size of dragonflies and damselflies to detect the effects of climate change (De Knijf et al. 2001, Ott 2001, Ott 2007). Work published by Hickling et al. (2005) detected a significant expansion of the total range, as well as the northernmost range extent, of non-migratory odonates in Britain. Hassall et al. (2007) have also found significant changes in the phenology of British odonates, with advances of  $1.51 \pm 0.060$  days per decade (or  $3.08 \pm 1.16$  days per degree rise in temperature) in the leading edge (first quartile date) of the flight period between 1960 and 2004. As odonates are a ubiquitous group of organisms, found on many continents and in many biomes, investigation of the response of this group could prove a useful indicator for the effects of climate change in regions throughout the world.

In this current study, we have assessed data on the distribution of dragonflies and damselflies in the province of Ontario, Canada, using surveys at different time periods (1950's and 2002) to evaluate potential changes in species ranges. We compare these

preliminary results to recorded changes in climatic conditions in Ontario that have arisen over this same time period. As with any survey work, one of the important interpretive constraints is knowing whether a recorded absence actually corresponds to a genuine absence. We discuss our results and their implications in the light of these constraints, and we suggest potential directions for future research.

### **Habitat and Climate in Ontario**

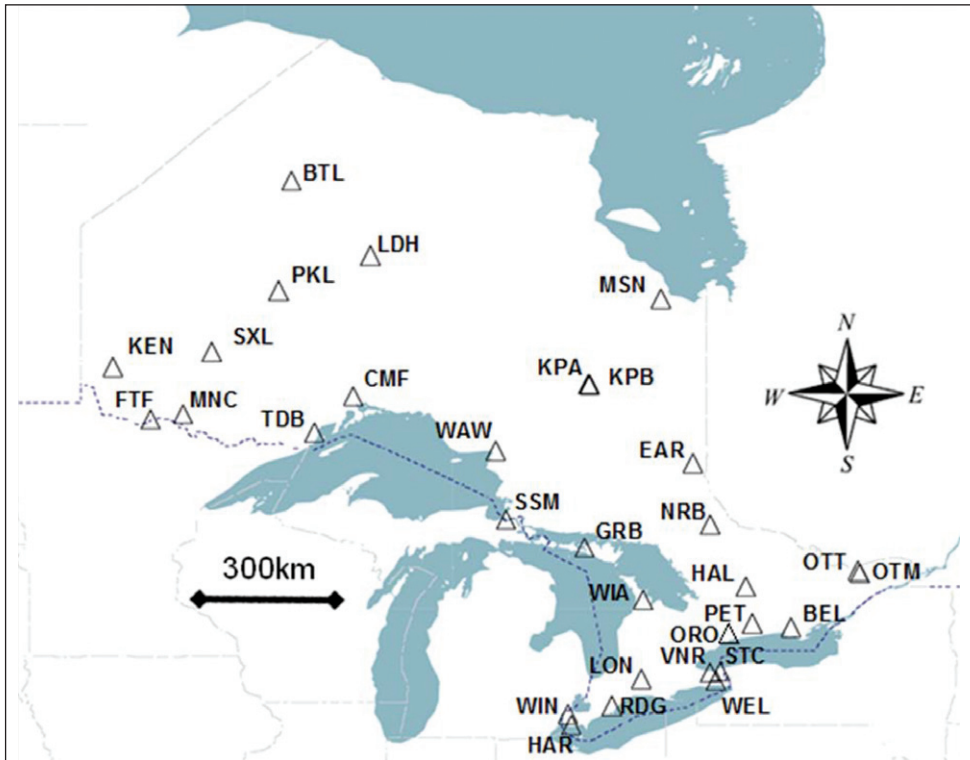
Ontario is a large province, covering an area of 1,076,395 km<sup>2</sup> (approximately 15% of which is covered with water) divided among three geographic regions: the Precambrian Shield (a rocky region with many lakes and wetlands that comprises over half of the province) in the northwestern and central regions, the Hudson Bay lowlands in the extreme north and northeast and the Great Lake/St. Lawrence Valley region in the south. The northernmost point of the province lies at 56°51'N, extending south to 41°54'N at the end of Point Pelee in Lake Erie, a distance of over 1600 km (the west-east extent of Ontario is from 95°10'W on the border with the province of Manitoba to 74°19' where it adjoins the province of Quebec, along the St. Lawrence River, just over 1500 km). There are a total of 47 administrative counties in the province (see Figures 1 and 2).

The climate of the province ranges from a moderate humid continental climate in the southernmost regions of southern Ontario (Peel et al. 2007) to a more severe humid continental climate in the central portions of the province. These regions have relatively hot summers and cold winters, though summers are shorter in the north. Northern Ontario (especially above 50°N latitude) has a much longer and more severe winter.

