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ORIGINAL PAPER

Mission Monarch: engaging the Canadian public for the conservation of a species at risk

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Abstract

Migratory populations of monarch butterflies have declined substantially in North America. In Canada, where the monarch is listed as a species at risk, protecting the butterfly's critical breeding habitat has been identified as a conservation priority. However, protection of the breeding habitats in this country was not readily possible due to the scarcity of monarch breeding data. Here, we describe Mission Monarch, a community science program launched in 2016 to address this knowledge gap. We compare the Mission Monarch dataset with the datasets of eButterfly, iNaturalist and the Monarch Larva Monitoring Project, three other longer-established community science programs, to highlight the unique knowledge gap that Mission Monarch helps fill at national to continental scales. Even though Mission Monarch is a relatively young program, it has already provided more records of monarch caterpillars and milkweed than any other Canadian dataset from the aforementioned programs near the species' northern range. It has become the main monarch breeding monitoring program in Canada. We discuss the relevance of community science in filling knowledge gaps and addressing conservation issues.

Implications for insect conservation Community science programs can be specifically designed to fill knowledge gaps for insect conservation. They can be unique, yet complementary to other established programs.

Keywords Community science · Danaus plexippus · Butterfly conservation · Species at risk · Asclepias · Breeding hotspot

Introduction

Both eastern and western overwintering populations of the North American migratory monarch butterfly (*Danaus plexippus* L.) have substantially declined in the past two decades, putting at risk the unique migratory phenomenon (Pelton et al. 2019; Semmens et al. 2016; but see Crossley et al. 2022). Continental-scale drivers of this decline include loss of breeding, feeding and overwintering habitats, as well as climate change (Belsky and Joshi 2018; Crewe et al. 2019; Pleasants and Oberhauser 2013; Solis-Sosa et al. 2021; Zylstra et al. 2021). In response to these declines, the monarch has been granted a legal protection status in Canada, where the protection of breeding, nectaring and staging habitats is a conservation priority (ECCC 2016).

Monarchs lay eggs on milkweeds (*Asclepias* spp.), their obligate larval host plants. While both milkweeds and monarchs have wide distributions in North America, quantifying, and eventually protecting the butterfly's breeding habitat at such a large-scale requires fine-scale knowledge of milkweed distribution and milkweed use by monarchs. Fall migration counts conducted in Ontario over the past decades provide valuable data on the migratory population (Crewe and McCracken 2015; Ethier 2020), however the creation, conservation and enhancement of monarch breeding habitats during the summer season are top priorities (ECCC

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2016). Fine-scale data on milkweed distribution and its use across the monarch's potential breeding range are required to inform conservation actions needed and ultimately meet those objectives.

Community science is a powerful and flexible approach in conservation science, e.g. to model species distribution (e.g. Wilson et al. 2021, Soroye et al. 2018). Community science has greatly contributed to the knowledge of monarch ecology in the past decades, especially in the United States, thanks to well-established programs such as Monarch Watch (MonarchWatch.org) and the Monarch Larva Monitoring Project (MLMP, mlmp.org). There are several generalist community science monitoring programs that target a broad spectrum of species (e.g. iNaturalist, eButterfly, eBird), and researchers typically choose from these the data they need to answer specific questions. However, when the data necessary to address pressing questions are not readily available in existing programs, new community science projects can be specifically designed to fill knowledge gaps.

Here, we introduce Mission Monarch (MM), a community science program that documents monarch and milkweed distribution in Canada. We evaluate its success to date in filling knowledge gaps relative to monarch data collected by three other community science programs. Last, we provide two case studies that illustrate how MM data can be used and discuss where MM is headed in the future.

Methodology

To assess the monarch's coarse-scale potential breeding range in order to better orient outreach and sampling efforts, we modeled the distribution of the monarch butterfly and the seven most common milkweed species in Canada (*Asclepias incarnata*, *A. ovalifolia*, *A. speciosa*, *A. syriaca*, *A. tuberosa*, *A. verticillata* and *A. viridifolia*) using MaxEnt (Fig. 1). We selected bioclimatic variables describing temperature, precipitation, and soil conditions to model species distributions based on known drivers of plants and insect distribution in Canada (Kharouba et al. 2009). We used data available prior to the launch of MM from the Global Biodiversity Information Facility (GBIF 2022) and eButterfly (Prudic et al. 2017) to model potential breeding range. Methods used to model monarch and milkweed distributions are described in supplementary materials.

