Climate Warming as an Explanation for the Recent Northward Range Extension of Two Dragonflies, *Pachydiplax longipennis* and *Perithemis tenera*, into the Ottawa Valley, Eastern Ontario

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Climate warming is accepted as an explanation for the recent appearance of Blue Dasher, *Pachydiplax longipennis* (Burmeister, 1839), and Eastern Amberwing, *Perithemis tenera* (Say, 1839), in the Ottawa region, as this range expansion meets 6 criteria: (1) the climate in the newly occupied territory has warmed sufficiently to allow colonization; (2) a new range expectation based on the amount of climate warming is met; (3) other factors potentially promoting spread are excluded; (4) the possibility that range extension is a result of difficulty of observation and/or insufficient fieldwork in earlier times is excluded; (5) there is ample evidence for establishment; and (6) spread has been in the direction of the warmer territory or within it. By 2000, the mean daily temperature in the Ottawa region had increased by about 2°C since 1880 and about 1.1°C since 1960. This would allow new zonal boundaries and the prediction of expansion from a well-defined and long-occupied area into the Ottawa Valley. The two species entered this region in 2008–2012 and, subsequently, became well established.

Key Words: Climate warming; climate change; range extension criteria; dragonflies; Odonata; Blue Dasher; *Pachydiplax longipennis*; Eastern Amberwing; *Perithemis tenera*; Libellulidae; Ottawa Valley; Ontario

Introduction

The geographic limits of flora and fauna have shifted northward over the past few decades in response to recent climatic warming (Hickling *et al.* 2005; Flenner and Sahlen 2008; Mason *et al.* 2015). A sufficient number of examples now exist so that climate warming must be associated with range expansion. However, specific decisions to implicate climate warming are often not cautious and may be presented with limited understanding of other potentially contributing factors. Here, criteria are applied to such a decision with regard to dragonflies (Odonata), a group highly sensitive to climatic factors (Bush *et al.* 2013).

Although several articles have related changes in the distribution of Ontario's odonates to climate warming (Catling and Brownell 1998, 2002 [with statistics]; Bracken and Lewis 2002; Catling 2004, 2005, 2008), these alluded to warming only as a possible factor and were not rigorous in the association. The most compelling evidence for the importance of climate warming involves 2 dragonflies: Blue Dasher, *Pachydiplax longipennis* (Burmeister, 1839), and Eastern Amberwing, *Perithemis tenera* (Say, 1839), in the Ottawa Valley (Hanrahan 2011; Reddoch and Reddoch 2012; Hutchinson *et al.* 2014a,b). These species are investigated with respect to specific criteria.

Methods

The following criteria were developed to determine whether or not the range extension of *P. longipennis* and *P. tenera* is largely a result of climate warming.

Sufficient climate warming

The climate in the newly occupied territory must have warmed sufficiently to allow colonization. The warming should be of a magnitude equal to the difference between biogeographic zones. Biogeographic boundaries, such as Ontario's Carolinian Zone (which approximates the 7.8°C isotherm in Figure 1, also called the eastern deciduous forest in New York State, where it reaches its northern limit on the southeastern corner of Lake Ontario, or the middle south shore of the lake) are associated with climate boundaries, such as mean annual length of growing season, mean annual frost-free period, and mean daily temperature for the year (see Brown *et al.* 1980). The difference between biogeographic zones in southern Ontario, such as the Carolinian Zone, the Carolinian Zone with Georgian Bay and eastern Lake Ontario satellites (6.7°C isotherm in Figure 1), and the sub-Algonquin region (the northern boundary approximating the 5.5°C isotherm in Figure 1) is 1°C. Thus a rise in temperature of this magnitude may be sufficient to move to a new boundary.

Average yearly temperatures for Ottawa from 1880 to 2014 were acquired from the monthly averages data provided by Environment Canada (2015; Figure 2). These were plotted to determine whether there had been an increase of 1° or 2°, permitting zonal expansion. Statgraphics (Statpoint 2005) was used to produce a second-order polynomial regression plot. This method was employed because significance was above 95% and it explained more variation than other models.

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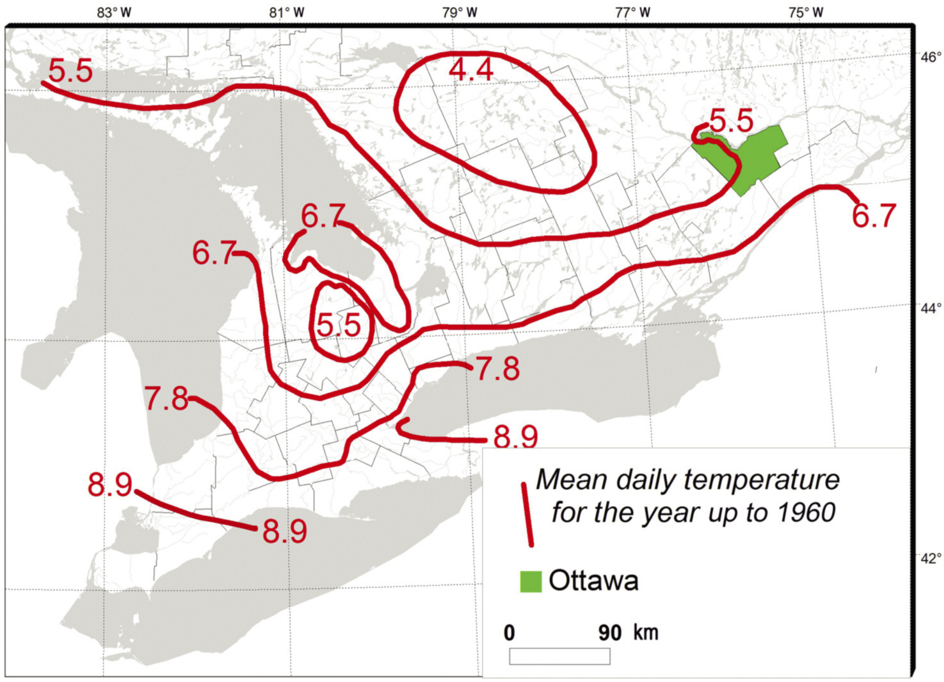

FIGURE 1. Mean daily temperature isotherms (°C) for southern Ontario. The City of Ottawa (previously Carleton County or the Regional Municipality of Ottawa-Carleton) is shaded in green. With immediately adjacent areas, this is considered to be the "Ottawa region." Source: Brown *et al.* (1980: Figure 7).

