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Bio-inputs and Waste Reuse in Aquaculture: A Scientometric Analysis

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Abstract

Aquaculture has expanded rapidly worldwide, increasing natural resource use and waste generation and reinforcing the need for more sustainable production practices. This study aimed to analyze scientific production related to bio-inputs and waste reuse in aquaculture through a scientometric approach, identifying global trends, leading countries, scientific impact, and emerging research fronts. Searches were conducted in the Web of Science and Scopus databases, resulting in a final dataset of 153 articles published between 2007 and 2024. Scientific production showed an average annual growth rate of 22.61%, with a marked increase after 2017. China and the United States led in publication volume, while Belgium and Finland showed the highest average citation impact. International collaboration was substantial, reinforcing the interdisciplinary and transnational nature of the field. The main research topics included effluent treatment, waste valorization, water quality, nitrogen dynamics, and environmental impact assessment. Overall, the findings demonstrate that bio-inputs and waste reuse have become strategic components of sustainable aquaculture, although regional inequalities, technology transfer, and broader adoption of innovative solutions remain important challenges.

1. Introduction

Aquaculture is the fastest-growing food production sector globally, playing a strategic role in food security and socioeconomic development. In 2022, global production reached 130.9 million tons, surpassing capture fisheries for human consumption. However, rapid intensification poses significant environmental challenges, particularly nutrient accumulation. Intensive systems convert only 20–30% of ingested nitrogen (N) and 10–20% of phosphorus (P) into biomass; the remainder is excreted as effluent, increasing organic loads and eutrophication risks. (Avnimelech 2015; FAO 2022; FAO 2024; Naylor et al. 2021; Timmons and Ebeling 2021)

To mitigate these impacts, productive circularity approaches have emerged, focusing on bio-inputs and waste reuse. Bio-inputs—including beneficial microorganisms, bioflocs, and natural compounds—improve water quality, enhance microbiological stability, and reduce dependence on synthetic chemicals. Concurrently, reusing aquaculture waste as secondary inputs for agriculture, biofertilizers, or composting reduces environmental liabilities and aligns with circular economy principles. This advancement supports the FAO's Blue Transformation agenda, which prioritizes innovative, low-impact, and circular production models. (FAO 2022; Kurniawan et al. 2025; Timmons and Ebeling 2021)

Despite growing interest, scientific knowledge regarding bio-inputs and waste reuse in aquaculture remains fragmented across diverse methodologies and species. Scientometric analysis is essential to map this evolution, revealing structural trends, leading countries, institutional collaboration networks, and research fronts. While these fields are expanding rapidly, integrated scientometric studies addressing both themes within aquaculture remain scarce. Therefore, this study aimed to map and analyze global scientific production related to bio-inputs and waste reuse in aquaculture, identifying the structural components, geographic hubs, and emerging trends driving this research field. (Melo et al. 2025; Santorio et al. 2021)

2. Materials and Methods

This study utilized the Web of Science (WoS) and Scopus databases to retrieve scientific articles on bio-inputs and waste reuse in aquaculture. Both platforms are widely recognized as primary indexing metadata sources for comprehensive large-scale bibliometric analyses. The complete methodological protocol for document filtering and refinement is structured into a streamlined workflow (Fig. 1). (Pranckutė 2021)

The search strategy integrated three central thematic axes using Boolean operators (AND, OR):

1. **Aquaculture axis**: Delimited the production environment using terms such as *aquaculture, fish farming, fish culture, aquaculture production, freshwater aquaculture*, and *inland aquaculture*.
2. **Waste axis**: Captured waste management indicators using descriptors like *waste, residues, effluents, wastewater, organic sediment*, and *organic matter*.
3. **Bio-inputs axis**: Identified valorization strategies using the core term *bio-inputs*.

Initial searches yielded 276 documents in WoS and 299 in Scopus. Refinement filters restricted results to peer-reviewed original research articles, excluding review papers, conference proceedings, early-access documents, and book chapters. This automated filtering resulted in 205 documents from WoS and 250 from Scopus. The metadata were exported in BibTeX format and processed in R software using the Bibliometrix package via the Biblioshiny interface.

A rigorous manual screening was then performed on the titles, abstracts, and methodologies to exclude studies outside the scope (e.g., waste management applied exclusively to terrestrial livestock systems like poultry, swine, or cattle). After this qualitative filtering, 89 articles from WoS and 159 from Scopus remained. Finally, duplicate records were removed automatically and verified manually via Digital Object Identifier (DOI) comparison, establishing a final consolidated database of 153 scientific articles for bibliometric analysis.

