Research Trends in Integrated Aquaculture from 1990 to 2024: Bibliometric Studies

Rusli - *

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Article

Research Trends in Integrated Aquaculture from 1990 to 2024 : Bibliometric Studies

Rusli 1

Fisheries Cultivation Engineering, SORONG Marine and Fisheries Polytechnic; rusli83@kkp.go.id

Abstract: This study is a bibliometric analysis of integrated aquaculture research trends from 1990 to 2024. The metadata from this study was obtained from the Scopus database. Using search keywords, publication year limits, and several criteria, metadata was obtained as many as 1,180 publication data that were included in the bibliometric analysis. The results of the analysis show a significant development in the number of publications over the past three decades, with the main focus on sustainability, resource efficiency, and technological innovation. Countries such as China, the United States, and India dominate the contribution in the field of integrated aquaculture research. However, there is a research gap in terms of the integration of new technologies and empirical studies related to the socio-economic impact of integrated aquaculture. This study provides a comprehensive understanding of the development and direction of integrated aquaculture research, as well as provides recommendations for further research in aspects of technological innovation, as well as evaluating sustainability issues from a social, economic, and environmental perspective.

Keywords: Integrated aquaculture; bibliometrics; and research trends

INTRODUCTION

Aquaculture has experienced rapid development over the past few decades, becoming a significant supplier and has a vital role for the global food supply (Pradeepkiran, 2019; Verdegem et al., 2023). Due to the ever-increasing world population, the demand for animal protein is also increasing, leading to the rapid expansion of aquaculture production (See et al., 2021). This rapid expansion has raised concerns about the environmental impact of aquaculture practices (Ahmad et al., 2022; Kurniawan et al., 2021), leading to the integration of various systems to improve efficiency and sustainability (Dawood, 2021; Sampantamit et al., 2020).

Aquaculture, the cultivation of aquatic organisms such as fish, mollusks, and aquatic plants, has evolved significantly in recent decades in response to the growing global demand for seafood (Carrera-Quintana et al., 2022). Aquaculture plays a vital role and has become an important component of global food security (Pradeepkiran, 2019). However, conventional aquaculture practices often result in environmental problems such as water pollution, depletion of natural resources, and habitat destruction (Kurniawan et al., 2021; Olaganathan & Kar Mun, 2017). To respond to this challenge, integrated aquaculture systems have emerged as a more sustainable alternative, designed to optimize the use of resources (Granada et al., 2016) and minimizing environmental impact by combining different species and farming practices in a complementary way (Hasimuna et al., 2023; Khanjani et al., 2022).

Integrated aquaculture, often referred to as *Integrated Multi-Trophic Aquaculture* (IMTA), is a method that leverages synergistic relationships between species to create a balanced and self-sustaining system (Khanjani et al., 2022). In such a system, the by-products or waste from one species are recycled as inputs (e.g., nutrients, energy) for another species (Khanjani et al., 2022; Knowler et al., 2020). This not only increases the productivity of the system but also reduces the impact of aquaculture on the environment (Ibrahim et al., 2023). For example, fish farms can integrate shellfish or seaweed farming, where excess nutrients produced by fish are absorbed by seaweed or filter-eating species, creating a closed-loop system (Lavaud et al., 2023). This approach reflects the growing

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recognition of ecological principles in aquaculture and has gained global attention for its potential to improve sustainability and efficiency (Verdegem et al., 2023).

Despite all the potential of integrated aquaculture, the adoption and development of integrated aquaculture systems faces a variety of challenges, including limited scientific understanding, the complexity of designing such systems, and socio-economic barriers (Cavallo et al., 2020; Neori et al., 2004). Nevertheless, research on integrated aquaculture has increased substantially since the 1990s (Boyd et al., 2020; Carrera-Quintana et al., 2022; Popp et al., 2018), driven by the need for more sustainable food production systems and technological advancements that allow for better system design and monitoring. Research in the growing field of integrated aquaculture reflects the scientific community's efforts to better understand the dynamics of integrated aquaculture, assessing its ecological and economic benefits (Mukherjee et al., 2023), and develop best practices for their implementation.

In recent years, bibliometric analysis has become a valuable tool for tracking research trends in various fields. It offers a systematic method of analyzing large volumes of academic literature to identify emerging patterns, research focuses, and fields of study (Donthu et al., 2021). By applying bibliometric techniques to the field of integrated aquaculture, researchers can gain insights into research trends or developments, the geographic distribution of research, collaboration networks, and the most influential researchers. This can inform future research directions, knowledge gaps, and support the development of policies that promote sustainable aquaculture practices.