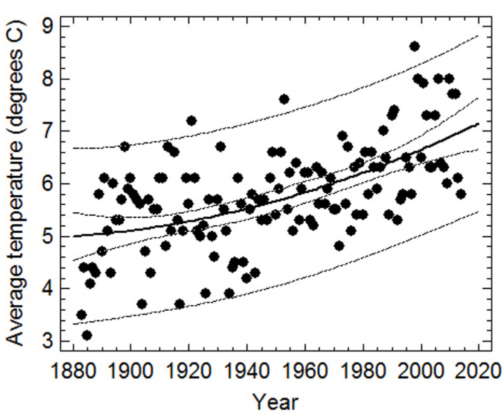

FIGURE 2. Mean daily temperature for each year, 1880–2014, at Ottawa, Ontario, Canada. The dark central line is the regression. The pair of lines closest to it are limits for confidence intervals for means (95%). The outer pair of lines are limits for predictions (95%).

New range expectation

The expansion should fulfill an expectation based on warming. If average yearly temperature has increased by 1°C during a specific period, and this is deemed sufficient, then the range may be expected to extend to the new limit, which is likely defined by an adjacent isotherm (assuming that factors governing isotherms, such as topography, have not changed). In this case, we would expect the 2 dragonflies to have extended their range to the 7.8°C isotherm, which was the former 5.5°C isotherm (Figure 1) based on extension from a 5.5–6.7°C boundary. This would include the Ottawa region defined as the City of Ottawa (previously Carleton County or the Regional Municipality of Ottawa-Carleton). The former 5.5°C isotherm is based on data from 1931–1960 (Brown *et al.* 1980), although the publication date is 1980. The latter date corresponds to a 0.8°C increase but, since the end of the record period for Brown *et al.* in 1960, the mean daily temperature for the year has increased by about 1.1°C. Plotting records contained in the Ontario Odonata Survey (Catling and Jones 2007) and the Ontario Odonata Atlas database (maintained by C. Jones at the Ontario Natural Heritage Information Centre in Peterborough) from

2007 onward enabled a consideration of the extent to which the new range expectation was fulfilled.

Exclusion of other factors

The rapid and extensive range expansion of several odonate species is thought to be related to new kinds of aquatic habitat provided by humans. Expansion of the Familiar Bluet, *Enallagma civile* (Hagen, 1861), in Ontario (Catling 1996) and the northeast generally (Catling 1998) is a good example of a species that occurs in eutrophic goldfish ponds as well as many other man-made and polluted habitats. To some extent, its expansion may be a result of these new man-made habitats. The same may be true of the Great Spreadwing, *Archilestes grandis* (Rambur, 1842), which in North America was confined to the southwestern states until the 1920s, then spread east and northeast to New England, presumably as a result of its extreme tolerance of poor water quality and degraded habitats (Kennedy 1977; Moskowitz and Bell 1998; Craves 2006). Many factors may play a role in range expansion, but for climate warming to be considered a major factor, some of these other factors must be eliminated.

Sufficient evidence for extension

An extension of range might result from occurrences that were overlooked in the past for any of a variety of reasons, particularly difficulty of observation or insufficient field study. The species must be conspicuous, and there must have been enough past fieldwork in the area under consideration to infer strongly that a particular species is a new arrival that, at one time, had a reliably more restricted occurrence. Insufficient data or limited recognition are sometimes referred to as the "recorder effect." This was evaluated in 4 ways.

Time-coded distribution: Distribution maps were produced with dates of occurrence coded for "prior to 1999" and "1999 and after," with the earlier period plotted last to emphasize differences since that time. These indicate expansion and also the number and distribution of records on which it is based. The year 1999 was chosen because it was during and after this date that significant expansion occurred based on mapping and observations (Tables 1 and 2; PMC, personal observation).

Comparison species: Comparisons were made with other species that have not changed their distribution in the region under study. This illustrates the distribution of observations of dragonflies and may suggest true absence of target species if the comparison species were present, occupied similar habitats, and were similarly conspicuous. The 2 comparison species used were Twelve-spotted Skimmer, *Libellula pulchella* Drury, 1773, which is slightly more conspicuous than our target species, and Four-spotted Skimmer, *Libellula quadrimaculata* Linnaeus, 1758, an equally conspicuous species. If these comparison species were present in the areas of the recently expanded range during the early period, then the 2 target species would have been noticed as well; if the target species were not noticed, they must have been truly absent.

Number of records: Number of records was plotted against time for each target species to indicate where and for what times the records are available. Ideally, there should be about the same number of records before and after a key date. At least there should be a relatively large number of records for each. The idea is that a much larger number of records for one period may include geographic areas not recorded for the other period of time because of unequal search effort.

Literature support: The older literature should support the idea that the expansion is recent by the absence of proposed recent immigrants and support for the earlier presence of comparison species.

Evidence for establishment

The species should be well-established, i.e., present in good numbers and over several years. Some populations, such as those of Citrine Forktail, *Ischnura hastata* (Say, 1839), appear to come and go at the northern limit of their range (Bree 2005; Catling 2008). Bree (2005) suggested that some populations of 3 odonate species with different dispersal mechanisms may establish only temporarily at their northern limit. Differences in weather from year to year have been associated with remarkable variations in abundance of mostly southern butterflies (PMC, personal observation). Thus, to accept that a species has extended its range, some evidence of permanent residency is necessary. This was considered in terms of records in consecutive years, presence of larvae or exuviae, and numbers of individuals encountered. Although this was sufficient in the present case, this criterion may be applied more rigorously (Bried *et al.* 2015a,b).

