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Review / Derleme

A Bibliometric Review of Histological Responses to Environmental Stress and Pollution in Birds (1975–2024)

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Abstract: Environmental stress and pollution pose significant threats to bird populations by impacting their health and survival and this study provides a comprehensive examination of the histological changes in avian tissues caused by such stressors and pollutants. Analyzing 151 scientific documents published between 1975 and 2024, the study utilized source analysis to identify publication trends, keyword analysis to highlight key topics, Lotka analysis to assess scientific productivity among researchers, and thematic analysis to categorize the research into main clusters. The findings indicate a growing scientific interest in this field since 2000 and show that the highest number of publications was reached in 2023, even though the dataset includes articles published up to 2024. The United States leads in the number of publications (30.5%), followed by Canada (17.2%), China (13.2%), and Spain (11.3%) and most articles have appeared in leading environmental science journals such as *Science of the Total Environment*, *Environmental Pollution*, and *Environmental Toxicology and Chemistry*. The most prominent topics identified include "histological changes," "heavy metal accumulation," "oxidative stress," and "plastic pollution." Lotka analysis shows that scientific productivity is driven by a small number of highly productive researchers, while the majority of authors have published only one (n=551) or two (n=68) articles. Thematic analysis revealed four main research clusters: (i) heavy metal accumulation, (ii) plastic pollution, (iii) the effects of organic and inorganic minerals, and (iv) histological changes. Overall, this study underscores the importance of histological analysis in understanding the impact of environmental pollution on avian health and provides a bibliometric framework that can guide future research priorities and conservation strategies, particularly by highlighting emerging contaminants, underrepresented regions, and key themes for long-term histopathological monitoring.

Keywords: Microplastics, metal accumulation, environmental pollution, birds, histopathology.

Kuşlarda Çevresel Stres ve Kirliliğe Karşı Histolojik Yanıtların Bibliyometrik İncelemesi (1975–2024)

Öz: Çevresel stres ve kirlilik, kuş popülasyonları için sağlıklarını ve hayatta kalmalarını etkileyerek önemli tehditler oluşturmaktadır ve bu çalışma, bu tür stres faktörleri ve kirleticilerin neden olduğu kuş dokularındaki histolojik değişikliklerin kapsamlı bir incelemesini sunmaktadır. 1975 ile 2024 yılları arasında yayınlanan 151 bilimsel belgeyi analiz eden çalışma, yayın eğilimlerini belirlemek için kaynak analizi, kilit konuları vurgulamak için anahtar kelime analizi, araştırmacılar arasındaki bilimsel üretkenliği değerlendirmek için Lotka analizi ve araştırmayı ana kümeler halinde kategorize etmek için tematik analiz kullandı. Bulgular, 2000 yılından bu yana bu alana olan bilimsel ilginin arttığını göstermektedir ve veri seti 2024 yılına kadar yayınlanan makaleleri içerse de, en yüksek yayın sayısına 2023 yılında ulaşılmıştır. Yayın sayısı açısından Amerika Birleşik Devletleri (%30,5) başı çekerken, onu Kanada (%17,2), Çin (%13,2) ve İspanya (%11,3) izlemektedir. Makalelerin çoğu "Science of the Total Environment", "Environmental Pollution" ve "Environmental Toxicology and Chemistry" gibi önde gelen çevre bilimleri dergilerinde yayınlanmıştır. Belirlenen en önemli konular arasında "histolojik değişiklikler", "ağır metal birikimi", "oksidatif stres" ve "plastik kirliliği" yer almaktadır. Lotka analizi, bilimsel üretkenliğin yüksek oranda üretken birkaç araştırmacı tarafından yönlendirildiğini, yazarların çoğunluğunun ise yalnızca bir (n=551) veya iki (n=68) makale yayınladığını göstermektedir. Tematik analiz dört ana araştırma kümesini ortaya çıkardı: (i) ağır metal birikimi, (ii) plastik kirliliği, (iii) organik ve inorganik minerallerin etkileri ve (iv) histolojik değişikliklerdir. Genel olarak, bu çalışma çevresel kirliliğin kuş sağlığı üzerindeki etkisini anlamada histolojik analizin önemini vurgulamakta ve özellikle ortaya çıkan kirleticileri, yetersiz temsil edilen bölgeleri ve uzun süreli histopatolojik izleme için kilit temaları vurgulayarak gelecekteki araştırma önceliklerine ve koruma stratejilerine rehberlik edebilecek bir bibliyometrik çerçeve sağlamaktadır.

Anahtar kelimeler: Mikroplastik, metal birikimi, çevre kirliliği, kuşlar, histopatoloji.

1. Introduction

Birds are an important part of biodiversity and ecosystems depend on them to work properly (Sekercioglu, 2012; Whelan et al., 2008). Therefore, the conservation of birds and the sustainability of their habitats are of great

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importance for the continuation of ecosystem balance. As asserted by Tkaczenko et al. (2024), environmental stressors and pollution (Abbasi et al., 2016; Montaño et al., 2013) pose a significant threat to the habitats and health of birds (Barton et al., 2023). These stressors can induce alterations in the physiological and psychological functioning of birds (Ackerman et al., 2024).