### **The Odonate Fauna of Ontario**

Ontario has a rich odonate fauna, attributable at least in part to the diversity of habitat types distributed on a north-south gradient within the province. Many species that are associated with more southerly habitats in the United States, such as the Carolinian forests, are found in southern Ontario, while more northerly-distributed species, such as those found within the boreal forests, are common to the northern regions of the province (Dunkle 2000, Catling et al. 2004). As such, species ranges within this region may be more significantly affected by climate change than in other geographies.

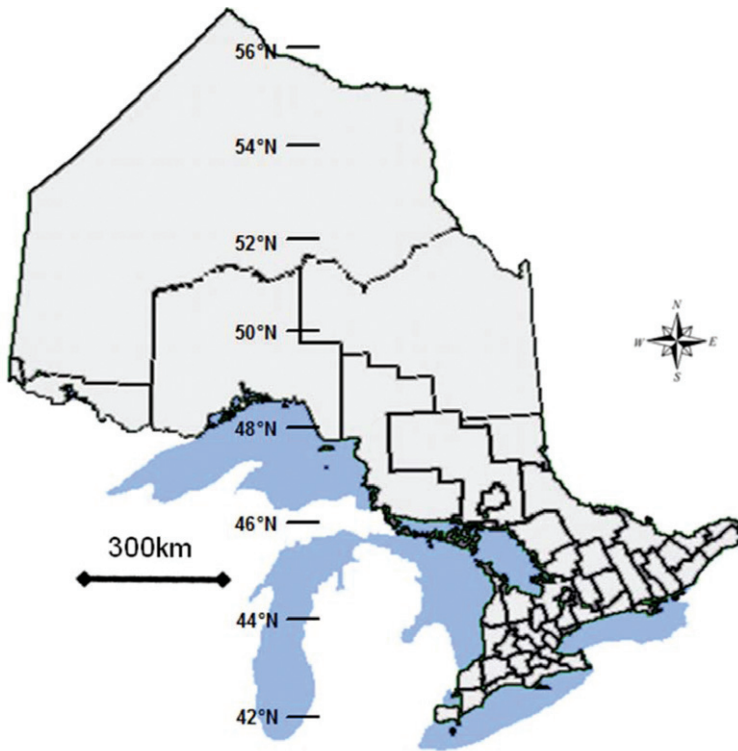
The data used for these analyses (see below) indicate the presence of 134 species of Odonate, distributed over a total of 9 families: Aeshnidae, Cordulegastridae, Corduliidae, Gomphidae, Libellulidae and Macromiidae in the suborder Anisoptera (dragonflies); Calopterygidae, Lestidae and Coenagrionidae in the suborder Zygoptera (damselflies) (see Table 1). The species within these groups utilize a large range of habitat types, from large lakes, ponds and marshes to small streams and large rivers.



**Figure 1.** Map of the Province of Ontario, showing weather station locations. Stations are labelled as follows: Belleville (**BEL**); Big Trout Lake (**BTL**); Cameron Falls (**CMF**); Earlton (**EAR**); Fort Frances (**FTF**); Gore Bay (**GRB**); Haliburton (**HAL**); Harrow (**HAR**); Kapuskasing A (**KPA**); Kapuskasing B (**KPB**); Kenora (**KEN**); Lansdowne House (**LDH**); London (**LON**); Mine Centre (**MNC**); Moosonee (**MSN**); North Bay (**NRB**); Orono (**ORO**); Ottawa (**OTT**); Ottawa MacDonald (**OTM**); Peterborough (**PET**); Pickle Lake (**PKL**); Ridgetown (**RDG**); Sault Ste Marie (**SSM**); Sioux Lookout (**SXL**); St. Catharines (**STC**); Thunder Bay (**TDB**); Vineland Ritterhouse (**VNR**); Wawa (**WAW**); Welland (**WEL**); Wiarton (**WIA**); Windsor (**WIN**).

Many species are habitat generalists, while some, such as *Nehalennia gracilis*, specialize in specific habitats (in this case, sphagnum bogs, similar to *N. speciosa* in Europe (Lam 2004, Dijkstra 2006)).

Due to their range of habitat preferences, some species are found in only a single region of the province; for example, many species, such as *Sympetrum vicinum* and *Celithemis elisa*, are found only in the southernmost regions of the province, while species such as *Aeshna juncea* and *Somatochlora whitehousei* are found only in the north. Still other species, such as *Leucorrhinia hudsonica*, are found throughout the province. Some species, while found over a large area, have a patchy distribution, due to the limited presence of their preferred habitat type. Finally, some species, such as *Anax junius*, are migratory: in this case, individuals will fly south in the fall, and the offspring they produce will return to Ontario in the spring. In the case of *A. junius*, only some



**Figure 2.** Map of the Province of Ontario, showing county boundaries and latitude ( $^{\circ}\text{N}$ ). Odonate presence/absence was recorded and analysed on a county by county basis. Northern range extensions were calculated by assessing the mean and northernmost extent of the counties in which each species was found.

populations are migratory; others, often found in the same habitats with individuals that migrate, remain in Ontario throughout the year, completing their entire life cycle in these lakes and ponds.

