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REVIEW ARTICLE

Global research trends on bats and One-Health: A systematic review

Tendencias globales en la investigación entre murciélagos y "Una Salud": Una revisión sistemática

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ABSTRACT

Bats play a crucial role in the health triad as key players in ecosystems and reservoirs of various pathogens. The study of bats and health requires a comprehensive approach such as One Health to address the various aspects of their impact on health in an interdisciplinary manner. Here, we present a systematic review and a bibliometric analysis with the aim of analysing the current state of knowledge on the interaction between bats, humans, animals, and environment under the context of "One Health" concept. We conducted our systematic review following the PRISMA reporting guidelines and assessed 386 articles published between 2009 and 2023. Many researchers adopted an interdisciplinary and collaborative approach, with 29.1% of international co-authorships and an average degree of collaboration between authors of 46.9. Thematic analysis highlighted the prevalence of studies on zoonoses and public health, and a gap in the inclusion of topics from the social and environmental context. Publications are biased towards viruses [coronaviruses (35%), paramyxoviruses (21%), and lyssaviruses (17%)], whereas other aspects related to the ecology of bat species or their social and economic impact are barely addressed. This is particularly notable in countries with a high diversity of bats. This represents an opportunity for scientifically capable nations to establish connections that will allow the development of representative research. It definitely is necessary to improve the interdisciplinarity between biologists, ecologists, medicine doctors, and veterinarians to apply the One Health concept in bat studies.

Keywords: bibliometric analysis, Chiroptera, conservation, PRISMA reporting guidelines, viruses, zoonoses.

RESUMEN

Los murciélagos tienen un papel crucial en la salud y son clave en los ecosistemas y como reservorio de varios patógenos. El estudio de los murciélagos y la salud require una aproximación desde el punto de vista del concepto de "Una salud", y que tiene un impacto considerable en la salud desde la interdisciplinaridad. Aquí, se hizo una revisión sistemática y un análisis bibliométrico con el objetivo de evaluar el actual estado del arte en la interacción entre murciélagos, humanos, animales y medioambiente bajo el concepto "Una Salud". Se realizó una revisión sistemática siguiendo el protocolo PRISMA y se evaluó 386 artículos publicados entre

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2009 y 2013. Muchas investigaciones adoptaron una aproximación interdisciplicar y colaborativa, con 29,1% de co-autorias internacionales y un grado de colaboración medio entre autores de 46,9. El análisis temático destaca la prevalencia de estudios de zoonosis y salud pública, con un déficit en los estudios sobre sociología y medioambiente. Las publicaciones estaban sesgadas a estudios con virus [coronavirus (35%), paramixovirus (21%), y lyssavirus (17%)], donde otros aspectos relacionados con la ecología de los murciélagos o su impacto en la sociedad o la economía son estudiados muy superficialmente. Esto es particularmente importante en países donde la diversidad de murciélagos es alta. Esto representa una oportunidad para las naciones avanzadas científicamente para establecer conexiones que permitan el desarrollo de una investigación representativa. Es necesario mejorar la interdisciplinaridad entre biología, ecología, medicina y veterinaria para aplicar el concepto Una Salud en los estudios con murciélagos.

Palabras clave: análisis bibliométrico, Chiroptera, conservación, guía PRISMA, virus, zoonosis.

INTRODUCTION

Humans have interacted with animals and their pathogens for millions of years (Wolfe *et al.* 2007). However, this interaction is currently exacerbated by anthropogenic factors such as global warming, habitat destruction, species extinction, human mobility and behaviour changes, antimicrobial resistance, etc. As a result, the dynamics of zoonotic disease emergence and pathogen transmission has changed becoming a risk to global health (Daszak *et al.* 2000). In this scenario, the One Health approach has emerged as an essential tool for scientific research (Gruetzmacher *et al.* 2021, Murray *et al.* 2022).

One Health is defined as an "*integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent*" (One Health High-Level Expert Panel (OHHLEP) *et al.* 2022). This concept allows us to understand and study the 'human-animal-environment' interface from a multidisciplinary and collaborative approach to develop effective strategies to detect, combat and prevent emerging, re-emerging, and endemic infectious diseases, in addition to improving the control of other threats to global health such as food safety and antimicrobial resistance (Gruetzmacher *et al.* 2021, Shaheen 2022), while also considering the environmental health and the preservation of ecosystem services (Stanworth *et al.* 2024).

Bats and environmental health

Bats representing more than 25% of biodiversity with >1,500 identified species (Simmons & Cirranello 2020). They play an important role in ecosystems, occupying a variety of ecological niches that are essential for maintaining the health of the environment (Ramírez-Fráncel *et al.* 2022, Tanalgo *et al.* 2023) where they provide several ecosystem (dis)service to humans (Meli *et al.* 2024), despite that the social perception of them still being negative (Pérez *et al.* 2021, Boso *et al.* 2021).

They are recognized as potential bioindicators, organisms that respond to changes in the environment (Russo *et al.* 2021), making them valuable tools for assessing ecosystem health by monitoring their populations (Lisón *et al.* 2017b, Racero-Casarrubia *et al.* 2021). Among the ecosystem services provided by bats, pollination and seed dispersal are the most prominent due to their importance in maintaining ecosystem stability (Ramírez-Fráncel *et al.* 2022, Tanalgo *et al.* 2023). Most of bat species are insectivorous and predators of insects considered crops' pest and disease vectors for cattle and humans (Tuneu-Corral *et al.* 2023), contributing to pest suppression and reduction in the use of pesticides (Köhler & Triebskorn 2013, Kim *et al.* 2017), having a considerable impact in regional and local economies (Tuneu-Corral *et al.* 2023), which may change as a result of global warming (Fialas *et al.* 2025, Matus-Olivares *et al.* 2025).

Despite their importance to ecosystems, about one-fifth of the world's bats are listed as threatened by the IUCN Red List of threatened species. This number

may be even higher, since of the 1,332 species of bats listed, 17.7% are in the "data deficient" category with respect to their conservation status, meaning it's not known for sure what category of threat they are really in (Welch & Beaulieu 2018). The conservation of bats and their habitats not only preserves biodiversity, but also promotes ecosystem conservation (Frick *et al.* 2020) and reduces the risk of bat-associated diseases spillover (Ramanantsalama *et al.* 2022). For this, Pruvot *et al.* (2023) cites them as an example of a species directly involved in ecosystem functioning and human well-being.

Bats and human health

Bats are important study models in various health-related disciplines associated with humans (Teeling *et al.* 2018). Firstly, they are a relevant source of pathogens due to their unique characteristics (Allocati *et al.* 2016). It highlights their greatly developed immune system (Jayaprakash *et al.* 2023, Baid *et al.* 2024), which, together with a broad capacity for temperature regulation, high metabolic rate, and control of oxidative stress, results in a controlled immune response and persistence of infection (e.g. Subudhi *et al.* 2019, Banerjee *et al.* 2020, Fjelldal *et al.* 2023, Rampelotto *et al.* 2023). This is enhanced by a longevity that is on average three times higher than predicted for the body size of these species, increasing the opportunities for co-evolution and persistence of pathogens (Wang *et al.* 2011, Wilkinson & Adams 2019).

On the other hand, their high species diversity, cosmopolitan geographic distribution, and flying capacity could facilitate the spread and transmission of certain pathogens that affect humans (Kuzmin *et al.* 2011, Beena & Saikumar 2019, Szentivanyi *et al.* 2023, Sacristán *et al.* 2025). In addition, many species live in large colonies with close contact between individuals, creating an environment conducive to virus exchange both within and between species, contributing to the diversity of pathogens they harbour (Woo *et al.* 2009), especially viruses related human epidemic outbreaks (Joffrin *et al.* 2018, Khan *et al.* 2022). In other cases, bats are carriers of other potential human pathogens such as those of the genus *Mycoplasma*, *Bartonella*, *Brucella*, *Histoplasma*, etc. (Allocati *et al.* 2016, Millán *et al.* 2019, Müller *et al.* 2020, Núñez-Montero *et al.* 2021). They can even transmit pathogens to other animal species, as seen with the Hendra virus (Khusro *et al.* 2020).

