

Evolution of Scientific Knowledge on the Monarch Butterfly Biosphere Reserve

Evolución del conocimiento científico sobre la Reserva de la Biosfera de la Mariposa Monarca

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Abstract

This study presents a comprehensive overview of scientific research conducted in the Monarch Butterfly Biosphere Reserve (MBBR) by identifying patterns, trends, and thematic areas of knowledge developed between 1997 and April 2025. A bibliometric analysis was conducted using data from the Web of Science and Scopus databases, considering indicators such as scientific output, citation patterns, author and institutional productivity, and keyword co-occurrence. Descriptive statistics and thematic mapping were used to examine the evolution of research, as well as the most influential countries, institutions, authors, and journals. A total of 106 unique articles were identified, showing a sustained growth in scientific production; 2020 was the most productive year and 2014 the most cited. Mexico leads scientific output, followed by the United States and Canada, with the National Autonomous University of Mexico (UNAM) standing out as the most productive institution. The thematic analysis identified six main research domains: conservation and environmental management, socioeconomic aspects and governance, forest ecology, research methodologies, monarch butterfly biology, and climatic and hydrological phenomena. Although

limited to WoS and Scopus, the study provides key evidence to inform conservation policies and strengthen the sustainable management of the MBBR.

Keywords: Monarch Butterfly; natural protected areas; Conservation and Sustainability; Biodiversity management; bibliometrics analysis.

JEL Codes: Q01, Q23, Q54, Q56, Q57, C80.

Resumen

Este estudio presenta una visión integral de la investigación científica realizada en la Reserva de la Biosfera de la Mariposa Monarca (RBMM) mediante la identificación de patrones, tendencias y áreas temáticas del conocimiento desarrolladas entre 1997 y abril de 2025. Se llevó a cabo un análisis bibliométrico a partir de datos de las bases Web of Science y Scopus, considerando indicadores como producción científica, patrones de citación, productividad de autores e instituciones y coocurrencia de palabras clave. Se utilizaron estadísticas descriptivas y mapas temáticos para examinar la evolución de la investigación, así como los países, instituciones, autores y revistas más influyentes. Se identificaron 106 artículos únicos, evidenciando un crecimiento sostenido de la producción científica; 2020 fue el año más productivo y 2014 el más citado. México encabeza la producción científica, seguido por Estados Unidos y Canadá, destacando la UNAM como la institución más productiva. El análisis temático identificó seis dominios principales: conservación y gestión ambiental, aspectos socioeconómicos y gobernanza, ecología forestal, metodologías de investigación, biología de la mariposa monarca y fenómenos climáticos e hidrológicos. Aunque limitado a WoS y Scopus, el estudio aporta evidencia clave para orientar políticas de conservación y fortalecer la gestión sostenible de la RBMM.

Palabras Clave: Mariposa Monarca; áreas naturales protegidas; Conservación y Sostenibilidad; Gestión de la Biodiversidad; análisis bibliométrico.

Códigos JEL: Q01, Q23, Q54, Q56, Q57, C80.

1. INTRODUCTION

Global biodiversity faces unprecedented threats due to numerous anthropogenic factors, such as habitat destruction, pollution, climate change and the introduction of invasive species. Industrial development has caused significant habitat loss, with approximately 24% of terrestrial ecosystems becoming increasingly modified between 1990 and 2020 (Theobald et al., 2025), and almost 25% of species are now at risk of extinction as a result of habitat fragmentation and degradation (Ramm et al., 2025). Pollution from various sources, such as air, water and soil, exacerbates biodiversity loss by directly damaging ecosystems and species (Singh, 2024). Climate change, particularly rising temperatures, poses a significant future threat to biodiversity by affecting the distribution and survival of species (Ramm et al., 2025). The introduction of non-native species also disrupts local ecosystems and often leads to the extinction of native species (Singh, 2024). Finally, human dietary habits, such as meat consumption, contribute to habitat degradation and predation, which also threaten biodiversity (Toibay et al., 2023). For all these reasons, it is essential to analyze how these phenomena are reflected in specific areas, particularly in protected natural areas with high ecological and cultural value.

Understanding the situations that threaten biodiversity has led to the creation of various conservation strategies. Among these strategies, biosphere reserves represent a model of territorial management, as well as being consolidated as living laboratories that seek to reconcile biodiversity conservation and sustainable development of local communities. These spaces are learning environments for sustainable development, where interdisciplinary approaches are applied to understand and manage the interactions between social and ecological systems, including conflict prevention and biodiversity management (UNESCO, 2025a). Biosphere reserves integrate local communities, customs, culture and heritage, promoting cultural diversity. Therefore, their

importance lies in their role in preserving biodiversity, promoting sustainable development and enhancing a sense of belonging and pride among local inhabitants, in addition to supporting tourism development, which is vital for economic growth and the preservation of cultural heritage in these unique ecosystems (Stojanović et al., 2024).

Biosphere reserves are ecosystems typical of different biogeographical regions designated under UNESCO's Man and the Biosphere (MAB) Program, whose status is internationally recognized, although they remain under the sovereign jurisdiction of the countries where they are located (Stojanović et al., 2024). Their structure, consisting of core zones (strict protection), buffer zones (activities compatible with ecological practices) and transition zones (sustainable economic activities), allows for the implementation of a management model that reconciles conservation and development (Stojanović et al., 2024), effectively protecting biodiversity and achieving sustainable land use (Samways et al., 2024). The World Network of Biosphere Reserves covers over 7,442,000 km² in 134 countries, home to approximately 275 million inhabitants (Stojanović et al., 2024).

Among Mexico's biosphere reserves, the Monarch Butterfly Biosphere Reserve (MBBR) is unique both nationally and internationally, as no other area has such a high concentration of butterfly populations (Martínez & Chávez, 2022). This territory was initially established as a wildlife reserve and refuge in 1980, later declared a protected natural area in 1986, with an area of 16,100 hectares, and finally upgraded to biosphere reserve status in 2000, expanding its total area to 56,259 hectares, of which 13,551 hectares correspond to the core zone (Champo-Jiménez et al., 2012). The MBBR is located on the border of the states of Mexico and Michoacán, in central Mexico and in the western part of the Central Trans-volcanic Belt (Brenner, 2006); it covers seven municipalities in the state of Michoacán (Angangué, Aporo, Contepec, Ocampo, Senguio, Tlalpujahua, and Zitácuaro) and four in the state of Mexico (Donato Guerra, San Felipe del Progreso, Temascalcingo, and Villa Allende (Vicente, 2020).

The MBBR, located in the Trans-volcanic Belt, has an ideal microclimate that ensures the survival of millions of monarch butterflies (*Danaus plexippus*) during the winter (Xu, 2022). On average, each year the overwintering colonies occupy around 2.72 hectares (Rendón-Salinas et al., 2023). The ecological importance of the MBBR lies not only in being the most important overwintering site for the species, but also in the role of its mature oyamel and pine forests in climate regulation, water catchment and erosion prevention.

In terms of conservation efforts, the reserve has made remarkable progress: between 2001 and 2012, large-scale illegal logging was reduced by approximately 98% thanks to collaborative monitoring and management strategies (Flores-Martínez et al., 2019). Similarly, mechanisms such as the Monarch Fund have encouraged the participation of local communities, although the support does not always cover opportunity costs (Catalan, 2015).

Despite this, the MBBR continues to face significant challenges. Between 2012 and 2018, 163.44 hectares were affected by deforestation caused by both illegal activities and natural factors (Flores-Martínez et al., 2019). These problems are aggravated by socioeconomic conditions that limit the effectiveness of management and the search for sustainable development alternatives in communities linked to the reserve (Xu, 2022). In this regard, the MBBR is a paradigmatic example of the challenges of balancing conservation, local governance and community well-being.

The creation of this protected area responds mainly to the need to safeguard the migratory phenomenon of the monarch butterfly (*Danaus plexippus*) and its overwintering areas (Solution for Sustainable Development, n.d.). Every year, this lepidopteran undertakes one of the most astonishing migrations in the animal kingdom by travelling thousands of kilometers from Canada and the United States to the temperate forests of central Mexico, where it forms overwintering colonies in the oyamel fir (*Abies religiosa*) and other tree species (Commission for Environmental Cooperation, 2017). The migratory phenomenon of the monarch butterfly is an outstanding natural treasure, which is why the Monarch Butterfly Biosphere Reserve was registered in 2008 on UNESCO's World Heritage List (UNESCO, 2025b). In addition to protecting the monarch butterfly and its migration, the MBBR is home to remarkable biological diversity, including endemic species of birds, mammals, plants and organisms such as salamanders, axolotls, wildcats and other species subject to special protection (Solution for Sustainable Development, n.d.). The MBBR also serves as an important aquifer for Toluca and the Mexico City Valley, highlighting its dual role in biodiversity conservation and water resource management, which are essential for both ecological health and the sustainability of local communities (Catalán, 2015).