3. Results

3.1. Overall Analysis

The bibliometric profile of the 153 analyzed articles reveals a field undergoing rapid scientific consolidation (Table 1). Spanning from 2007 to 2024, production expanded at an average annual growth rate of 22.61%. This rate is higher than that of traditional aquaculture fields, highlighting waste reuse and bio-inputs as emerging strategic priorities. The short average document age (4.27 years) confirms that this expansion is driven by recent global demands for circularity, stricter environmental frameworks, and low-impact production models. (Chen and Leydesdorff 2023; Melo et al. 2025; Naylor et al. 2021; Rusli et al. 2024; Sánchez-Pérez et al. 2025)

Table 1
Overview of key information

Description	Results
Main information about data	
Timespan	2007:2024
Sources (Journals, Books, etc)	83
Documents	153
Annual Growth Rate %	22.61
Document Average Age	4.27
Average citations per doc	19.58
AUTHORS	
Authors	827
Authors of single-authored docs	1
Authors collaboration	
Single-authored docs	1
Co-Authors per Doc	6.05
International co-authorships %	37.25
Document types	
Article	153

Scientific impact is robust, averaging 19.58 citations per document. This shows that the corpus serves as a foundational framework for subsequent research. High conceptual richness is evidenced by the identification of 2,798 Keywords Plus and 3,177 author keywords, reflecting an interdisciplinary interface across engineering, microbiology, ecotoxicology, and environmental management. Collaboration is a defining characteristic of this domain: 152 articles were co-authored, averaging 6.05 authors per document. Furthermore, a 37.25% international co-authorship rate underscores a transnational circulation of technological solutions—such as recirculation systems and microbial management—facilitating technology transfer across distinct climatic and economic contexts. (Arokiasamy 2024; Chen et al. 2023; Chozo 2024; Masi et al. 2024; Nolasco-Soria et al. 2018)

The temporal trajectory highlights a sharp inflection from 2017 onward, accelerating significantly after 2020 and peaking in 2024 (Fig. 2). This shift marks a transition from isolated, descriptive research toward applied technological consolidation, addressing operational bottlenecks like solids control, nutrient-use efficiency, and microbiological stability. This evolution aligns directly with international sustainable agendas, such as the FAO's Blue Transformation goals for 2030 and circular economy frameworks. (Almashhadany et al. 2024; AP News 2024; Garlock et al. 2024; Hossain et al. 2025; Liu et al. 2025; Usha Rani and Padmaja 2024)

3.2. Most Relevant Sources and Local Impact

The distribution of publications across 83 distinct sources reveals that core impact is concentrated within established environmental, engineering, and interdisciplinary journals (Table 2). *Science of the Total Environment* leads in productivity (15 publications) and exhibits a high g-index (14) relative to its h-index (6). This indicates that its influence is heavily driven by highly cited "anchor" papers that shape the environmental agenda. Conversely, *Aquacultural Engineering* represents the oldest source in this domain (beginning in 2007) and holds the highest total citations (245). This highlights its structural role in defining foundational engineering baselines, system designs, and solids management practices.

Table 2
Local-impact sources by h-index (TC: total citations; NP: number of publications; PY_start: first publication year within the analyzed period)

Source	h_index	g_index	m_index	TC	NP	PY_start
SCIENCE OF THE TOTAL ENVIRONMENT	6	14	0.615	197	15	2013
AQUACULTURAL ENGINEERING	6	7	0.316	245	7	2007
ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY	6	6	0.500	54	6	2014
FRONTIERS IN MICROBIOLOGY	5	6	0.625	165	6	2018
WATER (SWITZERLAND)	4	7	0.833	97	7	2020
ENVIRONMENTAL POLLUTION	4	4	1.000	49	4	2018
SUSTAINABILITY (SWITZERLAND)	4	4	1.000	39	4	2022
WATER RESEARCH	4	4	0.500	133	4	2016
ANTIBIOTICS	3	4	0.600	37	4	2021
AQUACULTURE RESEARCH	3	4	0.429	44	4	2017

Legend: TC: total citations; NP: number of publications; PY_start: first publication year; h_index, g_index, and m_index correspond to the bibliometric indicators of the analyzed sources.

The simultaneous prominence of journals like *Ecotoxicology and Environmental Safety* (h-index = 6) and *Frontiers in Microbiology* (h-index = 5) underscores that sustainability in this field relies equally on chemical risk controls and biological optimization. Emerging platforms like *Water (Switzerland)* and *Sustainability (Switzerland)* display high m-index values (0.833 and 1.000, respectively), indicating accelerated recent growth. Additionally, the inclusion of specialized journals such as *Antibiotics* reflects a growing intersection with biosafety and One Health frameworks, where waste management acts as a proactive barrier against microbiological risks and antimicrobial resistance.