## Methods and results

### Unadjusted estimates of climate change in Ontario

We assembled data on maximum and minimum monthly temperatures collected at 31 weather stations throughout Ontario (Canadian Centre for Climate Modelling and Analysis, <http://www.cccma.ec.gc.ca/data/data.shtml>), starting in January 1945 and continuing through 2000, (Figure 1, Table 2). These data approximately coincide with the time period of our odonate distribution data (see below). Fluctuations in the mean monthly temperatures of three winter months and three summer months over these decades are shown in Figure 3a and 3b.

**Table 1.** List of Ontario odonate species found in datasets used in this analysis. Species are grouped by suborder and family. The change in northernmost latitude by county between the 1950’s and 2002 is listed as increased (+), decreased (-) or unchanged (U).

SUBORDER/ Family	Change	SUBORDER/ Family	Change
<b>ANISOPTERA</b>		<i>Somatochlora septentrionalis</i>	U
<b>Aeshnidae</b>		<i>Somatochlora albicincta</i>	U
<i>Boyeria vinosa</i>	+	<i>Somatochlora hudsonica</i>	U
<i>Boyeria grafiana</i>	U	<i>Somatochlora cingulata</i>	U
<i>Basiaeschna janata</i>	U	<i>Cordulia shurtleffi</i>	U
<i>Nasiaeschna pentacantha</i>	-	<i>Dorocordulia libera</i>	-
<i>Epiaeschna heros</i>	+	<b>Gomphidae</b>	
<i>Aeshna eremita</i>	U	<i>Hagenius brevistylus</i>	U
<i>Aeshna interrupta interrupta</i>	U	<i>Ophiogomphus colubrinus</i>	U
<i>Aeshna interrupta lineata</i>	-	<i>Ophiogomphus carolus</i>	-
<i>Aeshna canadensis</i>	U	<i>Ophiogomphus rupinsulensis</i>	+
<i>Aeshna clepsydra</i>	U	<i>Ophiogomphus anomalus</i>	-
<i>Aeshna tuberculifera</i>	+	<i>Lanthus albistylus</i>	-
<i>Aeshna sitchensis</i>	U	<b>Gomphidae (cont’d)</b>	
<i>Aeshna umbrosa</i>	U	<i>Gomphus lividus</i>	-
<i>Aeshna constricta</i>	+	<i>Gomphus graslinellus</i>	U
<i>Anax junius</i>	+	<i>Gompus exilis</i>	U
<i>Cordulegastridae</i>		<i>Gomphus quadricolor</i>	+
<i>Cordulegaster maculatus</i>	+	<i>Gomphus spicatus</i>	U
<i>Cordulegaster diastatops</i>	-	<i>Gomphus villosipes</i>	-
<i>Cordulegaster obliquus</i>	U	<i>Gomphus furcifer</i>	+
<b>Corduliidae</b>		<i>Gomphus cornutus</i>	U
<i>Neurocordulia yamaskanensis</i>	-	<i>Gomphus descriptus</i>	-
<i>Epithea princeps</i>	U	<i>Gomphus fraternus</i>	U
<i>Epithea cynosura</i>	+	<i>Gomphus vastus</i>	U
<i>Epithea spinigera</i>	U	<i>Gomphus brevis</i>	U
<i>Epithea canis</i>	U	<i>Gomphus scudderi</i>	+
<i>Helocordulia uhleri</i>	U	<i>Gomphus notatus</i>	U
<i>Williamsonia fletcheri</i>	-	<i>Dromogomphus spinosus</i>	U
<i>Somatochlora walshii</i>	-	<b>Libellulidae</b>	
<i>Somatochlora minor</i>	U	<i>Nannothemis bella</i>	-
<i>Somatochlora elongata</i>	-	<i>Perithemis tenera</i>	+
<i>Somatochlora williamsoni</i>	+	<i>Celithemis eponina</i>	U
<i>Somatochlora tenebrosa</i>	-	<i>Celithemis elisa</i>	U
<i>Somatochlora franklini</i>	U	<i>Libellula quadrimaculata</i>	U
<i>Somatochlora kennedyi</i>	-	<i>Libellula/Ladona julia</i>	U
<i>Somatochlora forcipata</i>	+	<i>Libellula lydia</i>	-
<i>Somatochlora whitehousei</i>	U	<i>Libellula luctuosa</i>	-