With regard to tourism, according to data from SEMARNAT and CONANP (2019), the MBBR is visited by over 100,000 tourists during the November to March season, while tourism activity comes to a standstill during the rest of the year (Esquivel et al., 2014). There is little international tourism, mainly due to its distance from the main Mexican tourist destinations, and domestic tourists come mainly from nearby areas in the center and west of the country, such as Mexico City, the State of Mexico and Michoacán (Godínez et al., 2018). There are currently six access points open to the public that have official permits to provide tourist services: El Rosario (Ocampo municipality, Michoacán), Sierra Chincua (Angangueo, Michoacán), El Capulín (Donato Guerra municipality, State of Mexico), La Mesa (San José de Rincón, State of Mexico) (Brenner, 2006), Macheros (Donato Guerra municipality, State of Mexico), and Senguio (Senguio, Michoacán) (Godínez et al., 2018). El Rosario sanctuary is the most visited area of the Reserve (Castañeda et al., 2021), home to the largest colony of monarch butterflies, which is why part of its territory is included in the core zone of the reserve (Ibarra García, 2011). It has tourist infrastructure and services such as food stalls, handicraft sales, guided tours, horse rentals, parking lots, restrooms and visitor centers, which are open during the season (Brenner, 2006).

On the other hand, the sustainability of the MBBR is faced by threats such as changes in land use, including deforestation and agricultural expansion, which have affected the ecological integrity of the reserve, leading to an increase in landslides and habitat degradation (López-García & Alcántara-Ayala, 2012). Several studies have documented forest degradation processes within the reserve and associate this environmental deterioration with factors such as illegal logging, forest fires, forest pests, agricultural expansion and demographic pressure (Champo-Jiménez et al., 2012). In addition, low food production and the degradation of natural resources, resulting in erosion, nutrient loss, and contamination of soil and groundwater due to the excessive use of agrochemicals, have contributed to problems of malnutrition and poor eating habits among the local population. This situation has forced farmers to buy food previously produced by them, thereby increasing their dependence on external markets and their economic vulnerability (Solution for Sustainable Development, n.d.). The loss of forest cover not only affects the monarch butterfly's overwintering habitat, but also jeopardizes the ecological integrity of the ecosystem and the environmental services it provides.

Tourism, along with illegal logging, agricultural expansion and forest pests creates constant tension between conservation, resource use and local development, making the MBBR a privileged laboratory for studying the relationship between biodiversity, community governance and sustainability.

In this context, scientific literature on MBBR has grown in a fragmented way, with contributions coming mainly from ecology, forestry, community governance and sustainable tourism. However, most of these studies have addressed specific issues, such as forest cover loss (Champo-Jiménez et al., 2012), illegal logging (Navarrete et al., 2011), tourism impact (Esquivel et al., 2014) or the social perception of conservation policies [26], without providing a comprehensive overview of the scientific field as a whole. Until now, previous research has not incorporated a comparative and systematic approach that simultaneously integrates thematic trends, collaboration networks, and productivity patterns, which limits the overall understanding of scientific development on MBBR.

At the international level, there are bibliometric analyses of protected natural areas and biosphere reserves (Kratzer, 2018; Martínez-Vega et al., 2022; Silva et al., 2023; Ospino et al., 2024; Pérez-Romero et al., 2025), which have proven useful for identifying key actors, collaboration dynamics and thematic trends.

In addition, recent bibliometric analyses applied to the conservation of migratory species and related environments show methodological approaches that are useful for our study. Li et al. (2025) analyze thematic developments in waterfowl conservation, identifying migratory birds and citizen science as emerging areas in the literature. In another study, Steven & Castley (2021) examines how scientific production in birdwatching tourism has grown, highlighting trends in conservation linked to nature tourism. Similarly, Silva et al. (2023) provide a comprehensive overview of nature-based tourism within protected areas, which is a topic closely connected to the ecosystem services present in the MBBR. This international background not only highlights the usefulness of bibliometrics for identifying actors and trends, but also the need to apply it specifically to the case of the Monarch Butterfly Biosphere Reserve.

This type of bibliometric analysis for the MBBR is particularly relevant in practical terms: its results can guide the formulation of public conservation policies in Mexico by identifying scientific gaps and key actors; provide evidence for adaptive management of the reserve; and promote its alignment with international conservation standards. Furthermore, given its status as a UNESCO-recognized site, the study provides exportable inputs for the World Network of Biosphere Reserves, reinforcing its position as a model for other protected areas seeking to balance conservation, culture, tourism and sustainability.

However, to date, no specific bibliometric study has been developed for the MBBR, which constitutes a knowledge gap, considering the importance of this site as a natural and cultural heritage site. This gap is particularly relevant, as the MBBR is the subject of an increasing volume of publications in different disciplines. However, there is no systematic overview that allows for an assessment of the level of scientific development achieved, academic collaboration networks and outstanding research priorities. This type of analysis not only strengthens academic knowledge but can also serve as input for decision-makers, conservation managers and international organizations interested in the sustainability of the reserve.

Beyond the absence of a bibliometric synthesis, there is also a conceptual gap regarding how the diverse ecological, social and governance-oriented studies on the MBBR interact, overlap or remain fragmented within the broader scientific field. Addressing this gap is essential to understand whether the evolution of research reflects an integrated socio-ecological perspective or, conversely, a disciplinary compartmentalization that may limit holistic conservation strategies. In this sense, a systematic analysis of scientific production is not merely descriptive, but contributes to evaluating the degree to which knowledge generation supports multilevel governance and adaptive management across the monarch butterfly's migratory system.

The overall objective of this research project is to conduct a bibliometric analysis of the scientific literature on the MBBR in order to define its evolution, productivity and impact, as well as to identify the main actors and thematic trends in research based on the Web of Science (WoS) and Scopus databases. These two sources were selected due to their broad and standardized coverage, as well as their established use in international scientific evaluation studies, which allows for methodologically robust comparisons and replicable results. Specifically, this study seeks to:

- Quantify the overlap and uniqueness of scientific literature on MBBR between the WoS and Scopus databases.
- Analyze the temporal evolution of productivity (number of publications) and influence (number of citations) of research related to MBBR.
 - Identify the most influential (cited) documents on MBBR.
 - Determine the most productive and influential authors in the field of MBBR.
 - Identify the countries and academic institutions with the greatest contribution to publications on MBBR.
- Determine the journals with the highest number of publications on MBBR, evaluating their quartile and impact factor/SJR.
- Analyze the most frequently used keywords by authors in publications on MBBR in order to identify thematic trends.

The article is organized into five sections. Section 1 lays the conceptual and contextual foundations of the study, providing the background, rationale and research objectives. Section 2 then describes the methods used for data collection and processing. The main findings of the study are presented in Section 3, which is structured into several subsections for better understanding. Section 4 discusses these results, contrasting them with the existing literature, and finally, Section 5 summarizes the conclusions drawn from the work. In this way, this article offers the first systematic overview of scientific production on the MBBR, providing evidence for researchers, managers and decision-makers interested in ensuring the long-term conservation of this natural heritage.

2. METHODOLOGY

The to address the objectives set out in this research, a bibliometric analysis was carried out following the five steps shown in Figure 1.

Figure 1. Steps in bibliometric analysis.



Source: Pérez-Romero et al. (2025)

To accomplish step 1, data collection, we began by defining the database to be used. Álvarez et al. (2018) point out that bibliographic databases play a key role in bibliometric research, as they allow for the analysis of scientific activity carried out by researchers, centers, regions and countries in order to detect their strengths and weaknesses and identify trends in research. To carry out this analysis, both WoS and Scopus were used. WoS is a platform created in 1960 and owned by Thomson Reuters (Álvarez-García et al., 2018), while Scopus is a multidisciplinary, international bibliographic database of scientific literature created by Elsevier in November 2004 (Durán-Sánchez et al., 2017). Both databases provide comprehensive coverage of high-quality peer-reviewed academic literature (Serrano Junco et al., 2023); Scopus provides broader coverage and more exclusive documents on tourism and community participation research, while WoS is known for its citation metrics (Salouw et al., 2024). Their importance lies in their ability to enhance the visibility and impact of research, support meta-analyses and track citation trends in various disciplines (Zhu & Liu, 2020). Both databases have become the primary sources of publication metadata and bibliometric indicators. Their combined use is widely recommended in bibliometric research to enhance data reliability, reduce database-specific bias, and increase coverage robustness (Sabando-Vera et al., 2025; Morante-Carballo et al., 2023).

The period analyzed was 1997–April 2025, which was selected because it corresponds to the years when MBBR was most firmly established as a biosphere reserve and world heritage site. The initial year (1997) is justified because it was during this period that the first indexed article on the MBBR appeared in international databases, representing the documented beginning of scientific production. Only scientific articles and reviews published in peer-reviewed journals were included, without language restrictions, although most of the documents are in English and Spanish. Books, book chapters, conference proceedings, and gray literature were excluded to ensure consistency in the quality of the sources. In addition, only studies whose research question, empirical evidence, or conceptual contribution explicitly addressed the MBBR were retained to ensure thematic relevance.