Mission Monarch: a community science program to document monarch breeding in Canada

Mission Monarch was launched in 2016 by the Insectarium—Montréal Space for Life, with funding support from Environment and Climate Change Canada. It is a web-based community science program in which participants share their observations of milkweeds and monarchs online (Mission-Monarch.org). The web platform is available in both official languages in Canada: English and French. The program focuses on monarch and milkweed density and distribution while evaluating the colonization and usage of milkweed species by monarchs. Data are open-access and

Fig. 1 Distribution models for the monarch and the seven most common milkweed species in Canada based on GBIF occurrences: *Asclepias incarnata, A. ovalifolia, A. speciosa, A. syriaca, A. tuberosa, A. verticillata and A. viridiflora*. Models generated using MaxEnt. See Supplementary material S1 for methodology

can be downloaded from the website (mission-monarch.org/explore).

As lay public participation may be halted by protocol complexity, the Mission Monarch protocol was designed to allow for collecting data addressing the program's objectives using the most user-friendly methodology (Roy et al. 2007). The MM protocol consists of counting the number of milkweed stems examined while looking for monarchs of any life stages, and counting individuals, if any. This allows the calculation of a caterpillar-per-stem ratio at each site, which can be extrapolated using the site size estimation and milkweed abundance index provided by participants and described in the supplementary materials. Participants can also share opportunistic monarch observations made in the absence of milkweed.

An observation is defined by a monarch and/or milkweed count from a specific location at a specific time. Photographs can be uploaded along with an observation, but are not mandatory. The resulting database consists of geolocated milkweed abundances associated with monarch abundances or absences. Details about the protocol are given in the supplementary materials S3.

Data quality is ensured by participant training online educational resources and observation vetting. During the summer, training sessions are provided to team leaders who act as multiplying agents in their communities. Workshops are hosted by local organizations such as parks and libraries and are open to the public free of charge. They consist of an informational part about monarch biology and population status, followed by a practical part during which a nearby milkweed patch is visited and data are collected and shared on the website. Workshop participants get to identify milkweeds and the monarch's different life stages as well as use the website to share and explore data. Resources are also available online to help participants with identification (mission-monarch.org). These trainings were targeted in provinces and regions that were within the area delineated by the MaxEnt model and initially poorly documented in the Mission Monarch database.

All observations submitted to MM are vetted by a regional expert to further ensure data quality. Vetting is done through an online admin panel, where each observation has a status that is either pending, vetted or invalid. Status appears in the database so that only vetted observations can be used for analyses, for example. An observation is invalidated if an associated picture shows a wrong species. Participants are encouraged to submit pictures along with their observations to facilitate validation. This is especially true for untrained participants, as training covers monarch and milkweed identification extensively. Observations submitted by trained participants are vetted right away unless they display obvious errors in terms of phenology and/or timing for both milkweed and monarch observations or in terms of location (far outside of the range of both species). Also, at the end of the season, a regional expert invalidates any duplicated observations (i.e. observations reported by the same user at the same location, at the same date, and at the same time).

Dataset comparison

We compared MM to three other community science programs in terms of data collected: eButterfly, launched in 2012 (e-butterfly.org, Prudic et al. 2017), iNaturalist, launched in 2008 (iNaturalist.org), and MLMP, developed in 1997 (mlmp.org). For each program, we extracted observations submitted from Canada between January 1st, 2016 and December 31th, 2021. The datasets are structured in different ways. eButterfly is based on species lists, i.e. the abundance of butterflies of each species observed at a specific location, over a given distance or area and during a given time period. iNaturalist is made up of presence-only records of single species, generally without information on sampling effort, abundance, or association with other species. Only data from "Research Grade" observations, i.e. with at least two thirds of converging validation by other users, were extracted. The structure of MLMP data is most similar to that of MM.

Results

Between 2016 and 2021, 9701 observations from 9 Canadian provinces have been shared by Mission Monarch participants. A total of 7638 photographs were uploaded along with 3805 observations. Participation has grown exponentially since the program was launched until the COVID-19 pandemic (Fig. 2). The number of active participants peaked in 2019 at 1178. Retention rate, i.e. the ratio of participants that returned from the previous year, was $19.7 \pm 6.4\%$ (mean $\pm$ sd).

No in-person recruitment activity was conducted in 2020 due to public-health safety measures, which is reflected in the participation drop that year. Eleven online workshops and webinars were given in 2020.

