Actual and potential distribution of an invasive canola pest, *Meligethes viridescens* (Coleoptera: Nitidulidae), in Canada

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Abstract—*Meligethes viridescens* (Fabricius), bronzed or rape blossom beetle, is a widespread and common pest of oilseed rape [*Brassica napus* L. and *Brassica rapa* L. (Brassicaceae)] in the western Palaearctic subregion. The establishment of *M. viridescens* in eastern North America has raised concern that its presence is a potential risk to the Canadian canola industry, especially to the prairie ecozone of western Canada where up to 4 million ha of summer canola (*B. napus* and *B. rapa*) are grown annually. Study of museum specimens indicated that *M. viridescens* was first recorded in Nova Scotia in 1947. Field surveys indicated that, as of 2001, *M. viridescens* was established as far west as Saint-Hyacinthe, Quebec. A CLIMEX™ model for *M. viridescens* in Europe was developed and validated with actual distribution records. In Canada the model predicted that once introduced, *M. viridescens* would readily survive in the canola-growing areas. The actual distribution of *M. viridescens* in eastern Canada matched the predicted distribution well. The westward dispersal to and establishment of *M. viridescens* in canola-growing areas of Ontario and western Canada, particularly southern Manitoba, appear to be inevitable. Establishment in these areas presents the risk of substantial production losses to canola producers.

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Résumé—*Meligethes viridescens* (Fabricius), le coléoptère des fleurs du colza, est un ravageur commun de colza oléagineaux [*Brassica napus* L. et *Brassica rapa* L. (Brassicaceae)] dans la sous-région de l'ouest paléarctique. L'établissement de *M. viridescens* dans l'est de l'Amérique du Nord suscite des inquiétudes parce qu'il représente un risque pour l'industrie de colza du Canada où l'on cultive jusqu'à 4 millions d'hectares de colza d'été, *B. napus* et *B. rapa*, chaque année. L'étude de spécimens de musée indique que *M. viridescens* est d'abord apparu en Nouvelle-

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Écosse en 1947. Les études sur le terrain ont démontré qu'en 2001, *M. viridescens* a progressé vers l'ouest jusqu'à Saint-Hyacinthe, Québec. Un modèle CLIMEX^{MD} a été élaboré et validé en Europe avec des données sur la répartition réelle de *M. viridescens.* Au Canada, le modèle prédit qu'une fois introduit, le ravageur peut facilement survivre dans les zones de culture de colza. La répartition actuelle de *M. viridescens* dans l'est du Canada correspond bien à la répartition prédite par le modèle. La dispersion vers l'ouest et l'établissement de *M. viridescens* dans les zones de culture de colza de l'Ontario et de l'ouest canadien, particulièrement dans le sud du Manitoba, semblent inévitables. La colonisation de ces régions pose un risque de pertes considérables pour les producteurs de colza.

[Traduit par la Rédaction]

Introduction

Meligethes viridescens (Fabricius) (Coleoptera: Nitidulidae), bronzed or rape blossom beetle (Kirk-Spriggs 1996), is a widespread and common pest of oilseed rape, *Brassica napus* L. and *Brassica rapa* L. (Brassicaceae), in the western Palaearctic subregion. It occurs throughout western North Africa, most of the European countries (northwards to around the 65th parallel in Scandinavian areas), Turkey, northern parts of the Middle East, the Caucasus, northern Iran, and eastwards to western Kazakhstan (Audisio 1993; Audisio *et al.* 2000). Larvae of *M. viridescens* develop on many genera of Brassicaceae, especially *Brassica* spp., *Sinapis* spp., *Cardamine* spp., *Arabis* spp., and *Erucastrum* spp., without showing preference for a certain genus or species (Audisio 1993). In Europe, *M. viridescens* is considered to be an important pest of spring-seeded crops such as summer rape (*B. napus* and *B. rapa*), whereas *Meligethes aeneus* (Fabricius), which appears 3 weeks earlier, is most injurious to winter rape (also *B. napus* and *B. rapa*) (Nolte and Fritzsche 1952; Karltorp and Nilsson 1981; Fougeroux 1987; Finch *et al.* 1990; Hokkanen 1993). Blossom beetle larvae, hatched from eggs laid inside buds, will eat stamens during early development causing flower bud losses (Winfield 1992). Adults feed on pollen, often from open flowers; however, they also feed on buds, eating through the bud to the developing flower parts (Ekbom 1995). In Europe, Nilsson (1987) showed experimentally that feeding by *Meligethes* spp. adults and larvae could reduce seed yields of summer oilseed rape up to 70%. Recently, the establishment of *M. viridescens* in eastern North America has been reported from Nova Scotia, Prince Edward Island, and Maine (Hoebeke and Wheeler 1996). The presence of *M. viridescens* poses a potential risk to the Canadian canola industry, especially to the prairie ecozone of western Canada where up to 4 million ha of summer canola (*B. napus* and *B. rapa*) are grown annually. The study objectives were to determine the actual distribution of *M. viridescens* in eastern Canada and to predict its potential distribution in canola-growing regions of Canada using a computer simulation model.