The search criteria were then defined, as shown in Table 1. The search was conducted on May 1, 2025. A total of 136 results were identified in WoS and 99 in Scopus.

Table 1. Search criteria.

WoS	TOPIC “Biosphere AND reserv* AND butterfl* AND monarch” OR “Reserva AND biosfera AND mariposa* AND monarca”
Scopus	ARTICLE TITLE, ABSTRACT, KEYWORDS “Biosphere AND reserv* AND butterfl* AND monarch” OR “Reserva AND biosfera AND mariposa* AND monarca”

Source: own elaboration

To perform data purging (step 2), the title and abstract of all the results obtained in step 1 were read out. Studies that were duplicates in the same database and those that mentioned MBBR only as a reference, but whose research focused on another topic were eliminated. Two researchers carried out the selection process independently and compared results to reduce bias. Any discrepancies between reviewers were resolved through discussion until consensus was reached, ensuring a consistent and transparent selection process. In addition, a standardization process was carried out

for the names of authors, institutions and countries to avoid duplication (for example, “UNAM” and “Universidad Nacional Autónoma de México” were treated as the same record), following the methodological recommendations by Donthu et al. (2021). A total of 97 valid results were identified in WoS and 78 in Scopus, which were used to conduct the bibliometric study.

Excel and WordClouds were used to analyze and visualize the data, considering the following research questions, which helped to guide the work towards achieving the objectives proposed. VOSviewer (van Eck & Waltman, 2010) was also used to create maps of co-authorship, co-citation and keyword co-occurrence networks. In addition, Bibliometrix (Aria & Cuccurullo, 2017) was used as a tool for statistical analysis of scientific output. This combination of tools made it possible to integrate a performance analysis (productivity and citations) with a relational analysis (scientific collaboration, thematic networks), increasing the robustness and triangulation of the results in comparison with methodologies based on a single tool.

Based on the methodological approach described above, the following research questions (RQ1–RQ7) were formulated to structure the analysis and guide the empirical assessment of the literature on MBBR:

RQ1: What is the overlap of the literature on MBBR in the WoS and Scopus databases?

RQ2: What have the evolution and changes in the productivity and influence of research on MBBR been?

RQ3: What are the most influential documents on the subject (most cited documents)?

RQ4: Who are the key authors in the field of study covered by this analysis?

RQ5: Which countries and universities have the highest number of publications?

RQ6: Which journals have the highest number of publications? In which quartile are the journals ranked and what is their impact factor?

RQ7: What are the keywords most used by authors in their publications?

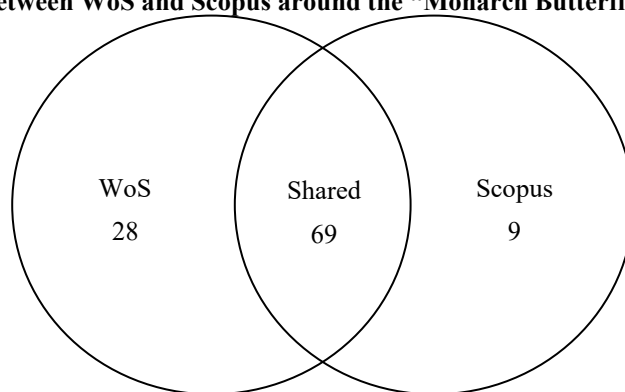
3. RESULTS

3.1. Overlap in databases

In order to quantify the overlap, or in other words, the uniqueness of scientific literature, the WoS and Scopus databases were compared. This comparison was based on overlap calculations such as Meyer’s Index, Traditional Overlap (TO) and Relative Overlap, as proposed by Durán et al. (2017). The combination of these three indicators provides a more complete picture: while Meyer’s Index measures the relative singularity of each database, Traditional Overlap estimates the overall level of overlap, and Relative Overlap shows the coverage capacity of one database in relation to the other. Furthermore, the joint selection of these three indicators is based on their recurring use in comparative studies between scientific databases, which allows maintaining methodological consistency with previous research in related areas.

The identification process resulted in 97 articles in WoS and 78 in Scopus, amounting to a total of 175 articles. After removing duplicates, 69 repeated articles were identified, resulting in 106 unique articles; 28 of these unique articles were found only in WoS, while 9 were found only in Scopus (Figure 2). Figure 2, represented as a Venn diagram, visually illustrates this distribution, showing the intersection of common documents and the proportion of unique articles in each database. These data reveal that although there is a significant overlap of 65.09% between the databases, the complementarity of 34.91% of unique documents justifies the relevance of using both sources for the present bibliometric analysis. In comparative terms, these percentages are in line with bibliometric studies on conservation and sustainable tourism, which have reported overlaps of 60–70% between both platforms, confirming that no single database is sufficient on its own to capture all relevant scientific production (Mongeon & Paul-Hus, 2016; Martín-Martín et al., 2018).

Figure 2. Overlap between WoS and Scopus around the “Monarch Butterfly Biosphere Reserve”.



Source: Own elaboration

The Meyer Index is a measure used to evaluate the coverage of a database on a specific topic (Pulgarín & Escalona, 2007). Its calculation, shown in Formula 1, assigns greater weight to unique document, those present in a single database, and progressively reduces this weight for duplicate documents (weight = 0.5), triplicate documents (weight = 0.3), and so on, depending on the total number of databases compared (Durán et al., 2017). A higher Meyer's Index value indicates greater singularity of the database, meaning that it contains a higher proportion of unique documents (Costas et al., 2008).

$$Meyer\ Index = \frac{\sum Sources * Weight}{Total\ Sources} \quad (1)$$

Table 2 shows the results of the Meyer Index. The analysis revealed that WoS has a higher singularity in the retrieval of articles related to the topic of MBBR, with 28.87% of unique content. This result is reflected in a Meyer Index of 0.64. Scopus, on the other hand, has 11.54% unique content, resulting in a Meyer Index of 0.56. Although the numerical difference between the two indices may seem small (0.08), in practical terms, it reflects that WoS provides a broader set of unique articles, especially in historical ecology and conservation journals, while Scopus is stronger in recent publications and applied disciplines such as tourism and social sciences.

Table 2. Unique articles of WoS and Scopus

Databases	Percentage Single	Meyer's Index
WoS	28.87%	0.64
Scopus	11.54%	0.56

Source: Own elaboration

To complement the evaluation of overlap between databases, Traditional Overlap (TO) was applied, a measure proposed by Gluck (1990) and expressed in Formula 2. This index quantifies the percentage of documents common between two databases (A and B), such that a higher TO value indicates a greater level of similarity between them (Durán-Sánchez et al., 2017). In the analysis, the traditional overlap calculated was 65.09%. This result reflects a remarkable similarity between the articles indexed in WoS and Scopus, indicating that a considerable percentage of the literature is found on both platforms. Therefore, the remaining 34.91% represents unique or non-overlapping content, i.e., the disparity between the two databases.

$$\%TO = 100 * \left(\frac{|69|}{|97 + 78 - 69|} \right) \quad (2)$$

$$\%TO = 65.09\%$$

Finally, Relative Overlap was also used as another way to evaluate the overlap between databases. This measure, originally proposed by Bearman and Kunberger (1977) and shown in formula 3, measures the percentage by which one database (A) covers another (B), and the result is interpreted as the level of coverage of A over B (Durán-Sánchez et al., 2017). In this study, Scopus

covers 88.46% of WoS articles, while WoS covers Scopus by 71.13%. These differences in article overlapping can be attributed to the different indexing policies of each database but are mainly explained by the discrepancy in the total number of journals that each one collects (Durán-Sánchez et al., 2020) This pattern indicates that although Scopus manages to capture a larger proportion of the documents contained in WoS, the latter continues to offer a significant set of unique, high-value articles, particularly in historical ecology and conservation journals. The observed complementarity demonstrates that an analysis based exclusively on a single database would lead to an incomplete picture, affecting the identification of trends and key actors in MBBR research.

$$\begin{aligned}
 \% \text{ Overlap in } A &= 100 * \left(\frac{|A \cap B|}{|A|} \right) \\
 \% \text{ Overlap in } B &= 100 * \left(\frac{|A \cap B|}{|B|} \right) \\
 \% \text{ Overlap WoS} &= 100 * \left(\frac{|69|}{|97|} \right) = 71.13\% \\
 \% \text{ Overlap Scopus} &= 100 * \left(\frac{|69|}{|78|} \right) = 88.46\%
 \end{aligned} \tag{3}$$

The results confirm that combining both databases is essential to obtain a comprehensive overview of scientific production on MBBR. Hereafter, all analyses are based on the purged set of 106 unique articles, which ensures the robustness of the findings presented.

