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Original article

Scientometrics of the Mexican axolotl (Amphibia: Ambystomatidae): thematic evolution on a model species

Cienciometría del ajolote mexicano (Amphibia: Ambystomatidae): evolución temática en torno a una especie modelo

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ABSTRACT. This study presents a comprehensive scientometric analysis of scientific output on *Ambystoma mexicanum* (axolotl), with the aim of understanding the evolution, structure, and dynamics of research surrounding this model organism. Using a descriptive and longitudinal approach, 1,450 articles and reviews indexed in Scopus (1963–2024) were analyzed, based on a restrictive search strategy in the title field to ensure thematic relevance. Bibliometric indicators and scientific mapping techniques were employed to evaluate trends in publication, authors, countries, institutions, and thematic evolution. The results

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show a non-linear publication pattern, with a peak between 1976–1983, a decline in the early 2000s, and a rebound after 2008, possibly associated with advances in genomics, regenerative medicine, and increased interest in conservation following its classification as a critically endangered species. The United States leads in scientific output, followed by European countries, while Mexico has a limited share despite being the species' country of origin. The thematic analysis reveals a transition from classical embryology and histology toward molecular biology, genetics, and, more recently, conservation studies and socio-environmental approaches. These results highlight structural inequalities in global scientific output and demonstrate how technological, economic, and social factors influence research priorities. The study underscores the value of scientometrics for understanding the historical development and changing priorities of research on A. mexicanum, providing a quantitative basis for identifying research trends and areas that may warrant further investigation.

Key words: *Ambystoma mexicanum*; bibliometrics; model organism; thematic evolution

RESUMEN. Este estudio presenta un análisis cienciométrico integral de la producción científica sobre *Ambystoma mexicanum* (ajolote), con el objetivo de comprender la evolución, estructura y dinámica de la investigación en torno a este organismo modelo. Mediante un enfoque descriptivo y longitudinal, se analizaron 1450 artículos y revisiones indexados en Scopus (1963–2024), a partir de una estrategia de búsqueda restrictiva en el campo título para asegurar la relevancia temática. Se emplearon indicadores bibliométricos y técnicas de mapeo científico para evaluar tendencias de publicación, autores, países, instituciones y evolución temática. Los resultados muestran un patrón de publicación no lineal, con un pico entre 1976–1983, una disminución a inicios de los años 2000 y un repunte posterior a 2008, posiblemente asociado con avances en genómica, medicina regenerativa y el aumento del interés en conservación tras su clasificación como especie en peligro crítico. Estados Unidos lidera la producción científica, seguido de países europeos, mientras que México presenta una participación limitada pese a ser el país de origen de la especie. El análisis temático evidencia una transición desde la embriología e histología clásicas hacia la biología molecular, la genética y, recientemente, estudios de conservación y enfoques socioambientales. Estos resultados evidencian desigualdades estructurales en la producción científica global y muestran cómo factores tecnológicos, económicos y sociales influyen en las prioridades de investigación. El estudio destaca el valor de la cienciometría para comprender el desarrollo histórico y los cambios en las prioridades de investigación sobre *A. mexicanum*, proporcionando una base cuantitativa para identificar tendencias de investigación y áreas que podrían requerir estudios adicionales.

Palabras clave: *Ambystoma mexicanum*; bibliometría; organismo modelo; evolución temática

INTRODUCTION

The rapid growth of scientific output over the past few decades has driven the development of quantitative approaches aimed at analyzing and understanding the structure, evolution, and dynamics of scientific research. Scientometrics - the application of mathematical and statistical methods to the study of scientific activity and systems (Gorbea-Portal, 2005) - provides a framework for describing patterns of scientific production, collaboration, communication, and thematic development (Michán & Muñoz-Velasco, 2013). Bibliometric analysis, as a key part of

scientometrics, focuses on written scientific output and the connections among publications, authors, institutions, and citations (Marginson, 2022) and has supported the systematic retrieval and analysis of scientific literature. Bibliometric indicators and network-based approaches make it possible to evaluate productivity, impact, and collaboration (Vinkler, 2010), and to identify influential authors and institutions, study the structure of scientific fields, and detect emerging or underexplored research topics (Waltman & van Eck, 2019). Citation networks (Zhao & Strotmann, 2015), co-word analysis, and conceptual network visualization (Callon *et al*., 1983) further enable the intellectual and thematic organization of a research field. Several bibliometric studies have examined scientific production associated with model organisms in different areas of the biological sciences (de Oliveira *et al*., 2025; Dougnon & Matsui, 2025). For example, studies on *Escherichia coli* Migula, 1895; Castellani and Chalmers, 1919 (Kastrin & Erjavec, 2022), *Campylobacter* (Sweileh *et al*., 2016), *Caenorhabditis elegans* Maupas, 1900 (Berk *et al*., 2024), and *Arabidopsis thaliana* (Zhou *et al*., 2024) have been among the most interesting organisms involved in bibliometric studies. However, relatively little attention has been given from a scientometric perspective to one of the most distinctive model organisms in contemporary biological research: the Mexican axolotl, *Ambystoma mexicanum* (Shaw, 1798). *Ambystoma mexicanum* is a neotenic amphibian endemic to the Xochimilco basin in Mexico City and is recognized for its distinctive biological properties and profound cultural and historical significance. Its extraordinary regenerative capacity, developmental plasticity, and retention of larval traits into adulthood have established the species as an important model organism in developmental biology and regenerative biomedicine (Vieira *et al*., 2020). These characteristics have attracted sustained international scientific interest in the Mexican axolotl and have incrementally expanded the spectrum of disciplines in which the species is studied. As a result, research on *A. mexicanum* now includes a broad range of scientific disciplines and has generated a substantial body of literature. However, assessments of this scientific output from a comprehensive scientometric perspective remain scarce. Research growth has not been systematically examined and evaluated by jointly considering its temporal trajectory, individual authors and institutions, geographic distribution, collaboration networks, and thematic evolution. This assessment can also shed light on the research growth in the Mexican axolotl and the contributions of different scientific actors to the development of knowledge about this species. The objective of this study was to provide a complete scientometric review of the research on the Mexican axolotl. We examined the evolution of the scientific publications over time, found the most productive and influential authors and institutions, identified the research topics and their evolution, and mapped to what extent they are well-understood and related to scientific cooperation among the research community. By integrating these dimensions, this study aims to understand and characterize the scientific framework and development of the research on *Ambystoma mexicanum* and the major trends and research priorities that have shaped its evolution. It also seeks to identify the key researchers who are working in this field and the research areas being explored. Finally, the analysis allows the identification of areas requiring further studies to advance a more comprehensive understanding of the field.

