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Expanding geographical distribution of the mosquito, *Culex pipiens*, in Canada under climate change

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A B S T R A C T

An important first step in assessing the possible effects of climate change on the risk of mosquito-borne disease in Canada requires an understanding of the potential shifts in the geographic range of mosquito populations under projected future climate. Risk maps of potential habitat suitability of the mosquito *Culex pipiens*, an important vector of West Nile and other arboviruses, were created using logistic regression models under conditions of current and projected climate. Current predictions for *Culex pipiens* distribution are that suitable climatic conditions for the species can be found in southern Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and southern parts of Newfoundland and Labrador. Projected ranges of the mosquito were obtained using output from models of the Coupled Global Climate Model of the Canadian Centre for Climate Modelling and Analysis and the National Center for Atmospheric Research Community Climate System Model. Using both models, predictions of *Culex pipiens* range expansion were found for areas further north of the current estimated distribution in Ontario, Quebec, New Brunswick and Newfoundland and Labrador as well as increasing potential habitat suitability in parts of the prairies (Manitoba, Saskatchewan and Alberta) from the 2020s through to 2080s. The degree of range expansion varied according to the greenhouse gas emissions scenario ('A2' - high emissions scenario and 'B1' - low emissions scenario) used in calibrating the climate models. These findings suggest that through its effects on *Culex pipiens* survival and geographic range, climate change may broaden the range of some mosquito-borne pathogens and as a result expose new human populations to these disease-causing agents.

Introduction

Large scale environmental perturbations such as climate change may drive vector-borne disease emergence and re-emergence by changing their geographical distribution and dynamics (Confalonieri et al., 2007). Current projections suggest that Canada will experience greater warming than other regions of the world owing primarily to its northern latitude and large landmass (Lemmen & Warren, 2004). Given this, increased risk of vector-borne disease transmission may become problematic in Canada. Studies examining future trends of mosquito-transmitted diseases such as malaria and dengue have predicted increased transmission intensity and extended spatial distributions of these diseases with climate change (Hales, de Wet, Maindonald, & Woodward, 2002; Martens, Jetten, Rotmans, & Niessen, 1995; Ogden et al., 2008).

Evidence has been accumulating that the range distribution of a number of species has already started to shift as a result of changing climatic conditions and suggests that this pattern is likely to continue with further climate change (Ogden et al., 2008; Ogden et al., 2010; Parmesan & Yohe, 2003; Purse et al., 2005). Although mosquito abundance is strongly subject to biotic factors such as predation, competition and vector control activities at local scales (Brownstein, Holford, & Fish, 2005), at larger geographical scales, abiotic factors such as landscape and climate play more dominant roles. Ecological niche models (ENM) and bioclimatic envelope models have been increasingly used to model the potential impacts of climate change on species distributions (Gonzalez et al., 2010; Hales et al., 2002; Kuhn, Campbell-Lendrum, & Davies, 2002; McKenney, Pedlar, Lawrence, Campbell, & Hutchinson, 2007b; Pearson & Dawson, 2003).

Recent experience with West Nile virus (WNV) has shown that Canada is not immune to the threat of invasive vector-borne

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pathogens. Furthermore, mosquito surveillance has revealed the presence of new mosquito species that have recently invaded Canada (Thielman & Hunter, 2006). The potential for species invasion combined with rapid climatic change may further exacerbate the potential for pathogen emergence and transmission. Given that arthropod species such as mosquitoes are believed to be highly sensitive to changes in climate (Gage, Burkot, Eisen, & Hayes, 2008; Martens et al., 1995), it is likely that the distribution of a number of mosquito species may have already changed or will change under climate projections (Confalonieri et al., 2007). However, available data on national distributions of mosquito species in Canada are dated, of poor resolution, and in some cases unreliable (Berrang-Ford, McLean, Gyorkos, Ford, & Ogden, 2009). This highlights a need for up-to-date information on the distribution of vector species, including mosquitoes in and proximal to Canada. Maps of potential distributions of vectors and vector-borne diseases can serve as useful tools for public health policy development and planning for vector control activities to mitigate increasing vector-borne disease risks under projected future climate (Brownstein et al., 2005; N. Ogden et al., 2008).