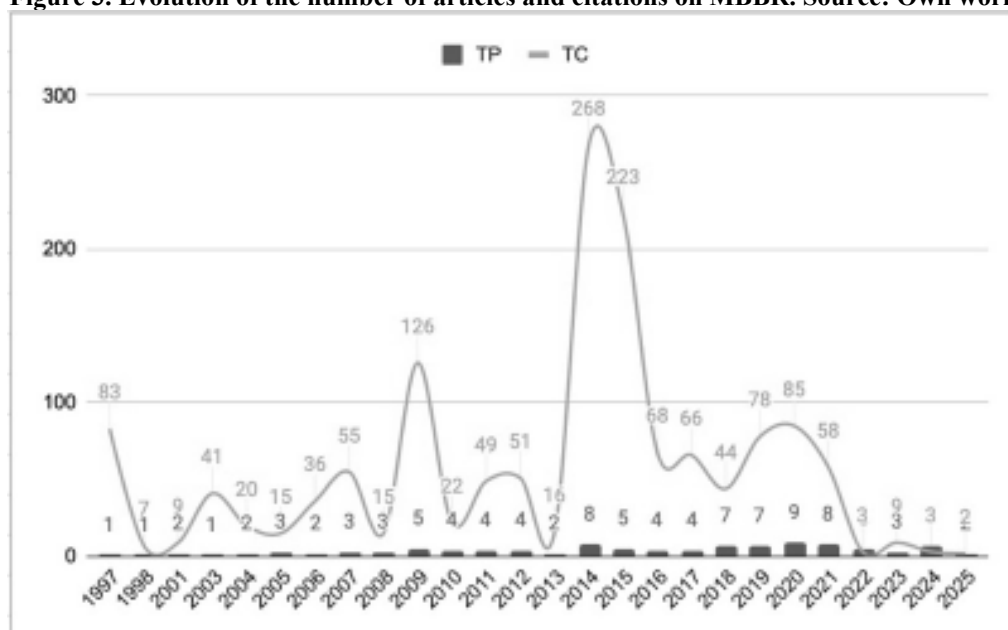
3.1. Productivity and influence

Figure 3 shows the evolution of scientific productivity on MBBR, measured in number of publications per year, as well as the volume of citations received. The temporal analysis enables to identify both the consolidation of the field and the existence of periods of particular dynamism. The first article identified on MBBR was published in 1997 and entitled “Use of lipid reserves by monarch butterflies overwintering in Mexico: Implications for conservation”. The study by Alonso Mejía et al. (1997), published in *Ecological Applications*, examined whether greater nectar availability could reduce lipid depletion in monarch butterflies during the overwintering period. The authors suggested that increased floral resources might enhance survival, which was used to justify tree felling in the MBBR to create forest clearings where more plants could bloom. They found that clustered butterflies had significantly higher lipid mass, water content, lean mass and wings than monarchs collected from flowers; differences that remained constant throughout the overwintering period. Therefore, they concluded that it is not necessary to create open areas in the core zones of the MBBR to stimulate flower production for monarchs overwintering in Mexico and that an intact, closed forest is necessary for successful overwintering because it allows monarchs to conserve their lipid reserves for spring migration (Alonso-Mejia et al., 1997). This groundbreaking work was the beginning of indexed scientific literature on the MBBR, establishing a sound ecological basis for future research.

From a comparative perspective, the growth in publications on MBBR reflects the global trend of expansion in scientific literature on biodiversity conservation and protected areas, which has shown steady growth since the 2000s (Li et al., 2025; Steven & Castley, 2021).

Figure 3 shows that the highest number of articles published per year on MBBR is 9, corresponding to the year 2020. This peak coincides with a period in which academic debates on climate change and the conservation of migratory species intensified, positioning the monarch butterfly as an emblematic case in scientific discourse. The year 2014 also stands out, with the highest number of citations, 268, accumulated among the eight articles identified in that year. This increase is mainly due to two articles by Vidal et al. (2014), which analyzed population trends and deforestation, becoming key references for subsequent research. The 106 articles analyzed have accumulated 1,452 citations. In relative terms, this volume of citations reflects a field that is still emerging, but with high-impact articles that attract a great deal of academic attention.

Figure 3. Evolution of the number of articles and citations on MBBR. Source: Own work.



3.3. Most cited articles

Table 3 shows the ranking of the 10 most cited articles related to the subject of analysis. In the first position, with 198 citations and indexed only in WoS, is the article “Unravelling the annual cycle in a migratory animal: breeding-season habitat loss drives population declines of monarch butterflies”, written by Flockhart, D. T. Tyler; Pichancourt, Jean-Baptiste; Norris, D. Ryan; Martin, Tara G. and published in the *Journal of Animal Ecology* in 2015. This document is also classified as the article with the highest average number of citations per year (19.8), which positions it as the most influential publication on the subject. In general, the most cited articles are divided into three main thematic areas: (i) ecology and biology of the monarch butterfly (e.g., Alonso et al. (1997); Flockhart et al. (2015)), (ii) conservation and forest management (e.g., Vidal et al. (2014); Navarrete et al. (2011)) and (iii) social and governance aspects (e.g., Brenner (2009); Honey-Rosés et al. (2009)). This thematic diversity highlights the interdisciplinary nature of research on MBBR.

A prominent pattern is that the articles with the greatest impact not only provide local diagnoses of MBBR, but have also been cited as paradigmatic cases in international discussions on the conservation of migratory species, the effectiveness of payment programs for environmental services, and the interaction between local communities and environmental policies.

Furthermore, the fact that several of the most influential articles were published in 2014–2015 reinforces the idea that this period was a turning point in academic production on MBBR, establishing lines of research that are still relevant today.

Table 3. Ranking of the most cited articles on MBBR

R	Article	Authors	Publication Year	Scopus		WoS		Main Results
				C	C/Y	C	C/Y	
1	Unravelling the annual cycle in a migratory animal: breeding-season habitat loss drives population declines of monarch butterflies	Flockhart, D. T. T., Pichancourt, J., Norris, D. R., & Martin, T. G.	2015	-	-	198	19.8	The study sought to understand the causes of the monarch butterfly's decline. It revealed that the primary factor behind the decline in the monarch butterfly population is the reduction of milkweed in the United States, due to the increasing adoption of genetically modified crops and changes in land use, and not climate change or the degradation of forest habitats in Mexico. Therefore, the conservation priority is to protect and restore milkweed in North American breeding grounds.
2	Dynamics and trends of overwintering colonies of the monarch butterfly in Mexico	Vidal, O., & Rendón-Salinas, E.	2014	125	11.4	118	10.7	This study, which monitored monarch butterfly colonies in Mexico from 2004 to 2014, revealed a critical decline in the overwintering habitat. The area occupied by monarchs fell to 0.67 hectares in 2013-2014, the lowest figure in two decades. This decline is attributed to the loss of milkweed in the U.S., climate change and deforestation in Mexico, as well as unregulated tourism. The study highlights the urgency of protecting and restoring overwintering sites in Mexico and habitat along the entire migratory route in North America.
3	Trends in Deforestation and Forest Degradation after a Decade of Monitoring in the Monarch Butterfly Biosphere Reserve in Mexico	Vidal, O., López-García, J., & Rendón-Salinas, E.	2014	105	9.5	96	8.7	The study aimed to monitor forest cover in the Monarch Butterfly Biosphere Reserve in Mexico and evaluate the effectiveness of conservation actions. The main findings showed that between 2001 and 2012, 2,179 hectares were affected, mainly by illegal logging (2,057 ha). Although efforts by authorities and financial support had succeeded in eliminating large-scale illegal logging by 2012, small-scale logging is still a growing concern. The study concludes that despite progress, socioeconomic problems that require a regional sustainable development strategy for long-term conservation persist.
4	Use of lipid reserves by monarch butterflies overwintering in Mexico: Implications for conservation	Alonso-Mejía, A., Rendon-Salinas, E., Montesinos-Patino, E., & Brower, L. P.	1997	97	3.5	83	3	This study investigated whether cutting down trees in the Monarch Butterfly Biosphere Reserve would benefit butterflies by increasing the availability of flowers. The main findings refuted this idea: butterflies clustered in closed forests had higher energy reserves (lipids) and were in better physical condition than those that frequented flowers. Butterflies on flowers, in fact, showed low lipid reserves, suggesting that they might not have enough energy for spring migration. The study concludes that an intact, dense forest is essential for monarchs to conserve their lipids during overwintering in Mexico, preparing them for migration, and conversely, openings in the forest are not beneficial.
5	To pay or not to pay? Monitoring performance and enforcing conditionality when paying for forest conservation in Mexico	Honey-Rosés, J., López-García, J., Rendón-Salinas, E., Peralta-Higuera, A., & Galindo-Leal, C.	2009	66	4.1	56	3.5	This study evaluated the effectiveness of the forest conservation payment program for landowners in the Monarch Butterfly Biosphere Reserve in Mexico, focusing on the reliability of monitoring. The main findings revealed a degradation of 161 hectares of forest between 2001 and 2003, which led to the withholding of payments to one landowner. However, an analysis using high-resolution aerial photographs did not detect changes at a finer scale, suggesting that current programs may be underestimating environmental degradation and overpaying non-compliant participants. The study concludes that it is crucial to improve monitoring methods and establish clear criteria for withholding payments, based on specific policy objectives, until the marginal value of ecosystem services is better understood.