MATERIALS AND METHODS

To identify the main actors in the research ecosystem on *Ambystoma mexicanum*, as well as the evolution of the conceptual structure of the research, a descriptive and longitudinal scientometric study was designed.

The Scopus database was used to search for documents directly related to *Ambystoma mexicanum*. The search was conducted in the "Title" field of the records, using the following equation: TITLE ("Ambystoma mexicanum") OR TITLE ("axolotl") OR TITLE ("A. mexicanum") OR TITLE ("Mexican axolotl"). Although this strategy is restrictive, it ensures the retrieval of studies in which the axolotl is the central focus of the research. The search was conducted in November 2024.

The search was limited to documents classified as articles and reviews, excluding the following categories: *conference paper*, *note*, *erratum*, book chapter, letters, *short survey*, *data paper*, editorial, and book. After applying these filters, the initial number of results (N = 1,767) was reduced to 1,650. Subsequently, 197 documents that did not directly address the topic of the Mexican axolotl or were popular science texts were eliminated based on a review of the title and abstract, resulting in a total of 1,453 records.

The records were exported to the EndNote bibliographic manager, where the metadata (publication year, authors, titles, and affiliations) were reviewed and duplicates were removed, resulting in a final total of 1,450 documents analyzed in this study. Using the *Subject Library* tool, information was obtained on the number of articles by year, by author, and by country, which was exported to Excel for analysis using descriptive statistics.

The bibliometric analysis was supplemented using the Bibliometrix package (Aria & Cuccurullo, 2017) in the R environment, from which information was obtained on articles by affiliation, as well as the thematic evolution of the research. The analysis was conducted using "Index Keywords" due to their greater terminological standardization, employing the weighted inclusion index method based on word occurrences, with a minimum weighting threshold of 0.1. Thematic evolution was examined across four time periods: 1963–1978, 1979–1991, 1992–2010, and 2011–2024, defined based on relevant historical and technological changes in biological research.

For each period, the thematic map was analyzed independently using co-word analysis (Callon *et al*., 1983). The use of scientific mapping techniques makes it possible to identify and analyze the underlying semantic structure of a scientific field by visualizing the relationships between concepts and their internal organization over time. Through the graphical representation of these relationships, it is possible to examine the evolutionary dynamics of knowledge, identify continuities, breaks, and thematic shifts, as well as understand how research priorities are reconfigured in response to scientific, technological, and social changes. The identified groups of keywords were considered research themes (Cobo *et al*., 2011) and classified into four types based on their density (Y-axis) and centrality (X-axis), in accordance with the criteria proposed by Callon *et al*. (1991) and He (1999).

RESULTS

Among the 1,450 articles analyzed for this study, publications were found from 1963 to 2024 (Fig. 1). The period from 1976 to 1983 recorded the highest number (244) of publications. From 2000 to 2007, there were fewer publications (125), with an uptick to 169 (2008–2015) and 241 (2016–2024).

This pattern is not typical in bibliometric distributions. Scientific literature usually exhibits linear or exponential growth, driven by the increase in the global number of journals and the expansion of document collections in bibliographic databases, and then tends to follow a logistic curve as the field matures and consolidates. The potential for this trend to exhibit divergent or

convergent oscillations, according to Price (1963) scientometric models, revealed the need for a more in-depth historical analysis to understand the causes of this decline beginning in the 1980s, which we will address in detail later. The increase from 2008 onward could be associated with renewed interest, possibly linked to genomic techniques, gene editing, and/or biomedical applications. Although it may also be because 2006 was the first year the species was declared "Critically Endangered," which served as a catalyst for interest in the species and continued research.

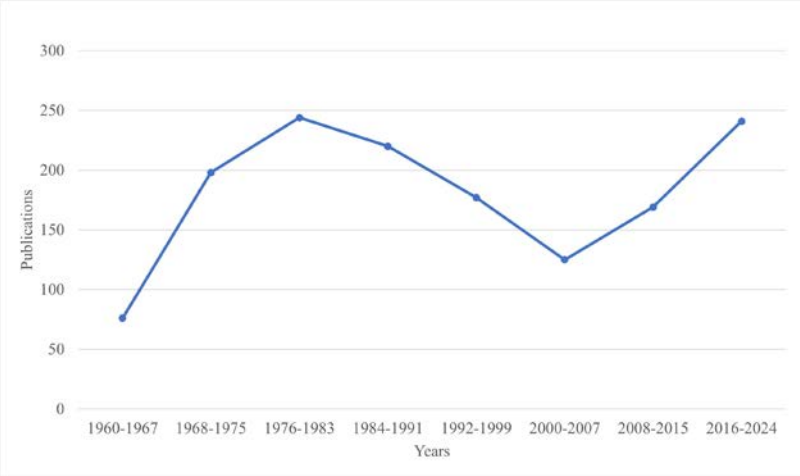


Figure 1. Classification by year of articles referring to *"A. mexicanum"* included in the study.

