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The monarch butterfly in Mexico: a conservation model

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Each fall, millions of monarch butterflies (*Danaus plexippus* L.) travel from Canada and the United States to overwinter in Mexico and California. In 2022, the IUCN listed migratory monarchs as endangered because of their population decline. The main accepted drivers are widespread use of herbicides, effects of climate, and land use change that causes habitat loss.

We analyzed the main actions taken to officially protect the overwintering sites and the migration phenomenon with the establishment of the Monarch Butterfly Biosphere Reserve in 2000. The conservation of the monarch overwintering sites in Mexico is an example of continuous work from their discovery to the present.

We highlight the importance of monitoring the areas covered by overwintering monarchs in Mexico. These colonies represent the largest concentrations of monarch populations in the world. In the last 10 years, the average area covered by monarchs was 2.72 (± 0.47 SE) hectares.

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Background

The eastern population of the monarch butterflies (*Danaus plexippus* L.) in North America is unique in nature because millions of butterflies travel from southern Canada and the northern and central United States to overwintering sites in central Mexico [1–3]. They form aggregations, also called colonies, on the border of Michoacan and the State of Mexico (Figure 1), locally known as the Monarch Region. This migration in the fall is marvelous because monarchs travel up to 4000 km to areas that were only known by their ancestors. It takes them 3–5 generations to complete the annual cycle in North America [4–7].

The IUCN listed the monarch as endangered in 2022. The decision was based on a 10-year reduction of the eastern and western migratory monarch populations, resulting in an index of decline for the eastern migratory population that ranges from 22% to 72% [8•]. Climate factors, host plant declines in the summer breeding range because widespread use of herbicides, land use change, and habitat loss in overwintering sites are considered the main attributable drivers [9–19]. Analysis of data from 2004 to 2018 indicates that climate in the areas where monarchs breed during the spring and summer months explains most of the variation in numbers of the eastern summer and winter populations [20•].