6	Mapping expert knowledge: Redesigning the Monarch Butterfly Biosphere Reserve	Bojórquez-Tapia, L. A., Brower, L. P., Castilleja, G., Sánchez-Colón, S., Hernández, M., Calvert, W., Díaz, S., Gómez-Priego, P., Alcantar, G., Melgarejo, E. D., Solares, M. J., Gutiérrez, L., & Del Lourdes Juárez, M.	2003	50	2.3	41	1.9	The aim of this study was to redesign the Monarch Butterfly Biosphere Reserve (MBBR) in Mexico by using decision analysis and expert consultation to identify optimal overwintering habitats. The results led to the selection of a new core area of 21,727 hectares. This redesign made it possible to accurately locate key habitats and minimize the inclusion of areas of interest to local loggers, thereby improving the conservation and management of the reserve.
7	Logging within protected areas: Spatial evaluation of the monarch butterfly biosphere reserve, Mexico	Navarrete, J.-L., Isabel Ramírez, M., & Pérez-Salicrup, D. R.	2011	37	2.6	38	2.7	The study analyzed the effectiveness of authorized logging versus strict protection in the Monarch Butterfly Biosphere Reserve (MBBR). Key findings showed that while planned authorized logging had a minimal impact (6% of disturbance), illegal logging (61%) and untimely extractions (33%) were the main causes of forest degradation (5,239 hectares between 1993 and 2006). Areas without Forest Management Programs (FMPs) experienced greater deforestation due to land use changes. The study concludes that FMPs are effective in maintaining forest cover and suggests that the analysis method used can be a useful monitoring tool for authorities in supervising logging licenses.
8	Recent evidence of Mexican temperate forest decline and the need for ex situ conservation, assisted migration, and translocation of species ensembles as adaptive management to face projected climatic change impacts in a megadiverse country	Sáenz-Romero, C., Mendoza-Maya, E., Gómez-Pineda, E., Blanco-García, A., Endara-Agramont, A. R., Lindig-Cisneros, R., López-Upton, J., Trejo-Ramírez, O., Wehenkel, C., Cibrián-Tovar, D., Flores-López, C., Plascencia-González, A., & Vargas-Hernández, J. J.	2020	46	9.2	41	8.2	This study aimed to highlight the decline of forests in the Trans-volcanic Belt and the temperate forests of north-western Mexico over the last decade, apparently due to climate change. The main findings include: massive infestation of <i>Pinus hartwegii</i> by mistletoe, insufficient <i>Abies religiosa</i> recruitment in the Monarch Butterfly Reserve, signs of inbreeding and defoliation in endangered <i>Picea</i> species and unusual outbreaks of pests and diseases. It therefore concludes that conservation strategies such as ex situ conservation, assisted migration and species translocation are required to enable Mexico's temperate forests to cope with the impacts of climate change.
9	Acceptance of environmental conservation policies: the case of the Monarch Butterfly Biosphere Reserve	Brenner, L.	2009	-	-	20	1.3	This article analyzed why conservation policies in the Monarch Butterfly Biosphere Reserve (MBBR) in Mexico have limited results. The objective was to identify the reasons for the low acceptance of these policies. The main findings indicate that the complexity of conflicts of interest between local communities and conservation policies is the key factor. Despite management initiatives and attempts to establish negotiation platforms, effective implementation is hindered. In conclusion, the study emphasizes the need to address these conflicts of interest and improve negotiation and coordination strategies to achieve greater acceptance and more robust results in environmental conservation in the MBBR.
10	Population Genetics of Overwintering Monarch Butterflies, <i>Danaus plexippus</i> (Linnaeus), from Central Mexico Inferred from Mitochondrial DNA and Microsatellite Markers	Pfeiler, E., Nazario-Yepiz, N. O., Pérez-Gálvez, F., Chávez-Mora, C. A., Lacleite, M. R. L., Rendón-Salinas, E., & Markow, T. A.	2017	31	3.9	29	3.6	This study aimed to evaluate the genetic variation and demographic history of the monarch butterfly in Mexico, comparing migratory and non-migratory populations. The findings show low genetic diversity and significant population structure between migratory and non-migratory monarchs, suggesting limited gene flow between them. Despite this, non-migratory populations in Mexico and Costa Rica shared genetic similarities. Demographic analyses indicate a population expansion at the end of the Pleistocene and a stable effective female population of approximately 6 million over the last 10,000 years.

Source: Own elaboration. R, Ranking; C, Citation; C/Y Citation per year

3.4. Authors

Table 4 shows the five most productive authors: Pérez-Salicrup, Diego R. and Ramírez, M. Isabel with 14 publications; López García José with 12 publications; Rendon Salinas, E. with 10 publications; and Saenz-Romero, Cuauhtemoc with 8 publications. Following Crane (1977), authors were classified according to productivity: high producers are those with more than 10 publications, and moderate producers are those with between 4 and 10 publications. The table also shows that four of the five most productive authors are affiliated with Mexican institutions and one with a Spanish institution. This predominance of Mexican institutions reflects that MBBR continues to be a locally led field of research, although with international connections that are beginning to be consolidated through specific collaborations, particularly in the areas of ecology, genetics and climate change.

Table 4. Top 5 of the most productive authors

Name	Affiliation	Country	TP	FA	TC	TC/TP	Crane
Perez-Salicrup, Diego R.	Universidad Nacional Autónoma de México	Mexico	14	0	205	14.64	High producers
Ramirez, M. Isabel	Universidad Nacional Autónoma de México	Mexico	14	5	185	13.21	High producers
Lopez Garcia, Jose	Universidad Complutense de Madrid	Spain	12	7	248	20.67	High producers
Rendon Salinas, E;	World Wildlife Fund, Terrestrial Ecosystems Program	Mexico	10	2	412	41.20	Moderate producers
Saenz-Romero, Cuauhtemoc	Universidad Michoacana de San Nicolás de Hidalgo	Mexico	8	2	95	11.88	Moderate producers

Source: Own elaboration. TP, Total of publications; FA, First Author; TC, Total of citations; TC/TP, average of citations per publication

Another noteworthy finding is the author transience index, which represents the number of authors who have only one article. In this case, the transience index is 66.81%, which means that the vast majority have contributed one article to the topic. This may be due to the fact that they have recently taken up the topic for research or due to a lack of interest in the same topic after completing a research project. This value is consistent with what has been observed in other bibliometric studies on protected areas, where there is a large base of “occasional” researchers, who complement the core of recurring authors (Mongeon & Paul-Hus, 2016). With regard to the collaboration index, a value of 3.8 was obtained. This data represents the average number of authors per published article, expressed as a percentage, with a collaboration rate of 83.96%. This high degree of collaboration indicates that research on the MBBR is mainly carried out by multidisciplinary teams, which is consistent with the complexity of the environmental and social problems addressed by this reserve. Finally, the productivity index represents the average number of publications per author, for which a value of 1.76 was obtained.

Table 5. Some indicators associated with authorship

Index	Calculation	
Transience Index	Number of authors with a single article published/Total number of authors X 100	66.81%
Collaboration Index or Index of Co-authorship	Number of authorship/Number of articles	3.801886792
Degree of Collaboration	Number of articles with multiple authorship/Total number of articles X 100	83.96%
Productivity Index	Number of authorships/Number of authors	1.759825328

Source: Own elaboration

Table 6 shows the classification of authors according to Crane's criteria (1977), and Figure 4 shows the number of signatures per article. It can be seen that 91.7% of authors are considered aspirants, having published 1, 2, or 3 articles. 7.0% of authors are considered moderate authors, having published between 4 and 10 articles on the subject, and finally, only 1.3% are considered high producers, having published more than 11 articles. This pattern of high concentration in a few authors and a majority of aspiring authors is typical of emerging fields: there is a “hard core” of consolidated researchers, who generate most of the knowledge and a broad periphery of

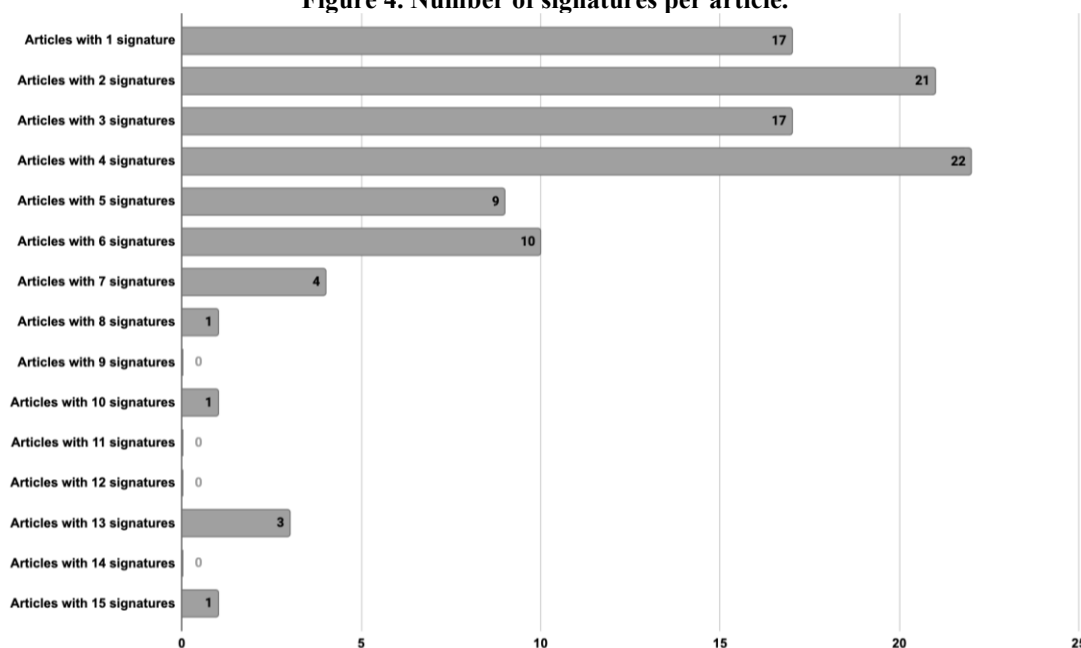
collaborators who participate occasionally (Price, 1963). In the case of the MBBR, this core has been fundamental in maintaining long-term monitoring series, without which it would be impossible to understand the population dynamics of the monarch butterfly and the socio-environmental pressures facing its habitat.