Table 1. Top 20 authors worldwide with the most articles on *"A. mexicanum"* recorded in this study. Note: USA: United States of America. AUT: Austria. CAN: Canada. FRA: France. JPN: Japan. GB-ENG: England, United Kingdom. DEU: Germany. MEX: Mexico.

Author	Publications	Affiliation
Lemanski, L.F.	61	Texas A&M University-Commerce (USA).
Tanaka, E.M.	49	Research Institute of Molecular Pathology (AUT).
Dube, D.K.	40	Norton College of Medicine (USA).
Voss, S.R.	40	University of Kentucky College of Medicine (USA).
Armstrong, J.B.	36	Gravesmith Lab. for Embryol (CAN).
Charlemagne, J.	32	Sorbonne Université (FRA).
Gardiner, D.M.	29	University of California (USA).
Bryant, S.V.	28	University of California (USA).
Satoh, A.	25	Okayama University (JPN).
Holder, N.	22	University College London (GB-ENG).
Maden, M.	22	College of Liberal Arts and Sciences (USA).
Epperlein, H.H.	22	Medizinische Fakultät Carl Gustav Carus (DEU).
Monaghan, J.R.	22	College of Engineering (USA).
Signoret, J.	22	Université de Caen Normandie (FR).
Fellah, J.S.	21	Sorbonne Université (FRA).
Tank, P.W.	18	UAMS College of Medicine (USA).
Tournefier, A.	17	Benemérita Universidad Autónoma de Puebla (MEX).
Malacinski, G.M.	16	Indiana University Bloomington (USA).
Humphrey, R.R.	16	Indiana University Bloomington (USA).
Stocum, D.L.	16	Indiana University-Purdue University Indianapolis (USA).

Table 1 lists the most productive authors worldwide. Larry F. Lemanski, a distinguished professor at East Texas A&M University and director of the Biomedical Institute for Regenerative Research (BIRR), was the author with the most publications (n=61). Biochemist Elly Margaret Tanaka, scientific director of the Institute of Molecular Biotechnology at the Austrian Academy of Sciences (n=49), was the second most productive. Meanwhile, Dr. Dipak K. Dube (n=40), Professor of Medicine at the State University of New York (SUNY), and Professor Stephen Randal Voss of the University of Kentucky rounded out the top four positions.

French researcher Annick Tournefier, who collaborated with Dr. María Rosa Padrón at the Benemérita Universidad Autónoma de Puebla (BUAP) during the 1980s, was the only author with a Mexican affiliation among the top 20 most productive. This position was based on collaborative projects between the two countries dedicated to the study of lymphocyte activation and cytokine production during axolotl tissue regeneration.

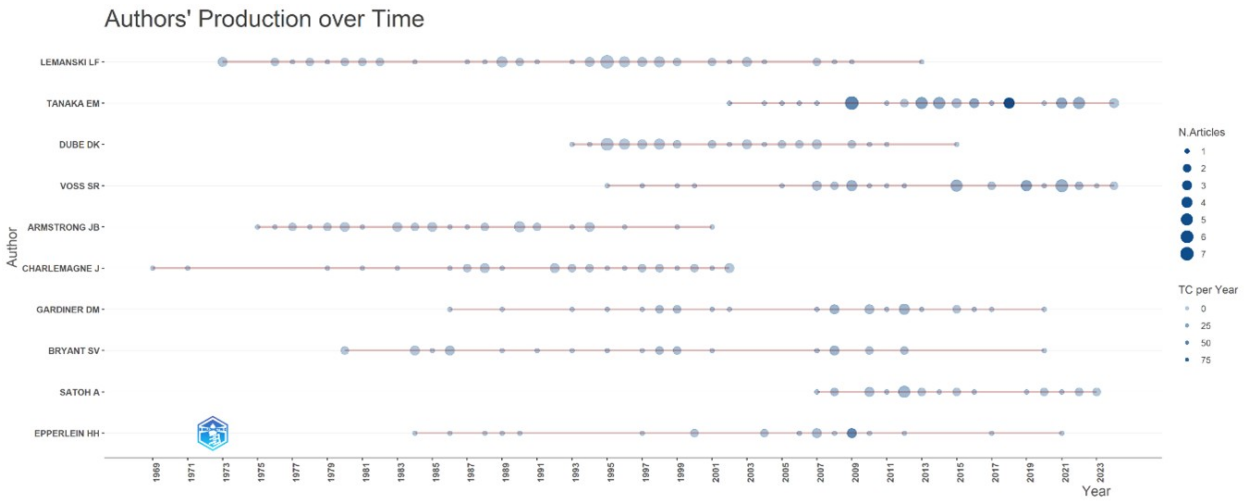


Figure 2. Output by author over the years.

Figure 2 shows the output of these most prolific authors over time. We can thus see that Lemanski was also the author with the longest recorded production span in this study, from 1973 to 2015 (42 years). Although Tanaka ranked second in output, her productivity spans only 22 years, and together with Professor Voss, they are the only ones among the leaders who are currently continuing to conduct research on the axolotl.