3.3. Author Production and Citation Impact

The analytical impact of the leading researchers is sustained by a combination of pioneering scientists and rapidly rising authors (Table 3). Li Y (h-index = 5, TC = 136) and O'Neill E.A. (h-index = 5, TC = 85) demonstrate

a balanced, consistent citation performance. In terms of citation density, Summerfelt S.T. stands out with the highest absolute impact (TC = 201, h-index = 4), representing a long-term trajectory dedicated to recirculating systems and effluent engineering.

Table 3
Authors with the highest impact

Author	h_index	g_index	m_index	TC	NP	PY_start
Li Y	5	5	0.625	136	5	2018
O'Neill E.A	5	5	0.667	85	5	2020
Rowan N.J	4	5	0.667	86	4	2019
Summerfelt S.T	4	4	0.211	201	4	2001
Wang J	4	4	1.000	132	4	2022
Wang X	4	4	1.600	100	4	2021
Amorim C.L	3	3	1.000	43	3	2022
Arregui L	3	3	0.600	40	3	2021
Castro P.M.L	3	3	0.600	43	3	2021
Li I	3	3	0.750	59	3	2020
Li X	3	3	0.375	27	3	2017
Liu X	3	3	1.500	75	3	2023
Mosquera-Corral A	3	3	0.600	43	3	2018
Santoro S	3	3	0.500	25	3	2019
Val Del Rio A	3	3	0.273	30	3	2013
Wang Y	3	3	1.000	25	3	2022

TC: total citations; NP: number of publications; PY_start: first year of publication within the analyzed period.

In contrast, contemporary dynamics are characterized by rapid thematic consolidation, as seen in Wang X (m-index = 1.600) and Liu X (m-index = 1.500). This rapid growth reflects an intense absorption of newer experimental models and applied biotechnologies by the scientific community. The internal consistency between the h-index and g-index across most authors demonstrates that individual influence is anchored in stable research lines rather than isolated citation spikes, providing a balanced foundation for the field's expansion.

3.4. Institutional and Geographic Landscape

The institutional mapping (Table 4) and temporal output (Fig. 3) show that scientific leadership is clustered around regions with mature aquaculture value chains and strong research infrastructures. The University of Aveiro (Portugal) leads globally with 10 publications, maintaining steady output since 2016. This continuous

growth aligns with European policies targeting the blue economy and marine sustainability. Similarly, Irish institutions—the Technological University of the Shannon (8 publications) and University College Cork (5 publications)—exhibit sharp upward trajectories post-2019, driven by North Atlantic green innovation initiatives. (Almashhadany et al. 2024; Hossain et al. 2025; Liu et al. 2025; Usha Rani and Padmaja 2024)

Table 4
Most Relevant Affiliations in Publications and Research

Affiliation	Articles	Country
Universidade de Aveiro	10	Portugal
Technological University of the Shannon: Midlands Midwest (TUS)	8	Ireland
South China Agricultural University	6	China
University College Cork	5	Ireland
Chulalongkorn University	4	Thailand
Freshwater Institute (Shepherdstown)	4	United States
Kasetsart University	4	Thailand
Norges teknisk-naturvitenskapelige universitet (NTNU)	4	Norway
Shanghai Ocean University	4	China
Technical University of Denmark	4	Denmark
Universidade Federal do Paraná	4	Brazil
University of Waterloo	4	Canada

Asian research hubs are anchored by South China Agricultural University (6 publications), Kasetsart University (4), and Shanghai Ocean University (4). This prominent representation directly mirrors China and Thailand's status as global intensive aquaculture leaders, where high-density farming demands immediate biotechnological solutions to balance nutrient loads. In the Americas, applied innovation is driven by the Freshwater Institute (USA) and the University of Waterloo (Canada), while the Federal University of Paraná represents the growing inclusion of Brazilian tropical aquaculture in the international circular bioeconomy debate. (FAO 2024)

Geographically, China (88 articles) and the United States (57 articles) form the primary production poles (Table 5; Fig. 4), facing massive environmental challenges from intensive production. However, qualitative citation analysis (Table 6) reveals a distinct pattern: while China leads in absolute volume (790 total citations), countries with lower numerical output like Belgium (47.80 citations/article) and Finland (47.00 citations/article) command the highest average impact. This underscores that international scientific influence is heavily determined by methodological rigor, life-cycle assessments, and ecotoxicological syntheses rather than raw publication volume. (FAO 2022; Garlock et al. 2024)

Table 5
Countries with the highest scientific output

Country	Freq
China	88
USA	57
Portugal	23
Ireland	21
Canada	20
Germany	18
UK	18
Brazil	17
Italy	17
Chile	16

Table 6
Countries with the highest average citations per scientific article in the international landscape

Country	TC	Average Article Citations
China	790	23.90
USA	337	25.90
Belgium	239	47.80
Canada	158	14.40
Bangladesh	123	20.50
Denmark	118	29.50
Thailand	109	27.20
Egypt	97	19.40
Finland	94	47.00
Portugal	91	13.00

3.5. Highly Cited Papers and Emerging Knowledge Fronts

The intellectual backbone of this domain converges around effluent treatment, waste-to-product conversion, and life-cycle sustainability (Table 7). The most globally cited work, by Pham et al. (2015) (146 citations), establishes a critical link between aquaculture waste, environmental health, and ecosystem integrity.

