IMPACTS OF CLIMATE CHANGE ON THE MONARCH BUTTERFLY IN ONTARIO; A CITIZEN SCIENCE-BASED APPROACH

By

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(Image via: Ann-Marie Conrad, USDA Forest Service)

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A CAUTION TO THE READER

This HBScF thesis has been through a semi-formal process of review and comment by at least one faculty member and one second reader. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty or Lakehead University.

ABSTRACT

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Keywords: Butterfly, Climate, Citizen science, Habitat, Migratory, Model.

The Monarch butterfly [*Danaus plexippus* (Linnaeus, 1758)], is an iconic insect native to North America. This butterfly is a migratory insect that flies to an overwintering site in Mexico every year. It is considered an endangered species in Canada due to habitat fragmentation and changing temperatures. This study utilized the maximum entropy modeling (MaxEnt) in conjunction with a research grade iNaturalist citizen science occurrence data and a Government of Canada climate dataset (CanDCS-U6) to display how the range of the Monarch butterfly will be impacted from climate change in Canada. In addition to the historic conditions the mid-century (2030-2050) and late-century (2080-2100) climate change scenarios utilized SSP 126, SSP 245 and SSP 585 emissions scenarios to create the species distribution models. The results showed that under these climate change scenarios there was northeastwards shift of suitable habitats for the Monarch butterfly. This can have an impact on future Monarch habitat affecting their migration and breeding grounds.

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INTRODUCTION

Monarch butterflies [*Danaus plexippus* (Linnaeus, 1758)] are a migratory insect and an important pollinator that is experiencing population declines within their two North American populations (Flockhart et al. 2019). The Monarch butterfly is a distinctive insect that is studied by both scientists and nature enthusiasts alike (Oberhauser et al. 2015). Their complicated life cycle makes them more vulnerable to environmental change which may impact the Monarch in various stages of their migration (Oberhauser et al. 2015). Shifts in weather conditions across the Monarch's native range will affect the suitability of the current Monarch habitat (Flockhart et al. 2014). Climate modelling will help us to better understand how future climatic scenarios will affect the Monarch butterfly populations (Barve et al. 2012).

Climate change is one of the recent environmental challenges that is affecting all ecosystem stability on Earth. This is due to human activity causing deforestation and other land use changes, fossil fuel consumption and causing global average temperature changes (Couture et al. 2015). Monarch butterflies are a migratory species that fly south to Mexico for overwintering (Flockhart et al. 2014). The Monarch is sensitive to changes in temperature as this factor is what controls their migration south and hibernation (UN Environment Programme 2020, Guerra and Reppert 2013). As our climate changes, this will impact the Monarch butterfly by disrupting important parts of their life cycle (Barve et al. 2012). These changes will eventually begin to affect Monarch populations and individual fitness over time (Ethier and Michell 2023).

In Canada, there is a significant Monarch habitat located in Southern Ontario (Flockhart et al. 2014). Within this region, the areas with more shrubland and less urban cover contain more Monarchs (MacNair 2021). A large amount of Monarch breeding ground includes portions of Southern Ontario which is where the first observations occur of the Monarch butterfly in the spring (Flockhart et al. 2014). There have been declines in Monarch butterfly populations due to climate change affecting weather patterns, land use changes and a decline in their host plant milkweed abundance within Ontario (Zylastra et al. 2021).

Climate modelling allows us to test the hypothesis of climate impacts on the Monarch butterfly in Ontario (Oberhauser and Peterson 2003). Predicting future habitats through modelling software has become a more common practice to determine what drives species to decline (Flockhart et al. 2014, Kantola et al. 2019). Maximum entropy or MaxEnt is a modelling system that can model the geographic distribution of a species such as the Monarch butterfly using presence-only datasets (Phillips et al. 2004). These datasets can be created using citizen science which is when public volunteers or amateurs aid in collecting data or monitoring of various species rather than professional scientists (Oberhauser et al. 2015). This type of research is important as it can give us a broad understanding of the changes to Monarch butterfly biology, population fluctuations, migration, and morphology over time (Oberhauser et al. 2015).

This study will examine the distribution of the Monarch butterfly in response to climate change and habitat destruction in Ontario. Utilizing a

Maximum Entropy approach to model monarch distribution, the MaxEnt software package was implemented (Phillips et al. 2024). I will examine multiple climate change scenarios at various stages in the future and how they may impact the habitat suitability of the Monarch butterfly. This is important because the Monarch butterfly is not only an indicator species that helps us monitor ecosystem health, but it is also an important pollinator. This study will include a general background on the Monarch including biology, life history, conservation, and impact of climate change on the Monarch. This study will explore how warming temperatures will affect the range of the Monarch butterfly across the province of Ontario.

OBJECTIVE

The objective of this thesis is to model the habitat suitability of the Monarch butterfly across Ontario under several climate change scenarios using citizen science data of the current Monarch butterfly distribution. This study explores the potential changes in habitat suitability for the Monarch through various future time periods using the Maximum Entropy (MaxEnt) model and citizen science data from the iNaturalist program. This thesis intends to be a useful contribution to determining how we can help the Monarch populations to better adapt to climate change across Ontario.

HYPOTHESIS

As minimum and maximum temperatures are expected to rise throughout Ontario, more favorable Monarch habitat conditions will be created further North of their current range.

LITERATURE REVIEW

THE MONARCH BUTTERFLY

The biology of the Monarch butterfly is closely influenced by the milkweed family (Asclepiadaceae) as this is the only group of plants that provide food for developing Monarch larvae. The Monarch butterflies breed across a large geographic range and lay their eggs on milkweed plants with the females laying approximately 350 eggs throughout their lifetime (Oberhauser & Solensky 2004). The Monarch goes through four major life stages including the egg, larva, pupa, and adult stages. The eggs are laid on milkweed and are off-white to yellow in color (The Monarch Joint Venture 2023). The eggs typically hatch after four days of being laid and the larval stage begins (Oberhauser & Solensky 2004).

During the larval stage, the Monarch is focused on growth and will begin eating their eggshell (chorion) and the milkweed on which they are laid. Monarch Butterfly larvae have a head with short antennae, mandibular mouth parts, and six simple ocelli (Figure 1). The Monarch's larval stage lasts approximately fourteen days and goes through five instars or larval molts before reaching the pupae stage (The Monarch Joint Venture 2023).

The pupa stage is the final stage before the Monarch reaches the adult stage (Oberhauser et al. 2015). Before pupation, the monarch will spin a silk mat from the spinneret at the bottom of their head from which they hang by their prolegs (The Monarch Joint Venture 2023). Their transformation takes place within a chrysalis from which the adult Monarch will emerge (Figure 2). The adult stage is the stage of reproduction for the Monarch butterfly (Figure 3) (Oberhauser & Solensky 2004). The adult male Monarchs have a black spot on a vein on each hind wing and the females often appear darker than the males (The Monarch Joint Venture 2023).

Milkweed (*Asclepias*) is a plant that the Monarch's life cycle depends on as it is the only food source of Monarch larvae. Milkweed plants can grow in a variety of habitats with fourteen different species found across the Canadian provinces (Taylor 2020). This plant can be distinguished by its milky latex, large clusters of flowers in a variety of colors, and brown oval wind-distributed seeds (Howard 2018). The milky latex contains cardiac glycosides which the plant utilizes as a toxin as protection from herbivores (Taylor 2020). The Monarch, however, can incorporate the cardiac glycosides and become toxic to potential predators (Taylor 2020).

Figure 1. Monarch larva on milkweed. Image via Rachel Powless, USDA Forest Service.

Figure 2. A Monarch chrysalis. Image via Anne-Marie Conrad, USDA Forest Service.

Figure 3. An adult Monarch Butterfly. Image via Ann-Marie Conrad, USDA Forest Service.

MONARCH HABITAT CONCERNS

The iconic migratory Monarch butterfly has been subject to population decreases over the past twenty years due to a variety of factors (Flockhart et al. 2014). The Monarchs migrate to their overwintering site in the Mexican Oyamel Fir Forests (Flockhart et al. 2014, U.S. Forest Service 2023). This area has been subject to habitat loss due to deforestation and extreme weather events (Flockhart et al. 2014). The Monarch's milkweed availability has also decreased due to a variety of factors which has affected their annual life cycle (Thogmartin et al. 2017). Milkweed was once abundant in the edges of agricultural fields, however, due to herbicide use such as glyphosate, the amount of milkweed has decreased (Thogmartin et al. 2017). Global temperature changes will also affect the growth of milkweed which directly affects Monarch populations (Pocius et al. 2017). When temperatures are elevated, there is an increase in milkweed growth and the flowering dates will occur earlier (Couture et al. 2015, Howard 2018). These effects on the milkweed will vary depending on the geographic location of the milkweed (Couture et al. 2015, Pocius et al. 2017). A Monarch butterfly will need approximately twenty-nine average-sized milkweed plants to become a migratory adult butterfly (Oberhauser et al. 2015).

Temperature changes may also affect the migratory timing for the overwintering Monarch butterfly (Ethier & Mitchell 2023). For these long-distance migratory insects, it is vital that the fall flight timing, food resources and overwintering ground conditions are optimal to provide the best chance of Monarch survival (Ethier & Mitchell 2023). Temperature changes affect the

Monarch's breeding range. When temperatures are warm early in the northern breeding range it will negatively impact the Monarch's population size (Crewe et al. 2019). However, when temperatures are warmer later in the season this produces a positive effect on Monarch populations due to the benefits of warmth on milkweed growth (Crewe et al. 2019).