Nearly 40% of the literature found was produced in the United States, a country with a robust research infrastructure. Germany (10.7%) and France (8%) (Fig. 3) also stand out as key countries in research on the species. In this case, Mexico accounted for only 4.5% of the output, ranking sixth on the list despite being the species' country of origin.

The leadership of U.S. universities (Kentucky, California, Indiana) (Table 2) is evident, occupying the top three spots among the most productive institutions. Although Mexico ranks sixth among countries, the National Autonomous University of Mexico (UNAM) ranked fourth, leading Latin American countries and ahead of European institutions.

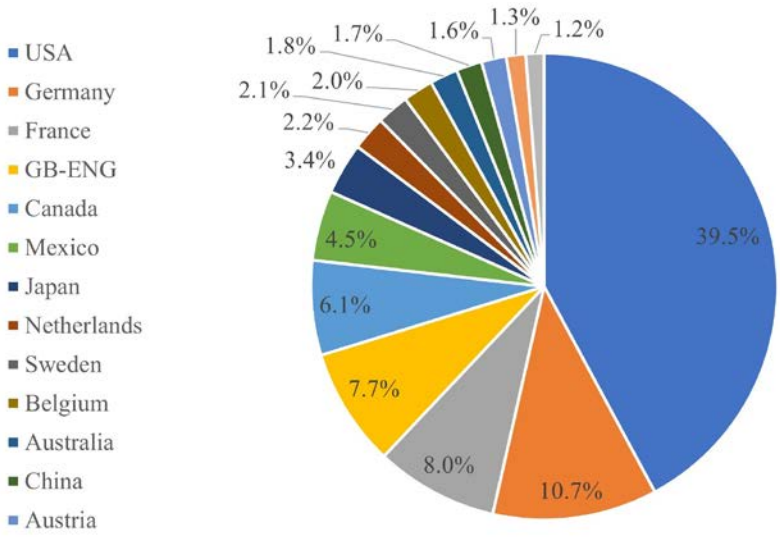


Figure 3. Output by country of articles referring to *"A. mexicanum"* included in the study. Note: USA: United States of America. GB-ENG: England, United Kingdom.

Table 2. Leading affiliated institutions with the highest scientific output in the study of *Ambystoma mexicanum*. Note: USA: United States of America. MEX: Mexico. DEU: Germany. CAN: Canada. JPN: Japan. TUR: Turkey. FRA: France. SWE: Sweden. TWN: Taiwan. GB-ENG: England, United Kingdom.

Affiliation	Publications	Country
University of Kentucky	82	USA
University of California	78	USA
Indiana University	65	USA
Universidad Nacional Autónoma De México	46	MEX
Technische Universität Dresden	38	DEU
University of Ottawa	36	CAN
Okayama University	30	JPN
Istanbul Medipol University	29	TUR
Université Pierre et Marie Curie	25	FRA
Université de Montréal	21	CAN
Harvard Medical School	20	USA
Uppsala University	20	SWE
Yale University	20	USA
Max Planck Institute of Molecular Cell Biology and Genetics	19	DEU
Northeastern University	19	USA
University of Florida	19	USA
National Taiwan University	17	TWN
University of Nottingham	17	GB-ENG
University of Michigan	16	USA
Ohio State University	15	USA
University of Illinois	15	USA
Upstate Medical University	15	USA
Princeton University	14	USA
University Of Manitoba	14	CAN

Figure 4 shows the thematic evolution of the domain's conceptual structures between 1963 and 2024. The flow lines between keywords reveal substantial changes in the continuity, transformation, and emergence of themes throughout the analyzed periods, suggesting an evolutionary dynamic of the field characterized by the constant reconfiguration of its conceptual axes. Unlike Figure 1, the periods used in this analysis were defined based on the need to capture the most representative-thematic transitions, which allowed for better identification of structural changes in the field's development.

