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Review

Bibliometric Analysis of Global Research on Sugarcane Production and Its Effects on Biodiversity: Trends, Critical Points, and Knowledge Gaps

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Abstract

The rising global demand for renewable energy and the urgency of mitigating climate change have positioned biofuels, particularly sugarcane ethanol, at the forefront of sustainability and conservation debates. Although promoted as a renewable alternative, sugarcane cultivation can cause habitat loss, biodiversity decline, soil degradation, and water contamination. This study presents a bibliometric assessment of 217 publications addressing the biodiversity impacts of sugarcane production, based on searches in the Web of Science Core Collection for papers published between 1998 and 2023. Using the bibliometrix package in R, we identified key publication trends, collaboration networks, and thematic structures. Between 1998 and 2006, no studies were returned by our searches, after which research activity increased substantially, peaking in 2021. Brazil, the world's largest sugarcane producer, was the most frequent contributor to scientific output, while other major sugarcane producers, such as Thailand and India, showed limited engagement. Thematic mapping of the studies returned by our searches revealed three clusters: (1) cross-cutting themes linking sugarcane, biodiversity, and sustainability; (2) niche themes on pest and soil dynamics; and (3) emerging themes on the ecological role of bats in sugarcane landscapes. Overall, the findings highlight the growing academic engagement in reconciling bioenergy development with biodiversity conservation.

Keywords: sugarcane; biodiversity; environmental impact; bibliometric analysis; conservation; research trends

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1. Introduction

Sugarcane (*Saccharum officinarum*) is one of the most widely cultivated crops in tropical and subtropical regions, and ethanol biofuel is a key product [1–3]. Given that global energy demand is increasing annually, and driven by environmental concerns and government policies aimed at promoting the adoption of renewable energies, the market for biofuels, including sugarcane ethanol, has experienced substantial growth in the last three decades [4–6].

However, concerns persist about the potential environmental impacts of biofuels, particularly feedstock crops like sugarcane [7,8]. While sugarcane ethanol holds promise as a renewable energy solution, its production may be associated with negative environmental impacts including increased carbon emissions and environmental degradation [9,10]. Deforestation of native areas for sugarcane cultivation results in the release of large amounts of stored carbon dioxide (CO_2) from trees and soil, while the burning of sugarcane straw before harvest directly releases CO_2 and other greenhouse gases into the atmosphere [9,11]. Mechanization of harvesting is an alternative in many countries, but also affects the environment, increasing the consumption of fossil fuels by agricultural machinery, further contributing to carbon emissions [12]. Additionally, intensive monocultures of sugarcane disrupt essential ecosystem services such as pollination, pest control, and nutrient cycling [13–16], and has impacts on habitat availability, connectivity and quality and hence potentially on species occurrences, abundances and diversity [17–19]. Moreover, intensive sugarcane production consumes soil nutrients and compacts the soil due to heavy machinery, reducing water infiltration, and increasing both surface runoff and the risk of erosion [11]. The extensive use of chemical fertilizers and pesticides contributes to soil degradation and pollution of surface and groundwater [20]. Runoff from sugarcane plantations can cause eutrophication of water bodies, leading to toxic algal blooms and fish mortality [21,22].

These environmental and ecological consequences illustrate that sugarcane production is not only an energy issue but also a complex interdisciplinary challenge. Its impacts span agronomy, ecology, environmental sciences, and biodiversity conservation, making it a subject of broad scientific interest [23]. Moreover, understanding these dynamics is essential for informing sustainable agricultural practices and providing evidence-based recommendations for policymakers at national and international levels [24].

Here, we propose to characterize the research landscape on the impacts of sugarcane on biodiversity by conducting a detailed bibliometric analysis to not only evaluate the breadth and depth of existing research but also highlight (1) the scientific output per year, (2) publication patterns and collaborations between countries, and (3) the main research topics and themes being investigated. We expect to find a growing trend in scientific output associated with the expansion of sugarcane production over the years, with those countries that are leading producers of sugarcane ethanol also emerging as key contributors to scientific research, including in collaboration with each other. We further expect to find that most research will be agronomic, with more emphasis on production optimization rather than conservation. By promoting a more sustainable approach to sugarcane production, informed by robust scientific analysis, we aim to contribute to environmental stewardship and support initiatives that mitigate the ecological impacts.

2. Materials and Methods

In the following sub-sections we describe in detail the key stages of our research method, detailing (1) the search strategy and data extraction; and (2) data analysis and visualization (Figure 1).