Table 6. Classification of authors using the Crane System

NAA	NA	%	Names	Crane
1	153	67.1%	Other authors	Aspirants
2	43	18.9%		
3	13	5.7%		
4	6	2.6%	Alcantara-Ayala, Irasema; Alonso-Mejía, Alfonso; Carlon Allende, Teodoro; Gomez-Pineda, Erika; Jaramillo-López, Pablo; Manzo Delgado, Lilia	Moderate producers
5	5	2.2%	Brower, Lincoln P.; Champo Jimenez, Omar; Lopez-Toledo, Leonel; Martínez Pacheco, Anuar Iram; Mendoza, Manuel E.	
6	3	1.3%	Bianco-García, Arnulfo; Espana Boquera, Ma Luisa; Lindig-Cisneros, Roberto A.	
7	-	-	-	
8	1	0.4%	Saenz-Romero, Cuauhtemoc	
9	-	-	-	
10	1	0.4%	Rendon Salinas, Eduardo	
11	-	-	-	High producers
12	1	0.4%	Lopez Garcia, Jose	
13	-	-	-	
14	2	0.9%	Perez-Salicrup, Diego R.; Ramirez, M. Isabel	
	228	100%		

Source: Own elaboration. NAA, Number of articles by author; NA, Number of authors.

Figure 4. Number of signatures per article.



Source: Own elaboration

3.5. Productivity by country and institution

In research on the Monarch Butterfly Biosphere Reserve (MBBR), with 148 publications. This predominance is consistent with the location of the Reserve, which naturally drives research by national institutions and scientists. However, research on the MRRB is not limited to the national sphere. The presence of authors affiliated with institutions in the United States (USA), Canada, Spain, France, Colombia, Australia, Chile, Germany, the Netherlands and Norway, indicates growing international involvement in the study and conservation of this natural heritage. This diversity of affiliations suggests global recognition of the MRRB as a relevant subject of study, thus fostering scientific collaboration across borders. It should be noted that although international participation is still limited in volume, it is concentrated in countries that are key to monarch butterfly migration (the United States and Canada), reflecting the need for multinational approaches to the research and conservation of this migratory species.

In addition, a characteristic pattern can be observed in protected natural areas of great ecological importance: there is a highly concentrated core of production in the country hosting the reserve, accompanied by international contributions that are often linked to cooperation projects, joint monitoring and comparative studies. This phenomenon coincides with findings in other bibliometric analyses of biosphere reserves (Silva et al., 2023).

Table 7. Main countries according to the affiliation of their authors.

Ranking	Country	TP	Crane
1	Mexico	148	High producers
2	USA	28	
3	Canada	9	Moderate producers
4	Spain	5	
5	France	3	Aspirants

Source: Own elaboration; TP, Total publications

In terms of productivity per educational institution, Table 8 shows the ranking of the most productive institutions. The leading university in the ranking is the National Autonomous University of Mexico with 59 publications in which it appears in the affiliation, followed by the Michoacan University of San Nicolás de Hidalgo with 16 publications; both universities are considered high producers according to Crane's classification. This institutional leadership reinforces the key role of Mexican public universities in research on MBBR, complemented by the work of non-governmental organizations such as the World Wildlife Fund (WWF), which also ranks among the entities with the highest number of publications. This pattern highlights the importance of cooperation between academia and civil society in generating knowledge applied to conservation.

An additional aspect to consider is institutional concentration: more than 70% of publications come from three Mexican institutions, which may imply a bias in the research agenda towards certain academic perspectives. However, it also represents an opportunity to promote greater institutional and international diversification, thus strengthening the plurality of scientific approaches applied to MBBR.

Table 8. Main universities according to the affiliation of their authors.

Ranking	University	TP	Country	Crane
1	Univ Nacl Autonoma Mexico	59	Mexico	High producers
2	Univ Michoacana San Nicolas de Hidalgo UMSNH	16	Mexico	
3	Universidad Autónoma del Estado de México	9	Mexico	Moderate Producers
	World Wildlife Fund	9	Mexico	
4	Colegio de Postgraduados	8	Mexico	
5	Comis Nacl Conocimiento & Uso Biodiversidad	5	Mexico	
	Inst Nacl Invest Forestal & Agr	5	Mexico	

Source: Own elaboration; TP, Total publications.

3.6. Journals

In relation to the resources used for scientific dissemination, a total of 72 journals that have published articles related to the subject of this analysis were identified. 79.17% of these journals have published only one article, while the remaining 20.83% have contributed two or more publications. For a broader view of the latter group, Figure 5 illustrates the 15 journals with the highest number of articles. This scatter plot confirms Bradford's law of scattering in bibliometrics, whereby a few journals account for most of the scientific production, while the majority contribute only occasional publications (Bradford, 1934).

Table 9 lists the five journals that have published the most articles on the subject, highlighting their impact and positioning. At the top of this list, with seven publications each, we find Madera y Bosques of the Instituto de Ecología A.C. (Q3, SJR 0.244) and Revista Chapingo Serie Ciencias

Forestales y del Ambiente of the Universidad Autónoma de Chapingo (Q3, SJR 0.226). Both Mexican journals are positioned in the third quartile (Q3), indicating their relevance within their categories. Investigaciones Geográficas of the Institute of Geography at the National Autonomous University of Mexico (Q4 and SJR of 0.161) is in the third position, also with seven publications, suggesting a lower impact compared to the previous two. In general, the importance of national publications in disseminating research related to the analysis is highlighted. This predominance of Mexican journals confirms that MBBR has mainly been studied in a local and regional context, which ensures contextual relevance, but limits its visibility in the international scientific community.

Finally, the presence of international journals such as forests (Q1, SJR 0.6) and Journal of Maps (Q2, SJR 0.61) in the 4th and 5th positions, respectively, although with fewer articles in this specific analysis, highlights the relevance of the topic in a global context and the possibility of achieving very high-impact publications. The inclusion of these higher impact factor journals opens up a strategic opportunity to internationalize research on the MBBR and increase its visibility in global debates on biodiversity, climate change, and migratory species conservation. In this regard, targeting future publications towards Q1 and Q2 journals could significantly contribute to reinforcing the international positioning of the MBBR as a benchmark in conservation.

Figure 5. Journals with two or more articles published on the topic of MBBR.



Table 9. Number of articles per journal

R	Journal	TP	Subject Area	Category	Q	SJR 2024	Publisher	Country
1	Madera y bosques	7	Agricultural and biological sciences	Forestry	Q3	0.244	Instituto de Ecología A. C.	Mexico
2	Revista Chapingo Serie Ciencias Forestales y del Ambiente	7	Agricultural and biological sciences	Forestry	Q3	0.226	Universidad Autónoma de Chapingo	Mexico
			Environmental Science	Ecology	Q3			
3	Investigaciones Geográficas	7	Earth and planetary sciences	Earth and planetary sciences (miscellaneous)	Q4	0.161	Instituto de Geografía, UNAM	Mexico
			Social Sciences	Geography, planning and development	Q4			
4	Forests	3	Agricultural and biological sciences	Forestry	Q1	0.6	Multidisciplinary Digital Publishing Institute (MDPI)	Switzerland
5	Journal of Maps	3	Earth and planetary sciences	Earth and planetary sciences (miscellaneous)	Q2	0.61	Taylor and Francis Ltd.	United Kingdom
			Social Sciences	Geography, planning and development	Q2			

Source: Own elaboration. R, Ranking; TP, Total publications; Q, Quartile

3.1. Keywords

In order to visualize and understand the core themes emerging from the research on MBBR, a series of word clouds have been generated from the keywords in the 106 publications analyzed here. Each cloud corresponds to a specific thematic grouping and highlights the relevance of key terms within each domain. It should be noted that the keywords “MBBR, Monarch Butterfly and Mexico” were excluded from this analysis, as they are the core theme of this study and therefore, as expected, these terms appeared many times. Six groups of keywords were formed, named as follows: a) Threats, conservation and environmental management; b) Socioeconomic aspects and governance; c) Ecology and forests; d) Research methodologies and tools; e) Monarch butterfly and its habitat; and f) Climatic and hydrological phenomena.