Methodology

The actual distribution of *M. viridescens* in eastern Canada was determined through field surveys in southern Ontario and southern Quebec in 2000 and 2001. Field collections were made on Brassicaceae, particularly canola fields, wild mustard (*Sinapis arvensis* L.), and wild radish (*Raphanus raphanistrum* L.) in July when these species were in bloom. Sampling methods included sweeping, using a standard sweep net, areas where these species were flowering or, when few plants were present, by examining individual flowers. Field collections were supplemented by studying material in the Canadian National Collection (CNC) of Insects, Arachnids, and Nematodes, and information reported by Hoebeke and Wheeler (1996).

Computer simulation models have been used successfully to predict the distribution and extent of insect establishment in new environments (Hughes and Maywald 1990; Sutherst 1991; Worner 1994; Evans and Hughes 1996; Dosdall *et al.* 2002). Simulation models normally require a great deal of biological information for a species to achieve the required precision for making predictions. These models are not an option in cases where little is known about the biology of a species yet timely prediction of distribution and abundance is needed, such as for invasive alien species (Worner 1994). Published information on the biology of *M. viridescens* is limited. Fritzsche (1955) documents some biological requirements, indicating that in the laboratory *M. viridescens* adults are active at temperatures above 10°C, optimum development being under conditions of 20–27°C and high relative humidity (95%). He also noted that their life span is 43–45 days under these conditions. Because of this limited information, CLIMEX^{TM} was used to estimate the potential geographic distribution and relative abundance of *M. viridescens* as determined by its climatic requirements.

CLIMEX^{TM} enables inferences to be made about relative abundance, seasonal variation in population numbers, and the geographic distribution of a species (Sutherst *et al.* 1999). The model assumes that the limits of distribution of a species are determined by climate and that the species experiences seasonal conditions favourable for population growth, as well as unfavourable conditions which put the species survival in peril at a given location. A set of growth indices (annual growth, weekly growth, temperature, moisture, diapause, and light) and stress indices (cold, heat, dry, wet, and interactions between these) are calculated and combined to describe the climatic suitability of a location as a number, an ecoclimatic index (EI). By assessing which locations have a favourable climate and by quantifying the stress factors that limit a species distribution, CLIMEX^{TM} calculates an EI that describes how favourable the climate of a location is for that species. EI values can range from 0 (not favourable) to 100 (ideal conditions that are only achievable under constant and ideal circumstances such as in incubators). Geographic locations where EI values are greater than or equal to 30 represent very favourable climatic conditions, conducive to potential pest infestations. Locations with EI values between 20 and 29 are considered favourable for establishment and survival; sites with indices between 10 and 19 are considered marginal; and locations with EI values less than 10 are unfavourable for establishment and survival of the species.

CLIMEX^{TM} has a database of meteorological information for over 2400 locations worldwide. To increase the resolution of the CLIMEX^{TM} model, it was desirable to increase the density of weather stations in the canola-growing areas of Europe and Canada. Maximum and minimum air temperatures, rainfall, and relative humidity were added to the CLIMEX^{TM} database. For Europe, data were obtained from weather stations with a minimum of 30 years of climate information and located within or near spring canola-growing areas. The data for Finland, Sweden, and Poland were obtained directly from each country's national weather service (www.fmi.fi, www.smhi.se, and www.imgw.pl, respectively). From these datasets, 29 stations for Finland (Finnish Meteorological Institute 1991), 20 stations for Sweden (Swedish Meteorological and Hydrological Institute 1991, 1994), and 20 stations for Poland (Institute of Meteorology and Water Management) were selected. Data from 11 weather stations in Germany were obtained from the Deutsche Wetterdienst. For Canada, meteorological data were obtained from the Environment Canada long-term normals 1961–1990 database (732 weather stations).