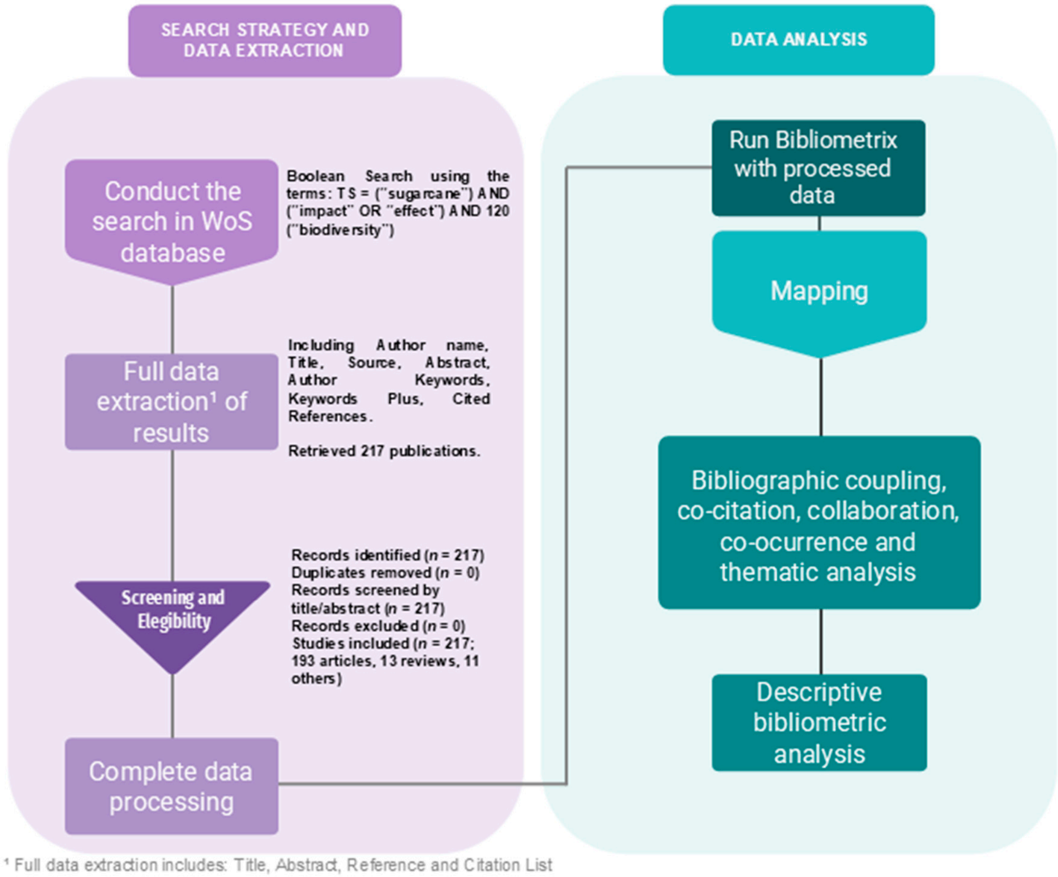

Figure 1. Flow diagram showing the main steps of data collection and analysis.

2.1. Search Strategy and Data Extraction

We conducted the bibliometric review using the Web of Science database core collection for five key reasons: (1) it offers extensive coverage including over 89 million publications, including journal articles, book chapters, and proceedings papers; (2) the content is carefully curated to ensure the accuracy of the information and avoid duplicated publications [25,26]; (3) Web of Science is the only major database with the "Keyword Plus" feature which is particularly useful for conducting bibliometric analyses; (4) it has longer historical coverage; and (5) it has curated and standardized metadata. These factors combined have led to its widespread adoption in bibliometric studies published in high-impact journals [27]. We acknowledge, however, that relying solely on WoS may introduce limitations, such as language and coverage bias, which should be considered when interpreting the findings.

Given our aim to characterize the state of knowledge on the impacts of sugarcane production on biodiversity, we defined a specific Boolean search formula: TS = ("sugarcane") AND ("impact" OR "effect") AND ("biodiversity"). No restrictions were applied regarding document type, language, or gray literature. This decision was deliberate, as our goal was to capture the widest possible range of scientific outputs, articles, reviews, proceedings, and other indexed materials, to provide a comprehensive overview of the research landscape. This timeframe was selected with the aim of covering from the beginning of the recorded data of the Web of Science collection until the end of the last complete year at the time the searches were conducted (26 February 2024). Complete data (Author names, Title, Source, Abstract, Author Keywords, Keywords Plus and Cited References) were extracted from the WoS Database for all papers returned using our search formula. After the data extraction process was completed, we conducted a normalization of the database, searching for and completing any missing information.

2.2. Data Analysis

We had three key aims for our data analysis: (1) to quantify the scientific production per year on the biodiversity impacts of sugarcane production, (2) to examine geographic patterns in publication on the impacts of sugarcane production on biodiversity, including collaboration between countries, and (3) to characterize the main research topics and themes being investigated in relation to the impacts of sugarcane production on biodiversity. In the following sections we detail how the data were analyzed to respond to each of these aims. All analyses were conducted using the 'bibliometrix' package (version 4.2.2) for R software (version 4.3.1; Vienna, Austria) [28].

2.2.1. Scientific Production per Year

To examine the temporal distribution of publications, we used the function annual scientific production in the "Overview" section. This function quantifies the frequency of publications annually. We also used the *Most Relevant Sources* function to identify the journals with most publications.

2.2.2. Geographic Patterns in Publication

To quantify the scientific production in each country over time and to quantify the collaborations between countries in scientific publications, we used the functions countries' scientific production over time and countries' collaboration world map, respectively. We then generated a map to view this information using the networkPlot function [28,29].