However, humans could also be vectors of pathogens which affect bat species. This is the case of the fungus *Pseudogymnoascus destructans*, known to cause White-nose syndrome which has led to significant declines in bat populations in North America (Whiting-Fawcett *et al.* 2024). These examples illustrate how bat pathogens can have significant impacts on both human and animal health and highlight the need to understand and manage these interactions to prevent future outbreaks and pandemics (Beena & Saikumar 2019, Plowright *et al.* 2024).

Nevertheless, bat biological capacities could be an interesting inspirational source due to their extraordinary biology. For example, study subjects in recent research on cancer prevention (Vincze *et al.* 2022, Li *et al.* 2023), medicine development (Tackett *et al.* 2022) and contamination (Zukal *et al.* 2015, Lisón *et al.* 2017b, Sotero *et al.* 2022).

Bats and One Health

Applying the One Health approach to the study of bats means recognizing their role in both disease dynamics and ecosystems. It also highlights the importance of understanding the impact of human activities, such as habitat modification, hunting and wildlife consumption, on bat welfare, conservation, and exposure to their pathogens, and thus on ecosystem health and global health security (Voigt & Kingston 2016). By understanding the epidemiology of disease, considering the human factor and the ecosystem in which the species are inserted, efficient surveillance systems can be established to control the spillover of pathogens that could pose a risk to global health (Wood *et al.* 2012, Guth *et al.* 2022, Pandit *et al.* 2022, Lange *et al.* 2023). In this sense, interdisciplinary and collaboration are key. However, it is important to note that although many studies address these issues under a One Health approach, true collaborative and interdisciplinary work is not always carried out (Errecaborde *et al.* 2019, Humboldt-Dachroeden *et al.* 2020).

Due to the exponential growth of scientific publications, there is a need for integrative reviews that synthesize research areas (Nakagawa *et al.* 2019). Given that, to date, no systematic review and bibliometric analysis has been conducted focusing on the study of knowledge on the relationship between bats and global health from a One Health perspective, this study is considered to fill an important gap in the scientific literature and contribute to a comprehensive understanding of the evolution of this topic. It is important to map the scientific literature,

identify trends and provide recommendations on areas for research. This will improve the understanding of the role of bats in global health and guide future research to ensure health security and promote harmonious coexistence between bats, humans, and other living things in their environment.

Our aim was to analyse, systematically, the current state of knowledge on the interactions between bats, humans, animals, and environmental health within the One Health approach. Specifically, 1) to analyse the scientific production of studies on this thematic; 2) to identify most of the studies topics related to the "bats" under a "One Health" perspective; 3) to identify the existence of interdisciplinary and collaborative work; and 4) to assess knowledge gaps, key topics, and future research areas.

MATERIAL AND METHODS

We conducted a systematic analysis of the scientific literature on the interaction between bats, humans, animals, and environmental health within the framework of the "One Health" approach. For this, we used the PRISMA methodology (https://www.prisma-statement.org/) because it provides and facilitates the production of transparent, complete, and accurate reports that explain the rationale for the review, the procedures used (such as searching and selecting studies), and the results obtained (Page *et al.* 2022).

Preliminary search

To identify previous systematic reviews that may have specifically addressed the topic of this review, we conducted a preliminary search of the PubMed and Web of Science databases using the terms "bats" and "systematic review". This search yielded a considerable number of articles, mainly related to ecology and zoonoses in bats, but without a One Health approach. A second preliminary search was then conducted in the same databases using the terms "bat" and "One Health". As the recommended number for a bibliometric analysis is more than 200 articles (Rogers *et al.* 2020) and the search engine results were lower, the databases used for the sources search were supplemented with the search engines ScienceDirect, Scopus, Scielo and the first 200 Google Scholar results (Lisón *et al.* 2020).

Systematic search

The systematic search for articles was carried out again on August 25, 2023 in the above-mentioned databases. In order to not limit the systematic analysis to zoonoses only, a broader search strategy was implemented for the present study. Specifically, the keywords "bat*" OR "chiropter*" AND "one health" were used in both Spanish and English. Results were filtered by text type only to "articles", "review articles", and "book chapters". A total of 1,060 results were obtained and exported to Zotero's bibliographic citation manager for duplicate removal.

Selection of papers

To reduce the possibility of bias, we reviewed the collected records twice, independent and randomly, to select articles. This selection was based on eligibility criteria that included work on the relationship between bats and global health from a "One Health" perspective (Fig. 1). Articles from all continents, with no restriction on year of publication and in all languages were included as long as the abstract was available in English or Spanish (Lisón *et al.* 2020). Articles were excluded if they focused on a species other than bats and did not establish a relationship with that species, as well as grey literature, editorial material, comments, letters to the editor, and articles for which the full text was not available to the researchers. In addition, we excluded articles that did not explicitly address the One Health approach (the term was not present in the text) or that implicitly addressed it but did not establish a relationship to the One Health concept, such as authors' affiliation with One Health organizations or funding of One Health research. Using these criteria, and after reading the abstract and sections where the search engine identified the words "bat" or "chiroptera", 358 articles were obtained. Subsequently, the studies were read in full, eliminating 32 articles mainly due to limited information on bats and documents such as "comments", "perspectives" and "editorial material", which were incorrectly indexed as "articles" by the databases.

The final dataset included 386 publications (Appendix S1, Supplementary Material) after adding 60 articles retrieved by database alerts (from 25 August to 5 November of 2023) from the personal library and the library of the BatOneHealth group (Fig. 1), a group of researchers working collaboratively to understand the zoonotic disease outbreak in bats (BatOneHealth, n.d.).It should be noted that these articles also underwent the

same review and filtering process based on the inclusion and exclusion criteria as those resulting from the August search. This is a normal procedure in systematic reviews (Lison *et al.* 2020)

Articles analysis

The following data relevant for the analysis were extracted from the selected studies: year of publication, language, article type, country, authors, affiliated organization, thematic categories addressed, keywords, pathogen addressed (if this was the topic of the article).

Data analysis was performed using the open-source bibliometric data management systems Bibliometrix, VosViewer version 1.6.20 and Gephi version 0.10.1. Bibliometrix, an R package created for the quantitative analysis of scientometric and bibliometric data, was used specifically with its Biblioshiny interface (Aria & Cuccurullo 2017). This tool facilitated the analysis of basic bibliometric indicators such as number of articles, languages, percentage of collaboration, and types of documents. These indicators were chosen to provide a global view of the scientific production related to the topic under study. In addition, scientific production maps were generated in the same interface to better understand the global distribution of production in the field. Furthermore, the cognitive and social structure of the research field was explored through the creation of cross-country collaboration maps and co-citation networks, which provided insight into the level of interdisciplinary and collaboration within the academic literature.

On the other hand, VosViewer, a network map visualization tool (van Eck & Waltman 2010), was used for the construction of co-authorship networks and keywords. Co-authorship networks helped to identify collaborative relationships and interdisciplinary work, while keywords networks provided a clear view of central themes and understudied topics within the research area. To ensure the accuracy of the keyword analysis, a prior cleaning of the terms was carried out, which consisted on the use of synonyms, the unification of plural/singular forms according to occurrence, and the elimination of keywords redundant to the research (Appendix S2).