SUBORDER/ Family	Change	SUBORDER/ Family	Change
<i>Libellula pulchella</i>	U	<i>Lestes inequalis</i>	-
<i>Libellula semifasciata</i>	-	<i>Lestes congener</i>	U
<i>Libellula incesta</i>	+	<i>Lestes unguiculatus</i>	-
<i>Libellula vibrans</i>	U	<i>Lestes dryas</i>	-
<i>Erythemis simplicicollis</i>	+	<i>Lestes disjunctus</i>	U
<i>Pachydiplax longipennis</i>	+	<i>Lestes forcipatus</i>	+
<i>Sympetrum corruptum</i>	-	<i>Lestes rectangulais</i>	-
<i>Sympetrum vicinum</i>	+	<b>Coenagrionidae</b>	
<i>Sympetrum costiferum</i>	U	<i>Argia moesta</i>	U
<i>Sympetrum semicinctum</i>	-	<i>Argia apicalis</i>	-
<i>Sympetrum danae</i>	U	<i>Argia tibialis</i>	+
<i>Sympetrum rubicundulum</i>	-	<i>Argia sedula</i>	U
<i>Sympetrum internum</i>	U	<i>Argia translata</i>	U
<i>Sympetrum obtrusum</i>	U	<i>Argia violacea</i>	U
<i>Leucorrhinia hudsonica</i>	U	<i>Chromagrion conditum</i>	-
<i>Leucorrhinia patricia</i>	U	<i>Amphiagrion saucium</i>	+
<i>Leucorrhinia glacialis</i>	U	<i>Nehalennia irene</i>	U
<i>Leucorrhinia proxima</i>	U	<i>Nehalennia gracilis</i>	+
<i>Leucorrhinia frigida</i>	U	<i>Coenagrion resolutum</i>	U
<i>Leucorrhinia intacta</i>	U	<i>Coenagrion interrogatum</i>	U
<i>Tramea carolina</i>	-	<i>Enallagma carunculatum</i>	U
<i>Tramea lacerata</i>	+	<i>Enallagma civile</i>	-
<i>Pantala hymeneia</i>	-	<i>Enallagma boreale</i>	U
<i>Pantala flavescens</i>	+	<i>Enallagma cyathigerum</i>	-
<b>Macromiidae</b>		<i>Enallagma vernale</i>	U
<i>Didymops transversa</i>	U	<i>Enallagma hageni</i>	U
<i>Macromia illinoiensis</i>	U	<i>Enallagma ebrium</i>	-
<b>ZYGOPTERA</b>		<i>Enallagma geminatum</i>	+
<b>Calopterygidae</b>		<i>Enallagma exsulans</i>	-
<i>Calopteryx maculatum</i>	-	<i>Enallagma antennatum</i>	-
<i>Calopteryx aequabilis</i>	U	<i>Enallagma apersum</i>	-
<i>Hetaerina americana</i>	+	<i>Enallagma vesperem</i>	-
<b>Lestidae</b>		<i>Enallagma signatum</i>	+
<i>Lestes eurinus</i>	+	<i>Ischnura posita</i>	+
<i>Lestes vigilax</i>	-	<i>Ischnura verticalis</i>	U

To test whether overall temperatures in Ontario have changed over this period, and estimate the size of these changes we fitted a General Linear Model (GLM) to the climatological data with year as a covariate and site as a random factor. These analyses indicated a significant increase in minimum, mean and maximum temperature over the period 1945 to 2000 (see Table 3 for results), as well as a significant site effect. The rates of temperature