2.2.3. Main Topics and Themes

We used three key tools to characterize the main topics and themes being studied in the papers returned by our literature search, including (1) a co-occurrence network analysis; (2) the construction of a thematic map; and (3) a keyword plus frequency analysis, each of which are described in detail here.

The co-occurrence network analysis was used to identify the frequency with which certain keywords appear together in different documents, revealing patterns of relationships between terms. To ensure accuracy, we used the keywords plus approach, that uses the traditional author keywords and title keywords, plus additional keywords that are repeated in the titles and/or in the abstract of the references of a publication [28–30]. To execute the analysis, we ran the co-occurrence network function, using the standard bibliometrix parameters.

The thematic map was constructed using the function thematic map, using the standard bibliometrix parameters. We then extracted a spreadsheet to identify and read the title, abstract, and if necessary, the full text of the papers in each cluster. The strategic diagram produced allows us to identify the centrality and density of the researched themes. Centrality measures how strongly a theme interacts with other themes and its importance within the field. Highly central themes are central concepts that connect various topics and contribute to shaping the overall structure of knowledge in the area. Density measures the internal connections within a cluster, indicating how cohesively its elements interact. The thematic map then separates themes into four quadrants according to the centrality and density of each theme.

3. Results

3.1. Scientific Production per Year

Our search returned a total of 217 publications (Supplementary Material Table S1) addressing the topic of the impact or effects of sugarcane on biodiversity over 25 years, from 1998 to 2023 (Supplementary Information). These included 193 original articles, 13 literature reviews, and 11 other types of publications (proceedings papers and book chapters). The earliest publication on the impact of sugarcane on biodiversity returned by our search was a proceedings paper published in 1998 [31] which reported on a project aimed at recovery of moist forest in a river basin where intensive sugarcane cropping had occurred. No further papers published between 1998 and 2006 were returned by our search terms, at which point publications began to gradually rise (Figure 2). The first original article returned by our search [32] was also published in 2006, presenting an analysis of earthworm diversity in four land use systems, including sugarcane croplands in Paraná, Brazil. In 2010, the number of publications rose abruptly to eight and while the number of publications each year fluctuated, the overall trend until 2019 was of an increasing number of publications, with the highest number of publications over the whole time period recorded in 2019 and 2022 (27 in each year). Over the entire study period (1998–2023), the number of publications increased at an average annual growth rate of 12.26%.

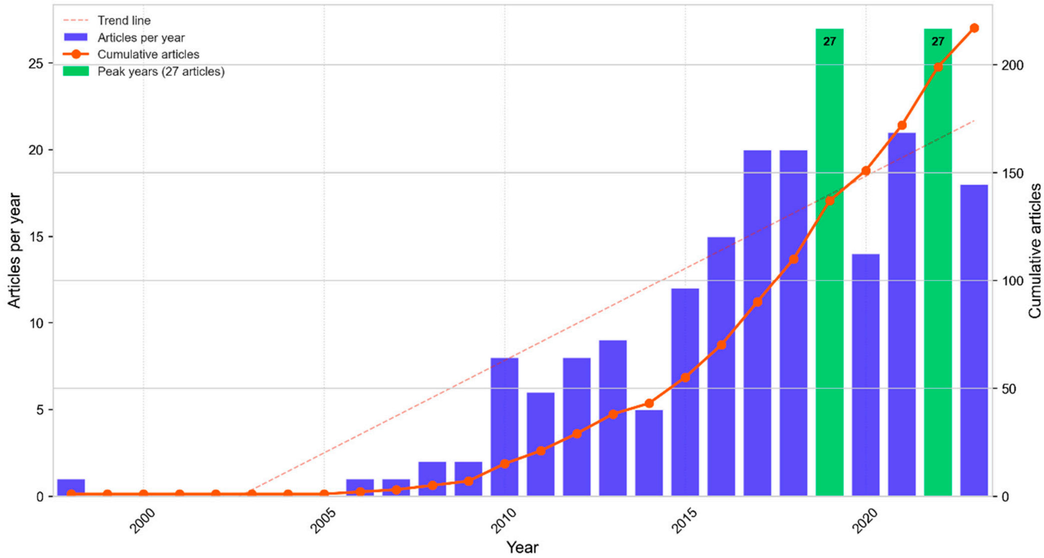

Figure 2. Annual scientific production on the impacts of sugarcane production on biodiversity between 1998, when the first paper was returned by our search, and 2023, which was the last complete year at the time the search was carried out. We obtained 217 publications with an annual growth rate in publications of 12.26%.

Excluding book chapters, the papers are published in 129 different journals (Table 1), with most (105) publishing 1 or 2 papers and only 14 publishing 4 or more (Table 1). Global Change Biology BIOENERGY (classified by Web of Science into the Agronomy and Energy and Fuels categories) and Applied Soil Ecology (Soil Science category) have the most publications with seven each, followed by Renewable & Sustainable Energy Reviews (6 papers), Science of the Total Environment (6 papers), PLoS ONE (6 papers), Agriculture, Ecosystems & Environment (5 papers), Journal of Applied Ecology (5 papers), Environmental Monitoring and Assessment (5 papers), Biomass and Bioenergy (4 papers) and Land (4 papers). The most common Web of Science categories were Energy and Fuels, Soil Science, and Environmental Sciences and Ecology.