In particular, substances such as chemical pollutants (Saxena et al., 2016), industrial waste (Wallace et al., 2020), agricultural pesticides (Dhananjayan, 2012; Nambirajan et al., 2024), and heavy metals (Ackerman et al., 2024; Ding et al., 2022) have a negative impact on bird health and populations. Histological examinations of avian tissues are important for understanding the effects of such pollution (Amri et al., 2017, 2018). These examinations identify cellular and textural changes in birds (Amri et al., 2018), enabling us to better understand the biological effects of environmental factors (Tkaczenko et al., 2024). Therefore, studying histological changes is crucial for revealing the impact of environmental stress and pollution on avian health (Kou et al., 2020; Tatlı et al., 2025; Wayman et al., 2024).

In this case, several studies in the literature describe how environmental stress and pollution affect the histology of bird tissues (Ding et al., 2022; Gray et al., 2024; Herring et al., 2014; Malila et al., 2022; Stojanović et al., 2023). For example, birds' kidneys and livers can show major histological changes when they are exposed to heavy metals (Mochizuki et al., 2013; Nardiello et al., 2019). Moreover, exposure to pesticides has been shown to cause significant structural alterations in the nervous and reproductive systems of birds (Narváez et al., 2016). These alterations include disruptions in the neural structure and changes in the gonadal tissue organization (Fry, 1995; Maitra & Sarkar, 1996). These studies show that environmental stressors and pollution can harm a wide range of bird tissues. To make conservation plans, it is important to know how different types of environmental stressors and pollution affect birds' histology. Histological studies can directly reveal the effects of environmental stress on bird tissues (Brooks et al., 2021; Ding et al., 2022; Kou et al., 2020; Tkaczenko et al., 2024).

However, it is also important to evaluate these findings from a broader perspective in order to understand the general dynamics of the scientific literature. A comprehensive analysis of existing studies can contribute to synthesize knowledge and determine future research directions (Schick-Makaroff et al., 2016). In addition to such scientific studies, bibliometric analyses also provide valuable insights into the scope and dynamics of literature in various fields including animal sciences (Celik et al., 2021), plant sciences (Kulak et al., 2019), social sciences (Ma, 2025), environmental sciences (Hu et al., 2025), and engineering sciences (Kwidzińska et al., 2025).

Bibliometric studies examine the quantity, distribution, and research trends of publications on a specific topic to elucidate the scope and dynamics of the scientific literature (Kulak et al., 2019). These analyses yield critical insights for pinpointing deficiencies in the research domain, directing further investigations, and enhancing scientific collaboration.

In this study, a bibliometric analysis of the extant literature on histological changes in avian tissues induced by environmental stressors and pollution was conducted. The objective of the present study is to characterize global research trends, key thematic areas and author productivity in this field, and to relate these bibliometric patterns to the main histopathological alterations reported in birds. The Methodology section provides a detailed exposition of the data sources, search strategy, and analytical procedures employed in this study.

Bibliometric network analysis was used to answer the following research questions:

RQ 1: How have histological studies on environmental stress and pollution in avian tissues changed over the years?

RQ 2: Which countries have published the most documents on these topics?

RQ 3: What are the main research themes in histological changes in avian tissues related to environmental stress and pollution?

RQ 4: Does author productivity in avian tissue research on environmental stress and pollution conform to Lotka's law?

RQ 5: What are the most frequently used keywords in studies on these topics?

RQ 6: How do the thematic maps resulting from bibliometric analyses show the effects of environmental stress and pollution on avian tissue?

2. Methodology

2.1. Bibliometric Studies Using Dimensionality Reduction Methods

Dimensionality reduction methods are widely used in bibliometric analysis due to their ability to comprehend complex datasets (Garson, 2022). Dimensionality reduction compresses the dataset allowing for more accurate identification of key structures and linkages. These methodologies are also beneficial for identifying hidden patterns and trends in high-dimensional data (Garson, 2022).

The employment of these tactics has been demonstrated to enhance data comprehension by facilitating the simplification of multidimensional and complicated relationships. In bibliometric studies, dimensionality reduction techniques are utilized to identify key themes in research fields, author collaborations, and trends in scientific output. Moreover, the simplification of academic literature enhances the capacity for conducting more comprehensive analyses of research trends and knowledge gaps (Ebidor & Ikhide, 2024). This approach facilitates more targeted explorations into emerging topics of research. Recently, bibliometric studies have attracted great attention. According to SCOPUS data, 46,992 documents on "bibliometrics" were published between 1969 and 2024 (Access date: 21.12.2024) (Fig. 1).