During the same period of time, MM has yielded results comparable to longer-established programs in Canada, such as eButterfly and iNaturalist (Table 1). While the number of records submitted to eButterfly is higher, most of them only include adult monarchs. Records of immature life stages, especially caterpillars, are more often reported to MM. Record numbers were higher for iNaturalist, but do not provide data on abundance, nor resource use by immature stages (i.e. milkweed species). Contrary to MM and MLMP, lifestage doesn't have to be specified prior to submitting an observation to eButterfly and iNaturalist, resulting in high numbers of undefined stage records in those datasets.

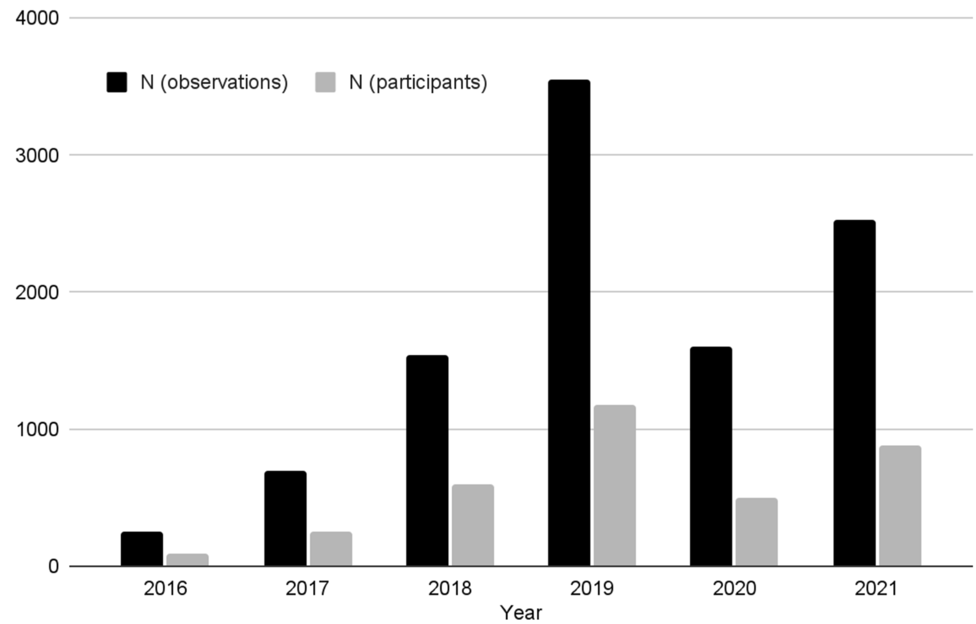

Fig. 2 Level of participation to Mission Monarch per year between 2016 and 2021

Table 1 Cumulative number of monarch and milkweed records submitted to Mission Monarch compared to eButterfly, iNaturalist, and the Monarch Larva Monitoring Project (MLMP) for Canada between 2016 and 2021

	Mission Monarch	eButterfly	iNaturalist	MLMP
Monarch (*Danaus plexippus*)	59,028	150,509	16,068	2,170
Adults	18,895	65,460	5564	490
Eggs	17,107	608	285	1359
Caterpillars	19,816	2198	4168	287
Chrysalises	3210	225	325	34
Undefined stage	0	82,018	5650	0
Milkweed[a] (*Asclepias* spp.)	411,829	NA	12,047	9150
Milkweed species	10	NA	13	6

eButterfly and iNaturalist data were downloaded from GBIF (GBIF 2022, 2023a, 2023b)

MLMP data were obtained from a direct request

[a]Milkweed count from different programs might not reflect the same metric. MLMP numbers refer to plants, while MM numbers refer to stems. See supplementary materials for details regarding the MM protocol

During the last decades, large amounts of data on monarch and milkweed distribution have been gathered by over 10 well-established monarch community science programs (and 5 general butterfly monitoring programs), most of which are located in the United States. However, although some of those programs are international, they failed to collect sufficient data in Canada. For example, the North American Butterfly Association runs 26 Canadian butterfly counts in Alberta, Ontario and Saskatchewan (NABA 2021). The Monarch Larva Monitoring Project has 129 Canadian registered monitoring sites in Manitoba, Ontario and Québec (MLMP 2022). In comparison, MM has gathered observations from 3341 unique locations distributed in 9 Canadian provinces (Fig. 3).

Case studies

MM data document monarch and milkweed distribution and density in Canada. With respect to breeding productivity, its protocol allows for comparing caterpillars-per-stem ratios throughout space and time. Areas associated repeatedly with high ratios might represent breeding hotspots of potential conservation value. Conversely, areas with low ratios can be simultaneously investigated to determine the drivers of low breeding productivity and may help establish candidate locations for habitat restoration activities. This section presents two case studies illustrating how MM data can be used.