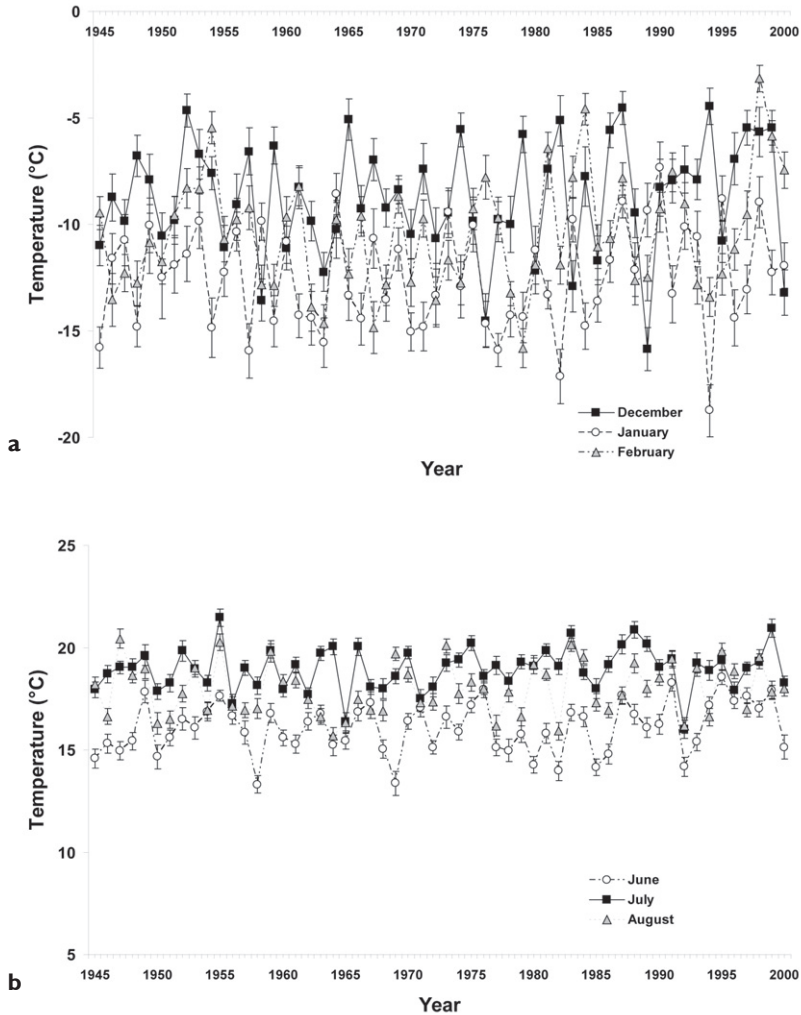


**Table 2.** List of Ontario weather stations with their latitude and longitude coordinates.

Station Name	Latitude (N)	Longitude (W)
Belleville	44.15	77.40
Big Trout Lake	53.82	89.90
Cameron Falls	49.15	88.35
Earlton	47.70	79.85
Fort Frances	48.65	93.43
Gore Bay	45.88	82.57
Haliburton	45.03	78.53
Harrow (Aut)	42.03	82.90
Kapuskasing A	49.42	82.47
Kapuskasing B	49.40	82.43
Kenora	49.78	94.37
Lansdowne House	52.20	87.93
London	43.03	81.15
Mine Centre	48.77	92.62
Moosonee	51.27	80.65
North Bay	46.37	79.42
Orono	43.97	78.62
Ottawa	45.38	75.72
Ottawa MDonald	45.32	75.67
Peterborough	44.23	78.37
Pickle Lake	51.45	90.22
Ridgetown	42.45	81.88
Sault Ste Marie	46.48	84.52
Sioux Lookout	50.12	91.90
St Catharines	43.20	79.17
Thunder Bay	48.37	89.33
Vineland Ritterhouse	43.17	79.42
Wawa	47.97	84.78
Welland	43.00	79.27
Wiarton	44.75	81.10
Windsor	42.27	82.97

increase were relatively consistent throughout the year such that temperatures in Ontario have increased at the rate of about 0.02°C per year (1°C in 50 years) in both summer and winter months (Figure 3a and 3b, Figure 4). These results are in line with larger-scale assessments of climate change, which have found increases in mean annual temperatures throughout southern Canada ranging from 0.5°C to 1.5°C over the 20th Century (Bonsal et al. 2000, Zhang et al. 2001). Our analysis does not account for important effects such as urbanisation (Prokoph and Patterson 2004), which could artificially increase estimates of rates of change of temperature at many of our locations where weather stations are situated. The significant differences in temperatures among sites are not unexpected, since sites in the northern regions of Ontario are consistently colder throughout the year.





**Figure 3.** Mean annual temperature across each of 31 Ontario weather stations for **a** the months of December, January and February and **b** June, July and August from 1945 to 2000.

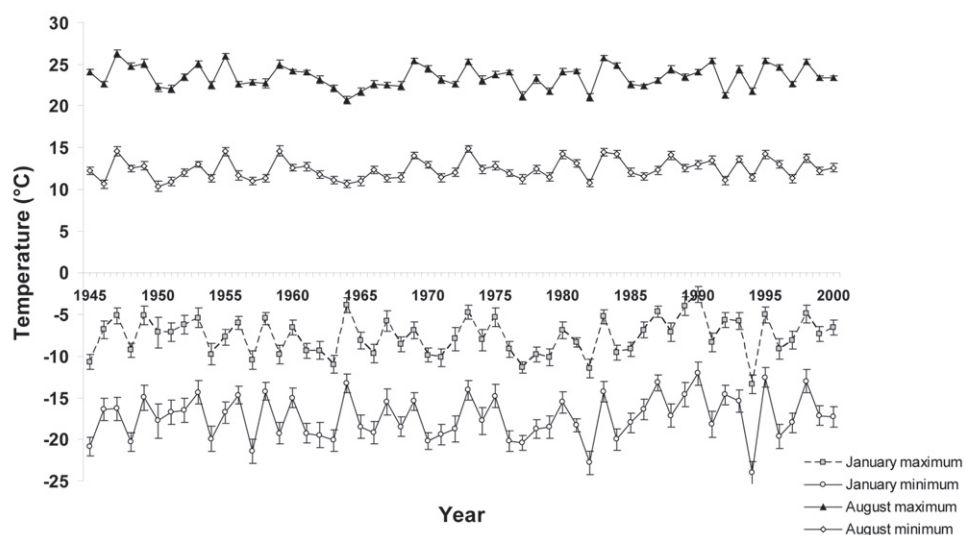
### Changes in Odonate Distributions in Ontario

To assess potential responses to the changing climate of Ontario, we assembled county distribution data for dragonflies and damselflies from two sources. First, historical distributions were gleaned from the volumes of *The Odonata of Canada and Alaska* by Walker (vol. 1, 1953, vol. 2, 1958) and Walker and Corbet (vol. 3, 1978). Data for suborder Zygoptera (damselflies) in volume 1 were collected from 1906 through 1952. For the Anisoptera (dragonflies), volume 2 provided data on the families Aeshnidae, Petaluridae, Gomphidae and Corduligratidae from 1906–1955, while volume 3 contained information on the anisopteran families Macromiidae, Corduliidae and Libellulidae from 1907–1973.