This study employs dimensionality reduction to visualize bibliometric relationships and to explore how the literature has conceptually addressed histological changes in birds. The bibliometric method combines quantitative publication data with our qualitative reading of histological studies by mapping co-occurring keywords and citation clusters associated with certain tissue types (e.g. hepatic, renal, pulmonary) and pathological processes (e.g. necrosis, vacuolation, fibrosis). These bibliometric clusters do not directly reveal biological pathways but rather patterns in how topics are framed and connected in the published literature. This dual perspective links bibliometric mapping with biological interpretation at the level of research themes, providing an overview of how scientists have studied and described changes in bird tissues over time.

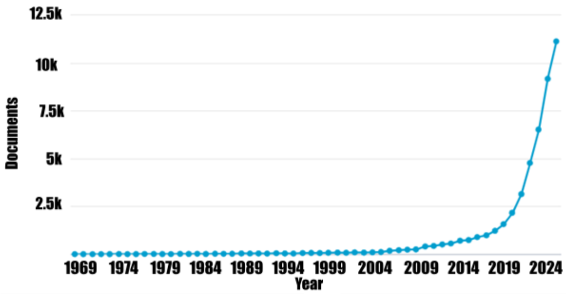

Figure 1. Annual publication growth of bibliometric studies between 1969-2024 (This graph was obtained from Scopus database. Accessed on December 21, 2024).

Bibliometric analyses serve as powerful tools for comprehending the dynamics of scientific output and scholarly cooperation (Kumar, 2025). In contrast to conventional reviews, bibliometric analyses provide the systematic and impartial evaluation of extensive datasets (Börner et al., 2003). Traditional reviews often use qualitative approaches, while bibliometric studies rely on quantitative methodologies yielding more complete and verified outcomes (Moed, 2009). Furthermore, bibliometric analysis may swiftly and efficiently discern significant patterns and knowledge deficiencies in the literature (Hood & Wilson, 2001). All visualizations and graphs generated from the dataset were produced using Bibliometrix (https://www.bibliometrix.org/home/), a complimentary web package based on R-Studio, and VOSviewer version 1.6.17 (Van Eck & Waltman, 2007). In generating the thematic and co-occurrence maps, VOSviewer's built-in VOS mapping technique was applied which relies on association strength normalization and a modularity-based clustering algorithm to achieve dimensionality reduction. This method projects high-dimensional bibliometric relationships (e.g., keyword co-occurrences and citation links) into a two-dimensional space, ensuring that the proximity between nodes accurately reflects their bibliometric similarity (Van Eck & Waltman, 2014).

SCOPUS records were used in BibTex and CSV formats for content analysis.

Histological context helped us to understand these bibliometric patterns. For instance, clusters containing many terms such as "liver", "kidney", or "oxidative stress" were considered to represent research into tissue-level toxicity. Conversely, clusters containing terms such as "microplastics", "apoptosis", or "cytochrome P450" were considered to demonstrate themes related to cellular and molecular pathology. Therefore, dimensionality reduction enabled the data to reveal not only publication patterns but also the biological pathways that histological research has focused on.

2.2. Data Collection and Analysis

In the modern research world, a plethora of databases are available for information access and bibliographic studies (Çeli̇k, 2025; Kulak et al., 2019). Some of the most important among these databases are Web of Science (WoS), SCOPUS, Google Scholar, PubMed, and MEDLINE (Gavel & Iselid, 2008). The critical goal for researchers is to obtain the largest collection of documents; therefore, making comparisons between different databases is of great importance. SCOPUS provides access to more documents than other databases due to its comprehensive database content and coverage of different document types (e.g. conference proceedings, notes, notes to editors) (Chadegani et al., 2013). Using the same keywords, SCOPUS was found to contain more documents than other databases.

In the present study, research data were collected from two major bibliographic databases, Web of Science (WoS) Core Collection and Scopus. The same search string was applied to both databases in the Title, Abstract and Keywords fields: ("birds" OR "bird" OR "aves") AND ("histology" OR "histological changes") AND ("environmental stress" OR "pollution") AND ("tissue"). The searches were performed on 20 December 2024 and were not restricted a priori by publication year; the earliest relevant record retrieved dated from 1975 and the latest from 2024. Studies assigned to the publication year 2025, including "early access" or "in press" items, were excluded so that the analysis would cover a complete and stable time window up to the end of 2024. This search yielded 26 records in Web of Science and 155 records in Scopus.