MacNair (2022) combined data from MM, eButterfly, and the Ontario Butterfly Atlas to model the probability of observing monarchs across southeastern Ontario (Fig. 4). She used a dataset comprising 5461 records to identify spatial clusters with greater (hotspots) or lower (coldspots) likelihood of observing monarchs. Using land cover data, she could link specific spatial attributes to areas with hotspots. This type of results help in locating and quantifying high quality monarch habitat, allowing for targeted conservation efforts.

Moczula et al. (submitted) used photographs submitted to MM, eButterfly and iNaturalist to document the use of nectar resources by monarchs during the spring and

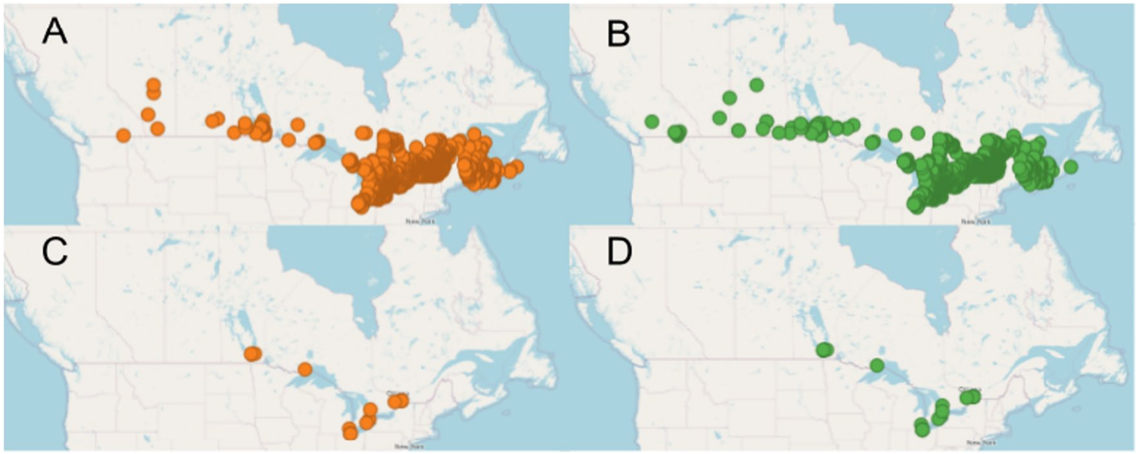

Fig. 3 Distribution of monarch (orange dots) and milkweed (green dots) observations submitted to Mission Monarch (**A** and **B**) and the Monarch Larva Monitoring Program (**C** and **D**). (Color figure online)