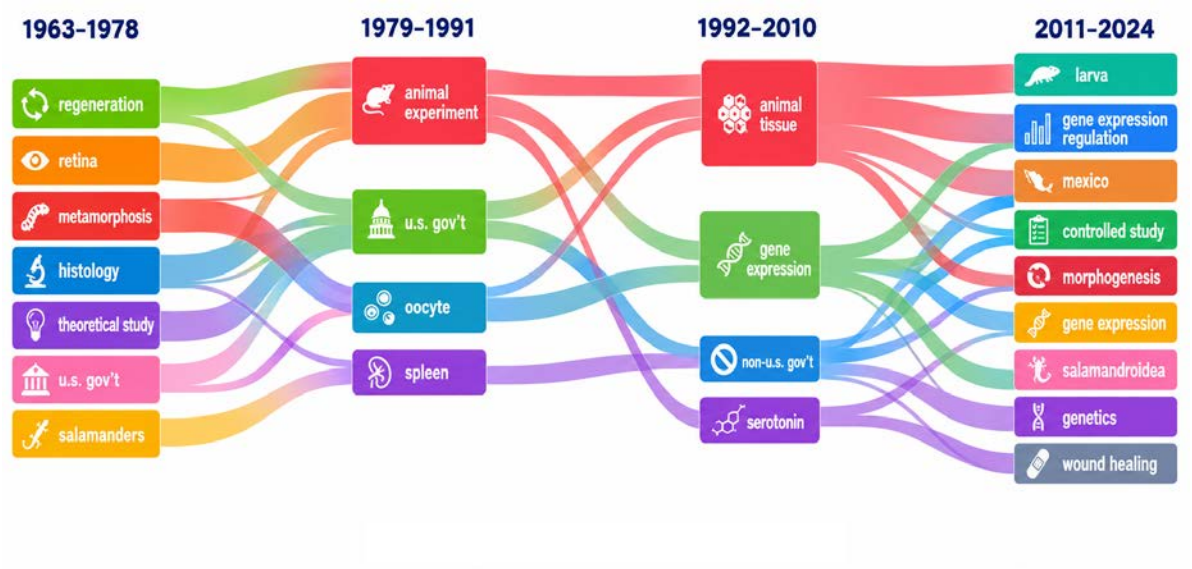


Figure 4. Thematic evolution of articles on *A. mexicanum* over time.

In the co-word analysis, centrality is interpreted as a measure of the degree of interaction of a theme with others within the scientific field, reflecting its structural relevance, while density expresses its level of internal development and conceptual cohesion. The combination of both metrics allows for the classification of research themes into driving, niche, emerging, or basic themes, providing an integrated view of the structure and evolutionary dynamics of knowledge. In the thematic maps (Figs. 5–8), driving themes are located in the upper-right quadrant, characterized by high centrality and high density; niche topics are concentrated in the upper-left quadrant, with high density but low centrality; marginal or emerging topics appear in the lower-left quadrant, with low centrality and low density; while basic or cross-cutting topics are located in the lower-right quadrant, combining high centrality with a low level of internal development.

In the first period analyzed (Fig. 5), from 1963 to 1978, no research topic falls entirely within the driving topics quadrant, but topics related to mutation-genes (niche-driving topic quadrant) and histological-microscopic studies (basic-driving topic quadrant) are partially present.

During the intermediate periods of 1979–1991 (Fig. 6) and 1992–2010 (Fig. 7), the number of research topics decreased compared to the first period (1963–1978). From 1979 to 1991, the topic of embryology remained, and emerging topics related to reproduction ("oocyte-ovum-oocytes"), niche topics related to hematology ("spleen-lymphocytes-immunoglobulins"), and the driving topic related to histological experiments appeared. From 1992 to 2010, the topic of molecular biology and genetics reappeared with "gene expression-amino acid sequence-molecular sequence data" in the driving topics quadrant. A niche topic regarding heart studies and

an emerging topic on neurotransmitters ("serotonin-nerve fiber-tongue") appeared. Within the basic topics quadrant is "animal tissue-controlled study-embryo," which appears to be a fusion of the topics from the previous period related to embryology and histology.

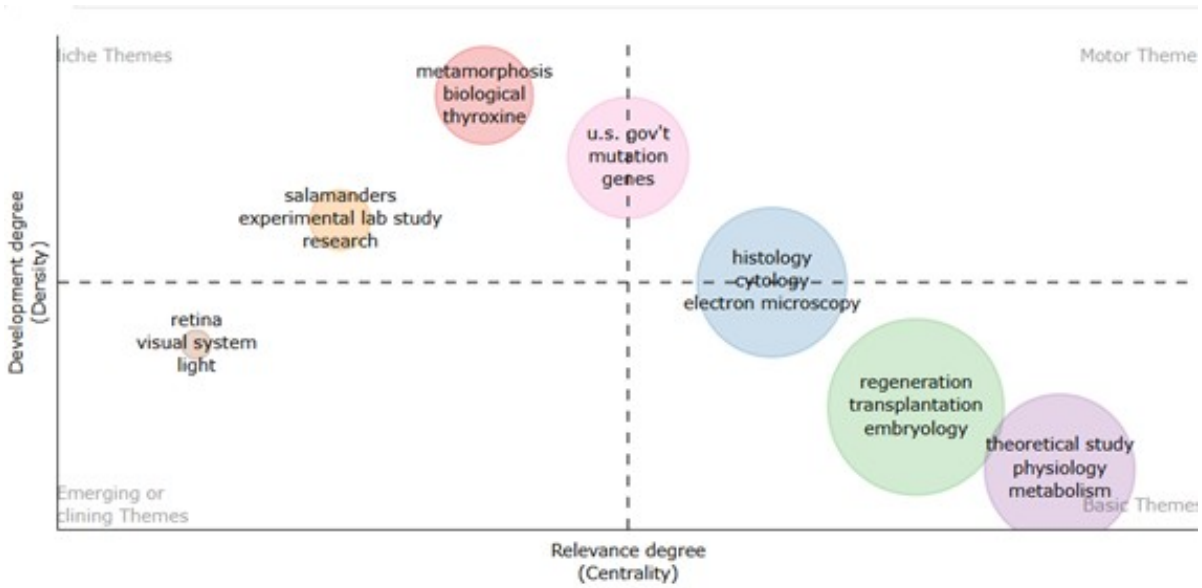


Figure 5. Thematic map for the period 1963–1978.