THE MONARCH AND CLIMATE CHANGE

The Monarch butterfly was listed as a Special Concern by both the Canadian Federal Government and the Ontario Provincial Government (Government of Canada 2017, Flockhart et al. 2019). In 2019, it was recommended by the Committee on the Status of Endangered Wildlife in Canada to be listed as Endangered due to the declining population (Government of Canada 2017, Flockhart et al. 2019). In 2023, the Monarch butterfly species status was changed to Endangered due to population declines (Government of Canada 2023c). The Monarch butterfly officially became reclassified as endangered by the Government of Canada on December 8, 2023 (Government of Canada 2023c). In Ontario, temperature fluctuations affect the number of growing days within a season which affects milkweed growth, larval development, and migration timing (Ethier et al. 2023). Climate change will increase drought conditions across the province, affecting the number of wild nectar sources and the Monarch butterfly (Ethier et al. 2023). Monarchs will either use environmental cues from light changes, temperature changes or signals from their host plant regarding their migration departure (Goehring & Oberhauser 2002).

Within the Monarchs' native range, we are seeing an increase in temperature and precipitation (Brower et al. 2011). These changes may influence the Monarch's life cycle, migration patterns and hibernation (Flockhart et al. 2019). The Monarch will track the blooming of milkweed to complete their migration, they fly southward to Mexico to overwinter as the temperature is low enough to keep their metabolism low but not freezing (Oberhauser et al. 2015). When these overwintering sites experience warmer temperatures, it could prevent the return trip northward in the spring (UN Environment Programme 2020). When temperatures are higher than average, this will affect milkweed growth and expand milkweed populations northward to be within their growing range (Lemoine 2015). This means that the Monarch will need to migrate further distances reducing their time spent at breeding ground (UN Environment Programme 2020).

To keep Monarch populations at self-sustaining levels they must be at healthy levels in terms of physical health, demographic health, and genetic health (Redford et al. 2011). This includes the body condition of the Monarch as it is sensitive to temperature changes which is reflected in their physical appearance, temperature changes can also affect their distribution across their range due to effects on their reproductive and growth rates (U.S. Fish and Wildlife Service 2020). The populations should also have a healthy gene flow between various Monarch populations with high genetic diversity (U.S. Fish and Wildlife Service 2020).

The variable environmental conditions that the Monarch is subject to will affect the population size, survival, and reproductive rates (Brower et al. 2011). For the Monarch population to have a strong growth rate they will need enough habitat to accommodate large population sizes that can survive in unfavorable environmental conditions (Voorhies et al. 2019). Large population sizes help Monarchs in maintaining genetic diversity, thermoregulation in the winter and mate finding (U.S. Fish and Wildlife Service 2020).

MODELLING THE MONARCH BUTTERFLY

The prediction of insect habitat through modelling software has become a more common practice to determine what drives species population declines (Flockhart et al. 2014, Kantola et al. 2019). Maximum entropy or MaxEnt is a modelling system that can model the geographic distribution of a plant or animal species (Phillips et al. 2004). This is important because when species, such as the Monarch butterfly, are endangered one must first learn where the species prefers to live and its survival requirements to assist in species survival (Phillips et al. 2004). MaxEnt does not require absence points (locations in which the species does not occur) for the distribution models, which allows for the use of presence-only datasets (Philips et al. 2006). Due to the use of the presence-only datasets within MaxEnt it produces a map of habitat suitability which can create issues when comparing the MaxEnt output to other presence-absence models (Philips et al. 2006). An issue with using presence only data is that the model can’t determine why species may be absent from an area. For example, a disturbance may have occurred in suitable habitat, and therefore the model will not find that area suitable due to the lack of local population (Elith et al. 2010). Another limitation of the MaxEnt modelling system is sample selection bias where some regions have a higher intensity of sampling as compared to other regions (Philips et al. 2006). However, this bias can be reduced by eliminating point aggregations which are samples found within a close range of one another (Philips et al. 2006).

CITIZEN SCIENCE AND CLIMATE CHANGE DATA

Citizen scientists and various Monarch monitoring programs have provided scientific researchers with insight into Monarch biology, populations, and life stages (Oberhauser et al. 2015). There are various citizen science programs across North America that help monitor Monarch butterflies or other insects such as Monarch Watch and the North American Butterfly Association (Oberhauser et al. 2015). Now, there are apps such as iNaturalist that allow citizen scientists to connect and share biodiversity information and confirm identification with professionals (iNaturalist 2023). Public participation in Monarch monitoring has grown overtime and citizens have been more involved in the design and implementation of research surrounding the Monarch butterfly (Oberhauser et al. 2015). Citizen scientists are playing a continuously increasing role in scientific research today and our technological advancements will continue to benefit citizen science research worldwide (Oberhauser et al. 2015).

There has been a consensus among scientists that there is human caused ecological consequences including increasing concentrations of carbon dioxide, alternations to the nitrogen cycle and land use and cover changes (Vitousek

1994). Greenhouse gas emissions such as carbon dioxide are the main cause of the increase of the global temperature (Mohajan 2017). Climate change is a serious issue that will have catastrophic effects on ecological values across the world (VijayaVenkataRaman et al. 2012). Climate change cannot be avoided entirely at this point however, there are ways we can mitigate the effects of climate change such as reducing greenhouse gas emissions (VijayaVenkataRaman et al. 2012).

When climate models are created, they require various scenarios that predict different emissions and how they affect radiative forcing which is a factor that changes Earth's radiative energy budget which will also affect the climate (VanVurren et al. 2011). The Intergovernmental Panel on Climate Change (IPCC) recognized the need for these scenarios and created the Representative Concentration Pathway (RCP) which consists of radiative force-based scenarios (Moss et al. 2010). There was a total of four RCPs that were developed including RCP2.6, RCP4.5, RCP6 and RCP8.5, which represent 2.6, 4.5, 6, and 8.5 W/ m^2 of radiative forcing (VanVurren et al. 2011). The RCP2.6 scenario represents low greenhouse gas emissions and medium-low air pollution. The RCP4.5 scenario has a low baseline for greenhouse gas emissions and medium to low mitigation with medium air pollution. The RCP6 scenario has a medium baseline for greenhouse gas emissions with high mitigation and medium air pollution. The RCP8.5 scenario has a high greenhouse gas baseline with medium-high air pollution (VanVurren et al. 2011; Moss et al. 2010).

To demonstrate the various effects of climate change on societal conditions the Shared Socioeconomic Pathways (SSP) were developed to predict the future impacts of climate change and the changes that follow within society (Figure 4) (O'Neill et al. 2017).

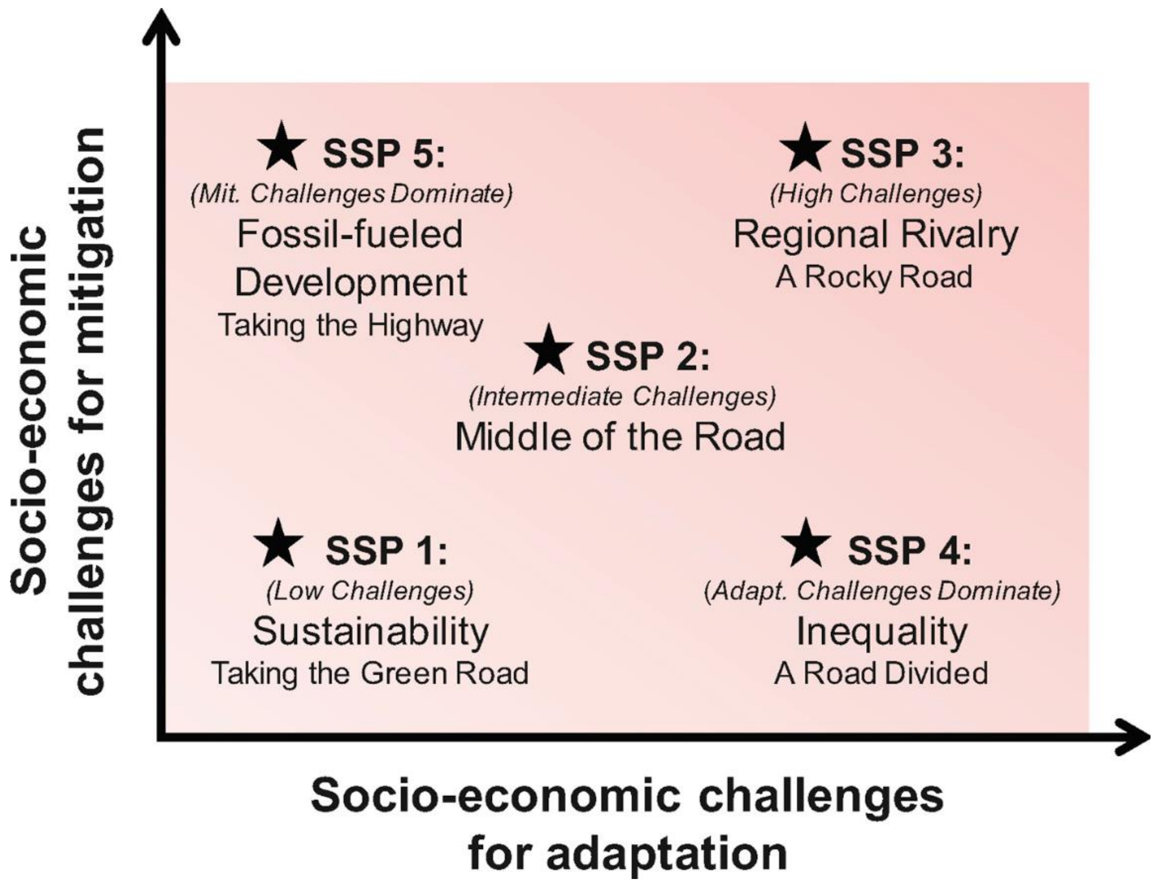

Figure 4. A breakdown of the various SSP pathways (O'Neill et al. 2017).