Direction and history of spread

Spread resulting from climate change should be in the direction of the warming climate. In the northern hemisphere, that direction would be north at uniform elevation. The range expansion of the damselfly, *Archilestes grandis* (see *Exclusion of other factors* above), is to some extent west to east; furthermore, the distance may have been more substantial than climate-warming effects alone can explain. Consequently, one is led to expect that factors other than, or in addition to, climate warming have played a role in the spread of this species. Criteria that support the climate warming explanation for range expansion include distance, terrain, direction, and timing.

Results

Sufficient climate warming

Since 1880, mean daily temperature for the year in Ottawa has increased by about 2°C, and since 1960 by about 1.1°C (Figure 2). The warming has been continuous. The P value for the ANOVA was < 0.001 and R^2 was 34.84%.

TABLE 1. Records of the Eastern Amberwing, *Perithemis tenera* (Say, 1839), in Ontario that are substantially outside of the pre-1999 distribution.

Year	Location*	Latitude, °N	Longitude, °W	Observer
1999	Blind Lake Bog, about 10.5 km N of Fordwich Post Office	43.9617	81.0511	M. J. Oldham, M. E. Austen
2001	Bloomfield Mill Pond	43.9863	77.2271	D. Bree
2002	Indian River mouth at Rice Lake, S of Keene	44.2388	78.1533	M. J. Oldham, V. and R. Oldham, M. Delisle-Oldham
2005	Indian River from bridge at Keene to mouth at Rice Lake	44.2517	78.1516	M. J. Oldham, M. Delisle-Oldham, R. Oldham
2010	Loughborough Lake at Perth Rd.	44.4181	76.4779	P. M. Catling
2011	Rideau River, Burritts Rapids	44.9823	75.7970	P. M. Catling
2012	N side E of Wellington opposite Conley Rd., West Lake	43.9587	77.3152	P. M. Catling
2012	Stoco Fen, Old Hungerford Rd., E of Stoco	44.4642	77.2322	J. Bartok
2012	Mud Lake pond, Britannia Conservation Area, Ottawa	45.2224	75.4743	B. Bracken, D. Moore
2012	Windsor Park, Rideau River	45.3938	75.6761	P. Hall
2012	Markham, opposite 7275 14th Avenue, about 0.5 km W of Reesor Rd.	43.8653	79.2082	B. Edwards, G. Yankech, I. Yankech, W. White
2012	Petrie Island inlet, Ottawa River	45.4995	75.4844	B. Bracken, C. Lewis
2012	Petrie Island inlet, Ottawa River	45.4995	75.4844	C. Hanrahan
2012	Haskins Rd., Burritts Rapids	44.9654	75.7934	B. Bracken, C. Lewis, M. Tate
2012	Petrie Island inlet, Ottawa River	45.4995	75.4844	L. de March
2012	Haskins Rd., Burritts Rapids	44.9654	75.7934	E. Thomson, B. McBride, D. Moore
2012	Snowdon Rd., Bolton Rd., Hanlon Marsh, Kemptville	44.5310	75.4434	M. Runtz, P. Hall
2012	Outlet River highway bridge, Sandbanks Provincial Park	43.8983	77.2212	D. Bree
2012	Outlet River above bridge, Sandbanks Provincial Park	43.9017	77.2177	D. Bree
2012	Lajoie Rd. and Trans-Canada Trail, Tweed	44.4769	77.3019	J. Bartok
2012	N of Stoco Lake, Tweed	44.4689	77.3153	J. Bartok
2012	N end of Conc. 4, N of Zephyr	44.2260	79.2504	J. Boxall, J. Hopkins, T. Lambert, D. Bishop, E. Poropat
2012	Trans-Canada Trail, Tweed	44.4667	77.3197	J. Bartok
2012	Trans-Canada Trail, Tweed	44.4826	77.2965	J. Bartok
2012	Moira River, "The Pointm", Tweed	44.4739	77.3072	J. Bartok
2012	Petrie Island, Trim Rd.	45.4995	75.4844	R. Yank
2012	Trans-Canada Trail, Tweed	44.4815	77.2978	J. Bartok
2012	Carrying Place, Rec. Field	44.0465	77.5786	D. Bree
2012	Trans-Canada Trail, Tweed	44.4592	77.3425	J. Bartok
2012	Haskins Rd., Burritts Rapids	44.9654	75.7934	B. Laporte, C. Lewis
2012	Quin-mo-lac Rd., S shore of Moira Lake	44.4750	77.4194	J. Bartok
2012	0.7 km W of Tweed	44.4689	77.3153	J. Bartok
2012	Stoco Lake, Tweed	44.4739	77.3072	J. Bartok
2012	Outlet River by County Rd. 18, Sandbanks Provincial Park	43.8983	77.2212	K. Kingdon
2012	Outlet River by County Rd. 18 Sandbanks Provincial Park	43.8983	77.2212	D. Bree
2012	Moira River and Stoco Lake, Tweed	44.4771	77.3018	J. Bartok
2012	Prince Edward Point	43.9433	76.8623	B. Ripley
2012	Outlet River, Sandbanks Provincial Park	43.8951	77.2186	J. Dewey
2012	Stoco Lake, Tweed	44.4741	77.3065	J. Bartok
2012	Outlet River, Sandbanks Provincial Park	43.8951	77.2186	J. Dewey
2012	Outlet River, Sandbanks Provincial Park	43.8951	77.2186	B. Ripley
2012	Outlet River, Sandbanks Provincial Park	43.8951	77.2186	J. Dewey
2012	Outlet River, Sandbanks Provincial Park	43.8951	77.2186	D. Bree
2012	Millpond, Bloomfield	43.9869	77.2258	D. Bree
2012	Sandbanks Provincial Park, Outlet River by County Rd. 18	43.8983	77.2211	J. Dewey
2015	W shore of Dow's Lake near marsh	45.3937	75.7031	P. M. Catling
2015	Petrie Island Causeway, E side	45.4993	75.4840	P. M. Catling

*Note: E = east, N = north, S = south, W = west.

TABLE 2. Records of the Blue Dasher, *Pachydiplax longipennis* (Burmeister, 1839), in Ontario that are substantially outside of the pre-1999 distribution.