All records were exported (Web of Science: plain text; Scopus: BibTeX and CSV formats) and imported into Zotero for screening and de-duplication. Duplicate records across databases were identified and removed based on DOI, title, authors and year. We then applied explicit inclusion and exclusion criteria. We included documents that (i) focused on wild birds, (ii) reported histological or histopathological changes in avian tissues, and (iii) examined these changes in relation to environmental stressors or pollutants (e.g. metals, pesticides, persistent organic pollutants, microplastics, thermal or nutritional stress). Records were excluded if they (i) did not involve avian species, (ii) did not report histological outcomes, or (iii) dealt exclusively with non-environmental experimental manipulations (such as purely pharmacological or surgical interventions unrelated to environmental pollution or stress). After this process, 151 documents remained and were used for the bibliometric analyses. Before running the bibliometric analyses, we harmonized author names and keywords. Obvious author name variants arising from differences in initials, spelling or diacritics were checked and merged, particularly for the most productive authors, to avoid splitting their publication records across multiple identities. Keyword variants and synonyms were also standardized (for example, "histological change" and "histology" were merged) to improve the robustness of co-occurrence and thematic analyses. The cleaned dataset was then imported into Bibliometrix and VOSviewer for subsequent analyses and visualizations.

This bibliometric dataset is limited to journals indexed in Web of Science and Scopus, which implies important caveats for interpretation. Research published in regional or non-English-language journals, as well as in grey literature such as these, technical reports or locally oriented bulletins, is only partially captured. Comparative evaluations of these databases indicate that their journal coverage is inconsistent across global regions and languages, frequently privileging well-funded institutions in the Global North and English-language publications (Amano et al., 2016; Asubiaro et al., 2024; Mongeon & Paul-Hus, 2016; Tennant, 2020). Consequently, our maps should be viewed as a conservative approximation of global activity on histological responses of birds to environmental stressors with the recognition that contributions from some countries and linguistic communities are probably underestimated.

2.3. Scientific Productivity According to Lotka's Law

Lotka's law of scientific productivity is a fundamental principle explaining the distribution of the scientific contributions of researchers in a given field (Lotka, 1926). This law asserts that the number of scientific contributions in a field of research decreases inversely proportional to the number of authors making these contributions. Lotka's law states that the productivity of authors has an exponential distribution and that the number of authors with k contributions is approximately $1/k^2$ times the number of authors with one contribution. This model is used to understand and assess the distribution of scientific productivity and is a powerful tool for analyzing productivity differences between authors (Rousseau & Rousseau, 2000). To test whether author productivity in this field follows Lotka's law, we modelled the relationship between the number of publications (n) and the number of authors contributing n publications (A_n) using a power-law function of the form $A_n = C\,n^{-b}$, where C is a constant and b is Lotka's exponent. Following standard practice, we applied ordinary least squares regression to the log–log transformed data, regressing $\log_{10}(A_n)$ on $\log_{10}(n)$ to estimate b and C and to obtain the associated confidence intervals and goodness-of-fit statistics. In addition, the Kolmogorov–Smirnov goodness-of-fit test was used to compare the cumulative empirical distribution of authors across publication counts with the theoretical distribution implied by the fitted Lotka model.

3. Results and Discussion

3.1. Annual Publication Growth, Scientific Trends and Key Topics

Research on the effects of environmental stress and pollution on avian tissues is increasing. In the SCOPUS database, 151 documents on the relationship between "environmental stress," "pollution," "histological changes," "birds," and "tissues" were found. The first scientific documents on the subject were published as research articles (N=2) in 1975 (Baris, 1975; Pass et al., 1975). Pass et al. (1975), the first of these studies, conducted a study on diseases and physiological changes in mallard ducks (*Anas platyrhynchos*) exposed to toxic substances such as methylmercury.

In the second study published in the same year, cases of pleural mesothelioma and asbestos pleurisy developing as a result of environmental asbestos exposure in Turkey were investigated (Baris, 1975). Between 1975 and 2024, documents on the subject were published in 43 different sources. The annual growth rate was 3.72% indicating a continuous increase in academic interest in this topic. These data reveal that studies on the histological changes in avian tissues due to environmental stress and pollution have increased extensively and continuously requiring broad international cooperation and an interdisciplinary approach (Fig. 2). Beyond describing these quantitative trends, our analysis links bibliometric patterns with the underlying histopathological evidence, thereby identifying the main tissue-level endpoints, contaminant classes, and keywords gaps that define this research field.

There is a significant rise in the annual production of research on histological changes in avian tissues. Fig. 3 shows the changes in the annual production of studies containing the keywords "environmental stress", "pollution", "histology", "histological changes", "birds", and "tissue". Between 1975 and 2000, very few articles were produced and limited number of studies were conducted on the effects of environmental stress and pollution on bird tissues.

Figure 2. Main information about the documents

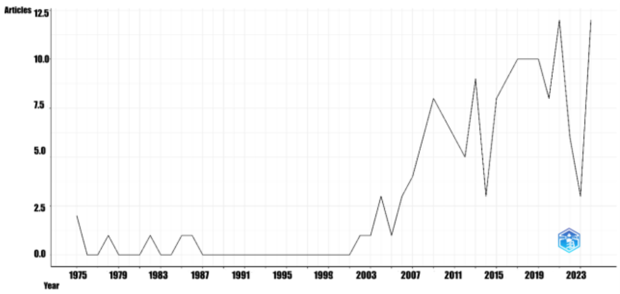

Figure 3. Annual scientific production on the topic between 1975-2024 (Source: Obtained from annual document production analysis of documents from SCOPUS using R-based Bibliometrix software: Accessed December 21, 2024)

In the post-2000 period, a significant increase in the number of articles was observed. Although there have been fluctuations since 2010, there has been a general upward trend, reaching peaks in recent years (2021-2023) (Fig. 3). This trend indicates a significant increase in scientific interest in the effects of environmental pollution and stressors on avian tissues.