A CLIMEX^{TM} model was developed for *M. viridescens* in Europe. Initial model input parameters (Table 1) were based on the CLIMEX^{TM} temperate-climate template; data based on Fritzsche (1955); data from cabbage seedpod weevil [*Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae)] (Dosdall *et al.* 2002), which is a

TABLE 1. Values for parameter settings for the CLIMEX™ model predicting *Meligethes viridescens* distribution in Canada.

		Index	Initial value	Best-fit value
Growth parameters				
	Temperature	DV0, lower temperature threshold	8.0°C	7.0°C
		DV1, lower optimal temperature	18.0°C	13.0°C
		DV2, upper optimal temperature	24.0°C	25.0°C
		DV3, upper temperature threshold	28.0°C	33.0°C
	Moisture	SM0, lower soil moisture threshold	0.25	0.02
		SM1, lower optimal soil moisture	0.8	0.10
		SM2, upper optimal soil moisture	1.5	1.00
		SM3, upper soil moisture threshold	2.5	1.30
	Diapause	DPD0, diapause induction day length	14.0	13.0
		DPT0, diapause induction temperature	5.0°C	11.0°C
		DPT1, diapause termination temperature	2.0°C	6.0°C
		DPD, diapause development days	120	90.0
		DPSW, winter diapause	0	0
Stress parameters				
	Heat	TTHS, heat stress temperature threshold	30.0°C	33.0°C
		THHS, heat stress temperature rate	0.005	0.01
	Dry	SMDS, dry stress threshold	0.2	0.020
		HDS, dry stress rate	0.005	0.003
	Wet	SMWS, wet stress threshold	2.5	1.2
		HWS, wet stress rate	0.002	0.005

NOTE: Indices are required inputs for the CLIMEX™ model. Initial values were derived from the CLIMEX™ temperate climate template and previously published studies. Iteration was based on expected distribution within the species range indicated by Audisio (1993).

species with a similar European distribution; and "climatic parameters inferred from an observed distribution" (Sutherst *et al.* 1999). The climatic requirements of *M. viridescens* were inferred from its known geographical distribution. Additional data, including species phenology and relative abundance, were used to "fine tune" the model. Parameter values were modified individually by an iterative process (*i.e.*, by re-running the parameter file with different values and noting the differences in EI that result) to develop a best-fit map within CLIMEX™ that approximated the distribution and expected abundance for *M. viridescens* in Europe (*i.e.*, in canola-growing areas in northern Europe). For example, initial results did not include Sweden and Finland in the modelled range for *M. viridescens*. Initial values for the lower temperature threshold (DV0) and for the lower optimal temperature (DV1) were incrementally reduced, and this resulted in the inclusion of Sweden and Finland in the modelled range. Temperature factors (*e.g.*, diapause induction and termination temperatures) affected EI values more than any other parameters. This was confirmed by conducting a sensitivity analysis on the final model to determine the effect of individual parameters on EI values. Each parameter value was increased/decreased by 20% and the resulting EI values were compared with the final model. Results showed that changes in parameter values related to temperature resulted in the largest change in EI values. Further analysis was done to assess EI values when DV1 and the upper optimal temperature (DV2) were increased and decreased by 10, 20, and 30%. The sensitivity analysis showed that increasing DV1 or decreasing DV2 resulted in a reduction in EI values and in the modelled range for *M. viridescens*. A 30% increase in DV1 resulted in an overall mean EI value that was