These scenarios consider the effects of climate change on social, political, technological, environmental, and economic values (O'Neill et al. 2017). Five scenarios, numbered SSP1 to SSP5, have been developed. These scenarios represent a range of adaptation possibilities (O'Neill et al. 2017). SSP1 represents a gradual shift in the world's path towards sustainability, with investments in education and health leading to a lower population (O’Neill et al. 2017). SSP2 represents a world path where the social, economic, and technological trends do not shift from historic patterns. In this scenario, there is slow progress towards the United Nations Sustainable Development Goals, environmental systems are degraded and energy usage declines (O’Neill et al. 2017). SSP3 represents a world path of negative change in which the environment is heavily degraded, and areas of the world are struggling to maintain living standards (O’Neill et al. 2017). In the SSP3 scenario, there is a decline in investments into education, technology and inequalities will worsen (O’Neill et al. 2017). SSP4 represents increasing disparities with an increase in inequalities and a widening gap between the internationally connected society and the lower income (O’Neill et al. 2017). SSP5 represents economic success of industries allowing for investments in health, education, and institutions (O’Neill et al. 2017). In the SSP5 scenario, economic success comes from relatively little effort to protect the environment on a global scale (O’Neill et al. 2017).

An intercomparison project that provides a framework for developing model datasets that incorporate SSP and RCP is the Coupled Model Intercomparison Project (CMIP) (O’Neill et al 2016). This method is used for various climate data across the world including the Canadian Downscaled Climate Scenarios-Univariate method (CanDCS-U6) which is downscaled using the Bias Correction/Constructed Analogues with Quantile mapping version 2 (BCCAQv2) (Government of Canada 2023b). The CMIP was able to create future climate scenarios using the SSP scenarios, with radiative forcing values creating a multi-model of climate projections (O'Neill et al 2016).

Monarch butterflies will need human intervention to help recover their population across Canada. In places such as southern Ontario, Monarchs occur yearly, and we should prioritize their habitat restoration and protection in these places. These actions will contribute to the long-term viability of Monarchs and their population levels across the province (Flockhart et al. 2019). Education will also be a vital resource in helping maintain the Monarch populations as educators can make connections between conservation and education (Oberhauser et al. 2025). Children and adults alike are fascinated by the Monarch butterfly as they are such an iconic insect (Oberhauser et al. 2025). Programs through the education system such as investigating monarch habitat or learning the developmental Monarch life stages can be implemented to help the youth of today learn about conserving for tomorrow (Oberhauser et al. 2025).

MATERIALS AND METHODS

STUDY SPECIES

The Monarch butterfly [*Danaus plexippus* (Linnaeus, 1758)] is found across Canada ranging from British Columbia to Newfoundland with extensive breeding taking place in southern Ontario (Government of Canada 2023a). The Monarch butterfly is scientifically classified from the kingdom Animalia, phylum Arthropoda, and class Insecta (Scott 1992). The Monarch butterfly is in the order Lepidoptera which is the second largest order in the class Insecta, consisting largely of butterflies and moths (Scott 1992). The next classification of the Monarch butterfly is the family Nymphalidae, which is a member of brush-footed butterflies, meaning that they have greatly reduced forelegs and stand on only four legs (Smith et al. 2005).

There are two North American populations of the Monarch butterfly (U.S. Fish and Wildlife Service 2020). These migratory populations consist of the Eastern Monarch Population and the Western Monarch population (U.S. Fish and Wildlife Service 2020). The Eastern Monarch Population overwinters in Oyamel Fir Forests in Mexico due to its humid microclimate and protection from frost (Government of Canada 2023c). The Western Monarch population overwinters along the Pacific coast of California as well as forests in central Mexico due to their high elevation (Government of Canada 2023c).

The milkweed is essential to the Monarch butterfly's life cycle and habitat as it is the only food for Monarch larvae to feed on (Government of Canada

2023a). Milkweed plants (mainly belonging to the genus *Asclepias*) are the only host plants for the Monarch butterfly in North America (Pocius et al. 2017).

Milkweed plants (*Asclepias* spp.) are perennial herbs that Monarch larvae are dependent upon for food. There are fourteen species of milkweed found across Canada with the majority of these being found in Ontario, which contains a larger variety of milkweed within its borders as compared to any other Canadian province (Table 1).

Table 1. Summary of Ontario milkweed distribution and status (White 1996).

Milkweed Species	Ontario Distribution & Status
Asclepias exaltata	Uncommon
Asclepias hirtella	Rare
Asclepias incarnata	Common
Asclepias lanuginosa	-
Asclepias ovalifolia	Rare
Asclepias purpurascens	Rare
Asclepias quadrifolia	Rare
Asclepias speciosa	-
Asclepias sullivantii	Rare
Asclepias syriaca	Common
Asclepias tuberosa	Uncommon
Asclepias variegata	Extirpated
Asclepias verticillata	Rare

Asclepias virdiflora	Rare

STUDY AREA

In this study, changes to Ontario's climate were modeled under several potential climate change scenarios and these scenarios were used to predict the future range of the Monarch butterfly. Ontario was chosen as the study area due to their abundance in southern Ontario and distribution across the province. The current Monarch distribution across Ontario can be viewed in Figure 5.

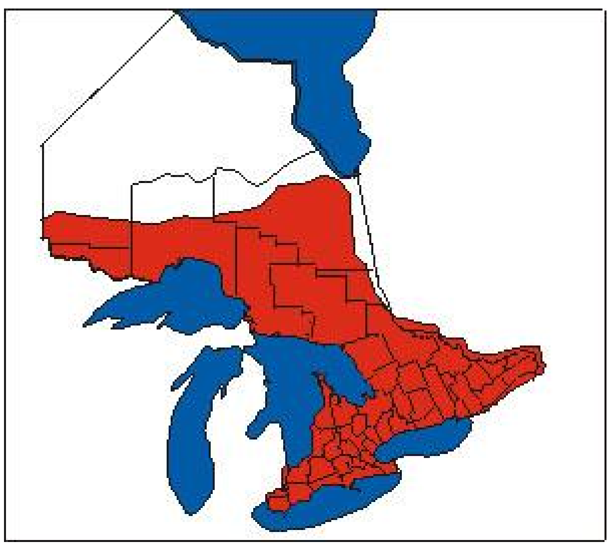

Figure 5. The current Monarch distribution across Ontario (Georgian Bay Biosphere 2024).

DATA SOURCE

Two primary datasets were utilized for this study, Monarch occurrence data and Canadian climate data for future climatic conditions. The "research-grade" occurrence dataset was accessed through iNaturalist on the occurrences of Monarch sightings across the province of Ontario (iNaturalist 2023). This dataset included the coordinate location (longitude and latitude), date, and occurrence of the Monarch butterfly for each observation across the province of Ontario. This dataset considers all stages of the Monarch from larvae to adult, meaning that there can be observations of the Monarch in a place where it cannot breed. This dataset was cleaned using ArcGIS to avoid selection bias for use in MaxEnt, by removing aggregated points closer than one kilometer to each other. The dataset utilized only Monarch sightings within the province of Ontario as this is the focus area of this study.

Climate data for this study was accessed through the Government of Canada. The dataset used for this model is the CanDCS-U6 which utilized univariate downscaling using the Bias Correction/Constructed Analogues with Quantile mapping version 2 (BCCAQv2). This dataset contains global climate models, variables, time period and SSPs. The variable chosen for this dataset was the maximum temperature which was tested under three SSPs (SSP 126, SSP 245, and SSP 585). These pathways were chosen to represent the variety of potential climatic change effects presenting minimal, moderate, and severe climatic change scenarios. This climate data is available for a period between 1950 and 2100, the years utilized for comparison are within a range with historical data between the years 1980 and 2000, the mid-century data between 2030 and 2050 and late-century data between 2080 and 2100. A summary of the selected SSPs and time periods are displayed below (Table 2).

Table 2. Displays the breakdown of the historical, mid-century and late-century data the SSP used for each.

Historical (1980-2000)	Mid Century (2030-2050)	Late Century (2080- 2100)
-	SSP 126	SSP 126
-	SSP 245	SSP 245
-	SSP 585	SSP 585

DATA ANALYSIS

Analysis of the Monarch's range under the various climate change scenarios was performed using entropy modelling. For this purpose, the Maximum Entropy (MaxEnt) model version 3.4.4 was utilized (Phillips et al. 2024). The Monarch Butterfly occurrence dataset was obtained from iNaturalist and was cleaned for both selection bias and misidentified specimens (iNaturalist community 2023). The cleaning was performed within an Excel datasheet where any species other than Monarch observations were removed from the dataset. The cleaned occurrence dataset was then used in conjunction with various climate scenarios from the Government of Canada to predict changes in the range of the Monarch butterfly under future climate scenarios. The SSP 126, SSP 245 and SSP 585 emissions scenarios were generated for the 2030-2050 and 2080-2100 time periods, reflecting mid-century and late-century projections, respectively. This resulted in seven species distribution models including the historical model that was generated with historical climate conditions.

There are various metrics that can be used to determine how important a variable is or how much it contributes to a final model. One of these metrics is percent contribution, which tracks the amount that a variable is contributing to fitting the model (Phillips 2010). Percent contribution is the increase in the gain that the environmental variables depend on converted to a percentage (Phillips 2010). Another metric is permutation importance which is calculated only on the final model to determine the significance of a feature and how much the model relies on it for accurate predictions (Phillips 2010). Another metric used to evaluate model quality is the Area Under the Curve (AUC) which represents the quality of the model. The AUC value ranges from one to zero and with a higher AUC value indicating higher model performance (Elith et al. 2010).