This growing trend not only reflects heightened environmental awareness but also indicates a paradigm shift toward molecular and cellular toxicology in avian research. The emphasis on histological endpoints suggests that researchers increasingly view tissue-level biomarkers as reliable indicators of ecological stress bridging classical ornithology with modern ecotoxicological approaches.

Recent studies have centered around a variety of keywords and topics. These include environmental stress (Rahbari et al., 2024; C. Zhang et al., 2017), persistent organic pollutants (POPs) (Gray et al., 2024; Quinete et al., 2020; Tanaka et al., 2015), avian health and biomarkers (Shifa et al., 2025; Tkaczenko et al., 2024), veterinary drugs and pollution sources (Herrero-Villar et al., 2023), heavy metal accumulation and avian tissues (Bassi et al., 2021; Ding et al., 2022), trace minerals and broiler performance (Hassan et al., 2022), and nutritional status (Brooks et al., 2021; Godwin et al., 2016).

3.2. Country Analysis (Authorship Cooperation)

Scientific knowledge reflects not only the intensity of research activities but also the scientific infrastructure of countries, regional needs, and the effectiveness of environmental policies (Hood & Wilson, 2001). Therefore, there are marked differences in the distribution of scientific publications between different countries (Table 1 and Fig. 4). The USA (n=46) stands out as the country with the highest number of studies. Canada (n=26), China (n=20), Spain (n=17), England (n=8), Turkey (n=7), France (n=6), Germany (n=6), and Japan (n=6) also have a remarkable number of studies in this field (Table 1). The difference in the number of documents between countries is due to the differences in research budgets and resources, research infrastructure, scientific collaborations, scientific culture and incentives, and the number of publications and citations. Countries such as the USA and Canada are able to produce more and more effective studies thanks to large budgets, well-equipped laboratories, and international collaborations. In addition, scientific studies in these countries are more cited and gain more visibility which increases the number and impact of research. These factors lead to differences in the number of documents and scientific activity among countries.

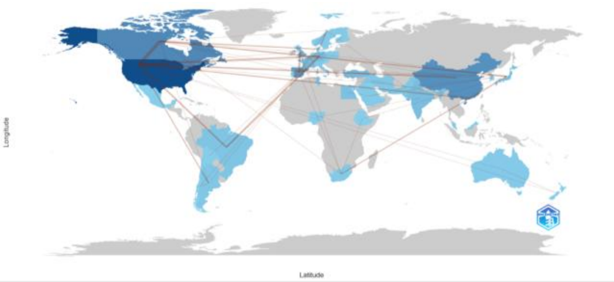

Figure 4. Authorship collaboration between countries (Dark blue= Countries that published the most documents and had the most collaboration)

Table 1. Scientific publication performance of countries: Number of documents, total citations, and link strength

Countries	Number of Documents	Total citations	Total Link Strength*
USA	46	1386	31
Canada	26	1800	26
China	20	609	2
Spain	17	561	10
England	8	122	8
Türkiye	7	130	0
France	6	241	4
Germany	6	136	7
Japan	6	879	8

*Total Link Strength the impact of a country's scientific publications on the work of other countries and the level of international cooperation

However, the observed dominance of high-income countries also reveals an imbalance in global research capacity. Regions with high biodiversity but limited funding—such as parts of Africa, South America, and Southeast Asia—remain underrepresented. This imbalance may lead to gaps in our understanding of histological responses to pollution in ecologically sensitive yet understudied avian populations.

Similar patterns of concentration in high-income countries have been seen in other areas, such as ecology and biodiversity conservation, where wealth, research capacity, and international collaboration have a significant impact on how many papers are published. In contrast, regions in the Global South have less data (Amano et al., 2016; Caldwell et al., 2022; Skaldina & Blande, 2025; L. Zhang et al., 2023). In the context of our study, this means that it is easier to find histology-based evidence of how pollution affects birds in well-studied temperate regions and model species. On the other hand, many areas with richer biodiversity but not enough resources may not have the tissue-level data needed to help with local conservation and risk assessment.

3.3. Source (Journal) Analysis

Scientific resources are important not only for sharing new discoveries and theories but also for indicating scientific interactions and collaborations between different countries and research institutions (Börner et al., 2003). Analyzing research intensity and focus areas helps us understand how scientific disciplines develop and which topics attract more attention. Examining scientific publications concentrated in specific research areas makes this interaction and collaboration clearer. Journals publishing scientific research on environmental stress and pollution demonstrate the distribution and concentration of scientific knowledge in these areas (Fig. 5).