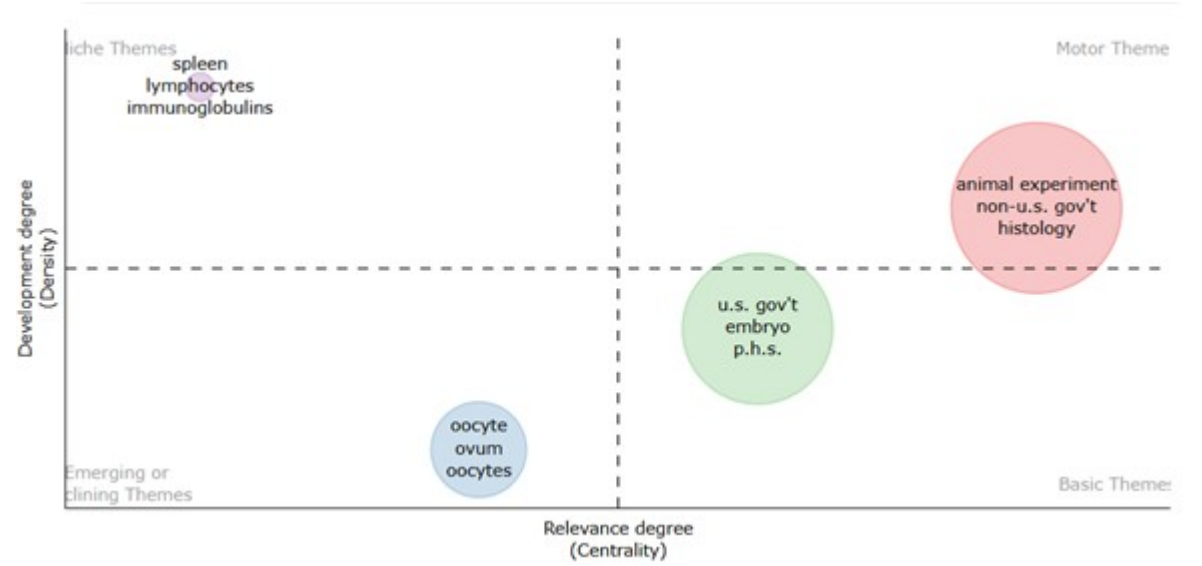


Figure 6. Thematic map for the period 1979–1991.

In the latest thematic period (2011–2024) (Fig. 8), we can observe how the topic of gene expression is developing with greater relevance, now including its genetic regulation. Among the emerging research topics, "endangered species," "federal district [mexico]" "mexico [north america]," and the niche topic "mexico history" suggest that the scientific community began to take an interest in the natural habitat where this species is endemic and to consider it a threatened species. This representation may be evidence that declaring *A. mexicanum* an endangered species

in 2006 did indeed influence the scientific community. Since then, these topics have gained prominence, highlighting how social events influence the focus of science.

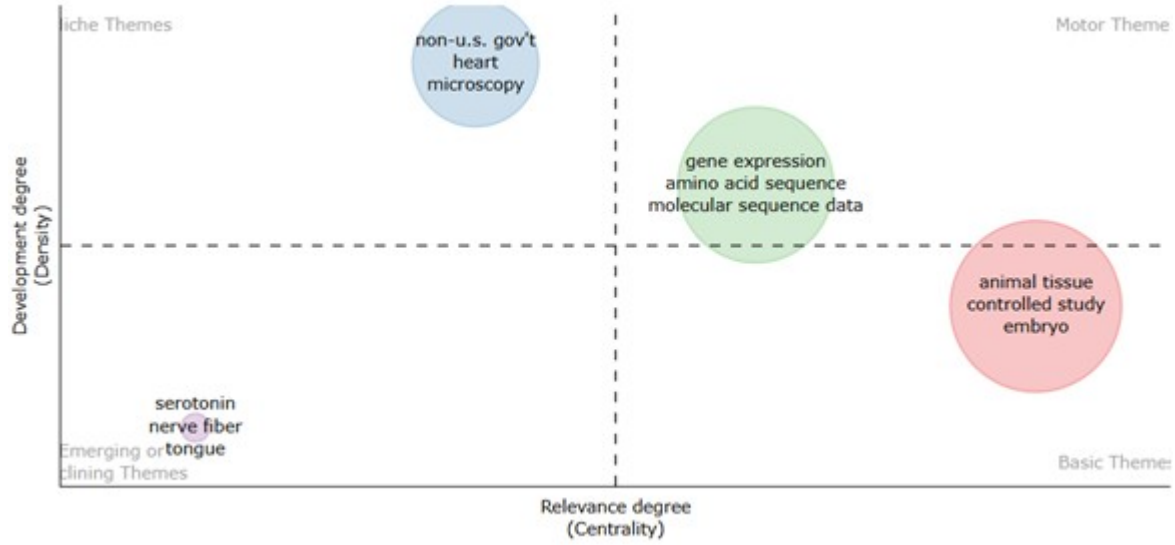


Figure 7. Thematic map for the period 1992–2010.