Year	Location*	Latitude, °N	Longitude, °W	Observer
2002	Indian River mouth at Rice Lake, south of Keene	44.2388	78.1533	M. J. Oldham, V. and R. Oldham, M. Delisle-Oldham
2002	Indian River mouth at Rice Lake, south of Keene	44.2388	78.1533	M. J. Oldham, R. Oldham
2002	Lakefield Marsh	44.4271	78.2776	C. D. Jones
2009	W shore of Fishog Lake	44.7899	78.8947	D. Barry, M. Carney, E. Poropat
2009	NW end of Fishog Lake	44.7965	78.8951	D. Barry, M. Carney, E. Poropat
2009	S end in outflow of Fishog Lake	44.7727	78.8827	D. Barry, M. Carney, E. Poropat
2010	Baxter Conservation Area, Rideau River near Reevecraig	45.0977	75.6247	C. Hanrahan
2011	William A. Holland Trail, Petrie Island	45.4995	75.4844	B. Bracken, C. Lewis
2011	Mud Lake pond, Britannia Conservation Area, Ottawa	45.3731	75.7965	B. Bracken, C. Lewis
2011	Mud Lake pond, Britannia Conservation Area, Ottawa	45.3731	75.7965	M. Tate
2011	William A. Holland Trail, Petrie Island	45.4995	75.4844	B. Bracken, C. Lewis
2011	Mer Bleue Bog Trail, Ottawa	45.3920	75.5130	K. C. Hannah
2011	William A. Holland Trail, Petrie Island	45.4995	75.4844	G. Mastromatteo
2012	Mud Lake pond, Britannia Conservation Area, Ottawa	45.3731	75.7965	B. Bracken, C. Lewis
2012	Big Cedar Lake boat launch	44.6028	78.1641	D. Bree, K Holloway
2012	Mud Lake pond, Britannia Conservation Area, Ottawa	45.3731	75.7965	B. Bracken, C. Lewis, M. Tate
2012	S of Haycock Island, at Shirley's Bay, Ottawa River	45.3672	75.8907	B. Bracken, C. Lewis, M. Tate
2012	Constance Creek, Thomas A. Dolan Parkway, Dunrobin	45.4520	76.0309	B. Bracken, C. Lewis, M. Tate, G. Mastromatteo
2012	N of Rifle Rd., Shirley's Bay, Ottawa River	45.3672	75.8907	B. Bracken, C. Lewis
2012	N of Rifle Rd., Shirley's Bay, Ottawa River	45.3672	75.8907	G. Mastromatteo
2012	William A. Holland Trail, Petrie Island	45.4995	75.4844	B. Bracken, C. Lewis
2012	William A. Holland Trail, Petrie Island	45.4995	75.4844	G. Mastromatteo
2015	Dow's Lake, W side near marsh	45.3939	75.7035	P. M. Catling, B. Kostiuk
2015	Chapman Mills Conservation Area on the Rideau River	45.2780	75.7029	P. M. Catling, B. Kostiuk
2015	Petrie Island causeway	45.4991	75.4843	P. M. Catling, B. Kostiuk

*Note: E = east, N = north, S = south, W = west.

New range expectation

The specific expectation of colonization of the Ottawa region based on climate warming is fulfilled (see references above and Figures 1, 3, and 4).

Some details of the expansion are also useful in this evaluation. In 2000 Catling and Brownell (2000) noted that *P. tenera* was "restricted to the Carolinian Zone and a good example of a species that is relatively widespread and common in this region although narrowly restricted to it." Its Carolinian distribution was also noted by Catling *et al.* (1998). This Carolinian distribution, corresponding to the 7.8°C mean daily temperature for the year, is well shown by pre-1999 dots on the distribution map (Figures 1 and 3). In 2001, it was first observed in Prince Edward County, extending the range 140 km to the east (Bree 2005). In 2002, up to 25 males were counted at Bloomfield suggesting establishment, but from 2003 to 2005 they were not observed there. It was also in 2002 that *P. tenera* was found in the Indian River on Rice Lake in Peterborough (Table 1). In 2007 and afterward, it was found for the first time in the eastern townships of Quebec (Bernard 2010). In 2011 and 2012, it reached the Ottawa region about 150 km north from the Kingston region (PMC, personal observation) and 125 km north of the Thousand Islands region of New York State (White *et al.* 2010) where it had been known since 2005. From 2012 to 2015, it was seen at several localities in the Ottawa region of Ontario (Table 1). In 2012 and 2013, it was reported from 5 localities near the Ottawa River in Quebec (Hutchinson *et al.* 2014b).

Before 1999, *P. longipennis* was confined to the Carolinian Zone and its northeastern Lake Ontario satellite (Figures 1 and 4). Significant extensions in its range occurred after that (Figure 4 and Table 2). The first records in the City of Ottawa were from Burritts Rapids in 2008 (Table 2) and from Baxter Conservation Area on the Rideau in 2010 (Hanrahan 2011). In 2011 and 2012, it was reported from Petrie Island and Mud Lake on the Ottawa River by Reddoch and Reddoch (2012) and Mastromatteo (2012). Hutchinson *et al.* (2014a) and Mochon (2012) reported it to be present at many other places near the Ottawa River in 2012 and 2013, and by 2015 it was well known in the Ottawa region.

Exclusion of other factors

Many of the occurrences of *P. tenera* and *P. longipennis* north of their pre-1999 range in Ontario are in natural habitats with little or no impacts of human activ-