Figure 6 shows the word clouds.



The cloud titled “Threats, Conservation and Environmental Management” (Figure 6, subsection a) reveals the challenges and strategies implemented to protect the MBBR. It is observed that “Climate Change,” “Deforestation” and “Illegal Logging” are the main challenges faced by the MBBR, suggesting that most of the research revolves around how these threats impact the ecosystem and the survival of the monarch butterfly. The appearance of “Soil degradation” is linked to deforestation and climate change, as these processes erode soil productivity and resilience. In contrast, the presence of words such as “Conservation,” “Protected natural areas,” and “Protection” shows that the main objective of the research is, in fact, the preservation of the area. This indicates an active search for solutions, including legal and governance frameworks (e.g., “Conservation policies” and “Environmental policy”), management mechanisms (e.g., “Monitoring,” “Forest monitoring,” and “Green security”), and economic mechanisms (e.g., “Payment for environmental services,” “Common resources,” “Subsidies,” and “Sowing Life”). This word cloud highlights the duality between the pressures faced by the MBBR and efforts to mitigate their impacts.

The cloud for “Socioeconomic Aspects and Governance” (Figure 6, section b) mainly shows the structures that influence the management of the MBBR, demonstrating that conservation is not only an ecological issue, but also a social and political challenge. “Local communities” are central to this cloud, highlighting their key role. The prominent presence of “Local communities” and “Community Forest management” indicates that the management and conservation of the MBBR cannot be understood without considering the active participation of the area's inhabitants. “Organizational culture,” “Community institutions” and “Ejidos” reinforce the above, indicating that the research focuses on how these communities are structured, make decisions and manage their resources. The indigenous group “Mazahua” is specifically and relevantly mentioned; highlighting that in addition to local communities in general, recognition is given to the importance of the worldview and practices of the indigenous peoples who inhabit or influence the MBBR. Words such as “public policy” and “public policy networks” are terms that reveal an interest in policy formulation and implementation processes. The term “networks” suggests that governance involves multiple actors (government, civil society, academia). The presence of the words “Conflicts” and “Tensions” reveals that the coexistence of conservation, local development and economic activities generates friction. Research on this topic probably addresses the causes, dynamics and possible solutions to these conflicts. The terms “forestry company” and “forestry exploitation” indicate that economic activity linked to forest resources is part of the analysis, possibly exploring sustainable models or the impacts of exploitation. Words such as “Tourism” and “Ecotourism,” along with “Tourism operation” (1), highlight the economic importance of this activity for the region, although it is noted that this approach has not been studied much. The words “Competitiveness” and “Competitive advantages” suggest that the economic potential of the region is being analyzed and how it can position itself in sustainable markets (e.g., ecotourism, certified forest products). Finally, the concepts of “amenity value,” “critical amenity value,” and “forest value” are interesting because they suggest that the research not only values the economic aspects, but also the non-monetary benefits of nature and the forest (scenic beauty, recreation, quality of life).

The “Ecology and Forests” word cloud (Figure 6, section c) shows the most researched natural components and forest processes focused on characterizing the RBMM ecosystem. It is observed that “*Abies religiosa*”, the oyamel species essential for the butterfly's overwintering, predominates in the cloud, highlighting its ecological importance. The presence of terms such as “Coniferous Forest” and “Temperate Forest” refer to the type of ecosystem that predominates in the region. This suggests a sound research base. The presence of “Dendrochronology,” “Radial Growth” and “Growth Rings” suggests an interest in studying tree growth and reconstructing the environmental history of forests. These methodologies help us to understand how trees respond to climatic factors and disturbances over time. Terms such as “Forest recovery,” “Forest disturbance,” “Forest cover loss” and “Ecological restoration” indicate that researchers are analyzing the processes of forest degradation and regeneration, which could help evaluate the effectiveness of conservation measures and plan future actions. The appearance of terms such as “Pests,” “Forest pests,” “*Pseudohylesinus* spp.” and “*Scolytus mundus* Wood” indicates that biotic threats (such as insect outbreaks) are relevant, though perhaps less predominant than the topics of deforestation or climate change. The inclusion of “Crop Health” and “Disturbance Regime” suggests research on forest health management and natural events that impact the forest (e.g., fires, windstorms). Terms like “Biomass” and “Stem Biomass” indicate studies on the accumulation of organic matter and carbon

in trees. Finally, “Saplings” and “Tree Planting Design” demonstrate an interest in natural and artificial forest regeneration.

The fourth cloud, “Research Methodology and Tools” (Figure 6, section d), groups the techniques and methods used in the studies, thus providing an overview of how research is approached in this area. The high presence of the terms “Spatial Analysis,” “Geostatistics” (2), and “Kriging” (a specific geostatistical technique) indicates a strong emphasis on understanding phenomena geographically, which is logical for a protected area, where the location and distribution of elements (forests, butterflies, deforestation) are essential. The presence of terms such as “GIS” (Geographic Information Systems), “Aerial Photography,” “Infrared Imagery,” “Small Format High-Resolution Imagery” and “SPOT” (a type of satellite that provides high-resolution images) demonstrates the use of remote sensing. This allows for monitoring of large areas, detecting changes in vegetation cover and deforestation, and assessing habitat over time. The high repetition of “Dendrochronology” indicates that tree rings have been frequently studied in the MBBR. This technique is essential for reconstructing climate stories, forest disturbances, and growth patterns over decades or centuries. It is complemented by “Dendroclimatology” (the use of tree rings to study climate) and “Dendrogeomorphology” (the use of tree rings to study geomorphological processes such as landslides), which demonstrates specific and advanced applications of this methodology. The inclusion of “Time Series” as a more general methodological concept reinforces the importance of analyzing data collected over time to identify trends, patterns and causal relationships in various phenomena. The presence of “Matrix Modeling,” “Generalized Linear Mixed Models” and “Mixed Models” suggests the use of advanced statistics to understand complex relationships between variables, predict behaviors or simulate scenarios.

The cloud titled “Monarch Butterfly and its Habitat” (Figure 6 section e) highlights the main areas of study directly related to the species, emphasizing the biology of the species and the management of its winter aggregation sites. The words “Winter Sites” and “Winter Habitat” reflect the focus of research on sites that are critical to the monarch butterfly’s winter survival; this may include research on the microclimatic conditions required, the quality of the forest at those sites and the factors that influence the success of overwintering. Terms such as “Migration” and “Migration Assistance” suggest an interest in understanding and supporting the complex movement patterns of the monarch butterfly. The words “Host,” “Haustoria,” and “Parasitic Plant” directly point to the monarch butterfly’s relationship with the plants it feeds on. The term “host” refers to the milkweed plant (*Asclepias*), which is essential for caterpillars. “Haustoria” and “Parasitic Plant” could relate to studies on specific trophic links or less common interactions that affect the butterfly’s health or development or key plants in its habitat. The word “Nectar” reinforces the importance of food sources for adult butterflies during their journey and at overwintering sites. The word “Wing Length” could indicate morphometric studies, which are useful for assessing population health, identifying subpopulations or even relating physical characteristics to migratory success. This cloud is very specific in understanding not only where and how the monarch hibernates, but also the ecological networks that support it and the interventions to ensure the continuity of its life cycle.

The “Climatic and Hydrological Phenomena” cloud (Figure 6, section f) focuses on environmental variables that impact the ecosystem, confirming the importance of atmospheric and water conditions in the Reserve’s dynamics. The high presence of “Precipitation” and “Temperature” indicates that these are the most studied climate variables. This is consistent, as both factors are critical for forest growth, nectar availability for butterflies and overwintering conditions. “Climate variability” and “Climate-related factors” suggest that research is not only focused on average climate conditions, but also on how these fluctuate over time (droughts, heat/cold waves, erratic rainfall patterns). Finally, although less frequently, the inclusion of “Flows,” “Water balance,” “Watershed management” and “Riparian systems” demonstrates that hydrology is an important component of research, primarily to understand water availability in the ecosystem.

The six keyword clusters show that research on the MBBR is organized around three cross-cutting themes: (i) ecological threats and conservation processes; (ii) the interaction between local communities, governance and economics; and (iii) the biophysical analysis of forests and climate supported by advanced methodologies. This overview confirms that the study of the MBBR has moved from traditional biological approaches to interdisciplinary perspectives, where ecology, social sciences and monitoring technologies converge. It also reveals underrepresented areas, such

as sustainable tourism and cultural services, that constitute strategic opportunities for future research.