Table 7
Most globally cited articles with citation totals and percentages

Paper	DOI	Total Citations	TC per Year	Normalized TC	Reference
Pham, D.K., 2015, *EcoHealth*	10.1007/s10393-014-1006-z	146	13.27	2.05	(Pham et al. 2015)
Sharrer M.J., 2007, *Aquacultural Engineering*	10.1016/j.aquaeng.2006.10.003	103	5.42	1.00	(Sharrer et al. 2007)
Li S., 2024, *Environmental Science & Technology*	10.1021/acs.est.4c00993	76	38.00	3.53	(Li et al. 2024)
Wong M.H., 2016, *Environmental Pollution*	10.1016/j.envpol.2016.05.035	76	7.60	2.02	(Wong et al. 2016)
Spiliotopoulou A., 2018, *Water Research*	10.1016/j.watres.2018.01.032	73	11.14	3.07	(Spiliotopoulou et al. 2018)
Barra, R.O., 2021, *Frontiers in Endocrinology*	10.3389/fendo.2021.611281	71	14.20	3.05	(Barra et al. 2021)
Bosma R.H., 2011, *International Journal of Life Cycle Assessment*	10.1007/s11367-011-0341-4	69	4.93	1.37	(Bosma et al. 2011)
Czyrnek-Delêtre M.M., 2017, *Applied Energy*	10.1016/j.apenergy.2017.03.129	68	7.56	2.78	(Czyrnek-Delêtre et al. 2017)
Shu H., 2022, *Bioresource Technology*	10.1016/j.biortech.2021.126541	64	21.33	3.79	(Shu et al. 2022)
Abdelzaher M.A., 2023, *Water*	10.3390/w15040780	62	31.00	2.60	(Abdelzaher et al. 2023)

Engineering benchmarks established by Sharrer et al. (2007) (103 citations) provide the mechanical basis for backwash treatment and biofiltration.

Recent high-impact entries, such as Li et al. (2024) (TC per year = 38.00) and Shu et al. (2022) (TC per year = 21.33), reflect a swift paradigm shift. Research is moving rapidly toward utilizing specific microbial strains—such as heterotrophic nitrifying-aerobic denitrifying bacteria—to actively convert environmental liabilities into valuable bio-inputs, linking aquaculture directly to bioenergy and circular biorefineries.

3.6. Thematic Structure and Keyword Frequencies

Word frequency analysis (Table 8) and visual mapping (Figs. 5 and 6) confirm that the field is anchored to the biological and chemical equilibrium of farming environments. The high frequency of aquaculture (135), animals/animal (94), and fish (35) isolates fish as the predominant zootechnical model. Methodological execution is characterized by high operational control, as shown by the recurrence of controlled study (39).

Table 8
Most frequent words used in the articles

Words	Occurrences
Aquaculture	135
Animals or Animal	94 (45 e 49)
Article	86
Nonhuman	74
Fresh water	51
Controlled study	39
Fish	35
Water quality	29
Nitrogen	28
Freshwater environment	26

The critical focus of the literature centers on *water quality* (29) and *nitrogen* (28). This concentration demonstrates that managing the dynamics of nitrogenous compounds—such as ammonia and dissolved effluents—is the primary bottleneck in preventing eutrophication and ensuring systemic viability. Emerging vocabulary like *biomass*, *microalgae*, and *microbial community* reveals a trend where waste is no longer just a pollutant to be treated, but a functional substrate for biological synthesis and circular optimization.

4. Discussion

The scientometric evidence indicates that research on bio-inputs and waste valorization in aquaculture has undergone rapid consolidation since 2007, with a marked expansion after 2017. The concentration of scientific output in China and the United States contrasts with the high average citation impact observed in countries such as Belgium and Finland, highlighting differences between publication volume and scientific influence. The strong level of co-authorship and international collaboration confirms the multidisciplinary and transnational character of the field. Across the analyzed literature, the main research fronts converge on

effluent treatment, waste-to-product conversion, water quality, nitrogen dynamics, and integrated sustainability assessment. These trends show that aquaculture waste is increasingly approached not only as an environmental liability but also as a potential resource for circular production systems. Overall, bio-inputs and waste reuse represent strategic pathways for improving resource-use efficiency and reducing environmental impacts, although regional inequalities in research capacity, technology transfer, and access to innovative solutions remain important barriers to broader adoption.