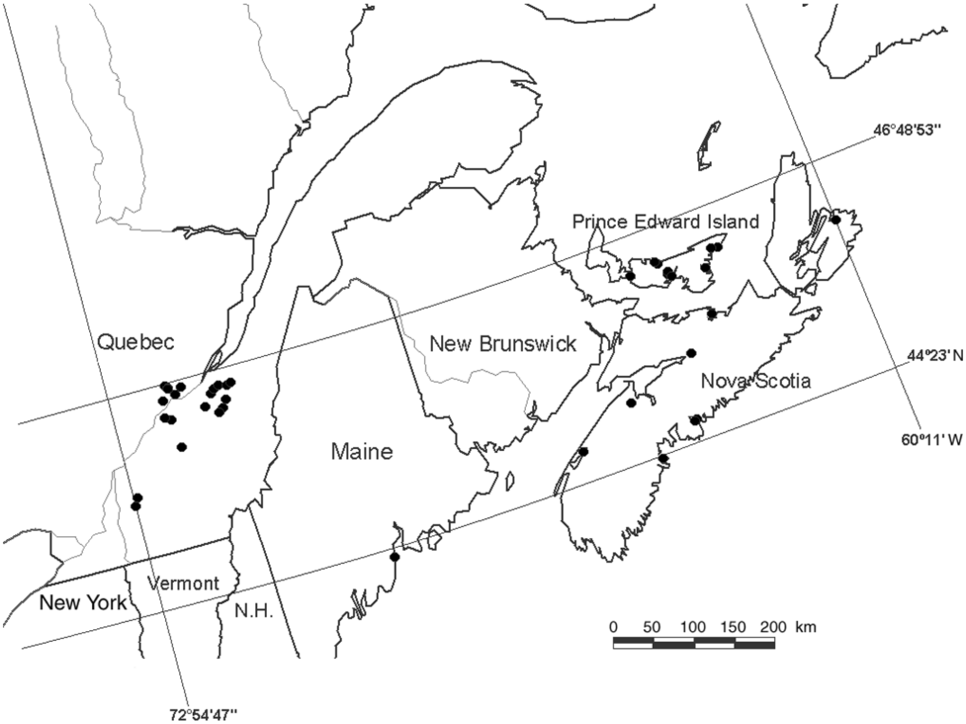

FIGURE 1. Locations in eastern North America where *Meligethes viridescens* was present (to 2001) based on museum records, published information, and our field surveys.

9% less than the final model and a 30% decrease in DV2 resulted in a 21% decrease in the mean EI value (for sites with EI values greater than 19.9). Temperature factors are important because diapause is essential for survival in northern climates where winters limit the length of the optimal growing season. The resulting best-fit parameter values (Table 1) were used to calculate subsequent EI values that matched the known distribution in Europe. The model was validated by comparing the known *M. viridescens* distribution in Europe and its estimated abundance with the derived indices. Once the model was validated for Europe, it was used to predict potential distribution and abundance in eastern Canada for which locality records were available. After confirming that the predicted and actual distributions matched, the model was used to predict the potential distribution across Canada.

Results and discussion

Material in the CNC indicated that *M. viridescens* was first recorded in Nova Scotia in 1947. Hoebeke and Wheeler (1996) reported that *M. viridescens* is widespread in Nova Scotia and Prince Edward Island and is present in the state of Maine. Our field surveys indicated that, as of 2001, *M. viridescens* was established as far west as Saint-Hyacinthe, Quebec (45°36′34′′N 72°54′47′′W), and did not occur in Ontario (Fig. 1). Dispersal from the Maritimes is likely *via* the shores of the St. Lawrence Valley because other invasive species [*e.g.*, *Harpalus rufipes* (DeGeer) and *Pterostichus melanarius* (Illiger) (Coleoptera: Carabidae)] have moved along this route (H Goulet, personal communication).