Table 1. The ten journals publishing four or more papers on the impacts of sugarcane production on biodiversity, ordered by number of papers returned and then by journal impact factor from highest to lowest, and showing the total number of papers returned by our search and the Web of Science categories of the journals. Notably, the diverse range of journals reflects the interdisciplinary nature of research on biodiversity and sugarcane production, with a focus on categories such as Agronomy, Energy and Fuels, Environmental Sciences, and Ecology. * Journal Impact Factor (JIF) and Journal Citation Reports (JCR) from 2023.

Journal	Number of Publications	Web of Science Categories	JIF *	JCR *
Global Change Biology Bioenergy	7	Agronomy ǀ Energy & Fuels	5.6	Q1
Applied Soil Ecology	7	Soil Science	4.8	Q1
Renewable & Sustainable Energy Reviews	6	Green & Sustainable Science & Technology ǀ Energy & Fuels	15.9	Q1
Science Of The Total Environment	6	Environmental Sciences	9.8	Q1
PLoS ONE	6	Multidisciplinary Sciences	3.7	Q2
Agriculture Ecosystems & Environment	5	Agriculture, Multidisciplinary ǀ Ecology ǀ Environmental Sciences	6.6	Q1
Journal Of Applied Ecology	5	Biodiversity Conservation ǀ Ecology	5.7	Q1
Environmental Monitoring And Assessment	5	Environmental Sciences	3	Q1
Biomass & Bioenergy	4	Agricultural Engineering ǀ Biotechnology & Applied Microbiology ǀ Energy & Fuels	6	Q1
Land	4	Multidisciplinary ǀ Ecology ǀ Environmental Sciences	3.9	Q1

3.2. Geographic Patterns in Publication and Collaboration Between Countries

The corresponding authors of the 217 publications are affiliated with institutions across 33 different countries. Authors with multiple affiliations were counted separately for each different country, with the highest concentrations of corresponding authors (CA) in South America (87 publications), Europe (38 publications), Southeast Asia (30 publications), and North America (22 publications). In terms of both corresponding authors (CA) and full author lists (FA), Brazil (78 CA, 266 FA), the United States of America (19 CA, 96 FA), China (11 CA, 34 FA) and Australia (10 CA, 38 FA) are the four countries producing the most research on the impacts of sugarcane production on biodiversity (Table 2). Brazil is the country with the highest number of publications in collaboration with different countries (83), followed by the USA (45) and South Africa (41) (Figure 3A). The most frequent collaboration is between Brazil and the USA, with 21 publications (Figure 3B).