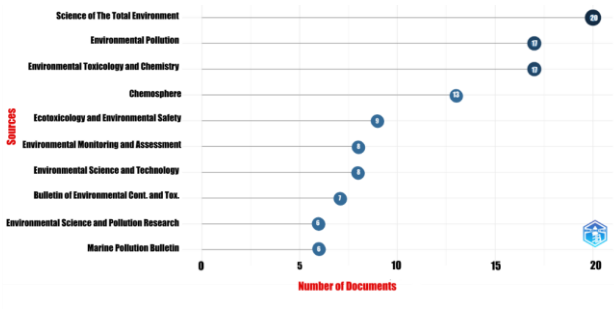

Figure 5. Main journals publishing research on histological changes in bird tissues in relation to environmental stress and pollution (1975–2024).

Science of the Total Environment (n=20) published the most documents on the subject followed by Environmental Pollution (n=17), Environmental Toxicology and Chemistry (n=17), Chemosphere (n=13), Ecotoxicology and Environmental Safety (n=9), Environmental Monitoring and Assessment (n=8), Environmental Science and Technology (n=8), Bulletin of Environmental Contamination and Toxicology (n=7), Environmental Science and Pollution Research (n=6), and Marine Pollution Bulletin (n=5).

The fact that these publications include many articles on the topic demonstrates its widespread coverage in well-known journals. This demonstrates that research into environmental stress and pollution is conducted using a multidisciplinary approach with various disciplines within environmental science collaborating to expand the existing knowledge in this field (Fig. 6).

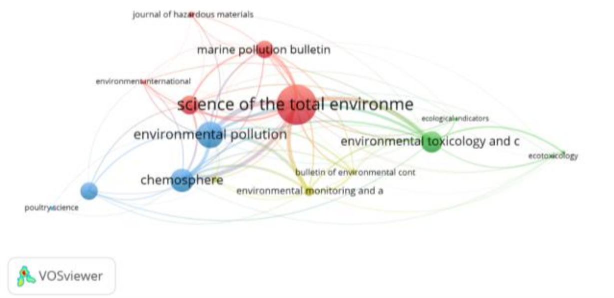

Figure 6. Citation network map between sources

3.4. Analysis of Researcher Productivity According to Lotka's Law

The Lotka law defines the productivity table of authors publishing in a subject area (Lotka, 1926). According to the analysis based on Lotka's law, it has been observed that most scientific publications are produced by a small number of authors, while most authors have published a small number of works. When examining the data of authors who published documents on the topics of environmental stress, pollution, bird tissues, and histological changes, it was found that the vast majority of authors published only one article (85.2%), while a smaller number of authors published multiple articles (14.8%). As a result of the log–log regression analysis based on Lotka’s law, the exponent of Lotka’s distribution was estimated as b = 3.73 (SE = 0.42) and the coefficient of determination of the fitted model was R^2 = 0.96, indicating a strong fit between the observed and expected productivity distribution (Table 2 and Fig. 7). The Kolmogorov–Smirnov goodness-of-fit test also showed no significant difference between the observed and expected cumulative distribution of authors across publication counts (D = 0.06, p = 0.03, N = 647).

Table 2. Author productivity according to Lotka's Law

Number of Document	Number of Author(s)	Ratio of Authors	Expected Author Ratio
1	551	0,852	0,852
2	68	0,104	0,213
3	22	0,034	0,095
4	5	0,008	0,053
5	1	0,002	0,034

Such a concentration of research output among a limited number of authors suggests the presence of specialized expert groups shaping this field. While this enhances methodological depth, it may also constrain theoretical diversity. Encouraging wider participation and interdisciplinary collaboration could foster greater theoretical diversity and methodological innovation.

3.5. Contributions by Keyword

Keyword analysis is a method that significantly contributes to the understanding of specific topics and trends in the scientific literature (Kulak, 2018). This analysis is used to determine the changes in research topics over time and which keywords have emerged in the literature (He, 1999). Furthermore, the analysis of keywords has been demonstrated to offer significant insights into the prediction of research field dynamics and future trends in research (Van Eck & Waltman, 2014). In the present study, a bibliometric analysis was conducted to evaluate research on environmental stress, pollution, and bird tissues, examining prominent keywords and their distribution over time. In the word cloud analysis, some of the prominent keywords include "animals," "environmental monitoring," "histology," and "bioaccumulation" [Fig. 8 (A)]. These words indicate the significance of the study topics and their frequent use in research.