Declarations

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Animal Rights Declaration

Not applicable. This study consisted exclusively of a scientometric analysis of published literature and bibliographic metadata and did not involve animals, animal experimentation, human participants, patient data, or human biological material.

Conflict of Interest

The authors declare that any potential financial or non-financial conflicts of interest must be confirmed by all authors before submission.

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Author Contributions

Author contributions must be confirmed by all authors before submission in accordance with the journal's authorship policy.

Data Availability

The bibliographic data analyzed in this study were obtained from the Web of Science and Scopus databases, as described in the Materials and Methods section. The processed dataset and analysis files may be made available by the corresponding author upon reasonable request, subject to the access conditions of the source databases.

Ethics Approval

Not applicable. This study was exclusively a scientometric analysis of published scientific literature and bibliographic metadata. No human participants, patient data, animals, animal experimentation, or biological

material were used; therefore, ethics committee approval and informed consent were not required.

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Figures

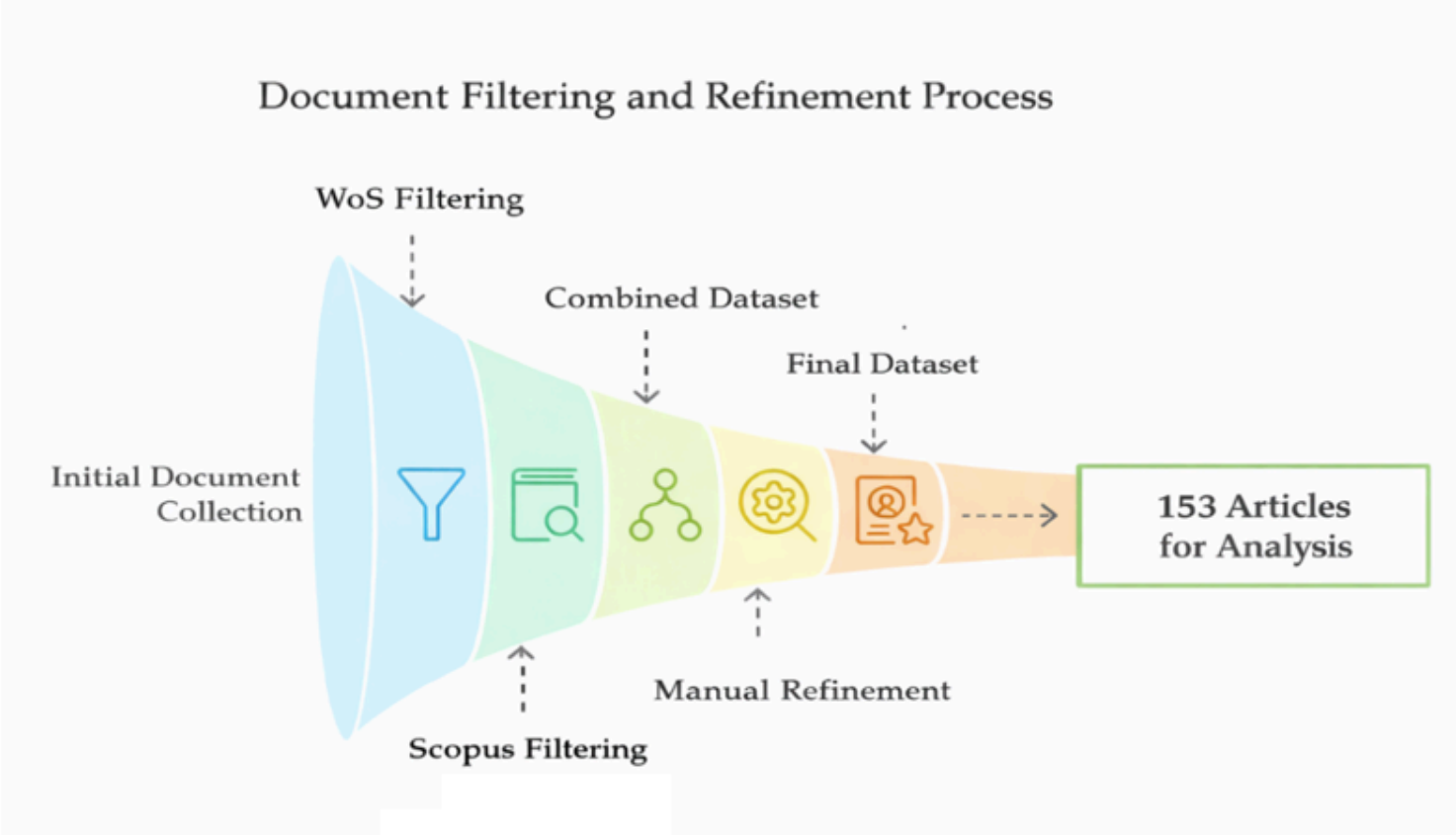


Figure 1

Flowchart of the document selection process for the scientometric analysis (source: adapted from Melo et al. 2025)