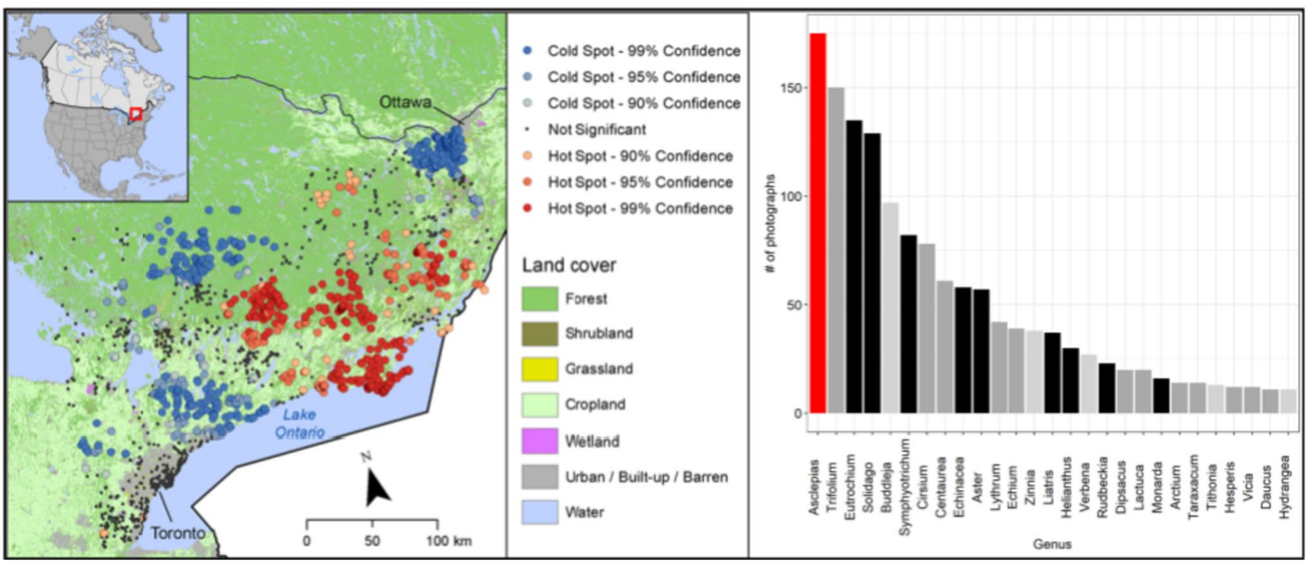

Fig. 4 Examples of use of Mission Monarch data. Left: Monarch observations of hot and cold spots in Southeastern Ontario. Data sources and methods are described in Supplementary Materials S2. Map reproduced with permission from MacNair (2022). Right: Frequency of flowering plant genera on which monarchs were observed nectaring from 2012–2018 for which a minimum of 10 observations were collected. The red bar represents milkweeds (*Asclepias* spp.), black bars represent native species, dark grey represents non-native species, and light grey represents cultivated species. Figure reproduced with permission from Moczula et al. (submitted). (Color figure online)

fall migrations and summer breeding period. 1843 photographs showing monarchs on flowers were to make 2034 flower identifications (there was more than one flower and monarch in some photographs). Monarchs were observed nectaring on 113 plant genera, with highest diversity in late summer (Fig. 4). These types of results are the first steps to identifying important areas for habitat protection and candidate floral species for restoration activities.

Discussion

While the monarch butterfly has been listed as a species at risk in Canada since 2004, data were lacking to locate and quantify breeding habitats. The community science program Mission Monarch was launched in 2016 to address this issue. Since then, it has gathered substantial amounts of data from several Canadian provinces, filling a knowledge gap.

While well-established American programs such as MLMP or NABA have gathered great datasets over the years using similar protocols, they cover only a small part of the Canadian monarch breeding range. Data from the species' northern range are crucial as its host plant's range is expected to expand northward due to climate change (Lemoine 2015). Other programs such as eButterfly and iNaturalist gather large amounts of data on monarchs in Canada, but lack information on larval stages, host plant selection (oviposition) and usage (presence of caterpillars). This leads to an underestimation of the extent of monarch breeding dynamics at its northern range limit. MM data therefore complement that of other monitoring programs such as eButterfly, providing data required for conducting continental analyses that delineate monarch and milkweed distribution in its entirety.

Community science programs have inherent biases and so does MM. For example, there is spatial bias as observations are concentrated in densely populated areas, which is largely the area between Montreal and Toronto. Still, several hundreds of observations were uploaded from other areas like southern Québec and the Maritimes (Fig. 3). Spatial bias can be mitigated using different statistical tools (Johnston et al. 2022). Gamification or providing an incentive can also be used to get participants to go to undersampled areas (e.g. Xue et al. 2016; Callaghan et al. 2023). Other possible biases include oversampling of later larval instars relative to earlier instars and eggs being overlooked or misidentified. Workshops and ID sheets provided to participants and expert review (vetting by a regional expert) helps reduce such bias. To assess the extent of oversampling bias in opportunistic data, a systematic comparison could be made between a subset of the latter and data from a more rigorous sampling design. Furthermore, the MM strategy to (1) engage a large number of participants from a broad public with (2) varied skill levels at detecting monarchs and milkweed is in line with a Big Data approach, where methods can be developed to address the issues of data quality (Bird et al. 2014; Kelling et al. 2015).

Moving forward, targeted monitoring efforts in areas less sampled by participants will be necessary to reduce spatial bias that typically emerges from data gathered through community science programs (Callaghan et al. 2019). New Mission Monarch tools will soon be made available to collect more detailed and spatially balanced data that is compatible with similar initiatives from the United States and Mexico. This spatially balanced sampling grid is strongly inspired by the Generalized Random Tessellation Systematic (GRTS) sampling framework used by the Integrated Monarch Monitoring program (IMMP) in the US (Cariveau et al. 2019). Details can be found at mmx.mission-monarch.org. Finally, we will continue to provide online and in-person workshops, particularly targeting areas with low participation to further reduce spatial bias and knowledge gaps.

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Declarations

Competing interests The authors declare no competing interests.

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