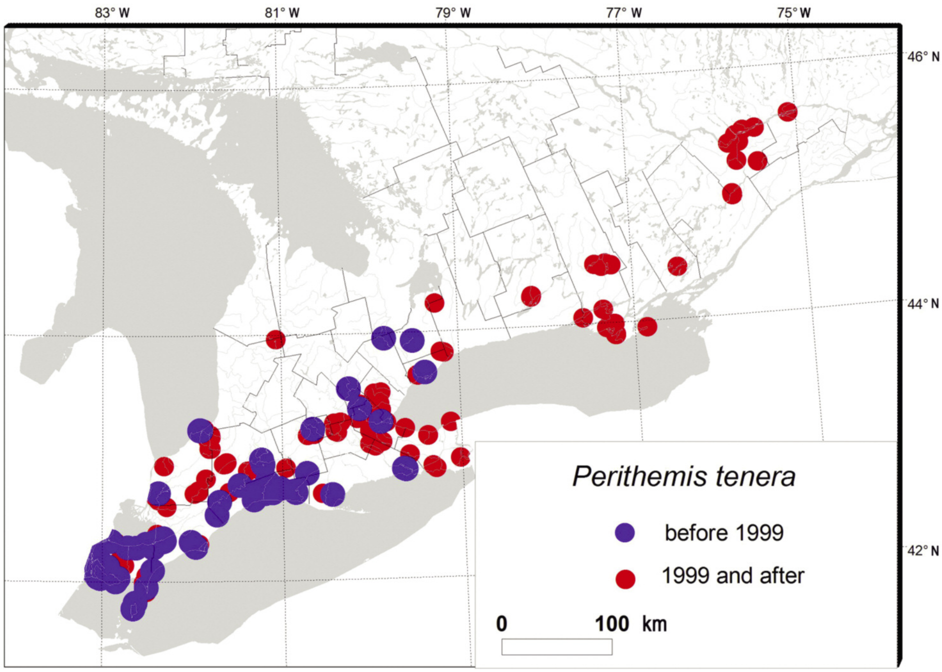

FIGURE 3. Distribution of *Perithemis tenera* in southern Ontario up to 1998 (blue dots) and 1999 and after (red dots). The blue dots were plotted over the red dots to emphasize recently expanded range.

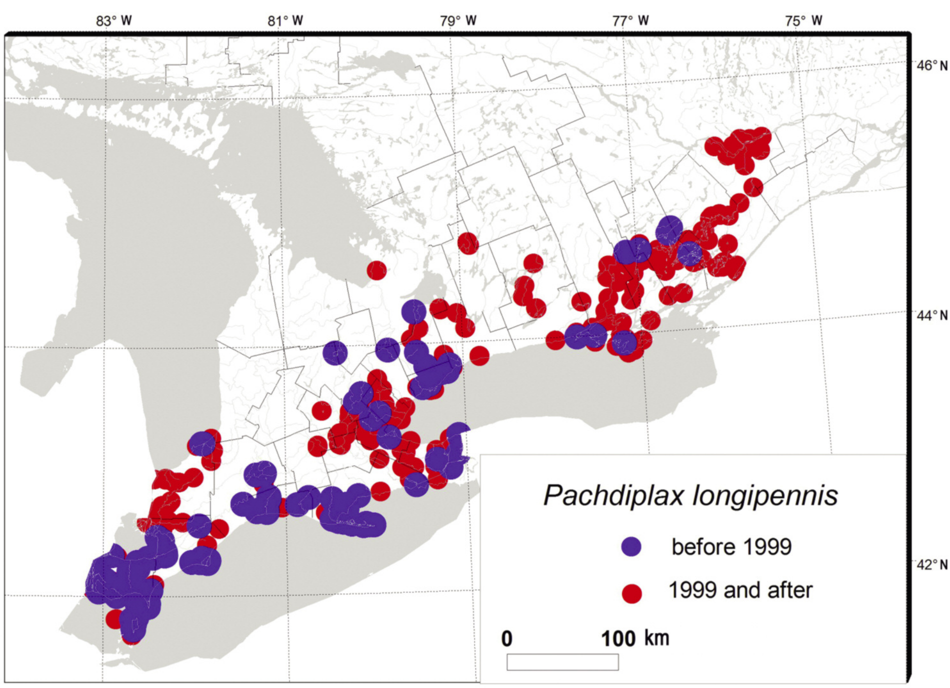

FIGURE 4. Distribution of *Pachydiplax longipennis* in southern Ontario up to 1998 (blue dots) and 1999 and after (red dots). The blue dots were plotted over the red dots to emphasize recently expanded range.

ity. *Perithemis tenera* is sometimes associated with polluted and turbid water, but only some of the new localities on and near the Ottawa River fit this description. In general, the habitats in the region that support expansion are not new.

Sufficient evidence for extension

Both *P. tenera* and *P. longipennis* are very conspicuous (Figure 5). Although females of the former may spend much time on land where they are not easily seen, the males, with amber wings, are conspicuous over water on lilypads (although often far from shore).

Time-coded distribution: The distribution mapping on Figures 3 and 4 clearly indicates expansion and suggests that it is based on ample records.

Comparison species: The presence of *L. pulchella* and *L. quadrimaculata* in the region of expansion and elsewhere (Figure 6) before 1999 suggests that recorders were present in pre-expansion times and their failure to encounter the 2 target species supports recent expansion.

Number of records: Although there are more records after the dispersal event, there are many before (Figure 7). For *P. tenera*, there are 361 records (unique date, place, and observer) beginning in 1929 (81 or 22.6% before 1998); for *P. longipennis*, there are 1135 records beginning in 1893 (201 or 17.7% before 1998; Figure 7). In the expansion area, there are 47 records (unique year, location, latitude, longitude, and observer/s) for *P. tenera* and 28 for *P. longipennis* (Tables 1 and 2). These expansion area records represent fewer than a quarter of the actual sightings in this area (PMC, personal observations), because many sightings were not accurately recorded nor submitted to the database.

Literature support: Comprehensive publications concerning dragonflies in the Ottawa region date back to 1886 (MacLaughlin 1886; Walker 1908; Ménard 1996; Sankey 1997; Bracken and Lewis 2004, 2005, 2008). No mention of *P. tenera* or *P. longipennis* was found in these. The 2 species selected for comparison were "rather plentiful" (*L. pulchella*) and "rather common" (*L. quadrimaculata*) in 1886 and noted consistently thereafter.