Subsequently, to perform a quantitative analysis of the co-authorship networks and keywords generated by VOSviewer, the networks data were exported to Gephi, an open-source software that allows the graphing and analysis of networks by calculating measures such as degree, betweenness and closeness, average clustering coefficient and modularity (Bastian *et al.* 2009). In addition, to determine thematic trends, a manual categorization of topics was performed in which each article was read in its entirety and classified into one or more of the five thematic categories and into one or more of the 44 topics listed (Appendix S3). For the precise definition of these topics, reference glossary from relevant international health organizations were used, such as the WHO glossary (World Health Organization 2020) and the One Health EJP glossary (available at https://aginfra.d4science.org/web/orionknowledgehub/catalogue). To facilitate understanding and analysis of the most frequently discussed topics, these were grouped into five more general categories identified by the authors. However, it should be noted that some topics could have belonged to another category due to their interdisciplinary nature.

RESULTS

According to the PRISMA protocol flowchart (Fig. 1), we found in 6 bibliography databases a total of 1060 documents following our search parameters (see above). We added 64 documents from other search methods or providing from researchers. A total of 493 (46.5%) documents were duplicates. After applying the filters, finally, we obtained 386 documents to make our review (61.1%; Fig. 1).

Analysis of scientific publications

These 386 documents were classified as scientific articles (67.6%), literature reviews (30.8%), and the remaining 1.6% were early access articles, book chapters, and conference proceedings (Table 1). The annual growth rate is 22.3% (Fig. 2) and with high levels of international co-authorships (Table 1). The documents have a time range between 2009-2023, where 78% of them were published in the last five years, although we observed a decrease from 2021 and on (Fig. 2). These results were motivated by a peak of publications with terms such as “SARS-CoV-2” in 2020 and “zoonoses” in 2021 (Appendix S4). The studies of bats and One-Health are distributed in all the continents, with a total of 76 different countries, where the USA produced the 29% of them, followed by Australia, Thailand, and Brazil (11%, 5%, 4% and 3%, respectively; Fig. 3).

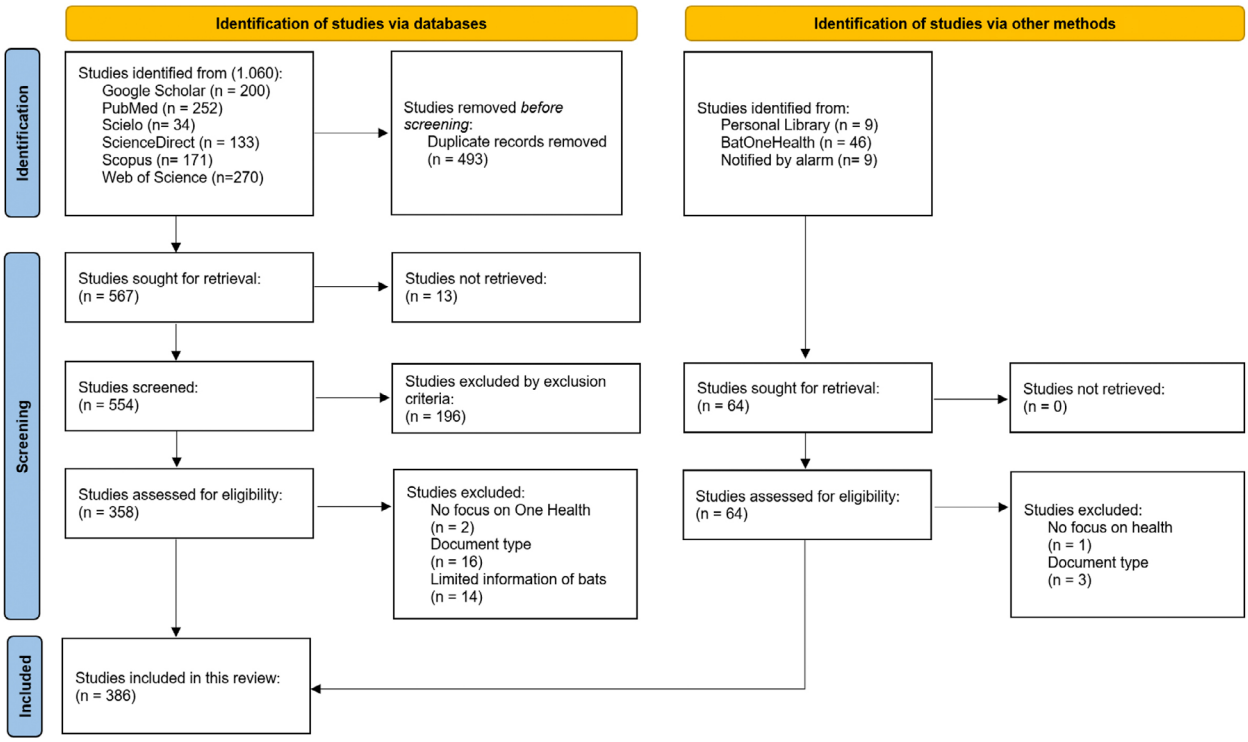

FIGURE 1: PRISMA flow diagram showing the process of identifying, evaluating, and selecting articles for inclusion in this review (modified from Page *et al.*, 2021). / Diagrama de flujo PRISMA muestra el proceso de identificación, evaluación y selección de artículos para ser incluidos en la revisión (modificado a partir de Page *et al.*, 2021).

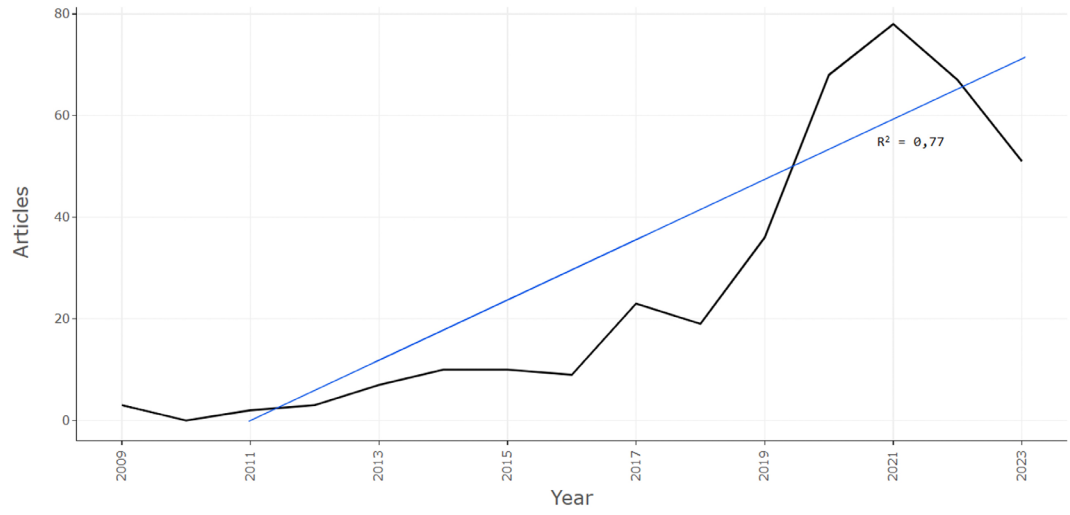

FIGURE 2: Annual scientific production from 2009 to 2023. A linear trend line was adjusted with an R2 coefficient of determination of 0.77. / Producción científica anual desde 2009 hasta 2023. La linea de tendencia fue ajustada con un coeficiente R2 de determinación de 0,77.

TABLE 1. Basic bibliometric data used in this analysis. / Datos bibliométricos básicos usados en nuestro análisis.

Description	Results
First article (year)	2009
Last article (year)	2023
Documents	386
Annual Growth Rate (%)	22,3
International co-authorships (%)	29,1
Document type	
Articles	261
Articles; early access	2
Articles; proceedings articles	2
Book chapters	1
Conference papers	1
Reviews	119
Language	
Spanish	3
French	1
English	382
Portuguese	1

Analysis of interdisciplinary and collaborative research

Of all the documents, 98% were authored by more than one person, indicating a strong collaborative effort. On average, the collaborative papers had nine co-authors per paper. We also found that the collaboration between countries was high with almost a 30% of the international co-authorships (Fig. 3). 90% of the countries with studies in bats and One-Health had some kind of collaboration with other countries. There was a special relationship between the USA with Australia, UK and Singapore with up to 9 shared documents. In this study, the USA is the country with the broadest collaboration network since they have interactions with 62 countries (Fig. 3).