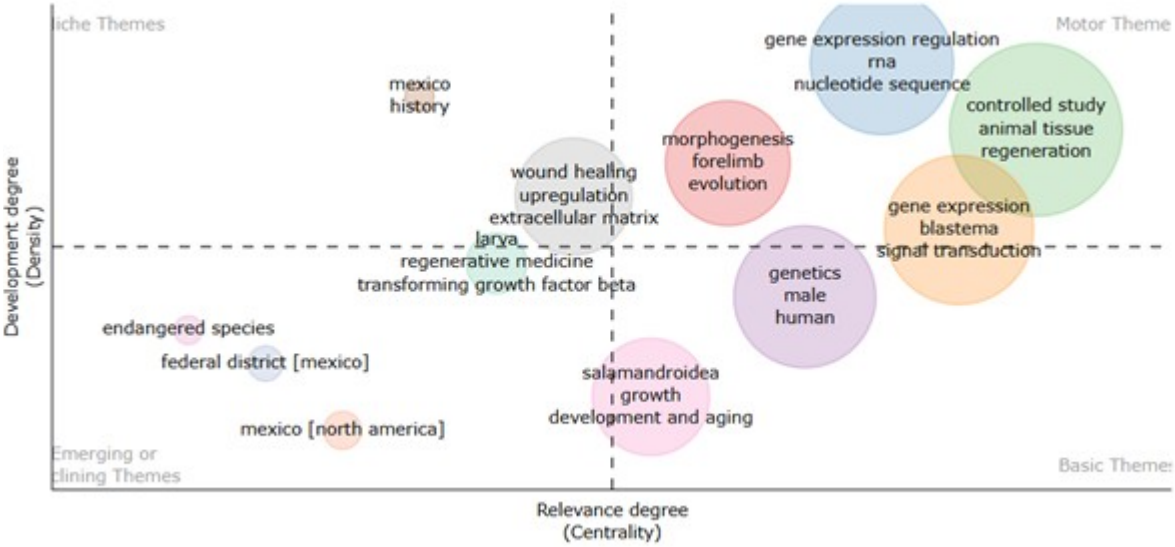


Figure 8. Thematic map for the period 2011–2024.

DISCUSSION

The evolution of scientific research on *Ambystoma mexicanum* cannot be understood solely as a succession of biological or technological advances, but also as the result of historical, geopolitical, epistemological, environmental, and conservation-related processes that have shaped knowledge production on a global scale. The scientometric results obtained in this study show patterns of growth, thematic reorganization, and institutional concentration that reflect persistent inequalities between regions, as well as the differential integration of countries into dominant scientific agendas.

From a geopolitical perspective on science, the global distribution of scientific output on *A. mexicanum* reflects well-documented patterns of knowledge concentration in the Global North, where the main research infrastructures, funding sources, and high-impact journals are located (Vessuri *et al*., 2014). These asymmetries have been extensively analyzed in the Latin American context, where scientific research may develop under conditions of epistemic dependency, with theoretical frameworks, methodologies, and research questions defined predominantly outside the region (Alatas, 2003; Kreimer, 2019; Beigel, 2014). In this sense, Mexico's relatively limited presence in the global literature on *A. mexicanum*, despite being the species' country of origin, may reflect the interaction of several factors rather than a single cause. These include the availability of specialized research groups, competing research priorities associated with the country's highly diverse herpetofauna, limitations in scientific infrastructure and funding, and broader structural inequalities in global knowledge production.

Historically, *A. mexicanum's* emergence as a model organism began in Europe when live specimens were sent from Mexico to the Natural History Museum in Paris (France). The surviving individuals reproduced successfully, producing numerous offspring that were distributed across Europe and Oceania, and subsequently returned to the Americas (Casas-Andreu *et al*., 2003).

Thematic maps allow us to observe how this unequal integration has manifested over time in the conceptual evolution of the field. The first decades of research on *A. mexicanum* were dominated by approaches typical of classical developmental biology, embryology, and experimental histology. This pattern coincides with the historical process of establishing the axolotl as one of the first self-sustaining laboratory animals, as extensively documented by Reiß *et al*. (2015). During this stage, the axolotl was integrated early into European and American scientific networks, which enabled its continuous maintenance and experimental standardization, laying the groundwork for its subsequent expansion as a model organism. From the earliest studies conducted with *A. mexicanum* on developmental biology, its regenerative capacity attracted the attention of embryology laboratories in the United States (USA), Germany, and France during the second half of the 20th century. This boom was further fueled by the global expansion of basic science after World War II, particularly in the USA, where institutions such as the National Science Foundation (NSF) were created, driving investment in research and strengthening international scientific exchange (Stephan, 1996).

From the 1970s to the 1990s, advances in molecular biology and genetics transformed the way the axolotl was studied. The development of new techniques such as PCR amplification and electron microscopy allowed for a shift from classical morphophysiology toward a more sophisticated cellular and molecular biology. This shift coincided with a period of growing scientific cooperation driven by the Cold War, during which industrialized nations invested in research infrastructure and the training of researchers. Thus, the axolotl evolved from a laboratory model into a key species for understanding the processes of tissue regeneration, cell differentiation, comparative embryology, and developmental evolution (Reiß *et al*., 2015). Starting in the 1970s and 1980s, thematic maps show a progressive reorganization of the field, with the emergence of lines of research related to reproduction, immunology, and cellular physiology. This thematic shift reflects broader transformations in experimental biology, associated with the development of new technologies and the transition from descriptive approaches toward functional and mechanistic ones. From a scientometric perspective, this process is consistent with the co-word analysis models proposed by Callon *et al*. (1983, 1991), which describe the evolution of scientific fields as a dynamic reconfiguration of conceptual networks rather than as linear growth.

The period between 1990 and 2010 constitutes a decisive turning point, marked by the full incorporation of molecular biology and genomics into axolotl research. The thematic maps highlight the growing centrality of gene expression, molecular sequences, and biochemical analyses, in line with the omics revolution that transformed contemporary biology. This shift cannot be explained solely by epistemological advances, but also by structural factors linked to funding and the priorities of global science. As Stephan (1996) points out, the direction of scientific research is strongly conditioned by economic incentives and by the concentration of resources in areas with high application potential, such as regenerative medicine, where the axolotl acquired increasing strategic value. However, various global economic crises, such as that of 2008 (Banguero, 2010), directly impacted science and technology systems by reducing institutional funding and limiting the training of new researchers. The decline in enrollment and support for these may affect the continuity of projects and academic productivity, especially in fields that require costly infrastructure and the maintenance of living organisms, such as the study of *A. mexicanum*.