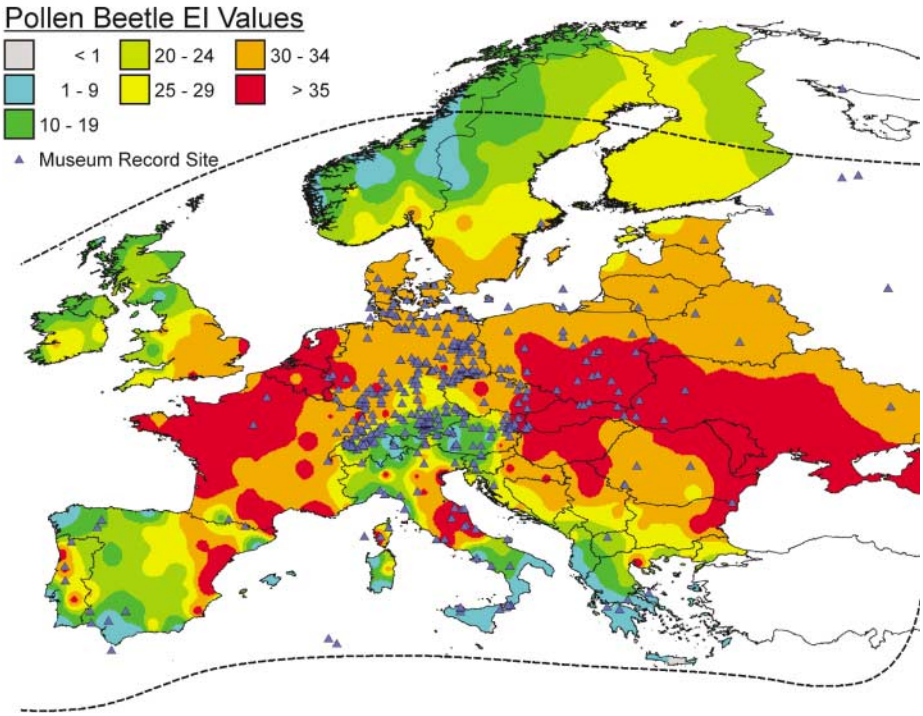

FIGURE 2. Surface map of European distribution of *Meligethes viridescens*, using the Ecoclimatic Index (EI) values generated by the CLIMEX^{TM} model with Geographic Information System (GIS) software (SPANS^{TM}). An EI value of 0 indicates that long-term survival is not favoured and values greater than 30 indicate that the location is favourable for the establishment of *Meligethes viridescens*. The distribution of *Meligethes viridescens* according to Audisio (1993) is indicated by the broken lines.

The CLIMEX^{TM} model developed for *M. viridescens* in Europe (Fig. 2) was compared against actual distributions for *M. viridescens* based on museum and literature records and showed that the model fit well with the actual range in Europe as shown by Audisio (1993). That suitable climate conditions (EI values 10–30) for establishment and survival of *M. viridescens* occur north of the distribution indicated by Audisio (1993) suggests that other biotic factors such as food–plant availability and daylength are limiting. Because many food plants (*Brassica* spp., *Sinapis* spp., *Cardamine* spp., *Arabis* spp., and *Erucastrum* spp.) do occur in this region (Anderberg and Anderberg 2002), another explanation may be a lack of collecting effort, as there are no records of *M. viridescens* in northern Scandinavia. The record in northern Russia, outside the area modelled, supports this possibility. Thus, the CLIMEX^{TM} model could be used to predict the potential distribution in North America.

The actual distribution of *M. viridescens* in eastern Canada matches the predicted distribution well (Fig. 3). For example, in the Maritimes the model showed that climate conditions are favourable for establishment and survival of *M. viridescens*, and in some areas conditions are conducive to potential pest levels (EI $\geq$ 30). That *M. viridescens* has been present in Nova Scotia since 1947 and has not been reported as a widespread pest suggests that the model is accurate. That pest levels have not occurred in those areas with an EI of 30–35 suggests that other biotic factors such as availability of suitable food plants and less than optimal temperature regimes for development are probably limiting. Furthermore in the area south of Quebec City, *M. viridescens* was abundant as

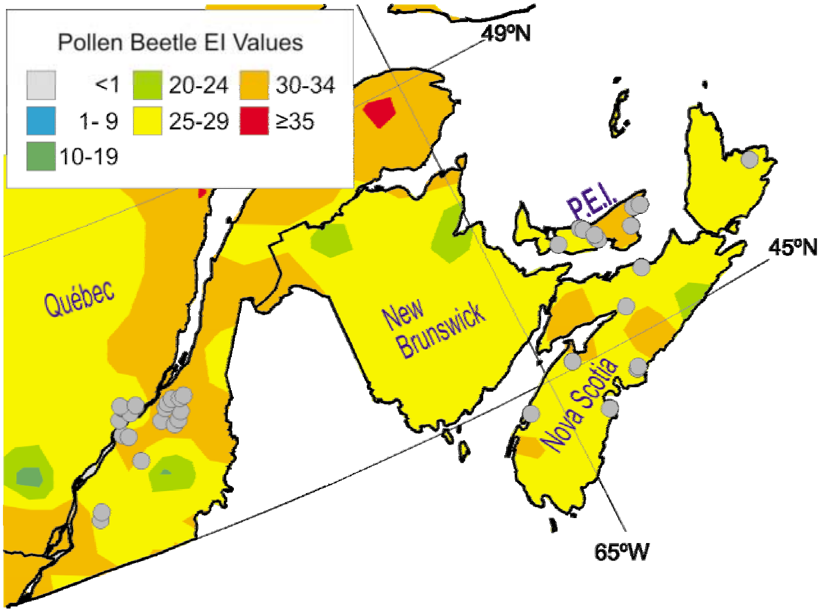

FIGURE 3. Surface map of the eastern Canada distribution of *Meligethes viridescens*, using EI values generated by the CLIMEX^{TM} model with GIS software (SPANS^{TM}). An EI value of 0 indicates that long-term survival is not favoured and values greater than 30 indicate that the location is favourable for establishment of *Meligethes viridescens*. Actual distribution records of *Meligethes viridescens* are indicated by the grey circles.