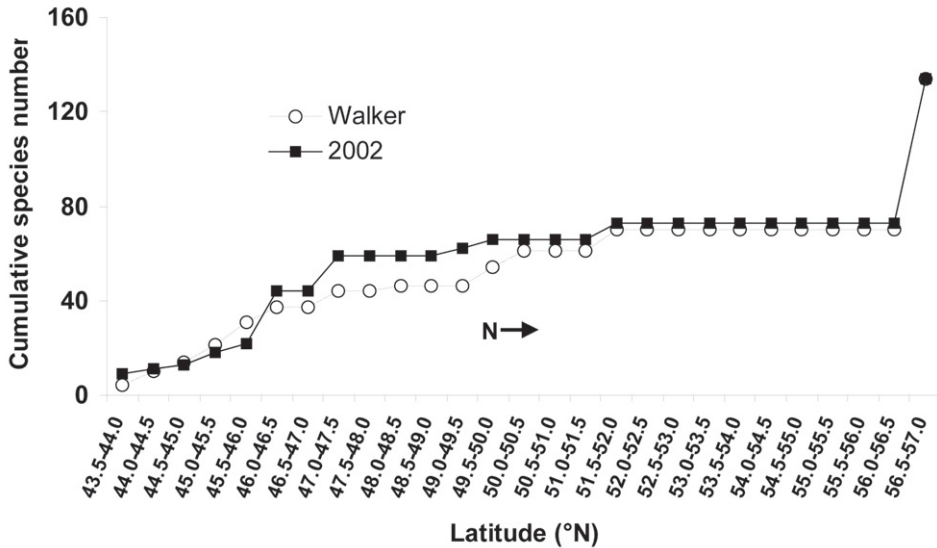
**Table 3.** Mean estimated yearly rate of temperature increase in degrees Celsius (°C) over 31 weather stations in Ontario in the years 1945–2000 (un-adjusted for factors such as urbanization).

	Minimum Temp.	Mean Temp.	Maximum Temp.
January	0.022**	0.017**	0.012*
February	0.033**	0.029**	0.026**
March	0.020**	0.017**	0.014**
April	0.010**	0.013**	0.016**
May	0.034**	0.037**	0.040**
June	0.021**	0.016**	0.012**
July	0.017**	0.010**	0.003
August	0.018**	0.011**	0.004
September	0.018**	0.013**	0.008**
October	0.011**	0.024**	0.037**
November	0.005	0.004	0.004
December	0.032**	0.028**	0.024**

\*Denotes significant departure from 0 at  $P \leq 0.005$ ; \*\* $P \leq 0.001$

**Figure 4.** Maximum and minimum temperatures (°C) in January and August averaged across 31 weather stations in Ontario from 1945 to 2000.

For current distributions we have synthesized data from volume 4 of Ontario Odonata by Catling, Jones and Pratt (2004). These recent data represent known distributions as of 2002 and comprise 6,700 recorded sightings by 43 different contributors. Records were compiled into databases at the regional level and then passed to a provincial compiler to create a single database. Unusual records were discussed with contributors to ensure a level of certainty. Voucher specimens were required for the most