This study aims to analyze research trends in integrated aquaculture during the period from 1990 to 2024 to assist researchers in understanding the global landscape of integrated aquaculture, namely profiles of integrated aquaculture publications, the most cited authors, publication patterns of integrated aquaculture, and visualization of integrated aquaculture research trends from 1990 to 2024. In addition, this study will analyze the geographical distribution and collaboration networks between researchers and institutions in the field of integrated aquaculture.

Through this bibliometric analysis, the study also aims to provide resources for future researchers, practitioners, and policymakers interested in the development of integrated aquaculture. With this, it is hoped that this research can contribute to researchers in the field of integrated aquaculture so that the results of research in this field can make a maximum contribution not only to the academic world but also to practitioners in the field of aquaculture.

RESEARCH METHODS

Bibliometrics is a discipline of science that uses statistical methods and data analysis to examine patterns, trends, and characteristics of scientific publications that aim to determine the impact, productivity, and relevance of scientific research (Salinas-Ríos, 2022). To measure this, through bibliometric analysis, the number of citations, characteristics of citations, collaboration between researchers, distribution of scientific publications in various topics or research focuses are carried out (Żarczyńska, 2012).

This study uses a bibliometric research method formulated by Donthu et al. (2021) by taking steps gradually and systematically to obtain good and comprehensive research results using the PRISMA flow (Page et al., 2021).

This research goes through several stages starting from the stage of preparing the problem formulation, determining keywords (*Keyword*) for metadata or reference lookups on *database*, data filtering process, data preparation (*data preparation*) and data cleaning (*data cleaning*), data visualization and the last stage is the data interpretation stage (*data interpretation*) (Wijaya et al., 2023).

The metadata search process was carried out on October 4, 2024 by applying several limitations or filters and using the *Scopus database*. The limitation in the metadata search is the use of keywords contained in the title, abstract, and publication year range, In the metadata search, keywords are used with *the search string TITLE-ABS-KEY (integrated AND aquaculture) AND PUBYEAR > 1989 AND PUBYEAR < 2025*. The complete metadata search process and some of the limitations used in the metadata search process are seen in the following figure 1.

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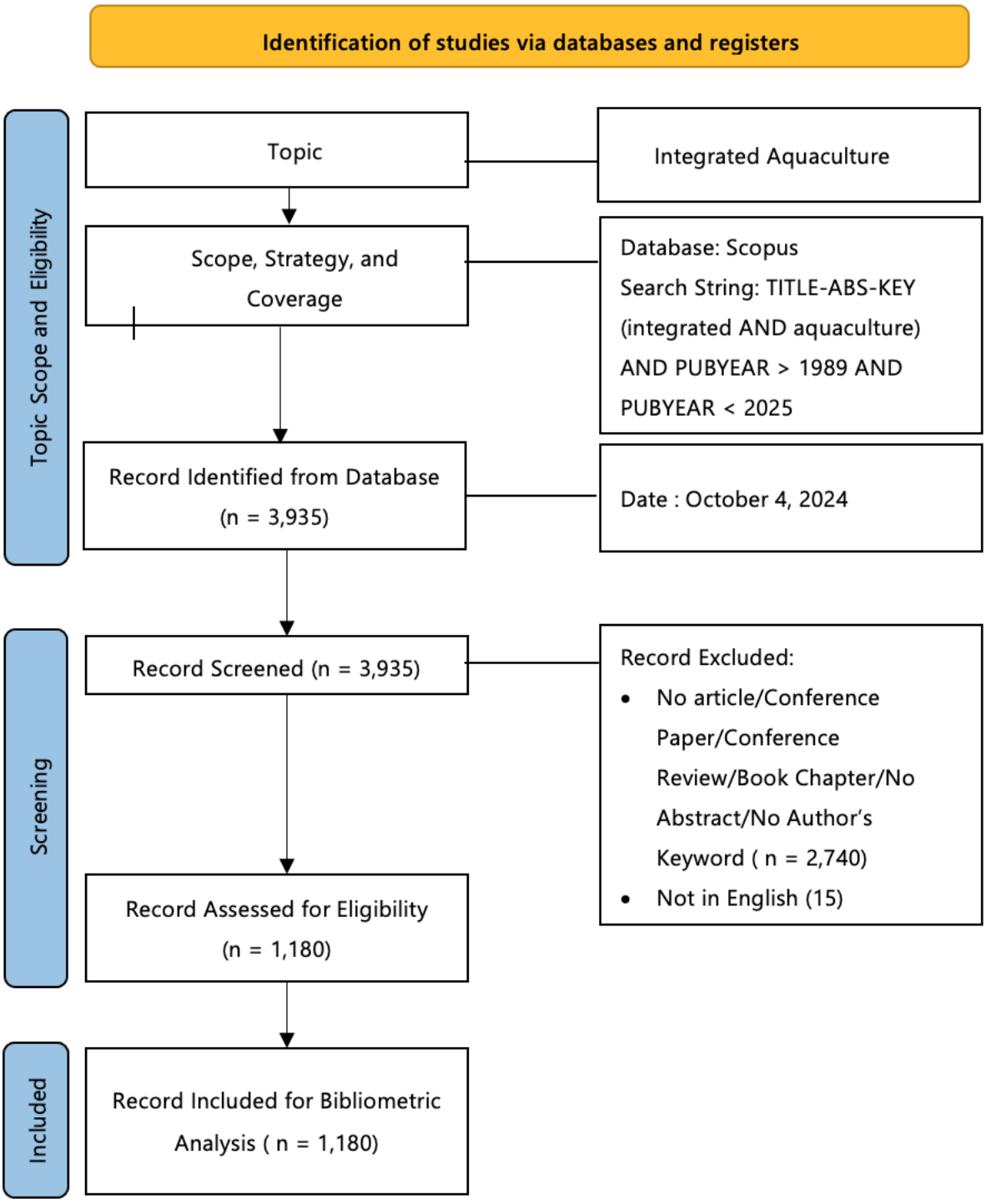