the model predicted (EI 30–35). This is an area where canola is grown and host plants are readily available. Although wild radish appeared to be more attractive than wild mustard or canola, quantitative comparisons are needed to properly assess host plant preferences.

The CLIMEX^{TM} model predicted that once introduced, *M. viridescens* would readily survive in the canola-growing areas of Canada (Fig. 4). If populations increase, canola producers who are presently unaware of pollen beetle presence and damage may need to control pest populations. Further research is required to assess damage potential in Canada.

The westward dispersal to and establishment of *M. viridescens* in canola-growing areas of Ontario and western Canada, particularly southern Manitoba, appear to be inevitable. Dispersion is likely to occur *via* cruciferous weed hosts such as wild radish, wild mustard, and volunteer canola. Establishment in these areas presents the risk of substantial production losses to canola producers. Continued monitoring of *M. viridescens* movement and developing management strategies are recommended to minimize the impact of this species on Canadian canola production.

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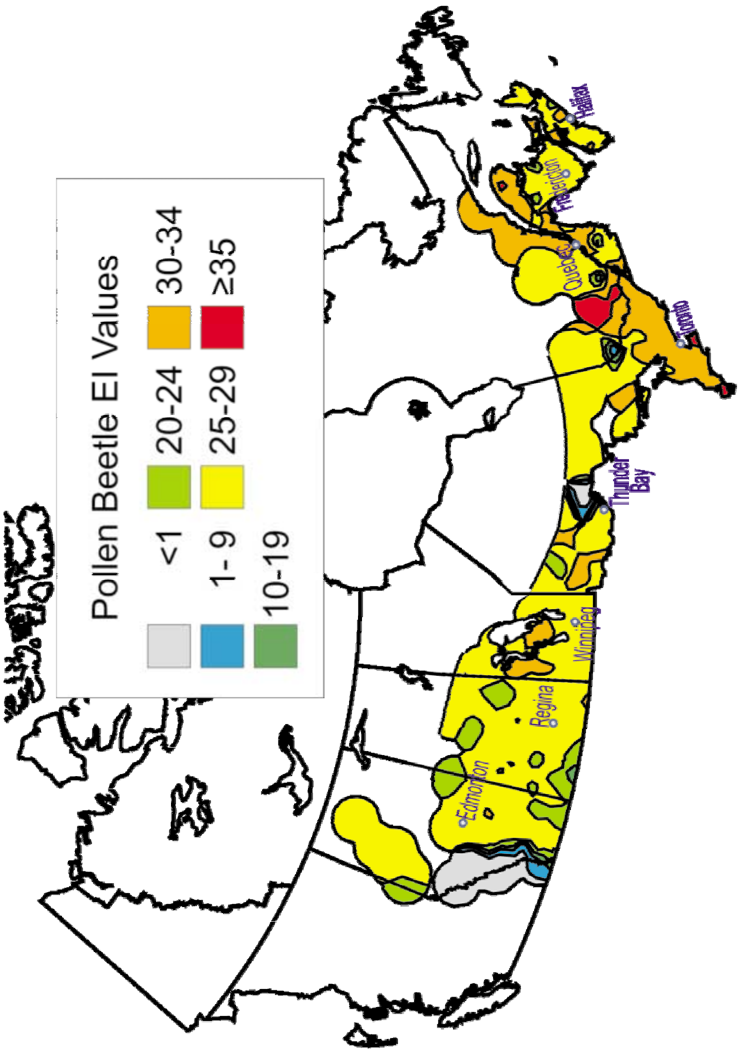

FIGURE 4. Surface map of potential Canadian distribution of *Meligethes viridescens*, using EI values generated by the CLIMEX™ model with GIS software (SPANS™). An EI value of 0 indicates that long-term survival is not favoured and values greater than 30 indicate that the location is favourable for the establishment of *Meligethes viridescens*.

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