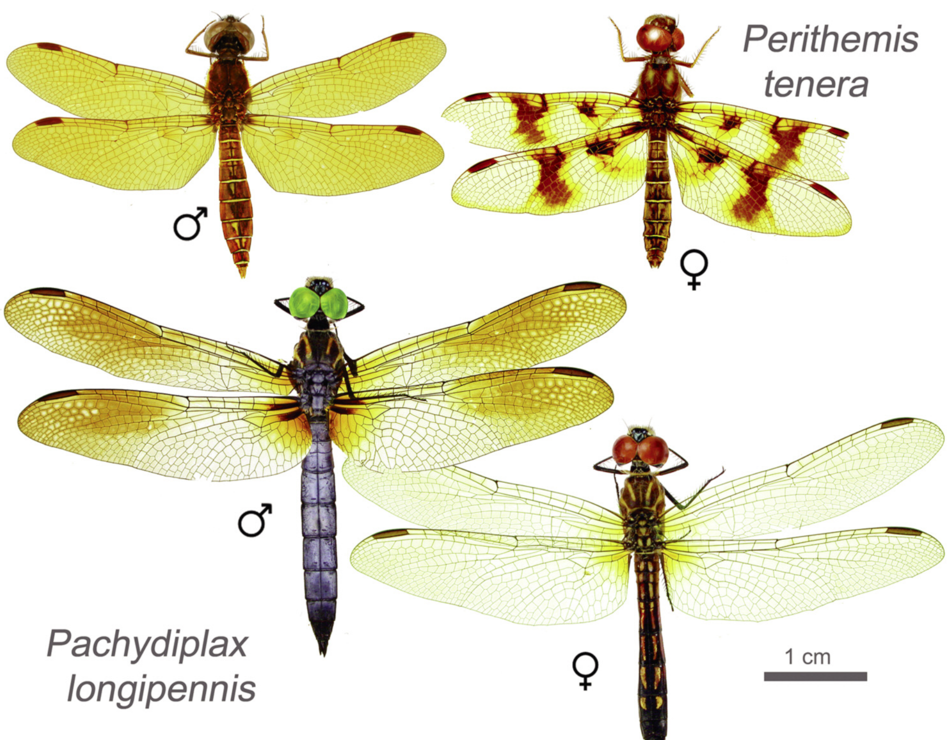

FIGURE 5. Two dragonflies that have recently expanded their ranges into the Ottawa Valley. Top: *Perithemis tenera* male, London, Ontario, 42.9444°N, 81.2197°W, P. M. Catling, 10 July 1997; female, Tilbury Conservation Area, Ontario, 42.2722°N, 82.4369°W, P. M. Catling, 5 July 1997. Bottom: *Pachydiplax longipennis* male, Crotch Lake, Ontario, 44.6583°N, 76.9708°W, P. M. Catling, 24 July 1997; female, Crotch Lake, Ontario, 44.6583°N, 76.9708°W, P. M. Catling, 9 August 1997. Photos: P. M. Catling.

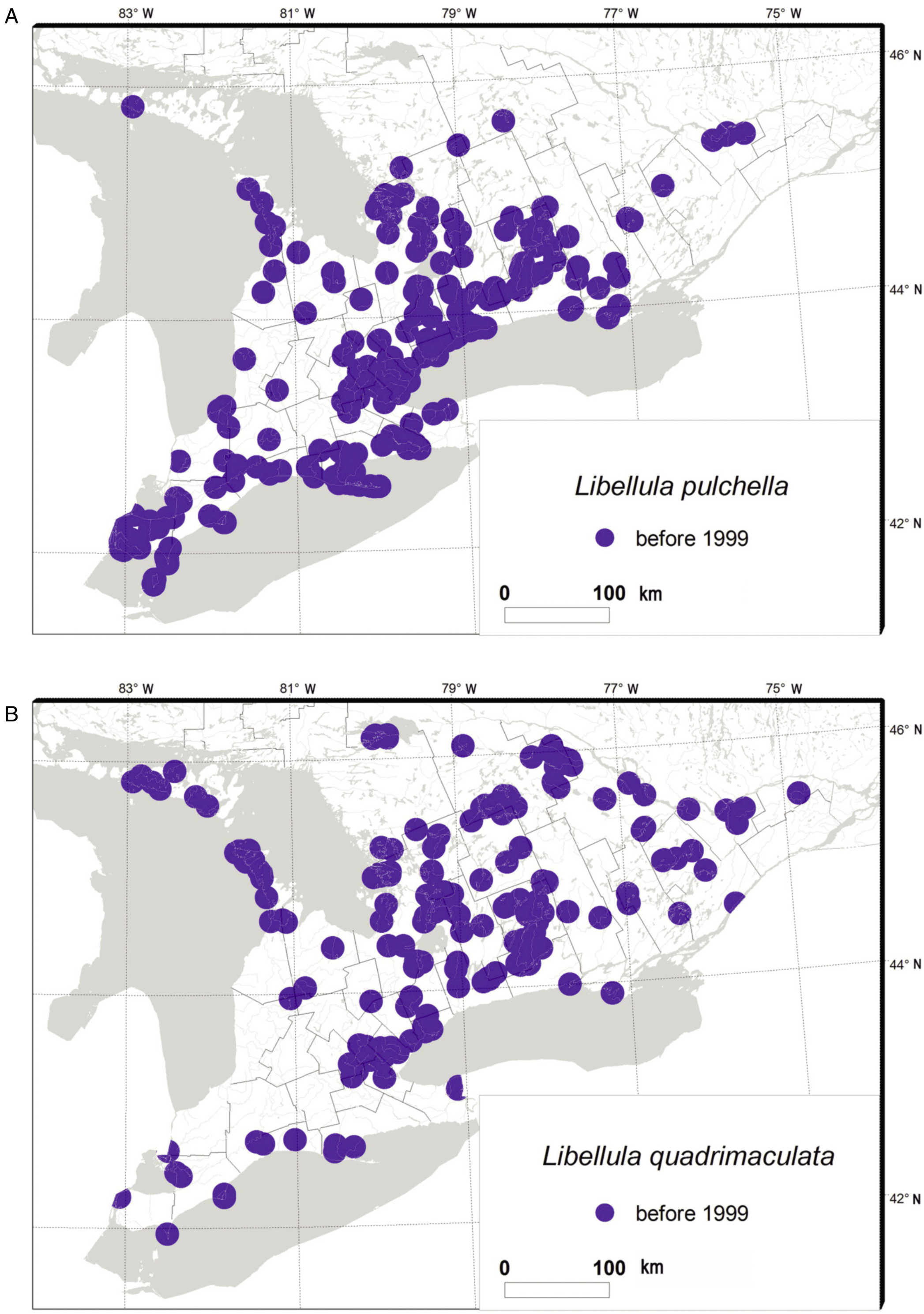

FIGURE 6. Records of (A) *Libellula pulchella* and (B) *Libellula quadrimaculata* in southern Ontario before 1999 to show distribution of dragonfly observations up to that time.