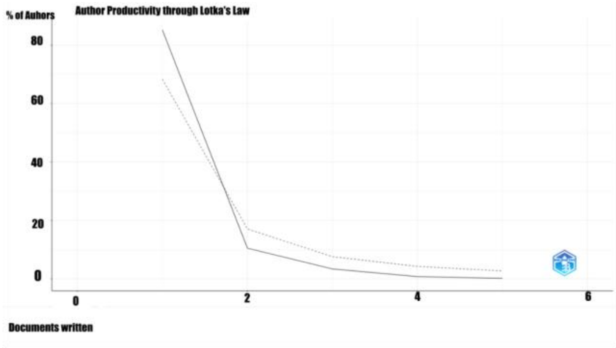

Figure 7. Author productivity according to Lotka's Law

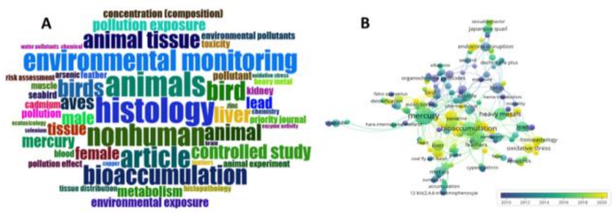

Figure 8. Keyword structure and temporal trends in the literature. (A) Word cloud of author keywords related to histological changes in bird tissues under environmental stress and pollution with word size proportional to keyword frequency. (B) Temporal trends of the most frequently used keywords over the study period

For example, the term "environmental monitoring" emphasizes the importance of studies aimed at monitoring the effects of environmental stress and pollution on bird tissues (Al-sabaawy et al., 2024; Bauerová et al., 2020; Rebez et al., 2023; Xie et al., 2020). The words "histology" and "histological change" indicate that research related to the study of histological changes is widespread (Karasov et al., 2011; Mateo et al., 2003).

In the trend analysis, we observe the distribution of certain keywords over the years [Fig. 8 (B)]. Among the prominent keywords before and in 2010 are "mercury," "bioaccumulation," and "heavy metals." These words indicate that research on biological accumulation and metal toxicity related to environmental pollution was concentrated in earlier periods (Bianchi et al., 2008; Houserová et al., 2007; Malik & Zeb, 2009; Zolfaghari et al., 2007). Between 2012 and 2018, keywords such as "oxidative stress" and "endocrine disruption" garnered more attention, indicating that the effects of oxidative stress and endocrine disruptors on bird tissues were more extensively studied during this period (Costantini, 2013; Henry et al., 2015; Mohanty et al., 2017; Skrip &

McWilliams, 2016; Sletten et al., 2016). Among the prominent keywords in 2020 and beyond are "microplastics," "histopathology," and "climate change," indicating that microplastic pollution and climate change are current research topics (Charlton-Howard et al., 2023; Haave et al., 2021; Imoobe et al., 2024; Stephen & Duncan, 2022).

The evolution of these keywords underscores a conceptual transition from studying single pollutants to evaluating cumulative and synergistic effects. Recent literature increasingly integrates histological analysis with molecular markers such as oxidative stress enzymes and apoptotic pathways, revealing a more mechanistic understanding of tissue damage in polluted environments.

3.6. Thematic Maps

The bibliometric thematic map groups the effects of pollution and environmental stress on bird tissues into four categories. The following themes are identified: emerging or declining themes, basic themes, motor themes, and niche themes. It is evident that microplastics and climate change represent two novel environmental threats that are particularly salient among the Emerging or Declining Themes. This demonstrates a marked increase in the level of interest among scientists in these issues in recent years (Fig. 9).

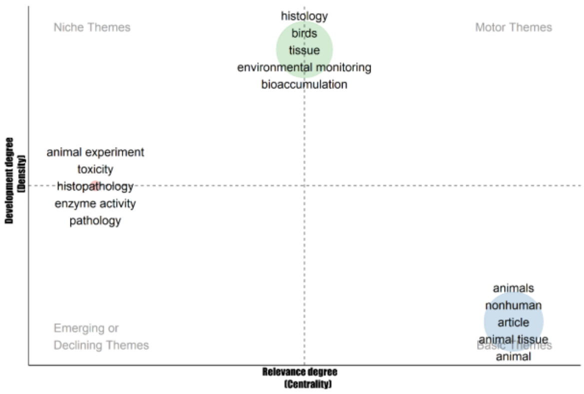

Figure 9. Thematic areas on environmental stress and pollution in bird tissues (1975-2024) (Obtained from R Studio Biblimetrix)

Keywords include apoptosis, cytochrome P450, and cadmium. The main themes include the long-term effects of environmental stress and pollution on birds; heavy metal accumulation threatens bird health by causing toxic effects, particularly in the liver and kidneys. Keywords include Japanese quail, fipronil, tissues, metals, tree swallows, mercury, pollution, heavy metals, bioaccumulation, birds, endocrine disruption, and marine debris. Core themes are the key methods and approaches used to understand the effects of environmental pollution on birds with histological analyses at the center of this theme. Among the keywords are lead, oxidative stress, histopathology, metabolism, detoxification, migration, contamination, food web, bird, avian toxicity, and ecological risk assessment. Niche themes, on the other hand, include more specific and less studied topics; for example, the role of organic minerals in bird nutrition and their environmental impacts indicating areas that require further research in the future.