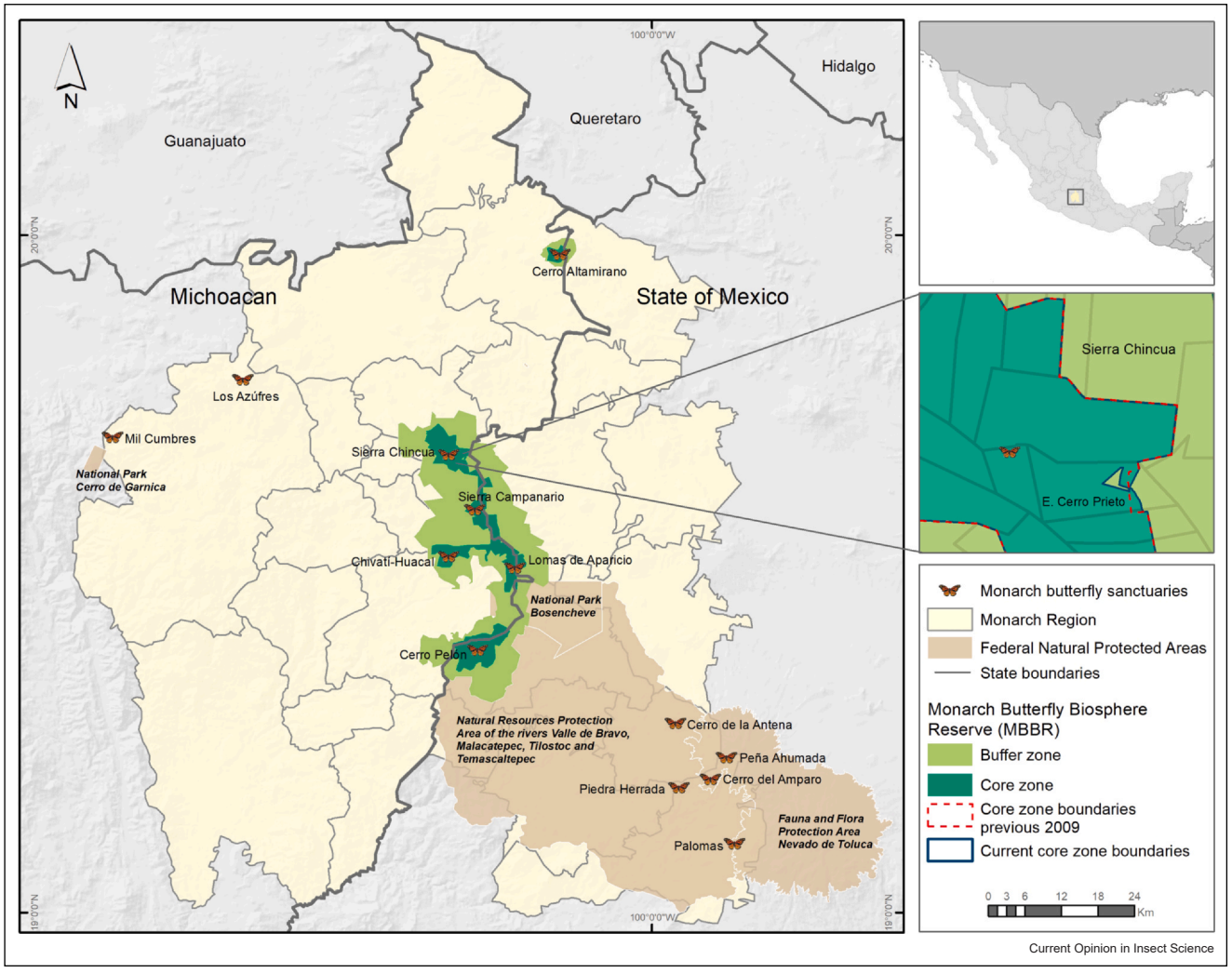
We rebuild the history of the monarch conservation in Mexico using a qualitative document analysis complemented by a chronological approach, through a bibliographic review [21]. We also systematize and report new data and historical facts. The highlights are the monitoring of the monarch butterfly overwintering established in 1993, the establishment of the Monarch Butterfly Biosphere Reserve (MBBR) in 2000, and the consolidation of the Monarch Fund (MF), as well as the monitoring of forest changes in the core zone of the MBBR since 2003.

Results

Monarch overwintering monitoring

Monarch overwintering monitoring in Mexico was established in 1993 using the method of Dr. William Calvert. It consists of the geographic location and delimitation of polygons of the forest occupied by the

Figure 1



Monarch Region and current boundaries of the MBBR. The Monarch Region comprehends 16 municipalities of Michoacan and 11 of the State of Mexico. In the limit between these two states was established the MBBR, which is surrounded by other Federal Natural Protected Areas where monarch butterfly overwintering sanctuaries and colonies have been located.

overwintering butterflies [22]. The area reported each year corresponds to the sum of the forest surface occupied by colonies present in all the sanctuaries during the second half of December. During this period, colonies are formed, and their arrival is completed. The name of each 'colony' corresponds to the name of the owners of the property and that of 'sanctuary' refers to the name of the mountains given by the local inhabitants.

Monarch butterflies in Mexico have formed 7–14 colonies every year, during the last 10 years, regardless of how large the total occupied forest area is in a given year (Table 1). The average area covered by monarchs during this 10-year period was 2.72 (± 0.47 SE) hectares (ha). The latest record, in December 2022, documented 11 colonies, three in Michoacán and eight in the State of Mexico, which occupied a total area of 2.21 ha of forest (Figure 2) [23]. Six colonies (1.52 ha) were located within the MBBR, while five (0.69 ha) were located outside of the Reserve. To date, we have documented 13 sanctuaries and 23 colonies in the region in total (Table 1).

One pending question is if the density of the monarchs in the colonies has changed over time. Even though no studies have been conducted to analyze the density of the clusters in the branches nor the trunks of the trees, we consider that it has been quite stable for the most part. Research ought to be conducted to determine the density of the butterflies at the overwintering sites.