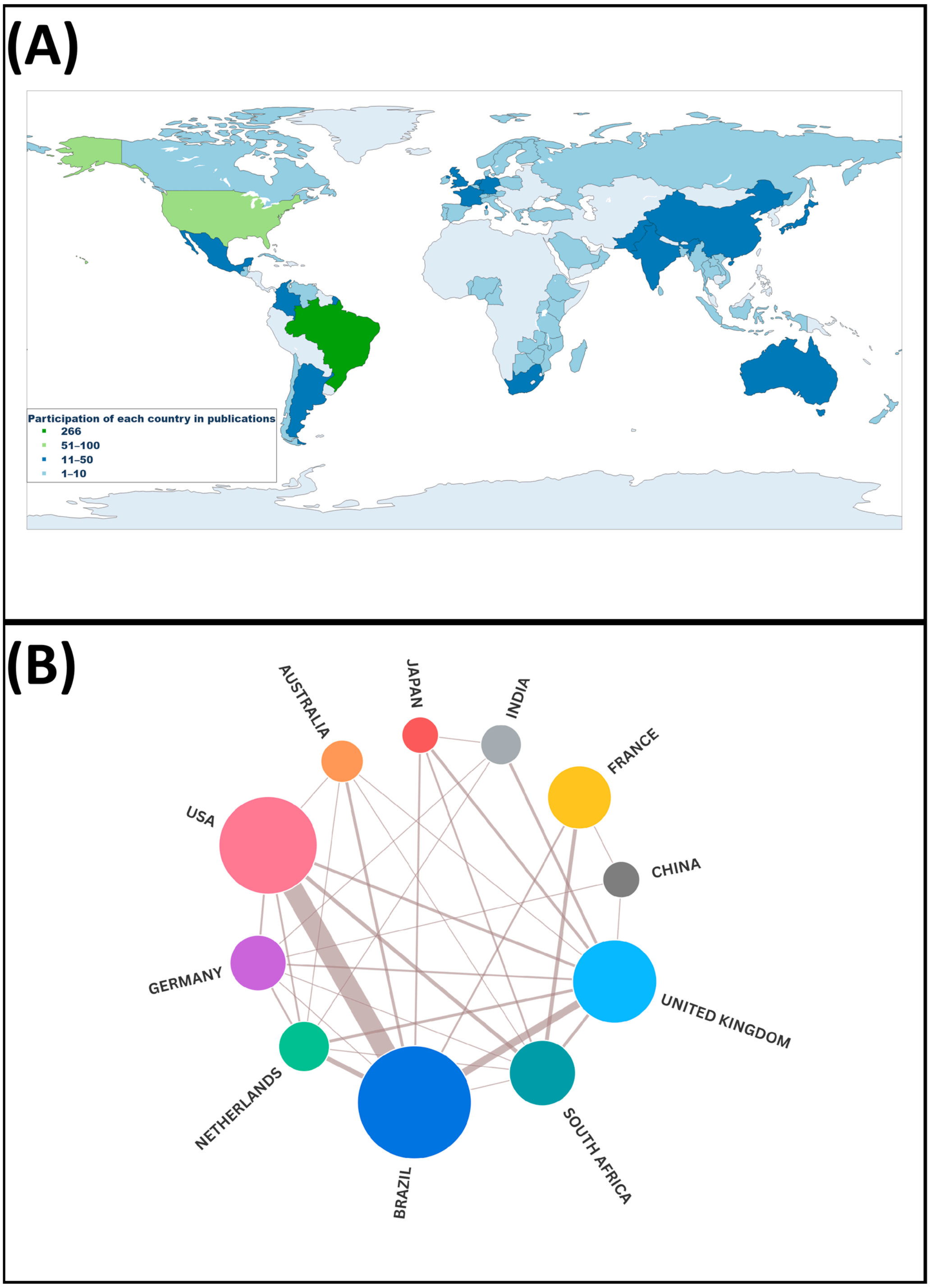

Figure 3. (**A**) Number of publications per country and (**B**) collaboration between countries. The map in (**A**) illustrates the geographical distribution of the number of publications per country, with the colors indicating the number of publications in which authors affiliated in the country participated, ranging from 1 to 266. Countries in dark blue, such as Brazil, have the highest participation in publications (266), while those in light blue have between 1 and 18 publications. The chord network chart in (**B**) shows collaborations between different countries, with the highest number of collaborations occurring between Brazil and other countries (83), followed by the United States with 45 collaborations. Other countries that have more than 10 collaborations include South Africa, Canada, China, and the United Kingdom.

Table 2. The table displays the distribution of publications and collaborations by country, including the number of articles with the corresponding author affiliated with an institution in each specified country (CA), the total number of authors across all 217 publications with at least one affiliation in that country (FA), and the quantity of articles resulting from international collaborations.

Country	Number of Papers Whose Corresponding Author Is Based at an Institution in That Country (CA)	Papers in Collaboration with Other Countries	Total Number of Authors Across All 217 Publications Based at Institutions in That Country (FA)
Brazil	78	83	266
USA	19	45	96
China	11	10	34
Australia	10	9	38
Netherlands	8	14	18
Japan	8	6	15
South Africa	7	41	41
India	7	17	38
France	6	21	28
Germany	6	21	18

3.3. *Research Topics and Themes*

3.3.1. Co-Occurrence Network Analysis

The co-occurrence network analysis of research on the biodiversity impacts of sugarcane production (1998–2023) revealed three distinct clusters of keywords (Figure 4). Each cluster highlights thematic foci within the broader research field: Cluster 1 centers on topics related to land-use change, bioenergy production, and its associated environmental impacts. Keywords such as "land-use change", "sustainability" and "greenhouse gas emissions" are prominent. Cluster 2 emphasizes themes around conservation management, ecosystem services, and agricultural sustainability. Cluster 3 addresses the diversity of species within sugarcane crops and their responses to agricultural practices. Key themes include "habitat fragmentation," "species richness," and "abundance," pointing to publications that assess the direct and indirect effects of sugarcane cultivation on local biodiversity.

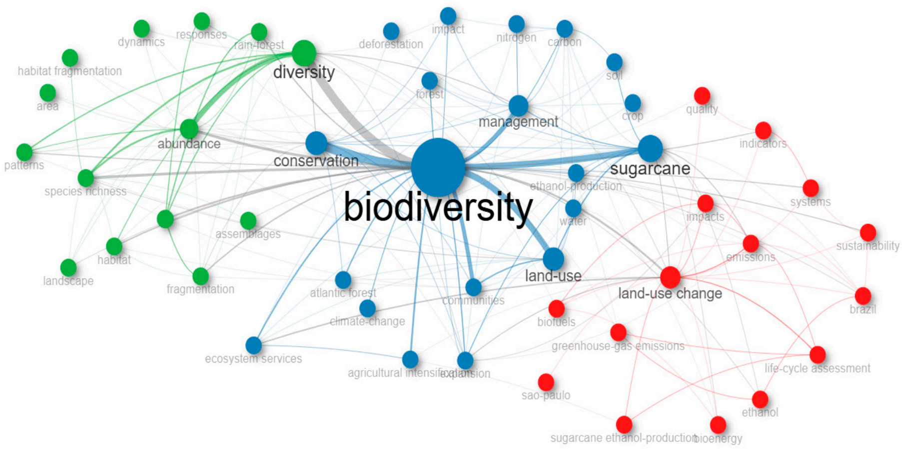

Figure 4. Co-occurrence network showing the clusters of keywords. Cluster 1 (red)—Land Use- and Bioenergy-related topics: land-use change, impacts, emissions, life-cycle assessment, ethanol, greenhouse-

gas emissions, biofuels, Brazil, quality, Sao Paulo, sugarcane ethanol-production, bioenergy, biomass. Cluster 2 (blue)—Conservation- and Biodiversity-related topics: biodiversity, sugarcane, management, carbon, ecosystem services, expansion, impact, forest, climate-change, nitrogen, soil, agricultural intensification, water, ethanol-production, systems, agriculture, community. Cluster 3 (green)—Effects on Diversity of Species-related topics: diversity, land-use, conservation, abundance, communities, species richness, Atlantic Forest, patterns, dynamics, habitat, responses, fragmentation, habitat, fragmentation rainforest, assemblages, deforestation, landscape, area, Brazilian Atlantic Forest.