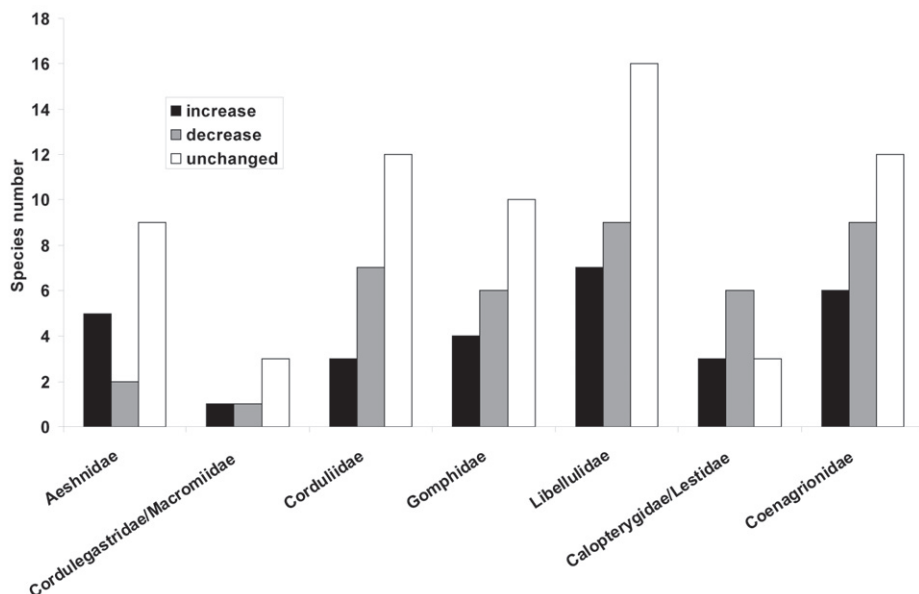


**Figure 5.** Cumulative number of species that have reached their northernmost extent in each of our two datasets, as a function of increasing latitude. Both datasets include the same 134 species of odonate. Between latitudes of 46°N and 50°N, a higher number of species were detected at their northernmost extent in 2002 than were detected in the 1950's. This reflects a marginal overall decrease in the maximum extent of several species in the 2002 dataset – the opposite trend would be expected for a pattern of climate-driven northward range expansion. The final increase in species number in the highest latitude range represents those species whose latitudinal extent reaches the northern border of Ontario.

significant records. Included in these different surveys over several decades are data on 134 species, with 39 damselflies (suborder Zygoptera) and 95 dragonflies (suborder Anisoptera) (see Table 2 for species list).

Since the records of occurrence were only at the county level, some analysis was required to match historic and current distributions of Ontario odonates to geographical latitudes. For each county, the geographic boundaries were used to determine the northern extent of the county in terms of latitude, which allowed for an estimate of the maximum northerly latitude of a species based on the northern-most county observation. The median latitude of each county was also determined given the geographical boundaries of the county. The median latitude of the county enabled an estimation of the average latitude of the range of the species within Ontario given its presence in a number of counties. Some counties that had been sampled by Walker were not sampled in the 2002 data; when historic and current data were matched, data from a total of 41 counties could be assembled, though inevitable variation exists as to the extent of sampling within different counties.

Of the 134 species of odonate included in the study, 29 showed an increase in northern range extension between the two datasets (based on the northernmost latitude of the northernmost county in which the species was detected), while 40 species actually showed a decrease. Sixty-five species showed no change in their

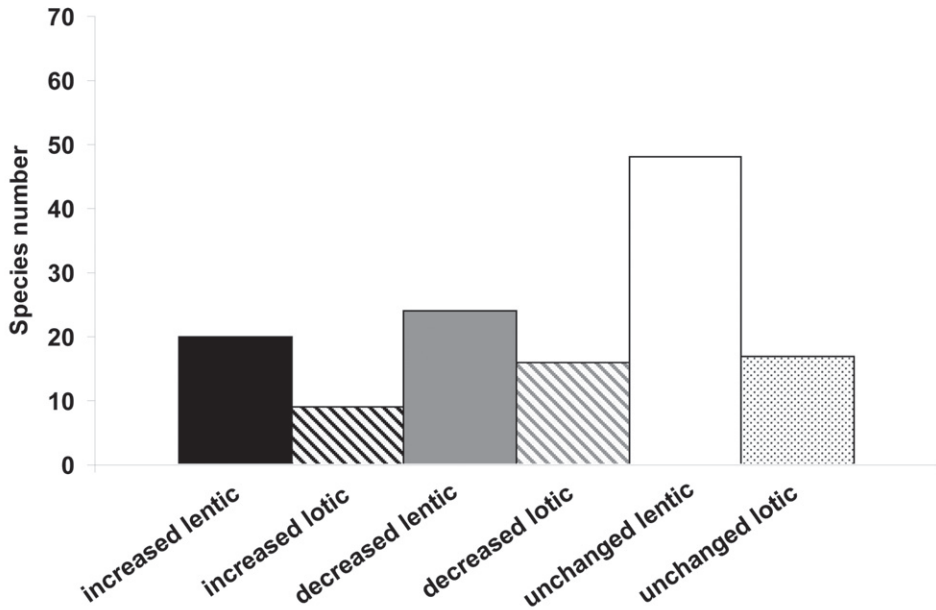


**Figure 6.** Differences in northern latitudinal extent between 1950's and 2002 of Ontario odonate species, showing species broken down into family groups. For most groups, the number of species with increased and decreased ranges is not significantly different; the majority of species remain unchanged.

most northerly distribution. Comparing the total number of species at their northernmost extent in each survey as a function of latitude (Figure 5) we do not see, as might be expected, an increase in the northern ranges of species in the 2002 dataset. In fact, a larger number of species in the 2002 dataset reach their latitudinal maximum between 46° N and 50°N than in the Walker dataset, indicating a slight trend toward a decrease in the latitudinal ranges for some species between the 1950's and 2002.

To determine whether differences could be found among taxonomic groups, we compared family-level distributions between datasets. We found similar patterns within family to those for the overall order (Figure 6) – thus, even at the family level, no significant overall increase (or decrease) was detected for any group.