The co-authorship networks (Fig. 4) visualised 188 of the 2590 authors to facilitate the visualisation of co-authorship relationships. In this network, we identified 15 collaboration groups which they had three or more publications. The mean degree of the network was 46.95, therefore, a closer analysis of the entire network, including all 2590 authors, reveals additional data. The network had an average clustering coefficient of 0.95 and a modularity of 0.829, both of which are measures of network that indicate the degree of cohesion among the members of each collaborative group.

The main authors of the network are Plowright R.K., Goldstein T., and Peel A.J. (Fig. 4), where two of them had low degree values or “betweenness” (frequency with which a node appears on the closest path between nodes in the network). According to the centrality measures of the analysis the green cluster formed by Goldstein T., Mazet J.A.K., Johnson C.K., Epstein J.H., and Daszak P. are the most influential authors in the One Health bat research collaboration, with a total of 501, 462, 450, 430, and 411 links, respectively, and a high degree of betweenness (Fig. 4).

Our analysis of the relationship between the top five authors of the five most productive clusters showed that high levels of collaboration do not always imply interdisciplinarity (Fig. 5). These five authors encompass almost all the thematic categories, with a particular interest in topics related to zoonoses, covering more than half of the research flow. However, topics related to global health, research methods, and disease ecology have fewer documents in comparison, suggesting that these topics may not be the focus of the collaborative research.

We evaluated the interdisciplinarity of research, a co-citation network of the 20% of the most productive scientific journals, observing that there is a panorama of broad citation, without isolated groups and with many connections. These scientific sources cover a wide range of disciplines, including infectious diseases, immunology, virology, and multidisciplinary sciences (Fig. 6).

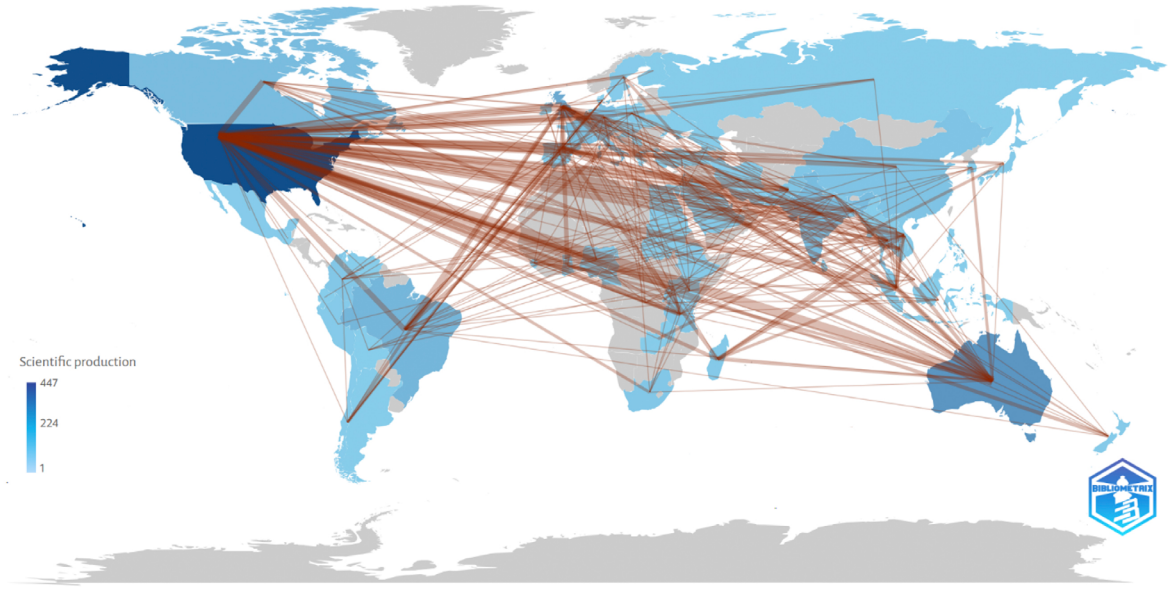

FIGURE 3: Scientific production by country. The colours represent the number of authors who have contributed with scientific papers, with colours being darker when the productivity is higher. Map of collaborations between countries. The grey colour indicates the absence of authors with international collaborations. Shades of blue, from lighter to darker, indicate an increase in collaborating authors. The links indicate the number of collaborations, becoming wider as more collaborations are present. / Producción científica por país. Los colores representan el número de autores que han contribuido en los artículos científicos, cuando la tonalidad es más oscura significa que la productividad es mayor. Se presenta el mapa de colaboración entre países. La coloración gris indica que hay ausencia de autores dentro de las colaboraciones internacionales. La coloración azul, de más claro a oscuro, indica que se incrementa la colaboración entre autores. Las lineas indican el número de colaboraciones, donde a mayor grosos hay más colaboración.

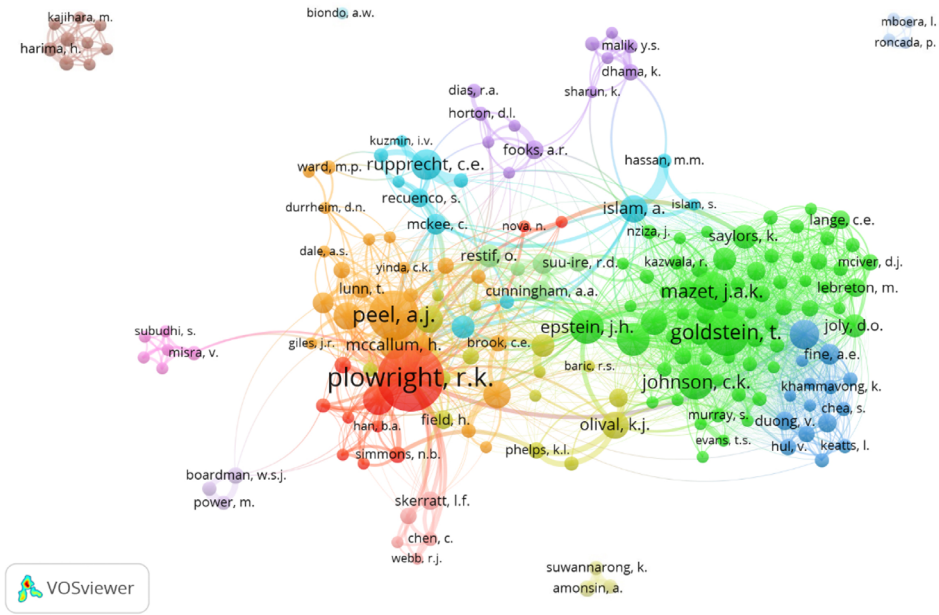

FIGURE 4: Collaborative network of authors. Visualization of the network of 188 authors. The size of the node represents the number of publications, and the thickness of the link indicates the degree of collaboration between the authors. /Red de colaboración para los autores. Se visualiza la red para 188 autores. El tamaño de los nodos representa el número de publicaciones y el grosor de las líneas indican el grado de colaboración entre los autores.