Table 1

Forest area occupied by monarch butterfly colonies throughout the second half of December, and average of the last 10 years (2013–2022).

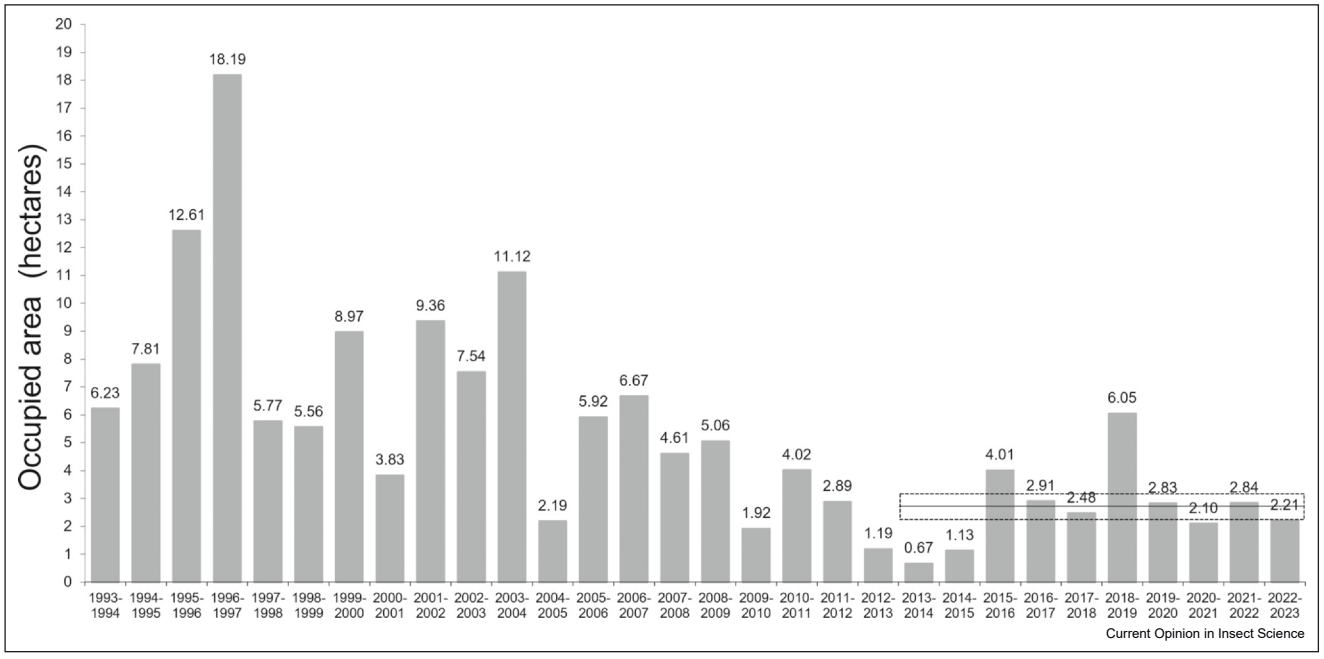
Location	*State*	*Sanctuary*	*Colonies (agrarian properties)*	*Surface (ha)*										
				2013	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*Average*
Inside the MBBR	State of Mexico	Cerro Pelón	E. El Capulín	0.03	0.18	0.13	0.10	*	1.37	*	*	*	0.04	0.31
			E. Mesas Altas de Xoconusco	*	*	*	*	*	*	*	*	*	*	
			I. C. San Juan Xoconusco	*	*	*	*	0.23	*	0.28	0.07	*	*	0.19
			I. C. San Pablo Malacatepec	0.04	0.06	0.80	0.04	0.51	0.07	0.44	0.42	0.016	0.141	0.25
		Sierra Campanario	E. San Joaquín Lamillas	*	*	*	*	*	*	*	0.01	*	*	0.01
			E. La Mesa	*	0.01	*	0.06	0.04	0.12	0.19	*	*	0.041	0.08
	Michoacan	Cerro Altamirano	E. Contepec	*	*	*	*	*	0.01	*	*	*	*	0.01
		Cerro Pelón	E. Nicolás Romero	*	*	*	0.18	*	0.30	*	*	0.556	*	0.35
		Chivatí-Huacal	I. C. Carpinteros	0.01	*	*	0.08	*	0.07	*	*	*	0.065	0.06
			I. C. Donaciano Ojeda	*	*	*	*	*	*	*	*	0.080	*	0.08
		Sierra Campanario	E. El Rosario	0.52	0.57	1.09	1.17	0.60	2.46	1.27	0.73	1.187	0.797	1.04
		Sierra Chincua	Propiedad Estatal	*	*	*	*	*	*	*	0.09	0.332	0.433	0.29