RESULTS

The MaxEnt model used in this study created future prediction maps of the Monarch butterfly's potential future distribution in Ontario. The most important climatic variable was found to be minimum temperature, followed by maximum temperature and then precipitation when the relative contribution of a variable was expressed as a percentage (Table 3). The minimum temperature showed the largest percent contribution in every output except for the SSP 545 scenario in the late century. When measured by permutation importance the maximum temperature was found to be the most significant followed by minimum temperature and then precipitation (Table 3). For this series of Monarch species distribution models, the MaxEnt software algorithm calculated the AUC value within a range of 0.887 to 0.890. This indicates that the models performed relatively high and were not overfit.

Table 3. The precent contribution and permutation importance of the climatic variables used for each species distribution model.

Century & SSP	Variable	Percent Contribution	Permutation Importance
Historic	Minimum temperature	93.2	18.8
	Maximum temperature	3.8	78.5
	Precipitation	3	2.7
Mid Century & SSP 126	Minimum temperature	94.1	55.6
	Maximum temperature	3.6	39.5
	Precipitation	2.3	5
Mid Century & SSP 245	Minimum temperature	83.5	16.3
	Maximum temperature	13	77.6
	Precipitation	3.5	6.1
Mid Century & SSP 585	Minimum temperature	87.8	1
	Maximum temperature	9.4	93.1
	Precipitation	2.7	5.9
Late Century & SSP 126	Minimum temperature	85.5	29.4

	Maximum temperature	12.6	63.9
	Precipitation	1.9	6.7
Late Century & SSP 245	Minimum temperature	48.1	8.2
	Maximum temperature	39.7	0.5
	Precipitation	12.2	91.3
Late Century & SSP 585	Minimum temperature	75	13.5
	Maximum temperature	21.5	82.9
	Precipitation	3.3	3.5

This model utilized occurrence data points of Monarch observations occurring across the province of Ontario (Figure 6). These points were cleaned for selection bias so that points within one kilometer of another would be removed, leaving points to be evenly distributed.

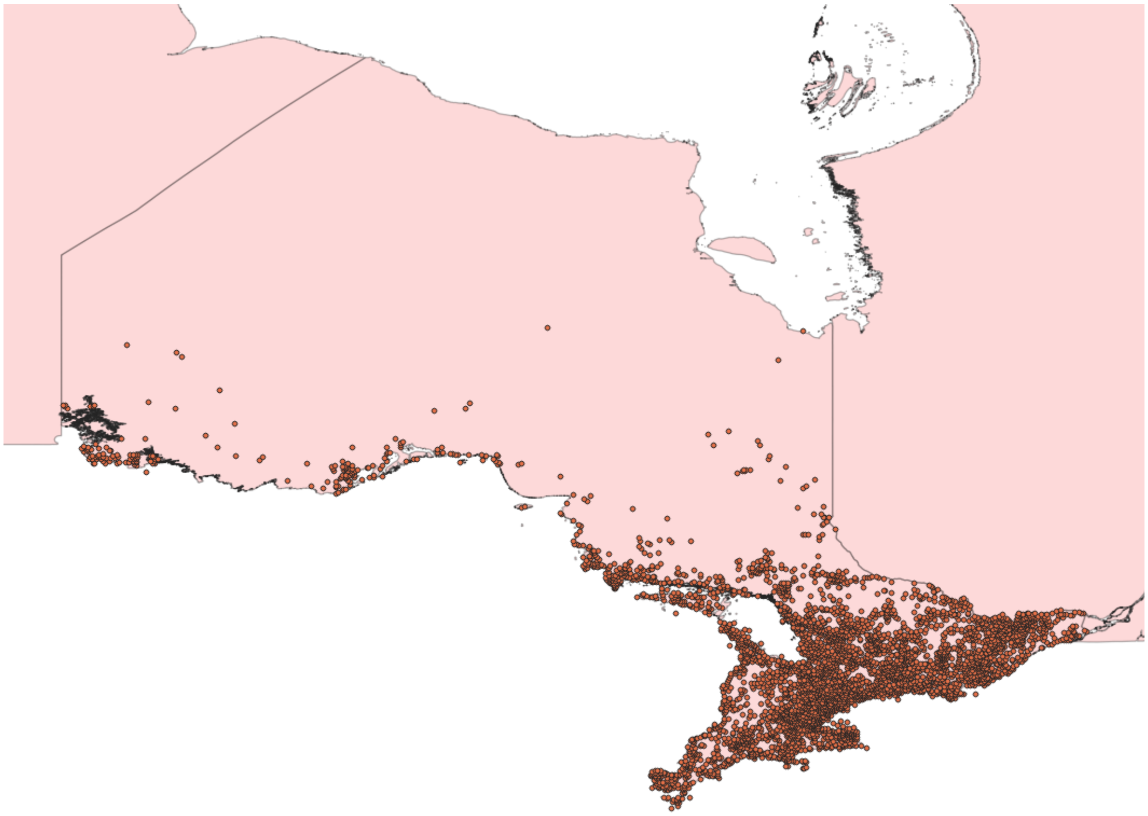

Figure 6. The occurrence points used within Ontario to generate the model.

The historic (1980-2000) species distribution model displayed the least habitat suitability for the Monarch Butterfly within Ontario. The majority of the Monarch's habitat at this time resides in Southern Ontario as seen in Figures 7 and 8.

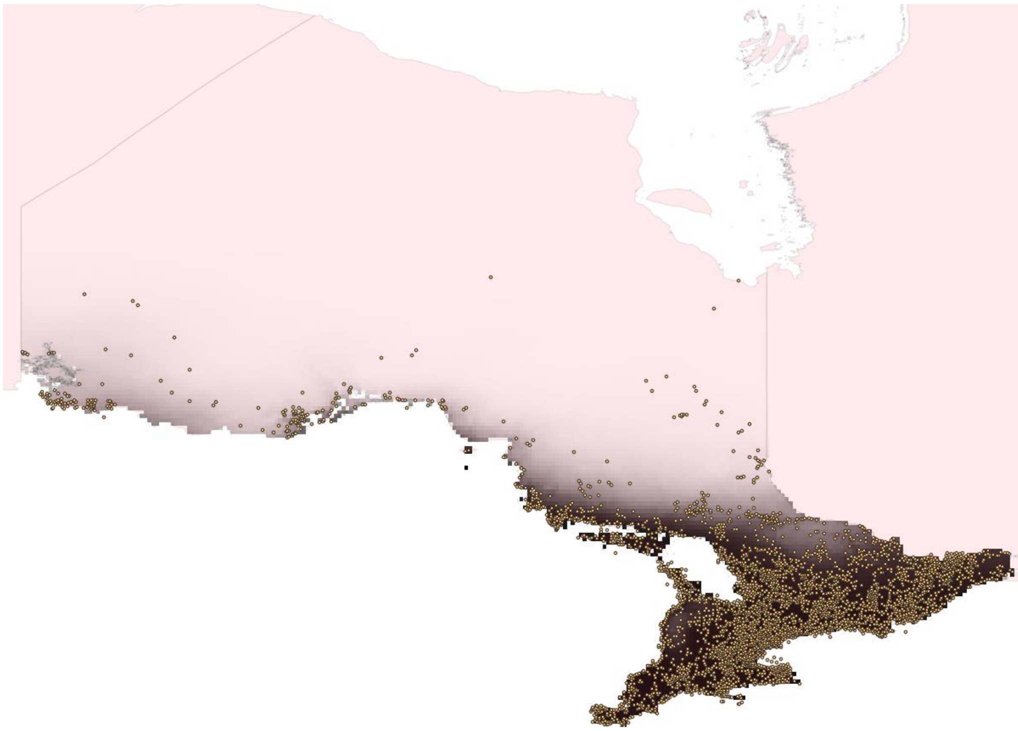

Figure 7. The species distribution map of the Monarch butterfly is based on historic (1980-2000) climatic data. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The pink coloration indicates no predicated suitability for the Monarch.