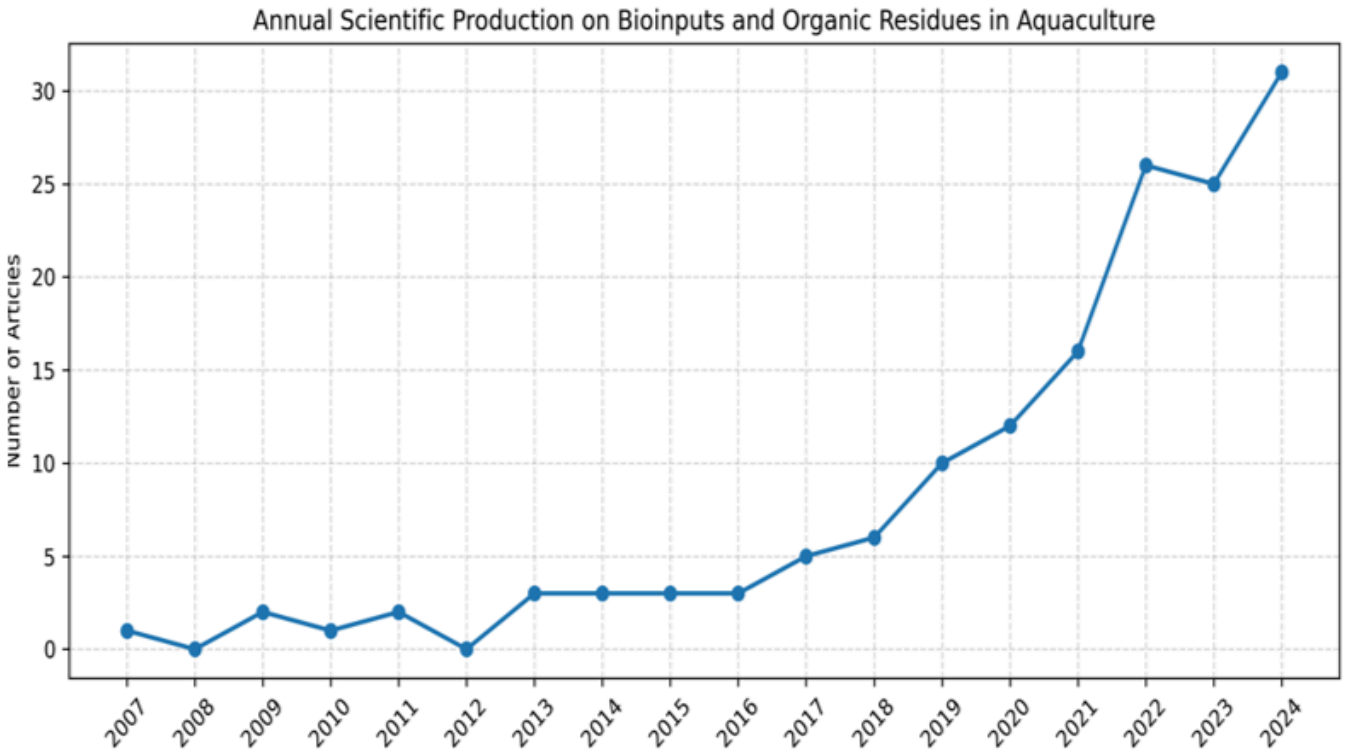


Figure 2

Annual scientific output on the use of bio-inputs and organic sediments in aquaculture (2007–2024)