			Propiedad Federal	*	0.05	*	0.17	*	*	*	*	*	*	0.11
			E. Cerro Prieto	0.02	0.05	0.89	*	0.12	0.58	0.28	*	*	*	0.32
			E. El Calabozo Fracción 1	*	*	*	0.42	*	*	*	*	*	*	0.42
		Lomas de Aparicio	E. Crescencio Morales	*	*	*	*	*	*	*	*	0.003	*	0.00
Area occupied inside the MBBR				*0.62*	*0.92*	*2.91*	*2.22*	*1.50*	*4.98*	*2.46*	*1.32*	*2.17*	*1.52*	2.06
Outside the MBBR	State of Mexico	Cerro del Amparo	E. San Francisco Oxtotilpan	*	0.02	0.14	0.13	0.04	0.20	0.03	0.05	0.011	0.086	0.08
		Palomas	E. San Antonio Albarranes	0.02	0.07	0.30	0.33	0.68	0.48	0.16	0.43	0.267	0.176	0.29
		Piedra Herrada	E. San Mateo Almomoloa	0.03	0.09	0.23	0.14	0.18	0.25	0.08	0.28	0.378	0.106	0.18
		Peña Ahumada	E. Ojo de Agua	*	*	*	*	*	0.07	0.05	0.02	*	0.318	0.11
		Cerro de la Antena	E. El Potrero	*	*	*	*	*	*	0.001	*	0.005	0.004	0.00
	Michoacan	Los Azufres	S. P. San Andrés	*	*	0.25	0.07	0.08	0.04	0.05	*	*	*	0.10
		Mil Cumbres	E. Río de Parras	*	0.03	0.18	0.02	*	0.03	*	*	*	*	0.07
Area occupied outside the MBBR				*0.05*	*0.21*	*1.10*	*0.69*	*0.98*	*1.07*	*0.37*	*0.78*	*0.66*	*0.69*	0.66
Total occupied area				*0.67*	*1.13*	*4.01*	*2.91*	*2.48*	*6.05*	*2.83*	*2.10*	*2.84*	*2.21*	*2.72*