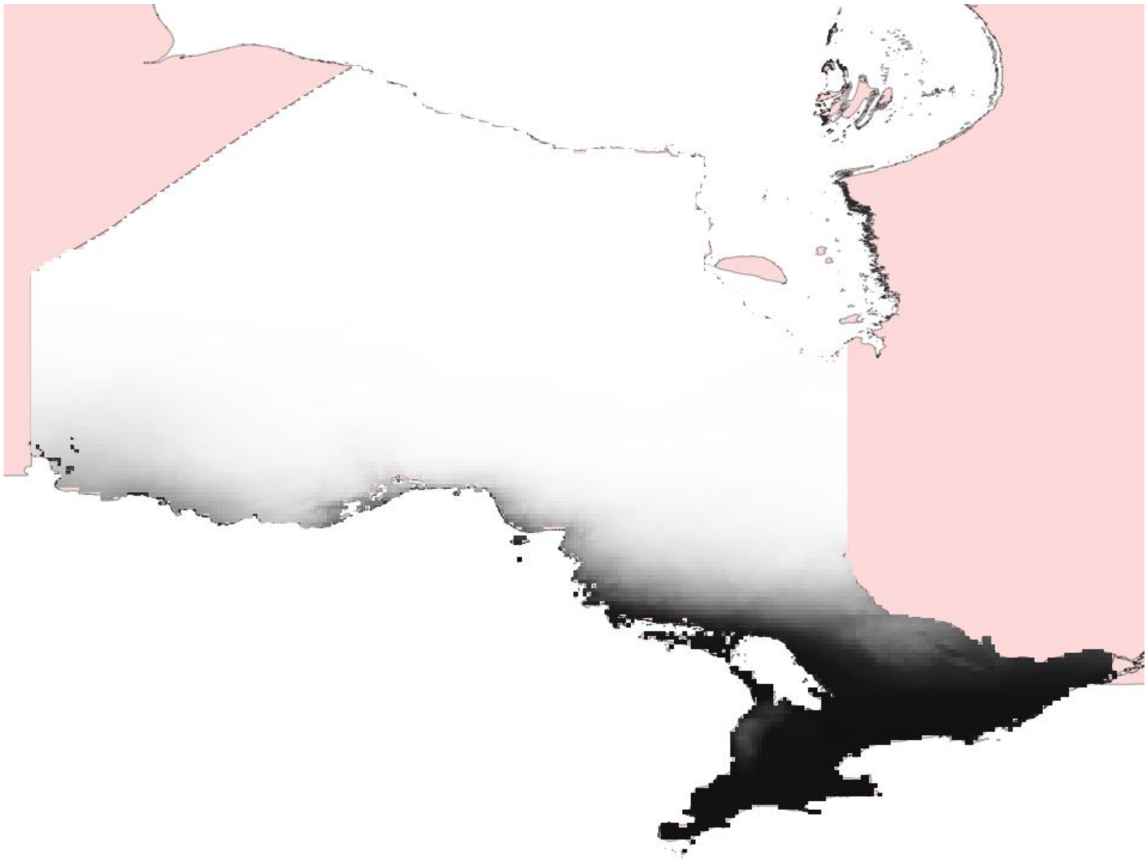

Figure 8. The species distribution map of the Monarch butterfly is based on historic (1980-2000) climatic data. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly.

The Mid-Century (2030-2050) future species distribution model displayed differences between the SSP 126, SSP 245 and SSP 585 scenarios. The Mid-Century SSP 126 scenario showed the Monarchs range moving the furthest North of the three scenarios as displayed in Figures 9 and 10. The Mid-Century SSP 245 scenario showed the Monarchs range moving eastward with a heavy presence of Monarch within Southern Ontario as displayed in Figures 11 and 12. The Mid-Century SSP 585 displayed the least amount of Monarch suitable habitat as compared to the other Mid-Century scenarios. This scenario moved the Monarchs suitable range further southeast as displayed in Figures 13 and 14.

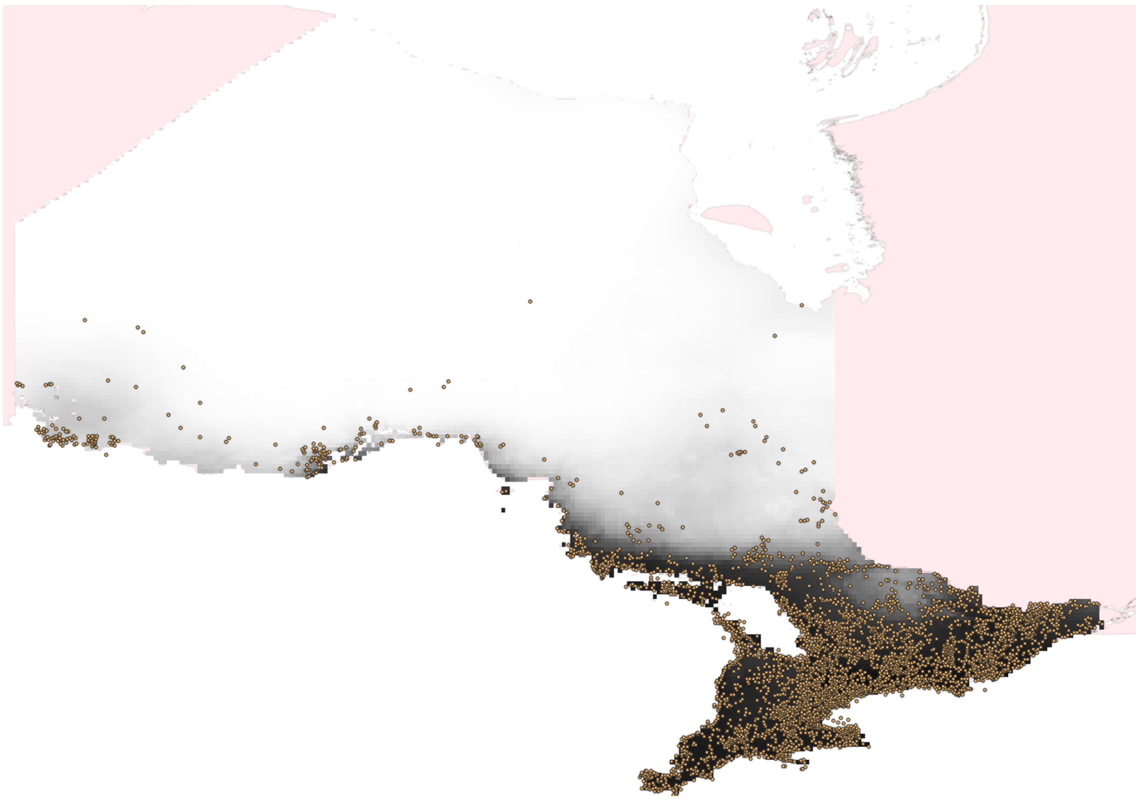

Figure 9. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 126 scenario. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

Figure 10. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 126 scenario. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

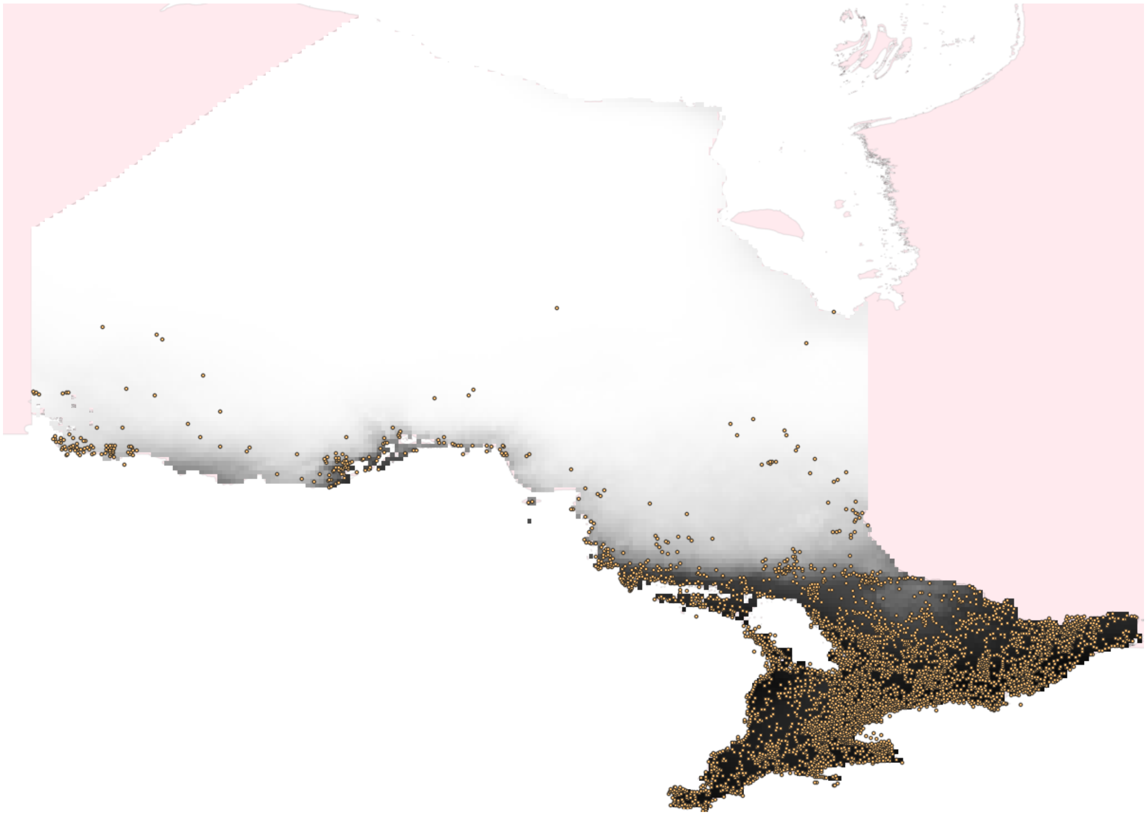

Figure 11. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

Figure 12. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario.