3.3.2. Thematic Map Analysis

The thematic map analysis revealed 10 clusters of keywords related to the impacts or effects of sugarcane on biodiversity (Figure 5). The majority of clusters are concentrated in the "Niche Themes" and "Basic Themes", while the remaining quadrants each contain only 1 cluster.

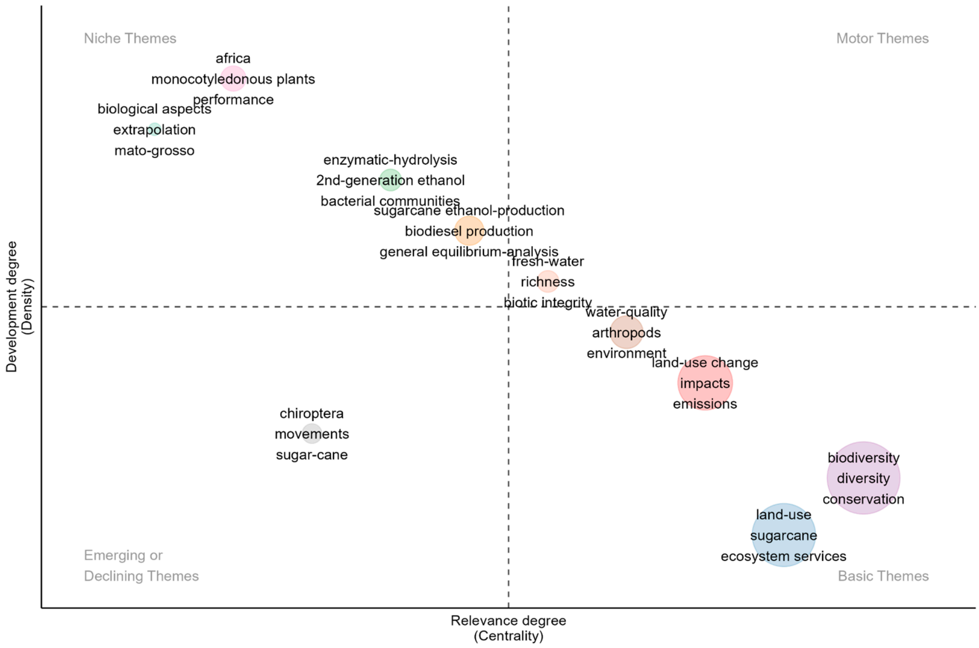

Figure 5. Thematic map showing clusters of keywords present in the publications retrieved from the Web of Science database. The X-axis represents the centrality (i.e., the degree of interaction of a network cluster with other clusters) and gives information about the importance of a theme and the Y-axis symbolizes the density (i.e., measures the internal strength of a cluster network, and is a measure of the theme's development). Accordingly, the upper right quadrant identifies motor themes (i.e., well developed and important themes for the structuring of a research field), and the lower right quadrant identifies the basic themes (i.e., important and foundational themes that are central to the field but have lower internal development). The upper left quadrant highlights niche themes, which are highly developed and specialized but less connected to the broader research field, often appealing to a more targeted audience or specialized publications. Finally, the lower left quadrant includes emerging or declining themes, characterized by both low centrality and low density; these themes may represent areas of nascent research or topics that are losing relevance within the field [33].

Motor: Themes in the motor quadrant are considered crucial because they are well-developed and play a significant role in the research domain. They have strong centrality and high density of development. The papers in the Motor Quadrant are clustered in a single cluster that focuses on publications with analysis of the effects of agriculture on aquatic biodiversity, such as the global impacts of nitrogen and phosphorus fertilizer on aquatic biodiversity and the effects of agriculture on tropical headwater streams [34,35].

Basic: The basic quadrant of research comprises fundamental and crucial themes to the field that have not yet undergone full development. These themes are generally transversal and have broad applicability across different research domains. They may represent key areas for future research investment and focus. In this study, the Basic quadrant encompasses a collection of publications on the broad theme of biodiversity. Within this quadrant, we found 4 major clusters; the first one has a strong emphasis on analyzing the impact of sugarcane production on specific taxa, with focus on arthropods and mammals analyzing the abundance, diversity, and composition of species in sugarcane fields [17,36–42]. The second one has publications which focus on water-quality change [43,44]. Lastly, we found two clusters of papers that aim to understand environmental changes as a result of land use changes [45–47] and effects of land use change on the provision of ecosystem services [8,48–50].