E = Ejido, I.C. = Indigenous Community, S.P. = small property, * No colony present.

Note: Ejido and Indigenous Community are the two main kinds of land tenure in Mexico.

In the Monarch Region, during the last overwintering season, the largest colony (0.797 ha) was recorded in the Ejido El Rosario (Sierra Campanario sanctuary), and the smallest colony (0.004 ha) was located in the Ejido El Potrero ejido (Cerro de la Antena sanctuary). Historically, 16 colonies have been located within the MBBR (six in the State of Mexico and 10 in Michoacan), and seven colonies have been located outside the reserve (five in the State of Mexico and two in Michoacan).

Figure 2



Forest area occupied by monarch butterfly colonies, in the second half of December, in Mexico from the 1993–1994 to 2022–2023 overwintering seasons. The figure shows the range of values derived from the average 2.72 ha (solid horizontal line) estimated from the area occupied from 2013 to 2022 (interval 3.19–2.25, dotted line). The overwintering monitoring has been carried out for 30 years and currently represents one of the most important scientific and conservation efforts for the monarch butterfly in North America.

Moreover, the density should be one of the variables that is estimated every year as part of the monitoring program.

The Monarch Butterfly Biosphere Reserve

Using basic scientific knowledge that was generated starting in 1977 and with support from environmentalists and scientists, in 1980, the Mexican government established the places where monarch butterflies overwinter as a 'Wild Reserve and Refuge Zone' [24]. However, this decree had effect only during the winter and did not have a defined geographical delimitation. In 1986, the 'Special Reserve of the Monarch Butterfly Biosphere' was established protecting 16 110 ha [25]. This presidential decree demonstrated the interest of the Mexican government in preserving the overwintering sites. The decree established core zones to promote scientific research to increase knowledge about overwintering monarchs, and buffer zones to promote sustainable forest management.

Unfortunately, the decree of 1986 was created without informed consent from the owners of the land [26], and without ecosystem connectivity between the core zones. In 1998, the World Wildlife Fund (WWF) supported the Ministry of the Environment to develop the technical analysis and redesign of the protected area, giving rise to the 2000 decree of the 'MBBR' [26,27]. This current reserve protects 56 259 ha of which 13 551 ha were designated as the core zone. This area increased in 2009 to 13 554 ha because the Ejido Cerro Prieto promoted a land exchange in the Sierra Chincua Sanctuary in order to build facilities for tourism (Figure 1) [28].

The Monarch Fund

The Trust for the Conservation of the Monarch Butterfly, or MF, is an initiative of WWF and the Mexican Fund for the Conservation of Nature, A. C. (FMCN), in coordination with the Ministry of the Environment and the governments of Michoacán and the State of Mexico [29,30]. The MF is a financial mechanism that provides economic incentives to the owners of properties in the core zone of the MBBR to not harvest the forest and to engage in forest conservation. It is based on a capital investment of 7.5 million dollars [31]. Its implementation was and continues to be a fundamental tool for MBBR conservation and management.

From 2003 to 2008, owners of 17 of the 38 properties that are within the core zone received incentives for not using the forest for wood (US$12 per m^3 not used). Owners of 14 properties received incentives for conservation (US$10/ha). During this time, the MF distributed US$1.36 M. Beginning in 2009, the FMCN and

the National Forestry Commission (CONAFOR) agreed to implement 'Competing Funds', adding to the MF incentives with payments from CONAFOR Environmental Hydrological Services. These funds currently benefit owners of 33 properties of the core zone. To date, US$5.17 M have been granted in total through these combined payment for ecosystem services strategies. This success is an important model and should be of interest to many conservation programs throughout the world.

Forest monitoring of the core zone of the Monarch Butterfly Biosphere Reserve

The MF uses the monitoring of the quality of the forest in the core zone of the MBBR to determine the payments made to the property owners, using data from 2001 to 2003 as a baseline. Forest quality is also used as the technical basis for the allocation of Competing Funds with CONAFOR, whose baseline was renewed in 2009 [31]. This monitoring is coordinated by WWF in collaboration with the National Commission for Protected Natural Areas (CONANP) and the FMCN. Technical support for this analysis is currently provided by the Institute of Biology of the National Autonomous University of Mexico. The Fund for Conservation of the Neovolcanic Axis is responsible for the implementation of payments.

From 2000 to 2012, monitoring of forest cover of the core zone in the MBBR documented 2179 ha of total affected forest. This included 2057 ha that were illegally logged, while wind damage, insect infestations, and drought also affected the rest of the forest during this time [32]. However, as a result of actions taken by conservation actors in Mexico, only 38 ha were illegally logged between 2012 and 2018 of 163 ha affected [33]. The latest records indicate that between March of 2021 and April of 2022, only 13.4 ha were affected by illegal logging of a total of 58.6 ha affected; 28.7 ha were cut due to insect infestation (locally known as sanitation), 15.1 ha were affected by fires, and 1.4 was affected by drought [34]. These data show that Illegal logging in the core zone of the MBBR has been minimized since 2012.