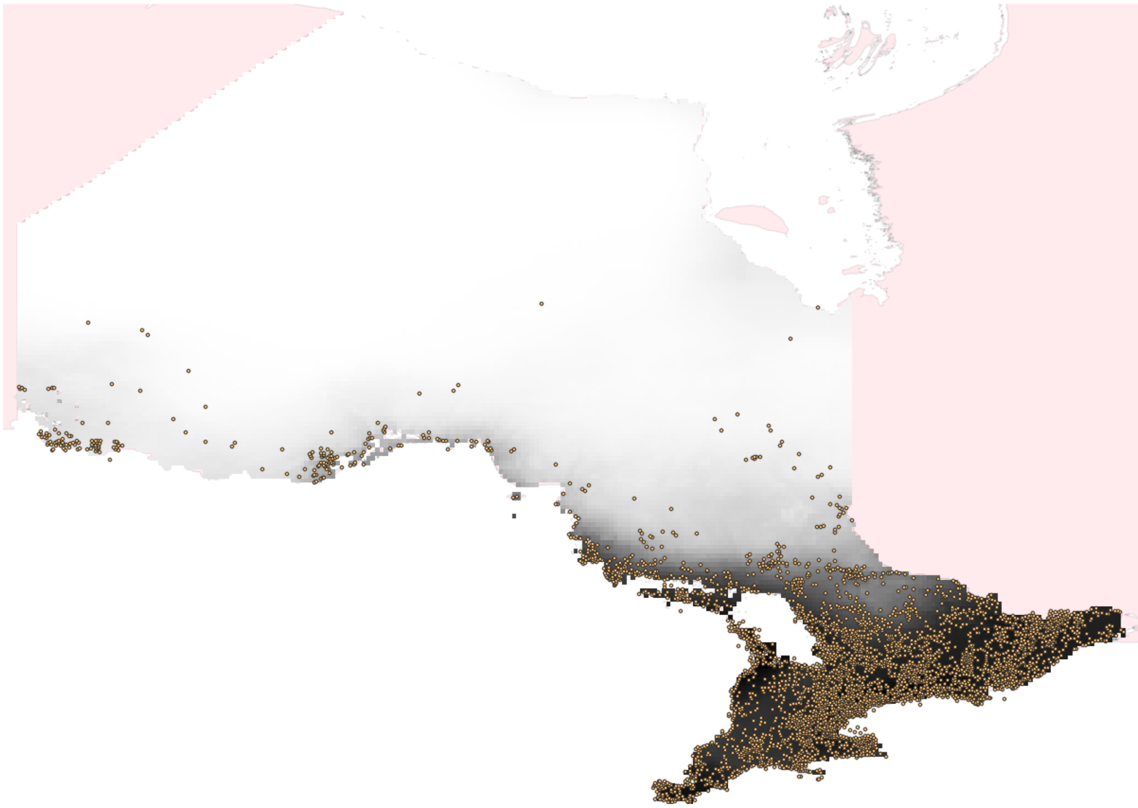

Figure 13. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 585 scenario. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

Figure 14. The future distribution map of the Monarch butterfly in 2030-2050 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 585 scenario. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

The Late-Century (2080-2100) future species distribution model also displayed differences between the SSP 126, SSP 245 and SSP 585 scenarios. The Late-Century SSP 126 scenario displayed Monarch suitable habitat within Southern Ontario with some habitat suitability continuing around Lake Superior as seen in Figures 15 and 16. The Late-Century SSP 245 scenario displayed heavy Monarch suitable habitat within Southern Ontario as seen in Figures 17 and 18. The Late-Century SSP 585 scenario displayed the least suitable habitat in the southeastern portion of Southern Ontario among three scenarios. The SSP 585 scenario also displayed heavy habitat suitability around the great lakes including Lake Superior into the Thunder Bay region as displayed in Figures 19 and 20.

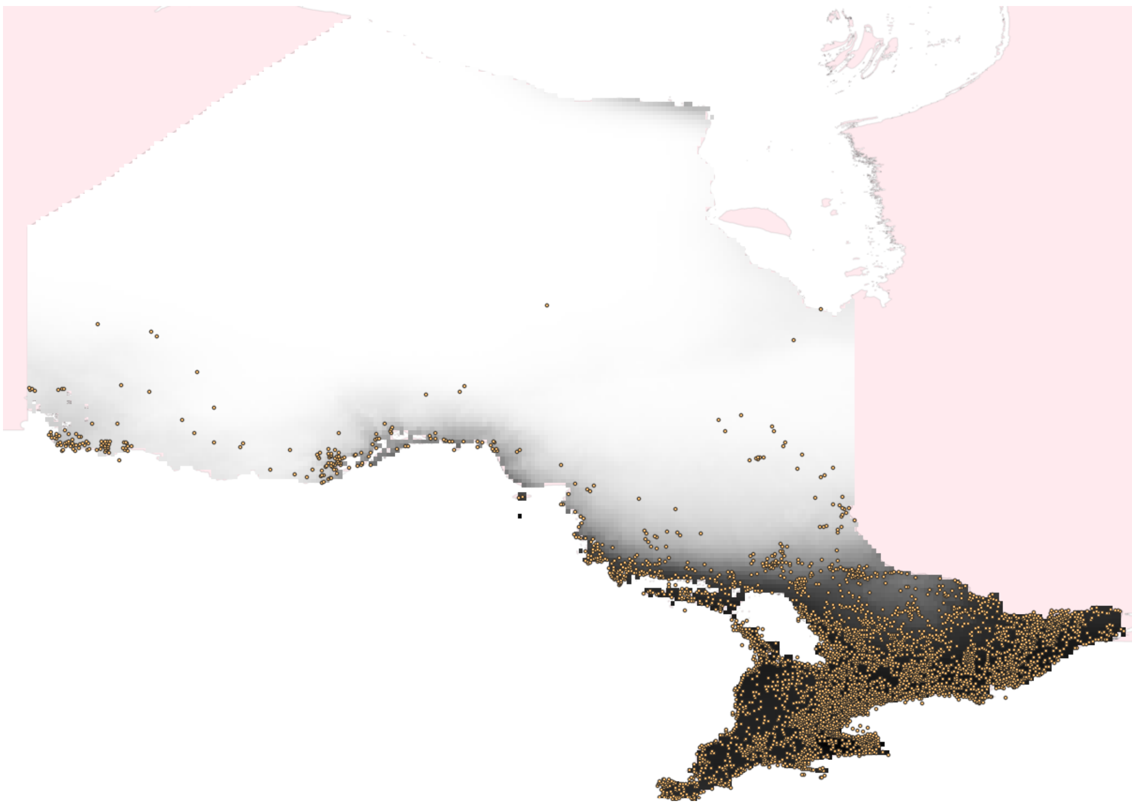

Figure 15. The future distribution map of the Monarch butterfly in 2080-2100 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 126 scenario. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

Figure 16. The future distribution map of the Monarch butterfly in 2080-2100 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 126 scenario. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

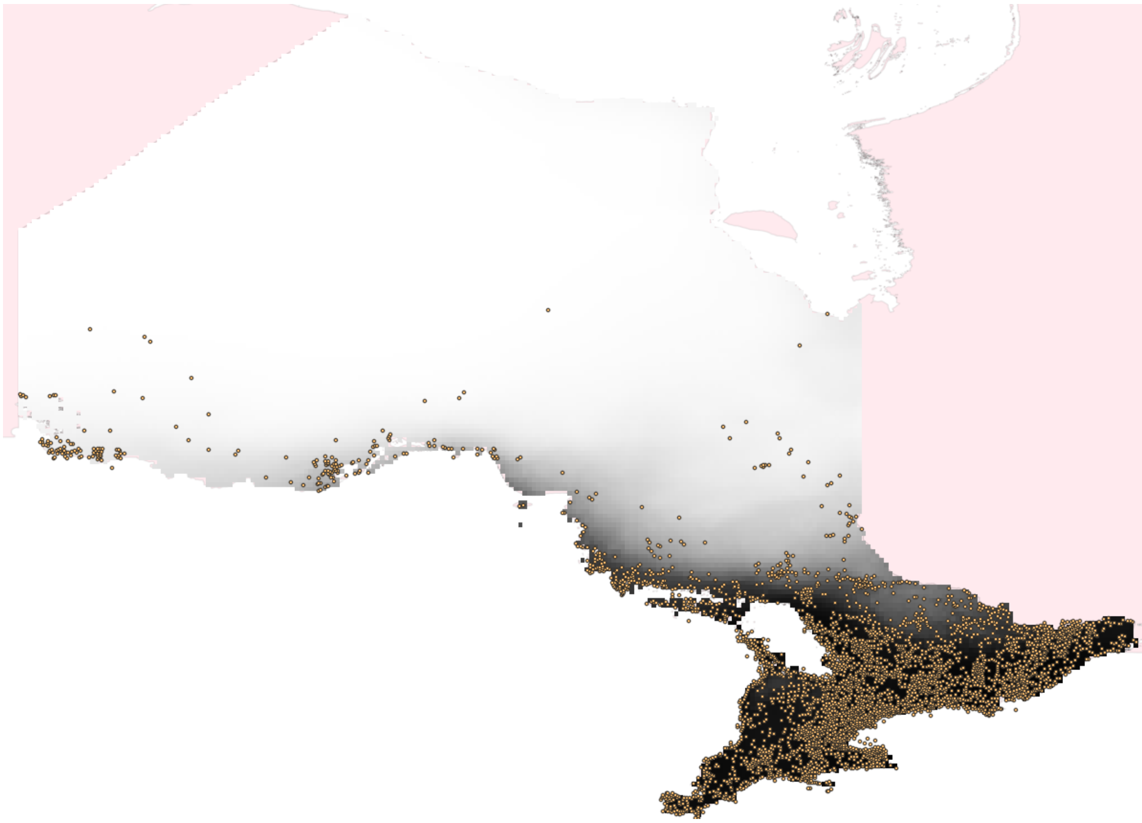

Figure 17. The future distribution map of the Monarch butterfly in 2080-2100 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

Figure 18. The future distribution map of the Monarch butterfly in 2080-2100 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