Niche: Themes in the niche quadrant have well-developed internal ties but tend to have unimportant external ties and are therefore of only marginal importance to the field, are peripheral and very specialized. The niche quadrant contains three clusters relating to ethanol production and utilization as a fuel source, each with its own highly specialized focus. In the first cluster, research is focused on *Sesamia cretica* (greater sugarcane borer) in the Afrotropical Region [51,52]. *Sesamia cretica* is one of the most important sugarcane pests in many regions of the world, including Africa and South America [52]. The second minor cluster focuses on the biological aspects of species of scarab beetles, another relevant species that damage sugarcane crops [53,54]. The third minor cluster specifically concentrates on the chemical analysis of soil and sugarcane quality to identify ways to optimize ethanol production [10,55]. Lastly, there is a fourth cluster, that is close to the boundary with the motor themes, containing publications that explore the impact of sugarcane on broad areas like soil health [56], a comparison of nine different sugarcane crops using a defined set of sustainability indicators [57], general implications of sugarcane in the ecosystem [58,59] and policy and economy analysis involving sugarcane crops [59].

Emerging or Declining: Themes in the emerging or declining quadrant are considered weakly developed and marginal, have low density and centrality and are typically emerging or disappearing themes. Only one topic falls in this quadrant in this study. The cluster that involves the keywords "Chiroptera", "movements" and "sugarcane" is gaining considerable attention. From the earliest publications, some have viewed bats as potential controllers of agricultural pests [60]. More recently, there have been a few analyses of DNA changes in species found on sugarcane croplands [61,62].

4. Discussion

4.1. Publication Trends and Knowledge Gaps

Research on the impacts of sugarcane production on biodiversity has grown over the last three decades, and a similar number of publications have been produced on this topic compared to other related subjects, such as the effects of land use on macroinvertebrates [63], terrestrial ecosystem services [64], and chronic anthropogenic disturbances in ecology [65]. Our results show that, since 2006, there has been an increase in scientific publications that coincides with a large expansion in sugarcane production reported by FAO [66]. Between 2000 and 2008, world sugarcane production grew from 1.25 billion tonnes to 1.72 billion tonnes (~38%), and with this growth of production came the expansion of harvest crops [66]. This trend continued in the following decade, with global sugarcane production reaching approximately 1.88 billion tonnes in 2020, an increase of 9.3% compared to 2008 [66]. Brazil, the world's largest producer, played a central role in this expansion, with harvested area increasing from about 6 million hectares in 2000 to 9 million hectares in 2008 (~50% growth) [66]. In 2020, FAOSTAT data confirm that Brazil has maintained its leadership, accounting for nearly 40.2% of global production, while other major producers such as India and Thailand also expanded their cultivated areas and yields [66].

Notably, Brazil and the United States have higher numbers of publications and higher numbers of international collaborations. Brazil's prominence in this research landscape is to be expected given its position as both a major sugarcane producer and a biodiversity hotspot [67]. The expansion of sugarcane cultivation has raised concerns about deforestation, habitat fragmentation, and the loss of ecosystem services, challenges that have stimulated international cooperation [68,69]. This dual role of Brazil as both a global leader in production and simultaneously a custodian of megadiverse ecosystems highlights the tension between agricultural expansion and biodiversity conservation, a theme widely discussed in ecological and policy-oriented literature [70]. For instance, debates on land-use trade-offs in tropical agriculture [71] and the implementation of conservation policies such as Brazil's Forest Code [72] illustrate how sugarcane expansion intersects directly with ecological theory and governance frameworks. However, this concentration of research in Brazil, with limited participation from other tropical producer regions such as Africa and Southeast Asia reduces the representativeness of findings and limits the capacity to generalize results globally [73,74]. From a policy perspective, this imbalance risks producing recommendations that are overly Brazil-centric, while neglecting the distinct ecological and socio-political contexts of other producer regions [75–78].

Methodologically, research is fragmented, frequently restricted to isolated aspects of land use, species richness, or production efficiency. Integrating remote sensing, field-based biodiversity surveys, and modeling approaches would enable more robust assessments of causal relationships [79]. Moreover, this bibliometric review is based on single-database searches, risks overlooking relevant studies published in local or regional journals, particularly in non-English languages. Future systematic reviews and meta-analytical studies should therefore combine multiple databases, such as Scopus, Google Scholar, and SciELO [80], to ensure more comprehensive coverage of global research. Such methodological improvements are not only technical refinements but also essential steps to provide policymakers with reliable, globally representative evidence for decision-making [81].

Taken together, these patterns reveal a paradox: while sugarcane is one of the most environmentally impactful crops globally, the scientific literature addressing its biodiversity consequences remains fragmented, geographically concentrated, and methodologically limited. This gap underscores the urgency of fostering more interdisciplinary and internationally integrated research agendas, aligned with ecological theory and conservation policy frameworks [82]. Without such efforts, policymaking will continue to rely on incomplete evidence [83], undermining the capacity to design effective strategies that reconcile agricultural expansion with biodiversity conservation [84].