Conclusions and next steps

The conservation of the overwintering sites of the monarch butterfly in Mexico is an example of continuous work from their discovery to the present. Institutions and individuals have devoted their resources and their lives to this purpose. Forest owners have changed their attitude toward monarchs, and through tourism and sustainable forest management, they have built an effective conservation model based on the coexistence of monarchs and people in the same ecosystems. One of the determining results of their impact is the maintenance of illegal logging at very low levels in the last decade.

However, the forests where monarchs overwinter remain at risk due to changes in land use in the Monarch Region [35•,36]. Therefore, institutional support to forest owners for their protection and conservation is urgent. Added to human impacts are the effects of climate change that affect natural regeneration and will impact the distribution of oyamel trees (*Abies religiosa*) at the overwintering sites [37•–39]. These effects are already evident, with trees dying due to drought and the resultant need for sanitation cuts in the core zones of the MBBR [34].

Trinational scientific and governmental coordination has been decisive for the protection of the monarch in Mexico [40,41•]. Instrumental meetings include The First Symposium on the Biology and Conservation of the Monarch Butterfly, in Cocoyoc (1981), the Second International Conference on the Monarch Butterfly, in Los Angeles (1986), and the North American Meeting on the Monarch Butterfly, in Morelia (1997) [42]. After the creation of the MBBR, the Monarch Butterfly Regional Forum, with six events held, also stands out [43]. Other important meetings were held during the six times that the International Monarch Butterfly Research and Conservation Symposium occurred, with participation of all interested parties. Another great contribution for the conservation of the monarch in Mexico was the publication of the North American Plan for the Conservation of the Monarch Butterfly in 2008 [44].

The recent publication of the National Strategy for the Conservation and Sustainable Use of Pollinators (ENCUSP) in Mexico presents a unique opportunity to better understand the role that monarchs have in pollination during the fall migration [45•]. The strategy responds to the estimated 40% decrease in pollinator populations in the world [46], and emphasizes the importance of understanding the networks of pollinators and floral visitors, and their underlying biological interactions, in order to establish effective strategies that allow pollinator recovery [47].

Monarch conservation could serve as a model for reversing pollinator declines in North America. For this reason, we are currently studying the flowering plants used by monarchs during their migration to establish scientific foundations for a National Strategy for Pollinator Gardens. The strategy includes using native species of pollen- and nectar-producing plants throughout the migratory route to support the conservation of the migratory monarch phenomenon in North America.

Institutions and people have invested a significant amount of resources on Monarch Butterfly Conservation in Mexico. These efforts have resulted in a good example of effective conservation. The local people

changed their behavior with respect to monarch presence in their forests and now live in better harmony with the overwintering phenomenon. Monitoring overwintering monarchs and their habitat is fundamental, as well as the economic incentives of the MF.

One example of this institutional intervention is the reforestation of 3185 ha in core zone and 7177 ha in the buffer zone of the MBBR. This reforestation has been a collaborative effort of many parties: the owners of the land where the MBBR is location and the WWF-Fundacion Telmex Telcel Alliance in coordination with CONANP, CONAFOR, and the governments of Michoacan and the State of Mexico. It involved sapling production in the community-based nurseries where local people work and learn to restore the forest through the reforestation. Additionally, we are working since 2018 in the Mexican flyway to determine the priority places for conservation and restoration to establish enough nectar sources for migrant monarchs and other pollinators.

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CRediT authorship contribution statement

Eduardo Rendón-Salinas: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Alfonso Alonso:** Conceptualization, Writing – review & editing. **Eligio García-Serrano:** Investigation, Review. **Adriana Valera-Bermejo:** Investigation, Review & editing. **Mauricio Quesada:** Investigation, Review.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

None.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.cois.2023.101112.

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