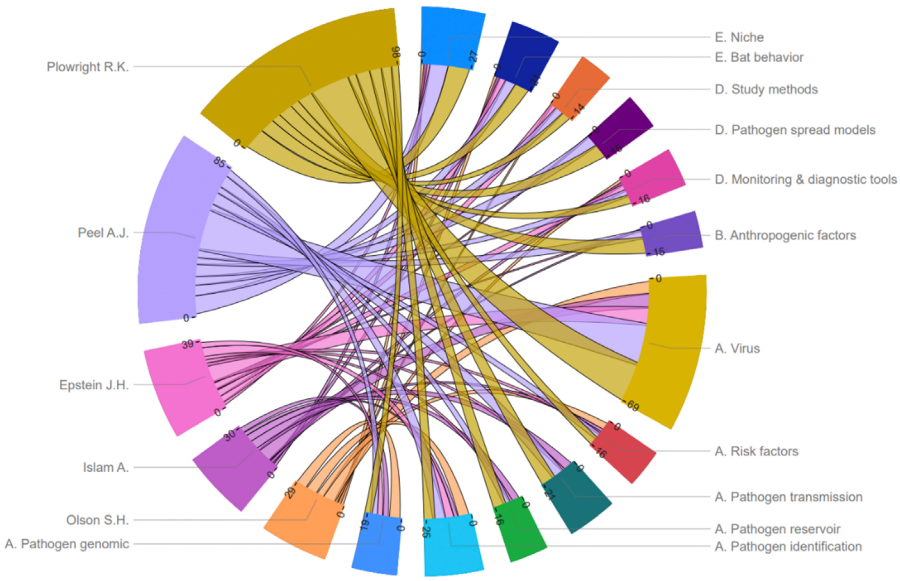

FIGURE 5: Chord diagram of the number of articles by author and by topic. The diagram shows the relationship between the five authors with the highest degree and the seven topics most studied by them. The topics are grouped into five thematic categories, four of which are shown in the graph: A. Zoonoses (viruses, pathogen transmission, pathogen identification, pathogen genomics, risk factors), B. Global health (anthropogenic factors), D. Research and monitoring methods (pathogen spread models, study methods, monitoring and diagnostic tools), E. Disease ecology (niche, bat behaviour). / Diagrama de cuerdas para el número de artículos por autor y por tópico. El diagrama muestra las relaciones entre los 5 autores con mayor grado de publicaciones y los tópicos abordados por ellos. Los tópicos fueron agrupados dentro de 5 categorías temáticas, cuatro de las cuales se muestran en el gráfico: A. Zoonosis (virus, transmisión de patógenos, identificación de patógenos, genómica de patógenos y factores de riesgo), B. Salud global (factores antropogénicos), D. Métodos de investigación y monitoreo (modelos dispersión de patógenos, métodos estudiados, herramientas de monitoreo y diagnóstico), E. Ecología de enfermedades (nicho, comportamiento de los murciélagos).

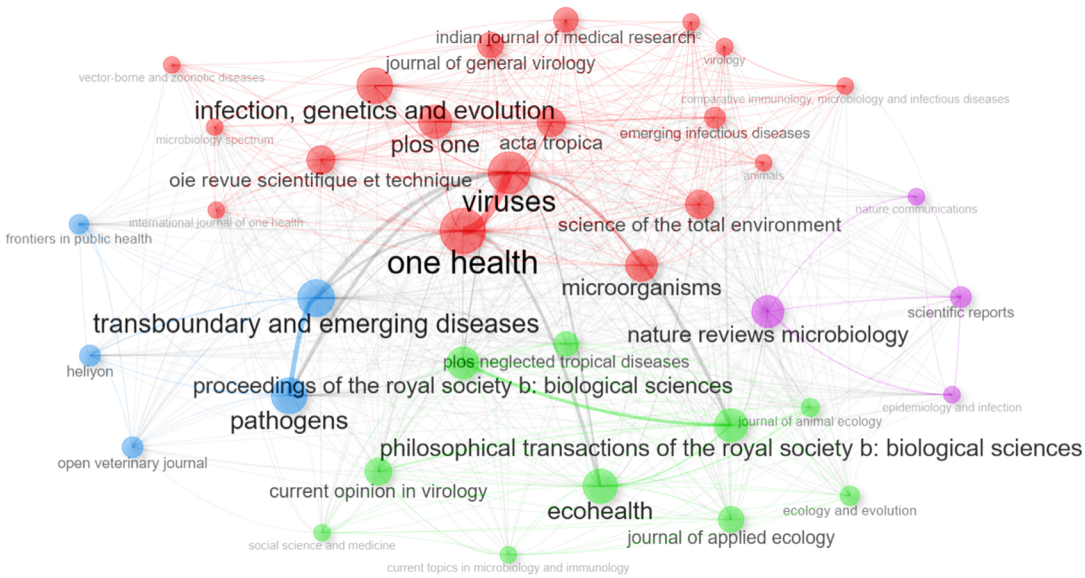

FIGURE 6: Network of source co-citation. The size of the nodes represents the influence of local citations, and the thickness of the link indicates that research from these journals is cited together more often. / Redes de fuentes de co-citación. El tamaño del nodo representa la influencia de las citas locales y el grosos de la línea indica como la investigación de esas revistas ha sido citada junto a otras.

Thematic analysis of the research

The relationship between thematic areas (keywords) of the analysed documents (excluding the words "bats", "One-Health" and "Chiroptera") shown that the studies were mainly focused in zoonoses and coronaviruses (Fig. 7), although the themes are not isolated completely, and we can find a high interconnection. The words with the highest frequency and therefore relevance in the network were "zoonoses", "SARS-CoV-2", "coronavirus", "emerging infectious diseases" and "rabies". Similarly, according to the analysis of centrality measures, in addition to the words already mentioned, "epidemiology", "wildlife", "spillover", "transmission", and "public health" were the most relevant in terms of degree of nodes and intermediation, revealing a thematic tendency towards the study of infectious diseases of zoonotic origin.

A detailed analysis of the degree of nodes and intermediation highlights the importance of these words but also points to less explored areas of potential interest. Some words that had a lower degree of nodes than the average (10.54), such as "human life-interface", various types of pathogens (e.g. "usutu virus", "arbovirus", "herpesvirus", "salmonella", "toxocara", "bartonella", among others), "resistance genes", and "communication" could be considered as some gaps in research. Most of the studies of zoonoses focused on the presence of viruses (Fig. 8), while the global health studies were centred in public health. Bat ecology and social context, in general, are received less attention (Fig. 8).

Most studied pathogens

The most studied pathogens were from the Coronavirus and Paramyxovirus groups (35 and 21%, respectively). Also, Lyssaviruses and Filoviruses were studied profusely (Fig. 9), while that researches with *Bartonella* spp., Reoviruses, *E. coli* and other pathogens did not exceed the 3%.