In this context, the axolotl has been progressively integrated into the global network of model organisms— a process described as experimental standardization, through which living organisms become reproducible platforms to produce knowledge (Kohler, 1994; Ankeny & Leonelli, 2020). This standardization has facilitated the international circulation of *A. mexicanum* lines, embryos, tissues, and data, giving rise to dynamics of the commodification of biological knowledge (Leonelli, 2016). The existence of biobanks and commercial suppliers of model organisms—a phenomenon also documented for other species such as *Danio rerio* or the laboratory mouse—illustrates how academic research and the biomedical industry are closely intertwined in contemporary science (Grupo de Trabajo de la SECAL, 2017).

Differences in countries' capacity to participate in these networks are closely linked to national investment in research and development. There is a strong correlation between R&D spending and scientific productivity, with countries investing more than 2% of their GDP concentrating the greatest capacity to sustain specialized animal facilities, genomic platforms, and long-term projects (OECD, 2023). In contrast, Mexico and other Latin American countries have historically maintained investment levels below 1% of GDP, which limits their structural competitiveness (CONACYT, 2021). Inequality in investment in research and development generates cumulative advantages that reinforce the leadership of high-investment countries and reproduce persistent inequalities in knowledge production (Merton, 1968; Wang & Barabási, 2021).

From an institutional perspective, the leadership of U.S. and European universities and research centers in axolotl research stems from the logic of hegemonic centers of science, where the concentration of infrastructure, human capital, and prestige enables the setting of global agendas and standards (Altbach, 2015). This dynamic generates forms of cognitive dependency, in which researchers from peripheral countries must align themselves with dominant conceptual frameworks to achieve international visibility (Connell, 2020). Bibliometric studies have shown that these asymmetries are reflected in patterns of authorship, collaboration, and intellectual leadership, particularly in biology and biomedicine (Sugimoto & Larivière, 2018).

A critical aspect in the case of the axolotl is the tension between its abundance in international laboratories and the precarious state of its wild populations in Xochimilco. This paradox has been analyzed within the framework of biological sovereignty and access to genetic

resources, where biodiverse countries contribute resources that are then transformed and, in some cases, patented outside their territory (Glowka *et al*., 1994). The concept of scientific extractivism is particularly relevant for describing these dynamics, in which the scientific and economic value of model organisms is decoupled from the socio-ecological realities of their place of origin (Grosfoguel, 2016). In the case of *A. mexicanum*, these tensions are particularly relevant in light of the severe decline of wild populations and the multiple threats affecting the species and its habitat, conditions that have resulted in its classification as Critically Endangered (IUCN, 2020) and its role as a strategic resource in biomedical research on regeneration (Voss *et al*., 2009).

The structure of collaborative networks reinforces this assessment. Latin America has fragmented scientific networks, with a strong reliance on North-South collaborations and weak South-South coordination, which limits the development of independent regional agendas (Narváez-Berthelemot *et al*., 1992; Gaillard, 1994). In the case of the axolotl, this lack of regional integration is particularly striking, given Mexico's potential to exercise scientific leadership and coordinate a Latin American network around an emblematic organism.

The resurgence of scientific interest in the axolotl since the late 2000s coincides with the rise of regenerative medicine, driven by advances in transcriptomics, gene editing, and single-cell analysis (Tanaka & Reddien, 2011; Gerber *et al*., 2018). Recent studies have established axolotl as a key model for understanding cellular plasticity and tissue repair mechanisms in vertebrates (Bryant *et al*., 2017). This alignment with global biomedical agendas illustrates how techno-scientific priorities influence the centrality of certain model organisms within the international scientific system (Leonelli & Ankeny, 2012).

Finally, the recent emergence of issues related to culture, identity, and conservation reflects a growing openness to interdisciplinary approaches that integrate science, ethics, and the local context. The axolotl has taken on a new prominence as a Mexican cultural symbol, a driving force behind environmental education initiatives, and a focal point for biocultural conservation proposals (Bride *et al*., 2008; Voss *et al*., 2015). These approaches respond both to the environmental collapse of Xochimilco and to a contemporary revaluation of situated knowledge and of emblematic species as bridges between science and society (Bride *et al*., 2008; Pérez-Belmont *et al*., 2019). The social factor has been equally decisive. The axolotl is not only a model organism in laboratories but also a symbol of Mexican identity and an internationally recognized cultural emblem. Pollution, urbanization, habitat transformation, and the introduction of exotic species have contributed to the drastic decline of wild *A. mexicanum* populations in Xochimilco (Contreras *et al*., 2009; Zambrano *et al*., 2010), resulting in its classification as "Critically Endangered" by the IUCN in 2006. It went from being solely a model organism in laboratories to becoming a symbol of ecological crisis, spurring an interdisciplinary dialogue between biology, ecology, and the social sciences. This generated new research topics that had not been addressed before.

The results of this study help explain the dynamics of scientific progress: the production of knowledge does not occur in isolation, but rather develops in constant interaction with technological, social, and environmental contexts. Technological advances redefined research questions and methodologies; the global economy shapes the institutional and human capacity to address these questions; and ecological and social changes broaden their scope and social relevance. Taken together, the evolution of studies on the Mexican axolotl as a model organism represents an example of how science adapts to challenges over time, further highlighting the

value of scientometrics as a tool for analyzing the dynamic relationship between scientific progress and the societal transformations that drive it.

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