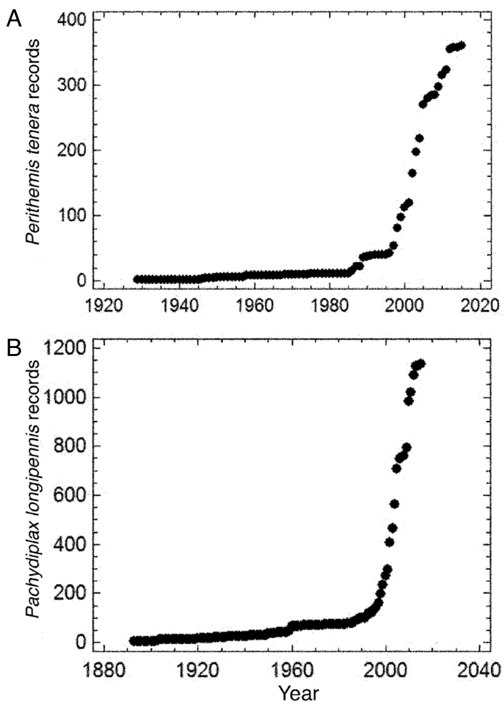

FIGURE 7. Number of records of (A) *Perithemis tenera* and (B) *Pachydiplax longipennis* that have accumulated over time.

In addition, Hutchinson *et al.* (2014a,b) noted that they had visited a large number of sites in the Ottawa region since 1987, but did not encounter the target species until 2012. Similar statements from others, with respect to over 500 recent site visits, many to areas where the target species currently occur, support their status as recent arrivals.

Evidence for establishment

Perithemis tenera was seen in 4 consecutive years in the Ottawa district (2012–2015, Table 1; PMC, personal observation), and both larvae and exuviae have been found at many sites. At one site, an estimated 300 individuals were present.

Pachydiplax longipennis has been seen in the same localities (e.g., Petrie Island and Dow's Lake) since 2011 (Table 2; PMC, personal observation). In 2012, larvae and adults were reported at 9 locations in the Ottawa region. Exuviae have been found at both Ottawa and adjacent Quebec locations.

Direction and history of spread

Both *P. tenera* and *P. longipennis* had a largely Carolinian distribution in 1999 and earlier in Ontario and probably also in New York State. *Perithemis tenera* was unrecorded in the northern counties of New York in 1992 (Donnelly 1992) and *P. longipennis* was known from only 1 northern county. The New York Dragonfly and Damselfly Survey, starting in 2005 (White *et al.* 2010), added locations for *P. tenera* on Wellesley Island and near Waterton (about 100 km south of the Ottawa region), and a number of localities near the St. Lawrence River (70–100 km south of the Ottawa region) for *P. longipennis*.

From these areas, the extension into the Ottawa region for both species is to the north, northeast, or north by northeast (or any combination). A northward movement of *P. tenera* in any westerly direction would have been unlikely due to the cooler regions of the Algonquin upland. Northeasterly movement would have involved up to 350 km. Any movement into eastern Ontario more directly from the south would have involved distances of about 250 km from the New York State equivalent of the Carolinian Zone in Oneida County. *Pachydiplax longipennis* would have had to move about 70 km from St. Lawrence County, New York, or about 90 km from Silver Lake, Ontario.

Although the origin and directions are unclear, both *P. tenera* and *P. longipennis* likely moved northward over more or less flat terrain into a warming landscape (Figures 1, 3, and 4).

Discussion

The northward spread of *P. tenera* and *P. longipennis* satisfies all noted criteria for identifying climate change as an explanation; sufficient climate warming has occurred, with a new range expectation that includes the Ottawa region. Other factors potentially associated with range expansion have been excluded. The literature and the relatively good coverage of records provide satisfactory evidence of recent arrival in 2008–2012. There is good evidence for establishment. The direction and history of spread is consistent with a climate warming explanation.

With climate warming continuously since 1880 (Figure 2; Brown *et al.* 1980: 14), both of these dragonflies have been moving north, probably at variable rates, since that time, but the most extensive and convincing evidence of a change in distribution comes from the period after 1998. Even after that time, the time of arrival in eastern Ontario may not be accurately known, but time of arrival and establishment in the Ottawa region is well established as 2008–2012.

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Literature Cited

Bernard, R. S. 2010. Découverte de *Perithemis tenera* (Say, 1839) (Odonata : Libellulidae), une nouvelle libellule pour le Québec. Le Naturaliste canadien 134(1): 23–24.

Bracken, B., and **C. Lewis.** 2002. Black Saddlebags (*Tramea lacerata*) — first records for Ottawa-Carleton and Prescott-Russell counties and possible range expansion. Pages 16–18 *in* Ontario Odonata, Volume 3. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Bracken, B., and **C. Lewis.** 2004. Odonata of the Britannia Conservation Area, (Ottawa-Carleton County), Ontario. Pages 15–22 *in* Ontario Odonata, Volume 5. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Bracken, B., and **C. Lewis.** 2005. Additions to the Odonata study area of the Britannia Conservation Area, Ottawa, Ontario. Pages 14–15 *in* Ontario Odonata, Volume 6. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Bracken, B., and **C. Lewis.** 2008. A checklist of the dragonflies and damselflies of Ottawa-Gatineau (2008 update). Trail and Landscape 42: 115–131.

Bree, D. 2005. Odonate range fluctuations as illustrated by occurrence records of three species from Prince Edward County, Ontario. Pages 16–20 *in* Ontario Odonata, Volume 6. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Bried, J., A. Dillon, B. Hager, M. Patten, and **B. Luttbeg.** 2015a. Inferring species residency in standardized adult dragonfly surveys. Argia 27: 11.

Bried, J. T., A. M. Dillon, B. J. Hager, M. A. Patten, and **B. Luttbeg.** 2015b. Criteria to infer local species residency in standardized adult dragonfly surveys. Freshwater Science 34: 1105–1113.