3.7. Synthesis of Reported Histological Alterations

In addition to thematic mapping, a qualitative synthesis of the reviewed studies reveals several recurring histological lesions in avian tissues subjected to environmental stress and pollutants. Heavy metal accumulation, especially lead, cadmium, and mercury, predominantly impacts the liver and kidneys resulting in hepatocellular vacuolation, sinusoidal congestion, nuclear pyknosis, and renal tubular necrosis (Kou et al., 2020; Nardiello et al., 2019; Bassi et al., 2021). Lipid accumulation and bile duct proliferation have been observed in the liver signifying chronic hepatotoxic stress (Amri et al., 2017; Ding et al., 2022).

Exposure to organic pollutants and pesticides, such as organochlorines and organophosphates, has been linked to the disruption of gonadal histology, testicular degeneration, and altered oocyte morphology signifying endocrine and reproductive toxicity (Mohanty et al., 2017; Narváez et al., 2016). Furthermore, studies addressing oxidative stress reported degenerative changes in myocardial and pulmonary tissues, along with an increase in lipofuscin granules and apoptotic nuclei, signifying systemic oxidative damage (Rahbari et al., 2024; Henry et al., 2015).

In the context of microplastic pollution, recent histological observations have shown fibrotic reactions and inflammatory cell infiltration in the gastrointestinal tract and hepatic tissues of seabirds, sometimes referred to as "plasticosis" (Charlton-Howard et al., 2023; Haave et al., 2021). Collectively, these findings provide a coherent picture that the bibliometric clusters correspond to distinct histopathological signatures, bridging quantitative mapping with biological outcomes.

Taken together, these results provide added value beyond conventional bibliometric summaries. By integrating co-word and citation clustering with a qualitative synthesis of reported lesions, this study (i) identifies which histological endpoints (e.g. hepatic vacuolation, renal tubular necrosis, gonadal degeneration, and microplastic-associated fibrosis) are most frequently used as biomarkers of environmental stress in birds, (ii) links these lesion patterns to specific contaminant classes and thematic clusters (heavy metals, microplastics, endocrine-disrupting pesticides, and nutritional or thermal stress), and (iii) highlights geographical and taxonomic gaps where such tissue-level indicators have rarely been applied. To our knowledge, this combined perspective—bridging global publication trends with concrete histopathological signatures—has not been systematically documented for avian responses to environmental stressors and pollution, and thus offers a basis for selecting sentinel species, target tissues, and key lesions in future monitoring and conservation-oriented ecotoxicological studies. From an avian health perspective, the convergence of bibliometric and histological evidence points to practical priorities for future research and monitoring. The most frequently reported lesions—such as hepatic degeneration, renal tubular damage, gonadal disruption, and microplastic-associated inflammatory changes—overlap with tissue endpoints already recognized as sensitive biomarkers in avian ecotoxicology and in the reviews of pollutant impacts on birds (Celik et al., 2021; Richard et al., 2021). These endpoints could therefore be used to design standardized histopathological panels for long-term surveillance in sentinel bird species, while the scarcity of histology-based studies on emerging pollutants and in under-sampled regions underscores the need to extend such tissue-focused approaches to a broader range of species and contaminant mixtures so that histopathology can more effectively inform ecological risk assessment and conservation planning.

4. Conclusion

This study provides a global bibliometric synthesis of research on histological changes in bird tissues in relation to environmental stressors and pollution over the period 1975–2024. Beyond quantifying publication output, the analysis integrates trends over time, keyword and thematic mapping, Lotka's law, and a qualitative synthesis of reported lesions to show how histology has been used as a biomarker of exposure and effect in avian ecotoxicology. The findings reveal that research endeavors are predominantly focused on a restricted number of countries, journals, and contaminant categories, with subjects like heavy metal accumulation, plastic pollution, and oxidative stress prevailing in the literature, while numerous regions, species, and stressors are inadequately represented. Simultaneously, the identification of recurrent tissue endpoints—such as hepatic and renal degeneration, gonadal alterations, and microplastic-associated inflammatory changes—underscores histopathology as a potent methodology for correlating environmental contamination with physiological impairment in avian species. In general, this study makes the current structure and gaps in this research field clearer. It can also help with the planning of future monitoring programs, the choice of sentinel species and tissues, and the ranking of new pollutants and histological biomarkers in ecotoxicological studies that focus on conservation.

5. Recommendations for Future Studies

More research must be conducted on how emerging contaminants like microplastics, and endocrine disruptors affect avian tissues over time. We also need to do additional study to find out how effectively organic minerals can keep hazardous compounds from piling up. Longitudinal monitoring studies are needed to determine how significant environmental changes — such as global warming and habitat loss — affect histological structures over time. We could learn a lot more about how birds react to stresses in their surroundings if we used modern technologies and biomarker analysis. In conclusion, it is highly crucial to support greater international cooperation to help slow down harm to the environment and make conservation efforts more effective.

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