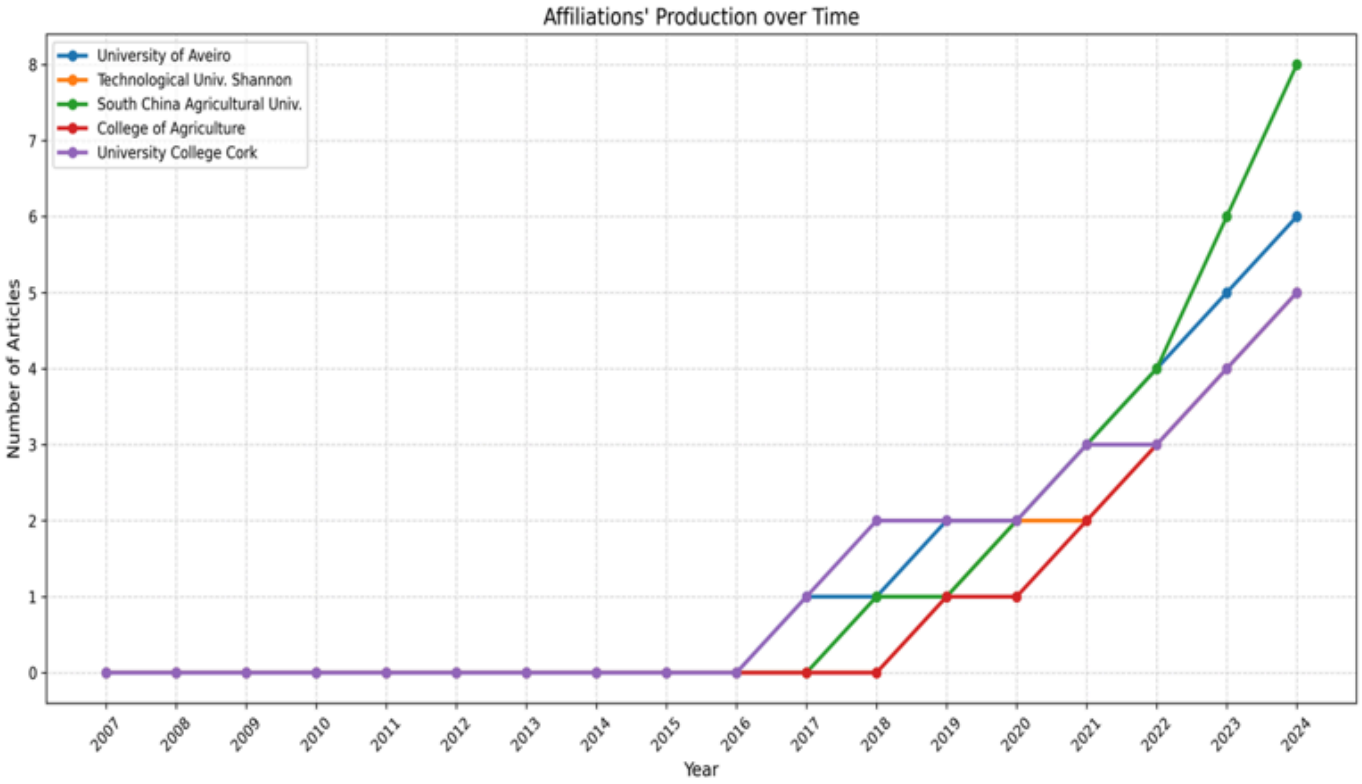


Figure 3

Affiliations’ Output Over Time

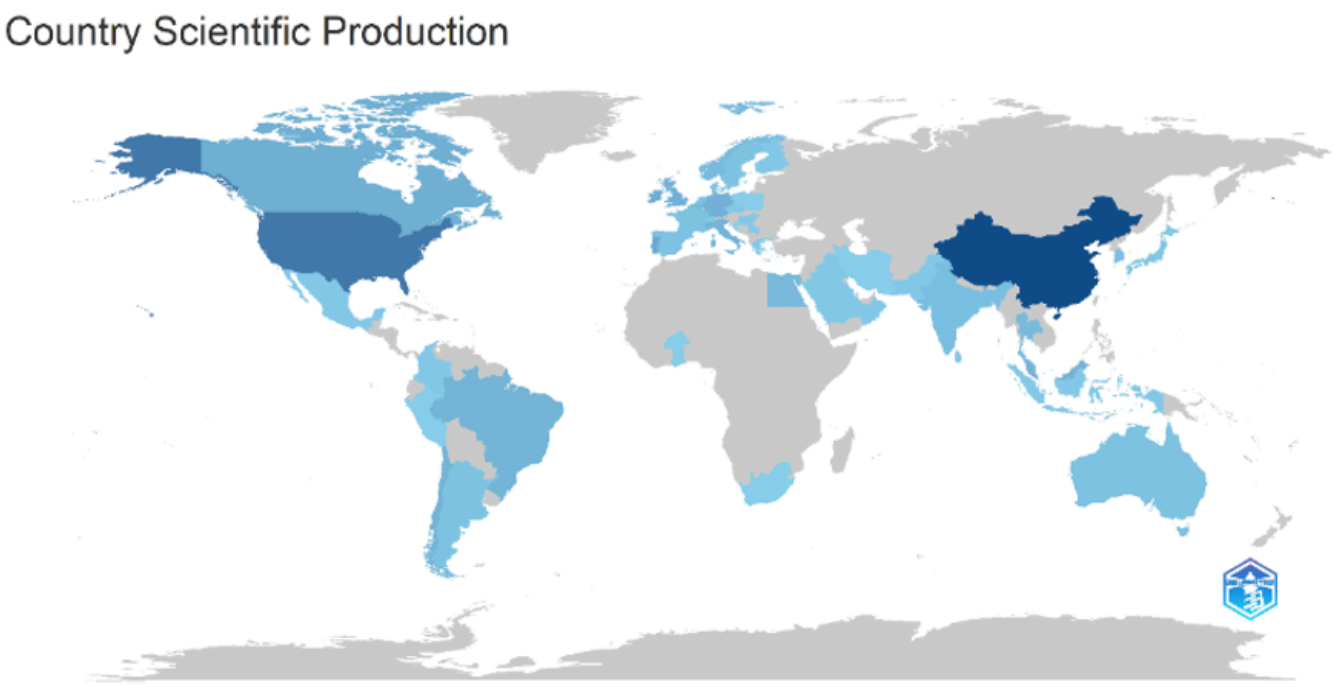


Figure 4

Scientific Output by Country



Figure 5