Brown, D. M., G. A. McKay, and **L. J. Chapman.** 1980. The climate of southern Ontario. Climatological studies 5. Meteorological Branch, Department of Transport, Toronto, Ontario, Canada.

Bush, A., G. Theischinger, D. Nipperess, E. Turak, and **L. Hughes.** 2013. Dragonflies: climate canaries for river management. Diversity and Distributions 19: 86–97.

Catling, P. M. 1996. Evidence for the recent northward spread of *Enallagma civile* (Zygoptera: Coenagrionidae) in southern Ontario. Proceedings of the Entomological Society of Ontario 127: 131-133.

Catling, P. M. 1998. Evidence for the recent northward spread of *Enallagma civile* (Zygoptera: Coenagrionidae) in New York State. Argia 10: 16.

Catling, P. M. 2004. *Anax junius* overwintering in eastern Ontario. Pages 9–10 *in* Ontario Odonata, Volume 4. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Catling, P. M. 2005. Global warming a potential explanation for the extension of known range of *Hetaerina americana*. Pages 40–41 *in* Ontario Odonata, Volume 6. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Catling, P. M. 2008. A new northern limit for Citrine Forktail (*Ischnura hastata*), possibly due to climate warming. Argia 20: 12–17.

Catling, P. M., and **V. R. Brownell.** 1998. Migratory concentrations of dragonflies on the north shore of Lake Ontario, and northward extension of migratory species. Argia 10: 19–22.

Catling, P. M., and **V. R. Brownell.** 2000. Damselflies and Dragonflies (Odonata) of Ontario. Privately published, Metcalfe, Ontario, Canada.

Catling, P. M., and **V. R. Brownell.** 2002. A preliminary assessment of changes in status of Ontario dragonflies since Walker's published survey in 1941. Pages 36–39 *in* Ontario Odonata, Volume 3. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Catling, P. M., R. Hutchinson, and **B. Ménard.** 1998. Dragonflies and damselflies. Assessment of species diversity in the Mixed Plains ecozone. Environment Canada, Ottawa, Ontario, Canada.

Catling, P. M., and **C. D. Jones.** 2007. Accessibility of electronic Odonata databases related to ONTARIO ODONATA publications. Page 50 *in* Ontario Odonata, Volume 5. *Edited by* P. M. Catling, C. D. Jones, and P. Pratt. Toronto Entomologists' Association, Toronto, Ontario, Canada.

Craves, J. A. 2006. *Archilestes grandis* (Rambur) (Odonata: Lestidae): new for Michigan. Great Lakes Entomologist 39: 88–90.

Donnelly, T. W. 1992. The Odonata of New York. Bulletin of American Odonatology 1: 1–27.

Environment Canada. 2015. Monthly climate summaries. National climate data. Government of Canada, Ottawa, Ontario, Canada. Accessed 18 September 2015. http://climate.weather.gc.ca/prods_servs/cdn_climate_summary_e.html.

Flenner, I., and **G. Sahlen.** 2008. Dragonfly community reorganization in boreal forest lakes: rapid species turnover driven by climate change? Insect Conservation and Diversity 1: 169–179.

Hanrahan, C. 2011. Blue Dasher (*Pachidiplax longipennis*): first known record for the Ottawa 50 km area. Trail and Landscape 45: 152–154.

Hickling, R., D. B. Roy, J. K. Hill, and **C. D. Thomas.** 2005. A northward shift of range margins in British Odonata. Global Change Biology 11: 502–506.

Hutchinson, R., B. Ménard, and **C. Piché.** 2014a. *Pachydiplax longipennis* (Burmeister) (Odonata: Libellulidae) dans la région de l'Outaouais. Nouv'Ailes 24: 5–7.

Hutchinson, R., C. Piché, and **B. Ménard.** 2014b. *Perithemis tenera* (Say) (Odonata: Libellulidae) nouveau pour la vallée d l'Outaouais québécois. Nouv'Ailes 24: 15–17.

Kennedy, J. H. 1977. The occurrence of *Archilestes grandis*, Zygoptera Lestidae, in Virginia, USA. Entomological News 88: 215–216.

Mason, S. C., G. Palmer, R. Fox, S. Gillings, J. K. Hill, C. D. Thomas, and **T. H. Oliver.** 2015. Geographic range margins of many taxonomic groups continue to shift polewards. Biological Journal of the Linnaean Society 115: 586–597.

Mastromatteo, G. 2012. Dragonfly discoveries at Petrie. Trail and Landscape 46: 23–27.

McLaughlin, T. J. 1886. Ottawa dragonflies. Ottawa Field-Naturalist's Club Transactions 7: 329–342.

Ménard, B. 1996. Liste annotée des odonates de la vallée de l'Outaouais. Fabreries 21: 29–61.

Mochon, A. 2012. Découverte de la libellule *Pachidiplax* au Québec durant l'inventaire de l'odonatofaune du ruisseau Castagne et Montérégie. Le Naturaliste canadien 136(3): 49–59.

Moskowitz, D. P., and **D. M. Bell.** 1998. *Archilestes grandis* (Great Spreadwing) in central New Jersey, with notes on water quality. Bulletin of American Odonatology 5: 49–54.

Reddoch, J. M., and **A. H. Reddoch.** 2012. Blue Dashers, Elusive Clubtails and other dragonflies in a suburban setting. Trail and Landscape 46: 19–23.

Sankey, J. 1997. A Field Guide to the Adult Dragonflies of the Ottawa District. J. Sankey, Ottawa, Ontario, Canada.

Statpoint Technologies Inc. 2005. Statgraphics Centurion 15. Warrenton, Virginia, USA.

Walker, E. M. 1908a. The dragonflies (Odonata) of the Ottawa district. Ottawa Naturalist 22: 16–23.

Walker, E. M. 1908b. The dragonflies (Odonata) of the Ottawa district. Ottawa Naturalist 22: 49–64.

White, E. L., J. D. Corser, and **M. D. Schlesinger.** 2010. The New York dragonfly and damselfly survey 2005–2009: distribution and status of odonates of New York. New York Natural Heritage Program, Albany, New York, USA.

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