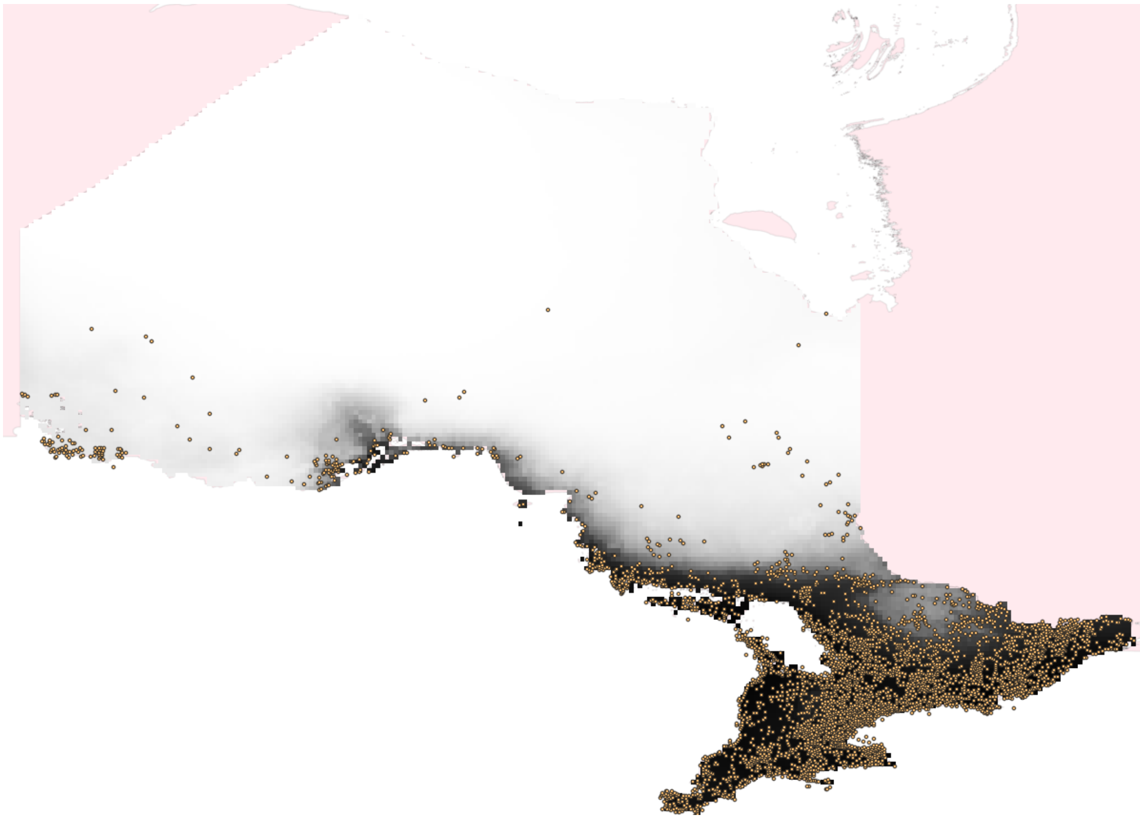

Figure 19. The future distribution map of the Monarch butterfly in 2080-2100 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 585 scenario. The yellow dots represent Monarch occurrence points used for the model training. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

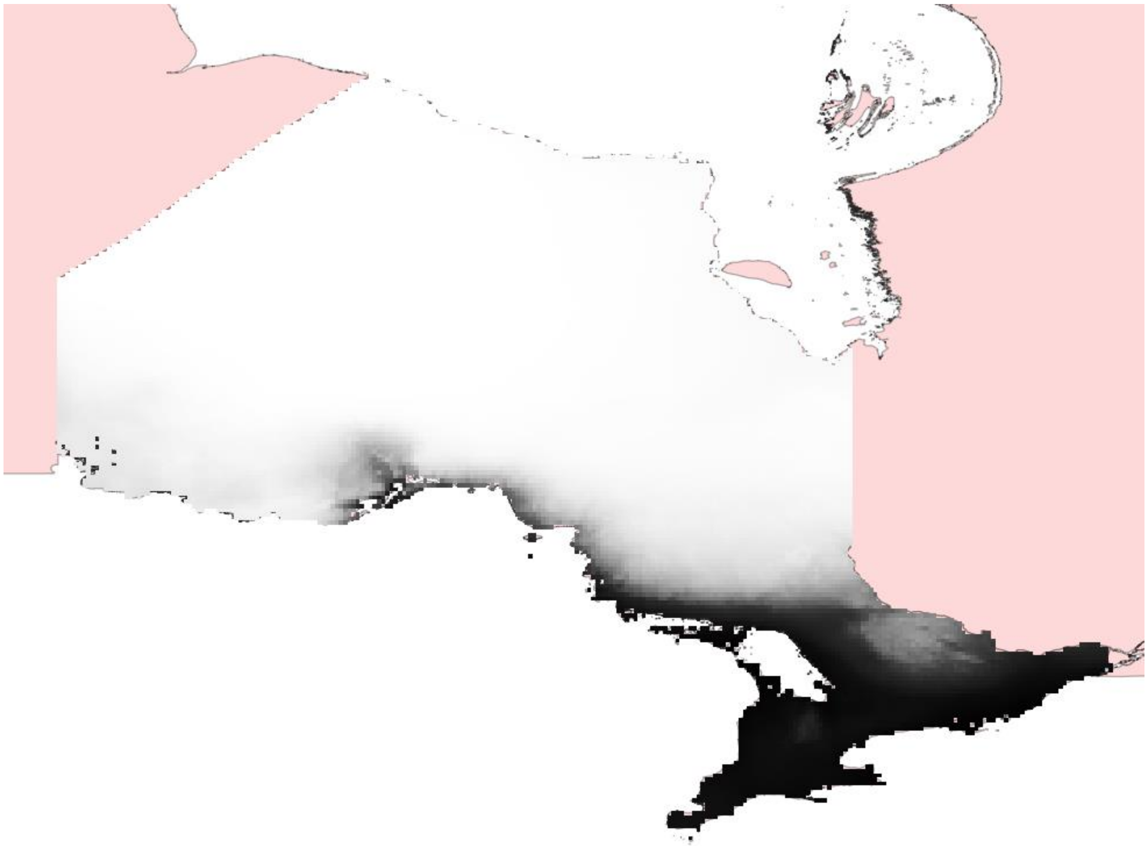

Figure 20. The future distribution map of the Monarch butterfly in 2080-2100 within Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 585 scenario. The dark and light gray colors indicate high and low habitat suitability for the Monarch butterfly. The white coloration indicates no predicated suitability for the Monarch.

The most significant difference was found in the southern portion of Ontario. This is where we see the largest change in Monarch habitat suitability. In the historical range we can see the Monarchs range staying in the southern portion of the province (Figure 21).

Figure 21. The species distribution map of the Monarch butterfly is based on historic (1980-2000) climatic data.

In the mid-century scenarios, the SSP 126 scenario displayed the largest range of suitable habitats for Monarch (Figure 22). The SSP 245 scenario displayed a smaller gap in suitable habitats between the Sault Ste. Marie and Sudbury areas (Figure 23). The mid-century SSP 585 scenario displayed similar suitable habitat to the historical habitat however there is less suitable habitat within the new scenario (Figure 24).

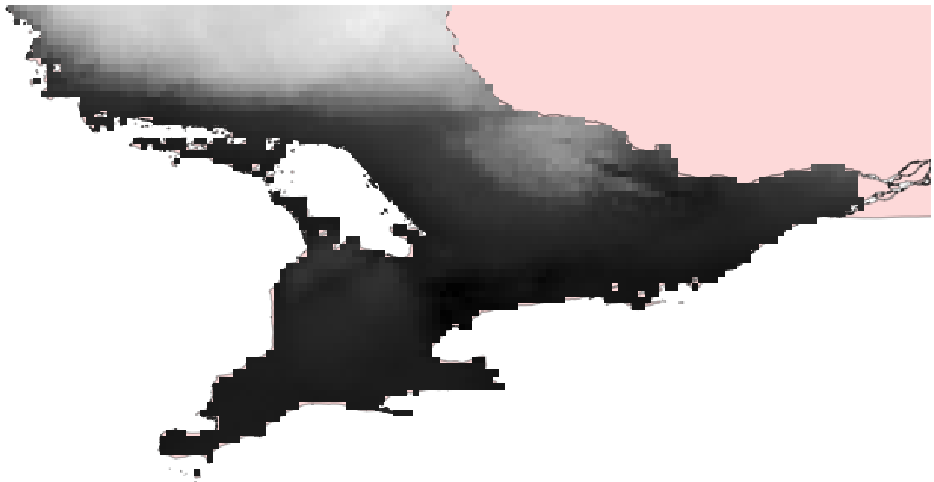

Figure 22. The future distribution map of the Monarch butterfly in 2030-2050 within southern Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 126 scenario.

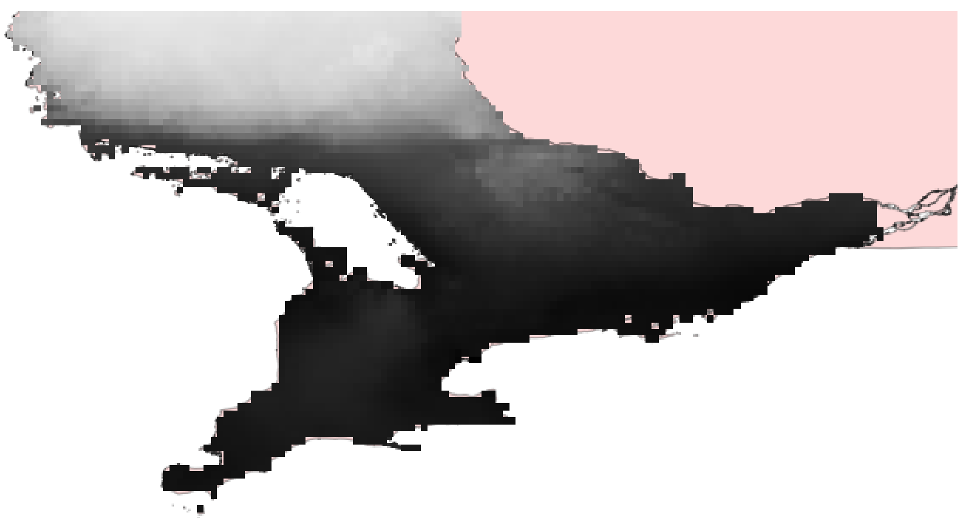

Figure 23. The future distribution map of the Monarch butterfly in 2030-2050 within southern Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario.