4. DISCUSSION

The findings confirm the growing relevance of the MBBR as a subject of scientific study, reflected in the number of publications over time. In line with what Pérez-Romero et al. (2025) observed, the geographic distribution of publications reflects a strong regional interest. Mexico leads the ranking of countries with the highest number of publications, and the National Autonomous University of Mexico (UNAM) is the leading educational institution. This pattern can be explained, as Pérez-Romero et al. (2025) also pointed out, by the region's commitment to the conservation of the Biosphere Reserve and the impact of research initiatives supported by the government or international cooperation agencies.

Beyond this national leading role, the analysis of productivity and citations reveals that the MBBR is also the focus of international attention, with significant contributions from the United States and Canada, key countries in the monarch butterfly migratory route. This finding highlights the need for transnational research that integrates the entire migratory cycle, in line with the proposals made by Flockhart et al. (2015) and Vidal et al. (2014). However, a more detailed interpretation of these findings indicates that ecological studies tend to dominate the thematic landscape, while social and governance-oriented research, although growing, remains comparatively less influential. This imbalance shapes the observable trends, as ecological approaches drive most citation dynamics and collaborative networks, whereas social and governance studies contribute primarily to localized or community-based perspectives. This asymmetry not only reflects differences in methodological traditions and funding priorities, but also influences how conservation problems are framed, often privileging biophysical indicators over socio-institutional dimensions. Consequently, the prevailing ecological emphasis may shape both research agendas and policy narratives, reinforcing a technically oriented understanding of conservation that does not always fully integrate community governance, local livelihoods, or multilevel institutional coordination.

Regarding productivity by author, a pattern characteristic of emerging fields is observed: a small core of highly productive researchers accounts for a large proportion of publications and citations, while the majority of authors are occasional authors. This phenomenon, previously described by Price (1963), reinforces the idea that the continuity and robustness of knowledge regarding MBBR depends largely on a relatively small group of specialists, particularly those linked to UNAM, the Michoacana University of San Nicolás de Hidalgo and WWF Mexico. This concentration may ensure the accumulation of experience, but also poses the risk of a poorly diversified research agenda. Additionally, the international collaboration patterns observed, particularly with institutions in the United States and Canada, suggest that existing partnerships focus primarily on ecological monitoring and migration biology. While these connections strengthen the continental perspective, they may still be insufficient to address governance challenges or socio-ecological integration across the entire migratory route, thereby limiting a more holistic management framework. From a practical standpoint, this means that current collaborative structures facilitate data sharing on migration dynamics and forest conditions, but may not yet provide equally robust platforms for coordinating policy instruments, harmonizing conservation incentives, or integrating community-based management strategies across national boundaries. Strengthening trinational research networks with an explicit socio-ecological orientation could therefore enhance the operational coherence of conservation actions throughout the migratory cycle.

The results for journals show that the majority of production is concentrated in national publications, primarily in *Madera y Bosques*, *Revista Chapingo* and *Investigaciones Geográficas*. Although this ensures local relevance and access for the Mexican academic community, it limits the international visibility of the studies. The emerging presence of articles in Q1 and Q2 journals such as *Forests* and *Journal of Maps* represents a strategic opportunity to increase the global projection of the scientific results generated around the MBBR.

Keyword analysis confirms the interdisciplinary nature of the field. The most frequent topics revolve around ecological threats (deforestation, climate change), forest conservation and restoration, community governance and monitoring methodologies based on GIS and remote

sensing. This thematic diversity shows that research has moved beyond purely biological approaches to incorporate social and technological dimensions. However, the analysis also reveals gaps: sustainable tourism, cultural ecosystem services and social perception remain underexplored areas, despite their relevance to the comprehensive management of the reserve. Addressing these gaps would contribute to a more integrative research agenda capable of linking ecological resilience with social legitimacy and long-term economic sustainability.

In summary, the results suggest that research on the MBBR is in a consolidation phase: there is solid literature of publications focused on forest ecology and biological conservation, accompanied by expanding social and governance studies. To progress towards a more balanced and globally influential field, it will be key to foster the internationalization of publications, diversify the research agenda towards emerging socioeconomic topics and promote transnational collaborations that integrate the full migration cycle of the monarch butterfly. Furthermore, these findings provide relevant insights for the reserve managers and public policymakers, highlighting both the existing scientific strengths and the areas where greater research investment is needed.

It is also important to explicitly acknowledge that the reliance on WoS and Scopus introduces a potential thematic, geographic and linguistic bias, as these databases tend to privilege English-language journals, Western institutions, and fields with higher publication standardization. This limitation may underrepresent community-based studies, locally published research and emerging interdisciplinary approaches. In particular, relevant gray literature, policy reports, and Spanish-language regional journals may not be fully captured, potentially leading to an underestimation of locally grounded governance initiatives and applied conservation experiences. In addition, future studies could integrate complementary data sources to better capture emerging research fronts and non-indexed regional contributions, as well as qualitative assessments that allow for a deeper understanding of the epistemic diversity shaping the field.

5. CONCLUSIONS

The bibliometric analysis provided a systematic overview of the state of knowledge regarding the Monarch Butterfly Biosphere Reserve (MBBR), highlighting its consolidation as an emerging and multidisciplinary field of research. The results show a sustained increase in scientific production, with a strong concentration in Mexico and the active participation of national universities such as UNAM. This is not to mention the growing international collaboration that positions the MBBR as a benchmark of global interest.

Identifying the most influential authors, institutions and journals provides a clear map of key academic actors, as well as the main channels for scientific dissemination. This information constitutes a strategic tool to guide researchers and decision-makers in defining conservation partnerships, projects and policies, providing an informed basis for formulating new research questions, fostering collaborations and optimizing scientific dissemination strategies.

A relevant contribution of this study is the thematic classification of the literature through keyword analysis, which made it possible to identify both the most consolidated areas (conservation, forest ecology, climate change, community governance) and research gaps. These gaps include: the effects of climate variability on the phenology and physiology of the monarch butterfly, in-depth socio-anthropological analysis of conflicts over resource use, the poorly studied biodiversity of the MBBR (herpetofauna, birds, pollinating insects) and the integration of climatic, hydrological and socioeconomic studies to assess risks and opportunities in the region. The interconnection of these dimensions reinforces the complex nature of the MBBR, which is not only a crucial habitat for an emblematic species, but also a territory of cultural and tourist value.

Although this study provides a comprehensive overview, it is important to acknowledge certain limitations. The reliance on Scopus and WoS databases, which are among the most relevant and widely recognized international databases, means that literature not indexed on these platforms was not included, potentially underestimating the total production at the local or regional level. This reliance may introduce a selection bias, as these databases tend to prioritize journals published in English and those with greater international visibility, thereby potentially underrepresenting research published in local journals or in other languages. The search criteria used, being very specific, may have excluded relevant articles that employed more general terminology. Additionally,

the analysis did not differentiate between the quality and methodological rigor of the included studies, an aspect that future work could incorporate to strengthen the interpretative depth of the findings. These limitations open the door to complementary research that includes regional repositories, alternative databases, such as Google Scholar or regional indexing systems, and comparative methodologies.

Future lines of research could include expanding the search to other databases and institutional repositories, a more in-depth analysis of international collaboration or a study of the impact of this research on Monarch Butterfly conservation policies. Furthermore, keyword analysis revealed the most studied research topics in the MBBR, while also identifying underexplored areas that represent future lines of research:

- How changes in temperature and precipitation patterns will directly affect butterfly phenology (breeding period, milkweed and nectar blooming), butterfly physiology (e.g., lipid mass for migration) and the long-term viability of overwintering sites or the need for new overwintering areas are scarce, which could contribute to defining specific and effective actions for monarch butterfly migration assistance.
- More qualitative and socio-anthropological research is needed on the deep roots of conflicts over land and resource use. This should include studies on the actual effectiveness of local governance models, the inclusion of all stakeholders, and the population's perception of the MBBR and policies.
- More extensive monitoring and studies of the Reserve's biodiversity in general are needed, not just of Oyamel and monarch butterflies. This includes herpetofauna, birds and other pollinating insects, soil microfauna and ecosystem interactions.
- More comprehensive studies are needed to model how climatic and hydrological changes (e.g., severe droughts or torrential rains) directly impact the community's livelihoods (agriculture, forestry), the risk of fires and pests and the viability of ecotourism.
- Finally, it is important to address persistent conservation challenges through sustainable management and the integration of scientific knowledge with local practices, which is essential for the long-term protection of the site.

This analysis confirms that the MBBR constitutes a strategic space not only for biological conservation, but also for interdisciplinary research, where ecological, climatic, social, economic and cultural dimensions converge. In this regard, moving towards integrated approaches that combine scientific production with public policies and local practices will be essential to ensure the long-term protection of this natural heritage. In particular, future research and management strategies should advance toward a genuinely socio-ecological and trinational framework that articulates ecological monitoring, community governance, and coordinated policy instruments across Mexico, the United States and Canada, thereby aligning scientific knowledge with the full migratory cycle of the monarch butterfly. In addition, incorporating mechanisms to periodically update the bibliometric evaluation would allow tracking emerging themes and detecting shifts in research priorities, enhancing the usefulness of this type of analysis for decision-makers.

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