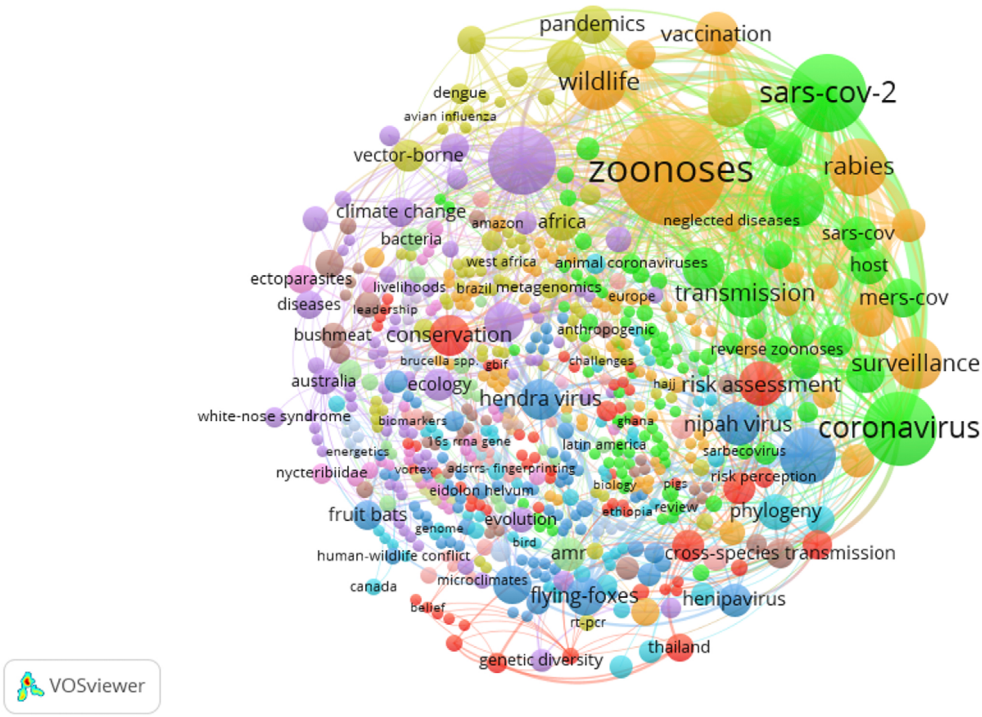

FIGURE 7: Keyword co-occurrence network. The network shows 664 keywords with 3,470 links. The size of the nodes represents the occurrence of the keywords, and the thickness of the link represents the times that both linked keywords appeared together in scientific publications. / Red de co-ocurrencia de palabras clave. La red muestra 664 palabras clave con 3.470 enlaces. El tamaño del nodo representa la ocurrencia de esas palabra clave y el grosor del enlace representa el tiempo que ambas palabras clave enlazadas aparecen juntas en publicaciones científicas.

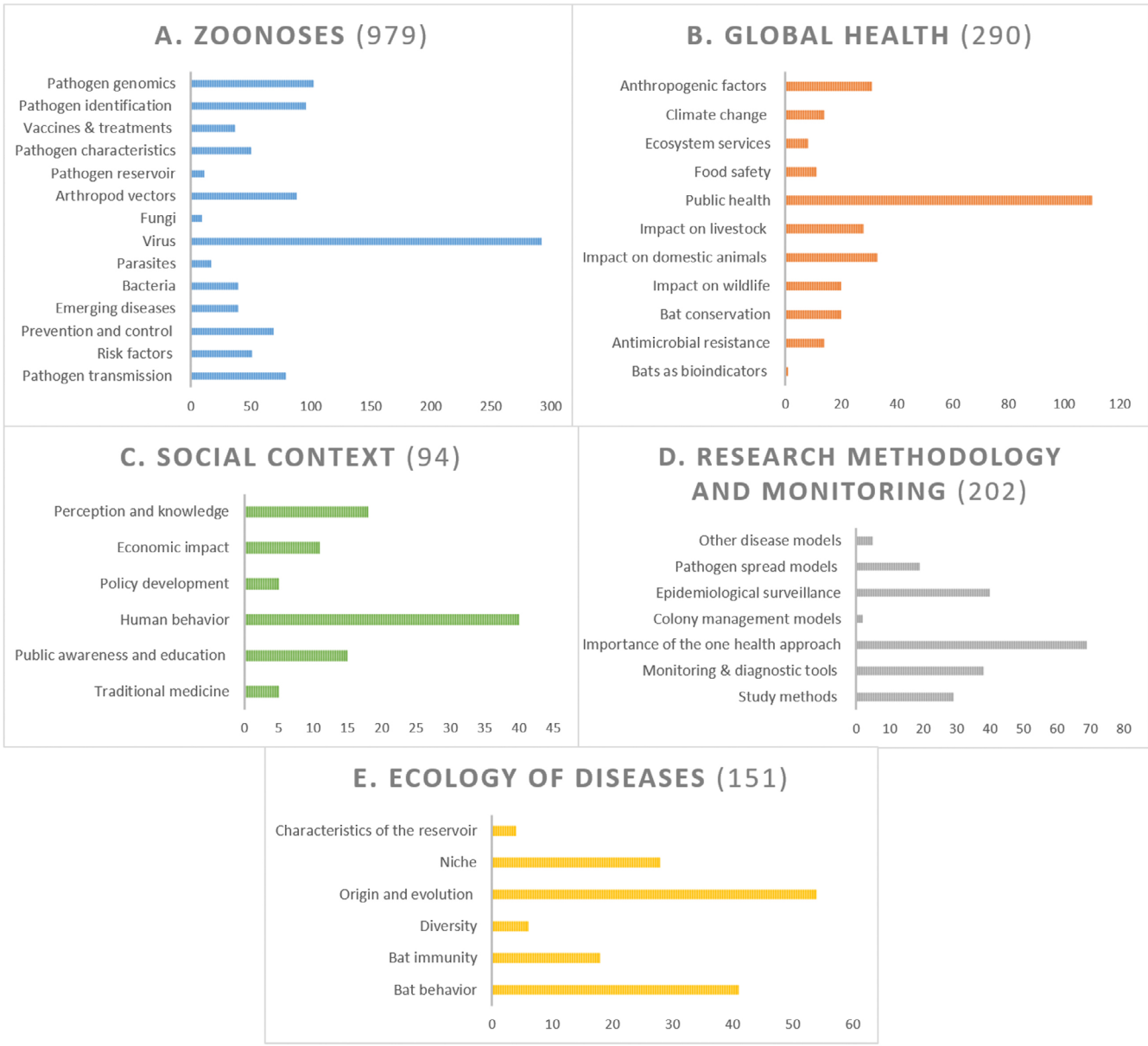

FIGURE 8: Bar graphs of the frequency of the most studied topics according to the thematic classification. The thematic categories were: (a) zoonoses; (b) global health; (c) social context; (d) research methodology and monitoring; and (e) disease ecology. Each study was classified into one or more thematic categories. / Gráfico de barras con la frecuencia de los tópicos más estudiados de acuerdo a la clasificación temática. Las categorías temáticas eran: (a) zoonosis; (b) salud global; (c) contexto social; (d) monitoreo y metodologías de investigación; y (e) ecología de enfermedades. Cada estudio era clasificado en una o más categorías temáticas.

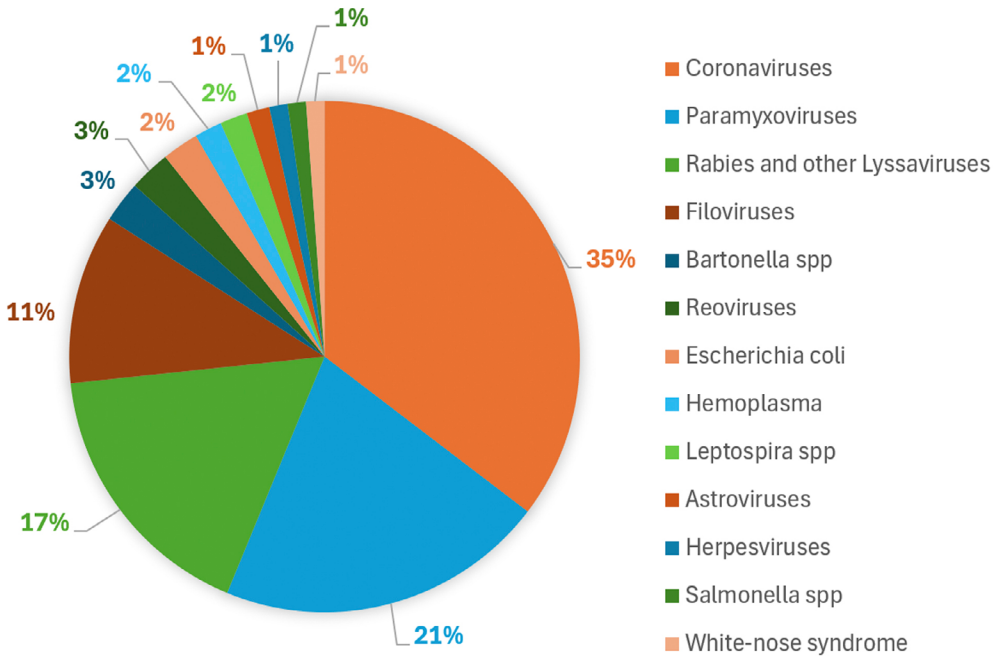

FIGURE 9: Pie chart of the most studied pathogens. Each segment represents a bat pathogen that has been studied in at least four publications. / Gráfico circular de los patógenos más estudiados. Cada segmento representa un patógeno de murciélagos que ha sido estudiado en al menos cuatro publicaciones.