Cloud of most frequent words in scientific papers on bio-inputs and waste in aquaculture

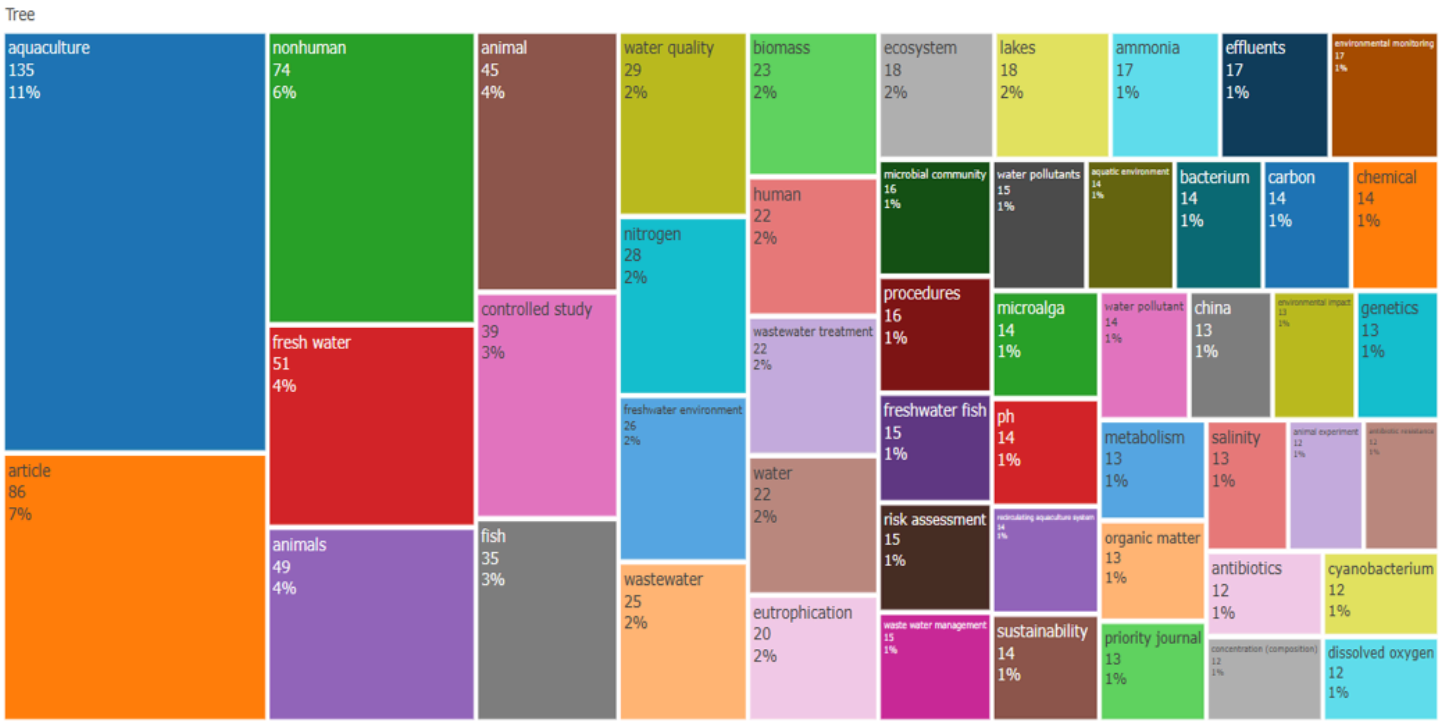


Figure 6

Tree Map of the most frequently cited words in the works