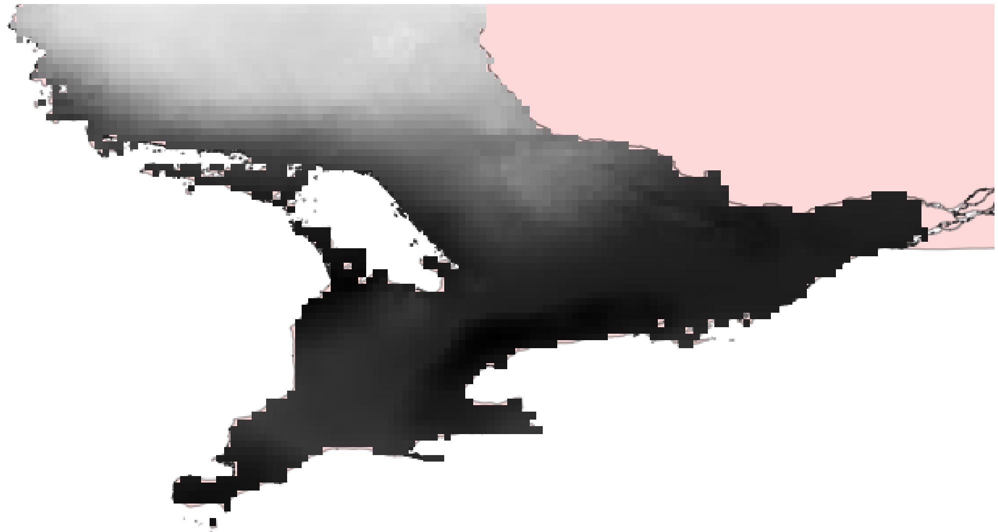

Figure 24. The future distribution map of the Monarch butterfly in 2030-2050 within southern Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 585 scenario.

In the late century scenarios, there were differences between the various suitable habitats found for Monarch butterflies. In the SSP 126 scenario, there were large amounts of habitat found below the Sault Ste. Marie and Sudbury areas (Figure 25). In the SSP 245 scenario, there was a larger gap between the two communities however the range extended further north than in the previous scenario (Figure 26). In the SSP 585 scenario, the suitable habitat range extended the furthest north travelling along Lake Superior (Figure 27).

Figure 25. The future distribution map of the Monarch butterfly in 2080-2100 within southern Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 126 scenario.

Figure 26. The future distribution map of the Monarch butterfly in 2080-2100 within southern Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 245 scenario.

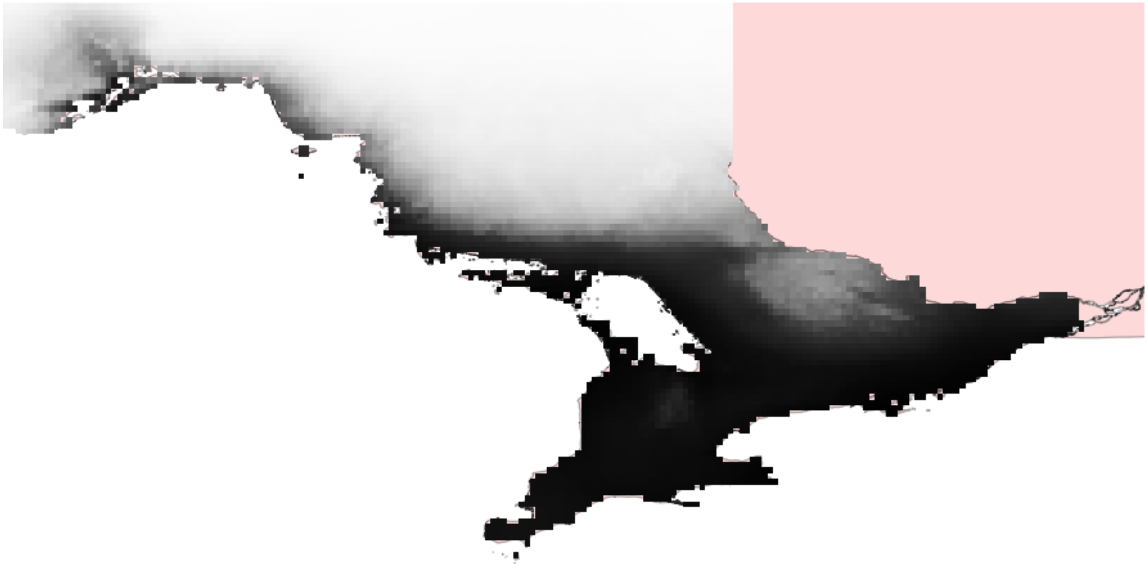

Figure 27. The future distribution map of the Monarch butterfly in 2080-2100 within southern Ontario based on downscaled climate data from the Government of Canada, CanDCS-U6 SSP 585 scenario.

DISCUSSION

The findings of this study indicate that there will be a shift in the Monarch's range in Ontario under future climate change scenarios. The species distribution models displayed a change in the Monarch's range even under a low-emissions SSP 126 climate change scenario. Most of the scenarios were shifting the Monarch's range northwards and eastwards. This trend is amplified when examining the late-century climate scenarios with the climatically suitable habitat moving north-east as well as surrounding Lake Superior.

Another aspect of the Monarch's range to consider is the effect of climate change on Milkweed (*Asclepias* spp.*)*. Monarchs are dependent on the survival of Milkweed which is predicted to move northwards under various climate change models (Lemoine 2015). Climate change may also alter the flowering dates of Milkweed which will affect their pollinators such as the Monarch butterfly and their flight periods (Howard 2018). The changing climate may also affect the cardenolide production of Milkweed, which is where Monarch butterflies get their chemical defense from (Faldyn et al. 2018). An effect on the milkweed chemistry could affect how Monarchs receive the cardenolide with the possibility of high concentrations being toxic to Monarchs (Faldyn et al. 2018).

Other studies that model climate scenarios have yielded similar results finding that the current range of the Monarch butterfly with change in various ways with climate change as they are a migratory species (Zylstra et al. 2022). Oberhauser & Peterson (2003) found that the two key environmental factors influencing suitable locations for Monarchs were precipitation and temperature, which were the two variables tested in this study. Climate change will likely impact more than the species migratory path it will also affect their winter range as climate modelling found that future increased precipitation in their winter range could increase Monarch mortality (Oberhauser & Peterson 2003). The Monarch summer breeding grounds may also be affected by climate change as Monarchs are projected to be in higher abundance in areas that have higher precipitation (Zylstra et al. 2022).

Citizen science will play a large role in future monitoring for changes in Monarch butterfly range. Citizen science was responsible for discovering that Canadian Monarch breeding ground was primarily located in Southern Ontario (Flockhart et al. 2019). Through citizen science data it was determined that Monarchs distribution through Ontario was largely limited by the availability of milkweed (Flockhart et al. 2019). A large advantage of citizen science is that it is easily accessible. However, there are some disadvantages as citizen science will often contain errors during the data collection process such as incorrect identification of species and bias errors due to the unbalanced regional sampling. Species distribution models can be another important aspect of citizen science, as they often utilize citizen science datasets to determine the presence and distribution of a species (Wiens et al. 2009). This type of modelling should be utilized in predicting what areas may become critical to future species conservation (Fisher et al. 2018).

The effect of climate variables other than temperature and precipitation on the Monarch butterfly range should also be further explored. This species distribution model predicts that the current range of the Monarch butterfly in Ontario will expand northeastwards under both mid and high emissions scenarios. This model also showed a slow expansion of their range around large waterbodies such as Lake Superior. There is research to suggest that Monarch breeding grounds around the Great Lakes may be a great site selection due to increased Goldenrod (*Solidago* spp.) cover, moderate forest cover and rural road cover (Fyson et al. 2023). There are already changes affecting the Monarch butterfly in Ontario. According to Crewe and McCraken (2015), the amount of these migratory insects has already been subject to long term population declines at various sites in southern Ontario.

There are steps that can be taken to help the current population of Monarch butterflies recover. Land managers should focus on both short- and long-term conservation of critical Monarch habitat such as their overwintering, breeding, and migratory habitat (Pelton et al. 2019). At a local level, land managers and owners can protect and increase milkweed abundance across the province (Fallon et al. 2015). There should also be additional research on the Monarch butterfly and its climate responses and recovery strategies (Pelton et al. 2019).

CONCLUSION

Overall, using an iNaturalist citizen-science dataset, the MaxEnt species distribution modelling of the Monarch butterfly under various future climate change scenarios discovered that the habitat of the species is likely to shift north-eastwards. This will have an impact on the migration and breeding of the Monarch butterfly within Ontario. Further studies should be performed to collect Monarch data within the far northern areas of the province to allow for further modelling opportunities in the province. Additionally, these studies should also examine other climatic variables other than precipitation and temperature such as relative humidity. This would allow for policy makers to determine the future range of the Monarch butterfly and would allow them to create policies protecting future Monarch habitat. Further studies should be performed to give land managers and policy makers the best tools for the Monarch butterfly conservation efforts.

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