DISCUSSION

Analysis of basic information of scientific publications

It is common in the scientific literature for articles to be the primary form of publication. However, this trend could also be influenced by preferences for certain types of papers, which are determined by each country's level of development and science policy, as explained by Zhang *et al.* (2011). Moreover, it is common for more consolidated topics to be presented in secondary research articles, such as reviews and book chapters, while emerging topics are mainly studied through scientific articles (Lapeña & Peh 2019). Therefore, our results suggest that the study of the relationship between bats and global health under the One Health approach is in full evolution, which is supported not only by the time interval covered by the publications, the oldest being in 2009, but also by the fact that 78% of the studies were published in the last five years.

In bibliometrics, the number of published articles is a metric that can indicate the level of interest in a field of study over time (Miao *et al.* 2022). In general, the volume of publications related to bats and their connection to global health from a One Health perspective has experienced a significant increase, reaching a figure nine times higher in 2023 than in 2009 and with at least one new publication on the topic every week (Wang & Crameri 2014, Davy & Willis 2023), similar to the academic literature of the One Health concept studied individually (Miao *et al.* 2022).

Covid-19 in 2019 caused a global pandemic around the world. The peak of scientific production in 2021 could be related to this association of bats with the origin of SARS-CoV-2. However, the literature on COVID-19 reveals that public health responses were the most studied topic, while the origin of the virus was less relevant (Abd-Alrazaq *et al.* 2021, Domingo 2021). Thus, while SARS-CoV-2 research may have contributed to

the increase in academic output, it was not the main cause. Similarly, the decrease observed from 2021 was related with a significant downward trend since 2022 for SARS-CoV-2 (Funada *et al.* 2023). On the other hand, the United States Agency for International Development included the Emerging Pandemic Threats program aimed at improving global surveillance capacity for One Health zoonotic viruses in high-risk fauna (including bat species), reinforcing the idea that the increase in scientific production is being driven by research on bat zoonoses, in this case through research funding.

Considering that one of the most studied topics of the analysed documents is zoonoses, this distribution could be correlated with countries with an abundance of zoonoses originating from bats. However, an inconsistency arises when examining the relationship between scientific production and zoonoses. Pathogen ecology suggests that zoonotic pathogen richness should be higher given host species richness (Morand *et al.* 2014). However, countries with high bat species richness according to the IUCN Red List of Threatened Species, such as Bolivia (124 species), Georgia (52 species), Myanmar (104 species) and Venezuela (159 species), contributed only one article each. The discrepancy deepens when comparing the results with the study by Han *et al.* (2016), where Mesoamerica, South America, Southeast Asia and equatorial Africa were identified as the geographical regions with the highest species richness of zoonosis-transmitting bats, of which only Brazil and Thailand stand out for its scientific productivity.

The scientific capacity of countries is strongly associated with their wealth and development (Docampo & Bessoule 2019), which could explain better the geographical distribution of research in this review. Furthermore, the most productive countries coincided with the One Health bibliometric study by Miao *et al.* (2022). However, we must not lose focus on countries that may be at risk for the emergence of diseases that threaten human and animal health. Research equity is necessary to generate appropriate preventive measures, since if only certain regions participate in research, the results may not be applicable to broader contexts (Wilson *et al.* 2016).

Analysis of interdisciplinary and collaborative research

The increase in the number of publications coincided with the growth patterns of internationalization of global scientific research (Lisón *et al.* 2020). United States highlight for their great scientific capacity and for harbouring a great variety of organizations and institutions dedicated to research at international level under the One Health approach, unlike other countries, such as China, which does not have the same academic or research entities and, for the same reason, does not stand out in this analysis for its collaborations, even though its research may include this approach (Miao *et al.* 2022). Although, this result could be associated with a bias in the chosen languages in our search (Lisón *et al.* 2020), where much information published in other languages is missed.

The prominent presence of journals such as *One Health* and *Nature*, which contain publications covering various fields of knowledge (Osterhaus & MacKenzie 2016, Zhang & Shen 2024), reinforces the idea that articles cite sources from various disciplines in their publications. Research under the One Health paradigm involves understanding the emergence of new infectious diseases and other health threats from a global framework, because given the complexity and multifactorial nature of these problems, individual study frameworks are insufficient to effectively address this challenge (Wood *et al.* 2012). In this sense, interdisciplinarity and collaboration are key, and the results of this study support the presence of these dynamics in bat research and its impact on global health, and in the current landscape, it is expected that these approaches in research will become increasingly common (Smye & Frangi 2021). Our results shown that although there exists a good network for collaboration international, it is mainly based on closed collaboration groups, where only some authors collaborate outside their groups and is therefore relatively weak and biased in the disciplines studied.

Thematic analysis of the research

The co-occurrence network reveals a complex web of relationships between keywords, showing a high degree of connection between different research topics. Despite the presence of some clearly differentiated groups, such as the orange and green clusters, the network shows a significant mixture between them, indicating the idea of thematic integration in studies related to bats and global health. In the case of pathogens, they may not be commonly reported, as is the case with the Usutu virus. However, this does not exclude its importance in research and periodic surveillance in bats, since this virus has been identified in bats and it is not yet known whether its

role is only as a dead-end host or if it could play a more important role in the epidemiology of the virus (López-Baucells *et al.* 2018, Phelps *et al.* 2019, Guth *et al.* 2022).

Despite the wide range of topics covered, there is a bias towards zoonoses, which is understandable given the importance of bats in these diseases. However, as mentioned above, it is essential to include different disciplines for a better understanding of global health threats. In this context, research gaps are identified in the areas of "bioindicators", "policy development" and "economic impact", as well as in the general category of "social context". This is important because bat conservation and environmental health are observed like as secondary issue and contribute to a negative vision of them (Boso *et al.* 2021, Meli *et al.* 2024). Indeed, many prevention measures are based on controlling pathogen outbreaks without being contextualized in the social environment. An example, in the study by Carmona *et al.* (2016), they found through interviews that the perceptions of Indigenous communities in Peru about vaccination against wild rabies were mostly negative. They considered vaccination to be detrimental to the development of the Awajún people and to have negative effects on children and adults. Influences of perceptions on prevention measures fostered by religious-cultural and socioeconomic aspects (Boso *et al.* 2021, Meli *et al.* 2024), underscore the importance of including social sciences in the study of viral zoonoses.

Within the category "zoonoses", the interest in viruses is remarkable, mostly dedicated to the study of the origin and species jump of the SARS-CoV-2 virus. In this context, the topics of "identification" and "genomics of new or already recognized viruses" were highly studied and occupied prominent positions in the classification. It is necessary to emphasize that although bats are an important source of viruses, only a small percentage of them affect human health (Guth *et al.* 2022, Pandit *et al.* 2022). Therefore, the identification of these viruses must go hand in hand with the determination of their impact on global health (Phelps *et al.* 2019). Unfortunately, the analysis shows that few studies have determined pathogenicity or other characteristics beyond the suspicion that they pose a risk to human health (Letko *et al.* 2020, Guth *et al.* 2022). This links with the thematic present in "global health" category, where public health impacts emerge as a critical issue, but focused on the effects of known bat viruses on humans.