Since the introduction of WNV into North America in 1999 (Lanciotti et al., 1999) and Canada in 2001 (Venter, 2001), mosquito surveillance has been undertaken in a number of provinces (Giberson, Dau-Schmidt, & Dobrin, 2007; Thielman & Hunter, 2006). The mosquito fauna of Canada include over eighty species (or subspecies) ranging in abundance and composition and occupying a wide range of temporary, permanent or semi-permanent habitats (Thielman & Hunter, 2006; Wood, Dang, & Ellis, 1979). Mosquito-borne arboviruses of human importance currently known to be endemic in, or occasionally introduced into, Canada include WNV, western equine encephalitis virus, St.Louis encephalitis virus (SLEV), eastern equine encephalitis virus, Jamestown Canyon virus, California Encephalitis virus and Snowshoe hare virus, the first three of which share common mosquito vectors primarily from the *Culex* species complex (*Culex tarsalis* and *Cx. pipiens* in particular) (Hongoh et al., 2009). *Cx. pipiens* has an historical record of association with diseases of human importance in Canada including SLEV and WNV. It is found primarily in the eastern provinces of Canada including: Ontario, Quebec, New Brunswick and Nova Scotia but also in the westernmost province of British Columbia. Larvae of this species develop in a wide variety of artificial containers (e.g., bird baths, used tires, catch basins) and other temporary standing water sites (e.g., roadside ditches); all of which usually have high organic content (Wood et al., 1979) and are most frequent in urban areas. Although *Cx. pipiens* has a reported preference for feeding on birds, some researchers suggest that it is precisely this which makes them ideal bridge (bird-to-human) vectors for humans as the species will switch to feeding on humans following avian host species dispersal (Kilpatrick, Kramer, Jones, Marra, & Daszak, 2006). Updated information on the current distribution of *Cx. pipiens*, and estimates of potential changes in the geographic distribution of this species with climate change are thus relevant to assessments of climate change impacts on emergent mosquito-borne disease risks in Canada.

Here we create a predictive model to examine the potential change in distribution of *Cx. pipiens* under climate change. To do this, we estimate the potential spatial distribution of *Cx. pipiens* at the national scale using a logistic regression model with data from Canadian provinces assembled in a geographical information system. We then examine how the distribution of this species is likely to expand under future climate scenarios using output from models of the Coupled Global Climate Model of the Canadian Centre for Climate Modelling and Analysis and the National Center for Atmospheric Research Community Climate System Model. Based on our model, we predict that climate change is likely to contribute to the expansion of *Cx. pipiens* distribution in Canada.

Material and methods

Mosquito data

Cx. pipiens presence and absence data were derived from mosquito surveillance carried out by provincial agencies or contractors across the country (Table 1). These data were primarily collected in the context of WNV surveillance, biological surveys or research studies carried out between the years 2000 and 2007.

Mosquito data included the collection date, location and mosquito species (where available). Adult mosquitoes were caught using CO_2-baited CDC light traps, gravid traps or New Jersey light traps. Trap locations were classified as either present or absent for *Cx. pipiens* based on recorded observations and used as the response variable in subsequently constructed logistic regression models. An absence location was one in which mosquito sampling took place but no *Cx. pipiens* was found. Data on the abundance of *Cx. pipiens* was available for most localities; however, because of inter-provincial variability in sampling methods and collection intensities, these data were not considered sufficiently comparable to include in the analysis.

Environmental data

Climate data were obtained from Natural Resources Canada (NRCAN) in the form of spatially continuous grids generated as individual Canada-wide climate years for the period ranging from 2000 to 2007 and matched with the mosquito surveillance data. These grids were created using data recorded from climate stations across Canada and modelled using the ANUSPLIN suite of programs developed by Hutchinson in 2004 which makes use of thin-plate smoothing splines to estimate climate variables as a function of latitude, longitude and elevation (McKenney, Pedlar, Lawrence, Campbell, and Hutchinson (2007a)). Climate predictors tested for inclusion in the current study consisted of measurements of annual mean, minimum and maximum temperature, annual mean precipitation, the annual temperature range, monthly minimum and maximum temperatures, monthly mean precipitation, the maximum temperature of the warmest period, the minimum temperature of the coldest period, mean temperature of the wettest, driest, warmest as well as coldest quarter, precipitation of the wettest, driest, warmest as well as coldest quarter as well as the julian day number of the start and end of the growing season and the number of resulting growing degree days. The growing season refers to the period of the year when temperatures exceed 5 °C for at least 5 consecutive days as of March 1st and ends when temperatures are less than −2 °C as of August 1st (NRCAN 2010). Vegetation and land cover data (advanced very high resolution radiometer (AVHRR) Land Cover Data, Canada) were obtained from the Government of Canada, Natural Resources Canada, Earth Science Sector at a 1 km × 1 km resolution and categorized into 12 land cover classes as described by Palko and colleagues (Palko, St-Laurent, Huffman, & Unrau, 1996). All environmental data layers

Table 1
Sources of mosquito data and years of surveillance.

Source	Years
Alberta Environment	2003–2007
Manitoba Public Health Division	2005–2007
New Brunswick Museum	2003–2004
Nova Scotia Department of Natural Resources	2000–2004
Ontario Ministry of Health and Long Term Care	2002–2007
Prince Edward Island Dept. Of Health and Social Services	2000–2001
Ministère de la Santé et des Services Sociaux (Québec)	2003–2006
Saskatchewan Ministry of Health	2003–2007