It has been suggested that odonate species which inhabit lentic habitats (non-moving water, such as lakes and ponds) have larger and more northern distributions than those that inhabit lotic (river and stream) habitats (Hof et al. 2006). Hof and colleagues found this to be the case for odonates throughout Europe and North America, suggesting that the lower stability of lakes and ponds through time (in comparison to streams and rivers) require lentic species to have higher dispersal rates. As such, lentic species might be quicker to respond to increasing temperatures, and thus might expand their ranges northward more rapidly than lotic species. We compared lentic to lotic species (92 species versus 42 species, respectively), but found no difference in the pattern of latitudinal extent between these two groups (Figure 7).



**Figure 7.** Differences in northern latitudinal extent between 1950's and 2002 of Ontario odonate species, showing species that are found in lentic (lake, pond and marsh) habitats versus lotic (stream and river) habitats. Species are listed based on whether they have shown an increase in latitudinal extent, a decrease in latitudinal extent, or no change.

## Discussion

### Preliminary conclusions

Our first-step analysis of evaluating the responses of Odonates to changes in climate has concentrated on temperature, although we recognise that rainfall may also have the potential to influence the breeding ecology (and hence distribution) of Odonates (Cannings and Cannings 1998). We have found that, while increases in the recorded minimum, maximum and mean monthly temperatures in Ontario have been observed over the time interval between 1945 and 2000, no consistent pattern of change in the northern extensions of our studied odonate species is detectable. This is surprising, as changes in range size and northward extent, as well as changes in life history, have been observed in odonates in a warming European climate (Hickling et al. 2005, Hassall et al. 2007, Ott 2007).

A number of difficulties often arise in the collection of time-series data such as those used for these analyses. First, uneven sampling effort may lead to differences in levels of detection at different times. For example, if a lower amount or intensity of sample effort (fewer sample events, or fewer collectors) takes place during a specific phase of the sampling, species may be underrepresented, and the full distribution of

some species—especially rare species—may not be determined (Southwood & Henderson 2000). As is often the case with survey data, later samples in our data (from the 2002 source) were done more consistently—by a large number of people—than our earlier data, which was collected by Walker and his colleagues. Thus, the detection of an expanded range for a species—particularly a species with low densities or a patchy distribution—may be an artefact of sampling.

Secondly, uneven sampling within a sample period (for example, our 2002 dataset) may lead to biased assessments of species distributions. Sampling may favour urban areas, with large numbers of collectors and with greater access to habitats. Large areas with low human population densities will likely be sampled less effectively and could result in uneven recordings of species distributions. This could be problematic in our dataset, in that the northernmost counties of Ontario are the largest, least populated and least accessible; these are also the most crucial to sample in the detection of northward range changes.

The use of county-level presence data is also problematic, in that there is a great range of sizes in county areas in Ontario (see Figure 2); thus, recording presence at the county level represents an uneven sample effort. Many modern surveys record latitude and longitude of the actual sample location – this is made all the more easy due to the availability of hand-held global positioning system (GPS) receivers. However, older data, such as those used here, often are not recorded with such accuracy. A potential problem with county record data when analyzing changes is distribution patterns comes if county sizes are clustered – that larger counties are grouped in an area together. In our data, the fact that larger counties in Ontario tend to be in the northern part of the province could lead to an inflated increase in northern range extensions in species, as any record within a large county could represent a considerable northward latitude increase for that species.

## **Future Work**

We observe that, while we did not find a significant trend in the change of species distributions in our dataset, this may be due not to absence of a change, but an inability to detect such change with the current data. Ontario is a large province, with many remote areas that are difficult to sample. Still, increased interest has been seen in recent years in dragonflies and damselflies, reflected by the development of regional groups of odonate enthusiasts throughout North America, and the increased availability of field guides. We welcome this increase in public interest and awareness, and hope that it continues to contribute to the growing availability of data species distributions. We encourage our readers, in Ontario and elsewhere, to become involved in the collection and synthesis of dragonfly distribution data, which will improve our understanding of these organisms. Those specifically interested in Ontario odonata can become involved by contacting the Natural Heritage Information Centre with the Ontario Ministry of

Natural Resources, the Toronto Entomological Society, or other naturalist organisations in the region.

When considering the distribution patterns of odonate species, intriguing trends can be observed. While some species in this survey were found throughout the province, others are limited to a distinct region. While some species distributions can be explained by the extent of a habitat type (Precambrian Shield lakes, for example) other species show distinct distribution boundaries that do not match to discrete landscape features. For these species – such as *Aeshna canadensis*, *Erythemis simplicicollis* or *Enallagma civile* – range boundaries appear to be limited primarily by a maximum latitudinal extent. It may be that climatic patterns are the limiting factor in the distribution of these species; We propose, in future work focusing on species such as these and employing a larger and more robust dataset for North American odonates, to further and more rigorously explore the relationship between odonate distributions and climate change

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