In the "social context" category, the most studied topic is "human behaviour", mainly related to risky behaviours and customs that predispose humans to the spread of zoonotic diseases transmitted by bats, such as consumption and hunting of this mammal. However, there is less research on other forms of contact related to behaviour, such as traditional medicine or the human attitudes towards bats (Boso *et al.* 2021, Meli *et al.* 2024). In some communities, it is common to use bat parts to treat pathologies, such as topical application of skins to treat burns, consumption of boiled brains to improve intelligence in children, inhalation and boiling of bats to cure respiratory diseases, among others (Tackett *et al.* 2022). This points up an important source of human exposure to zoonoses that is not being studied and therefore represents an area of opportunity for future research.

In the category "Research methodology and monitoring", the topic "Importance of the One Health approach" received the most attention which is consistent with the theme of this review. On the other hand, the least studied topic was "Colony Management Models", which was addressed in only two articles, demonstrating the lack of importance of this topic. The review by Reaser *et al.* (2021) proposes some case studies where measures to control chiropteran populations, such as "distance from the population" have been successful, as in the case of the Hendra virus in Australia, where the restoration of native habitat allowed to reduce the interaction with horses so they do not catch the virus that some bat species carry. Furthermore, the review by Seetahal *et al.* (2017) indicates several measures to control rabies in cattle in Trinidad, among which the management of colonies by their elimination stands out, since this practice continues to be used despite the fact that its effectiveness in reducing the prevalence of rabies has not been determined, and that in some cases it has led to an increase in outbreaks as a result of the biased elimination of adults immune to the virus. Therefore, it is necessary to study colony management from an ecological perspective to prevent zoonotic diseases in bats while not undermining the conservation of the species (Lisón *et al.* 2017a, Reaser *et al.* 2021, Pandit *et al.* 2022, Meierhofer *et al.* 2024). Some authors proposed the ecological vaccination of the bats (Li *et al.* 2026).

Within the "Disease Ecology" category, documents focused on the "origin and evolution" of pathogens. Bats are species that have evolved in parallel with their pathogens (e.g. Liang *et al.* 2021, Forero-Muñoz *et al.*

2024). Indeed, in the case of trypanosomes, several evolutionary theories have been postulated linking the high mobility of chiropterans to the global dispersal of the *Trypanosoma cruzi* clade and the high contact with other species to the subsequent adaptation of this parasite to different hosts (Cooper *et al.* 2017).

Most studied pathogens

We found a significant trend that can be observed in the study of viruses compared to bacteria, which are underrepresented in bat literature, as are fungi and parasitic organisms (Allocati *et al.* 2016). This may be because bat viruses have a higher zoonotic potential than other pathogens and therefore pose a more immediate risk to public health (Guth *et al.* 2022). First, bats have unique characteristics and exceptional viral diversity that make them an important reservoir of viruses with zoonotic potential. Second, there are already cases of viral spillover of zoonotic diseases from bats to humans (Phelps et al. 2019, Letko et al. 2020, Guth et al. 2022). Third, due to their high mutation rates and short infectious periods, viruses have a greater ability to switch hosts than other organisms, such as bacteria, which tend to be more generalist and less likely to specialize in new hosts (Becker *et al.* 2020). Fourth, despite the phylogenetic distance between bats and humans, which reduces transmissibility to humans, the virulence of these viruses can still have significant impact (Guth *et al.* 2019). Furthermore, these remains a gap in understanding the mechanisms that drive the circulation of bat viruses within bat species and what might trigger their spillover to other species (Letko *et al.* 2020).

The results indicate that they are coronaviruses, paramyxoviruses, rabies viruses, and other lyssaviruses, which happen to be the most abundant viral families in bats, accounting for approximately 70.5% of their virome (Letko *et al.* 2020). Nevertheless, it is important to not neglect the research on bacterial pathogens, especially in the context of antimicrobial resistance, which is on the rise in wildlife, and bats are not exempt. Indeed, among the studies included in this review, very important antimicrobial resistance genes have been identified that confer resistance to aminoglycosides, beta-lactams, quinolones, and macrolides (McDougall *et al.* 2019, 2021, Carrillo Gaeta *et al.* 2023), some of which are classified as antimicrobials of critical importance in medicine in the World Health Organization (WHO; Pruvot *et al.* 2023).

Limitations and opportunities in research

In this review, the scientometric techniques provided a comprehensive overview of existing research on the relationship between bats, human, animal, and environmental health. We found a series of limitations of our study with regards to this discipline. First, although we attempted to cover most of the available literature, there are many scientific publications that do not explicitly specify the use of the One Health approach, so some of the literature may have been excluded by the keywords used to search for articles. Second, some of the methods of analysis used are not free of bias, especially in the case of the classification of the documents into the different categories and themes, since although an attempt has been made to limit the bias through a complete reading of the texts, it should be considered that this categorization is limited to the researcher's understanding. Therefore, the results of this review should be interpreted with caution.

In terms of research approaches, the lack of representativeness in tropical countries, where predisposition to zoonotic diseases is higher, represents a significant gap and an opportunity for countries with greater scientific capacity to establish research links. Some bat species are migratory, therefore collaboration between countries that share their migratory routes can be critical. Information sharing and research collaboration will not only improve understanding of migration dynamics, but also help identify interactions between bats and incidental hosts that may facilitate the spread of zoonotic pathogens (Phelps *et al.* 2019).

The need to approach research from an interdisciplinary perspective is highlighted. As shown in the thematic analysis, bats have been extensively studied for their association with the emergence of infectious diseases. Although it is crucial to recognize this relationship, the study of the conservation of these species in relation to the social context should not be neglected. In this sense, public perceptions and knowledge about bats are important because they can undermine support for their conservation and increase risk behaviours for disease transmission, especially when the association of bats with disease is perceived as threatening and beyond people's control (Boso *et al.* 2021, Meli *et al.* 2024).

Therefore, it is essential to study and analyse public perceptions, behaviours, and knowledge about bats and bat-borne diseases to develop disease prevention and conservation measures for these species that do

not jeopardize human health or the well-being of bats. Communicating both the role of bats in disease and their ecosystem services is essential to achieve this balance (Pérez *et al.* 2021, Boso *et al.* 2021, Meli *et al.* 2024). López-Baucells *et al.* (2018) show in their review that about 50% of the literature on bat viruses treats bats as a possible threat to public health, while less than 5% emphasizes the importance of these species for their ecosystem services.

In addition, it is important to note that although bats can participate in the epidemiological cycle of zoonotic pathogens, in most cases they do not transmit directly potentially zoonotic pathogens to humans, as initial transmission often occurs via intermediate hosts (Letko *et al.* 2020). It is essential to continue to develop pathogen surveillance strategies in bat populations, especially when there is close contact between bats and humans, and to conduct comprehensive studies to improve our understanding of bat-human interactions from a societal perspective and to design effective ecologically based control measures (Miao *et al.* 2022).

CONCLUSIONS

1. Studies on the association between bats, humans, animals, and environmental health show a global distribution, with a notable gap towards tropical countries and those with a greater diversity of bat species. This field of research is still emerging and evolving, with a growing trend.
2. The most discussed topics on the link between bats and global health from a One Health approach focus on zoonoses, especially viral pathogens and their impact on public health.
3. Research on the relationship between bats and global health that applies One Health shows collaborative and interdisciplinary work, with a high degree of collaboration both between authors and between countries, covering disciplines such as virology and epidemiology and, to a lesser extent, ecology, and sociology.
4. Some gaps in the study of bats and global health under the One Health approach include research on bats as bioindicators, policy development, and the economic impact of bat-associated diseases. Central research themes were zoonoses, public health, emerging infectious diseases, and coronaviruses. Areas for future research were identified: the social context, the ecology of reservoirs and pathogens, and the study of non-viral pathogens such as bacteria and their pathogenicity.
5. It is necessary to incorporate ecosystem services and bat conservation priorities into One Health analyses, and the changes in the distribution of bat species as a result of global warming (Fialas *et al.* 2025, Matus-Olivares *et al.* 2025) can probably aid management and decision-making.

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