4.2. Thematic Analysis and Management Implications

The thematic map analysis corroborates the need for research that integrates a stronger ecological perspective into studies of sugarcane production. Three main thematic groups were identified. The first group comprises cross-cutting themes, represented by clusters of keywords such as biodiversity, diversity, conservation, sugarcane, land use, and ecosystem services. Although these terms indicate ecological relevance, most publications emphasize agronomic outcomes such as yield optimization, land-use efficiency, and soil management [85–87]. This pattern reveals an imbalance between agronomic productivity and biodiversity research, suggesting that ecological impacts remain underexplored [88]. Future work should incorporate systematic reviews and meta-analyses to synthesize existing evidence and quantify how land-use practices in sugarcane landscapes affect biodiversity, ecosystem services, and conservation outcomes [89,90].

Two niche clusters also emerged, focusing on geographically specific research conducted in Africa and the Brazilian state of Mato Grosso, respectively. In Africa, where sugarcane is cultivated in at least 14 countries, studies emphasize agronomic performance under favorable climatic and edaphic conditions [91,92]. In Brazil, the Mato Grosso and Mato Grosso do Sul clusters reflect recent investments to expand production [54]. In both regions, research interest converges on insect-related dynamics, especially pest control involving *Sesamia* species [57,93]. While such studies are valuable for agricultural management, it is essential to consider the broader ecological implications of pest management strategies. Many insects play vital roles in soil quality, nutrient cycling, and natural pest regulation [94,95]. Therefore, future research should assess the trade-offs and synergies between pest control and biodiversity conservation, particularly by comparing sugarcane fields with adjacent natural habitats to evaluate ecosystem-level responses [96–98]. A third cluster, located between niche and motor themes, encompasses studies addressing the environmental and socio-economic implications of sugarcane cultivation. Its proximity to motor themes suggests a transition toward interdisciplinarity, connecting ecological, economic, and policy-oriented approaches [99,100]. Publications within this group highlight governance and energy policy issues, such as the need for climate policies to mitigate the impacts of changing precipitation and temperature patterns on sugarcane productivity in India [101], and the potential for energy cogeneration from sugarcane residues in Thailand [102]. These findings illustrate a growing convergence between sustainability science and agricultural policy.

Finally, an emerging research focus on Chiroptera (bats) highlights their ecological importance as agents of pest control, pollination, and seed dispersal, all of which are key functions that sustain biodiversity and ecosystem health [103]. Their abundance, detectability, and ease of monitoring have made them increasingly common in agroecological studies [104–106]. Publications such as "DNA Damage as an Indicator of Environmental Vulnerability of Bats in Brazil's Caatinga Drylands" exemplify how sugarcane expansion may threaten local bat populations [61,68]. This emerging topic underscores the need for integrative ecological assessments that consider both the direct and indirect effects of sugarcane cultivation on vertebrate fauna and the ecosystem services they provide [107,108]. Collectively, these thematic patterns demonstrate that the field is evolving from a predominantly agronomic focus toward a multidimensional research agenda that includes biodiversity, ecosystem services, and governance. Strengthening this transition will require collaborative frameworks that link ecological monitoring, policy instruments, and sustainable land management, ensuring that scientific knowledge effectively informs decision-making in sugarcane-producing regions.

4.3. Policy Implications and Future Directions

This bibliometric review identified key trends, research gaps, and thematic areas that can guide future investigations and inform policy decisions aimed at promoting sustainable agricultural practices and biodiversity conservation. It is important to acknowledge that our search relied solely on the Web of Science database, which predominantly indexes English-language publications. This represents a potential limitation, as relevant research published in other databases and languages may have been excluded. Future studies should address this limitation by conducting systematic reviews that integrate multiple databases, such as Scopus, Google Scholar, and SciELO. to capture a broader and more representative body of evidence. Additionally, ecological field studies focused on the effects of sugarcane cultivation on specific taxa, as well as spatial analyses examining the relationship between crop expansion and deforestation, are needed to complement bibliometric findings. Such integrated approaches will strengthen the scientific basis for designing policies that reconcile agricultural development with biodiversity conservation.

5. Conclusions

This bibliometric review on the impacts of sugarcane on biodiversity reveals a growing body of research, aligned with the expansion of global sugarcane production. However, significant gaps remain, particularly in understanding the ecological consequences of this expansion. While countries such as Brazil, the United States of America, China, and Australia dominate the literature, major producers like India and Mexico are underrepresented, underscoring the need for more inclusive and collaborative international research efforts.

Most studies have focused on agronomy, soil science, and energy, with limited attention to biodiversity and ecology. Strengthening biodiversity-oriented research and promoting publications in ecology-focused journals will be crucial to balance agricultural productivity with conservation goals and to inform sustainable land-use policies.

Based on our findings, we recommend

- Conducting systematic reviews and meta-analyses that integrate ecological and agricultural data to better quantify trade-offs.
- Encouraging interdisciplinary collaboration among agronomists, ecologists, and policymakers to design strategies that reconcile sugarcane expansion with biodiversity conservation.
- Expanding ecological studies about other taxonomic groups such as mammals, birds, and fish, in order to capture broader biodiversity trade-offs and ecosystem dynamics.

By addressing these gaps and fostering cross-disciplinary and cross-national cooperation, future research can provide the evidence base needed to guide policies that ensure both energy security and biodiversity protection.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/conservation5040067/s1, Table S1: The 217 publications returned by our literature search.

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