Picture 1 Document Selection Stages Adopt the PRISMA Flow (Page et al., 2021).

RESULTS AND DISCUSSION

Publication Output, Document Sources, and Number of Documents Per Year

From 1990 to 2024, there are 3,935 documents related to integrated aquaculture topics recorded in the Scopus database consisting of 12 types of documents. The majority of these document types were dominated by articles (2,873 documents, 73.0%), conference papers (382 documents, 9.7%), reviews (359 documents, 9.1%), and book chapters (211 documents, 5.4%). In detail, the types of documents and the number of documents on integrated aquaculture published from 1990 to 2024 can be seen in Table 1 and Figure 2 below.

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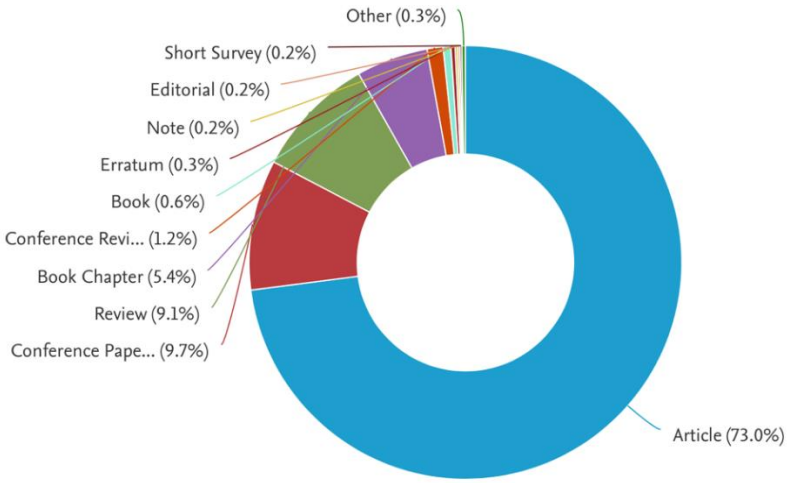
Table 1. Types and Quantities of Integrated Aquaculture Documents. from 1990 to 2024.

Document Type	Sum
Article	2873
Conference Paper	382
Review	359
Book Chapter	211
Conference Review	47
Book	23
Erratum	12
Note	8
Editorial	6
Short Survey	6
Retracted	6
Data Paper	2



Picture 2 Percentage of Integrated Aquaculture Documents by Document Type.

The following Figure 3 provides information on scientific publications in the field of integrated aquaculture from 1990 to 2024. In general, the trend of increasing The number of documents on integrated aquaculture every year has increased. From 1990 to 2000, the number of published documents was relatively low and fluctuated between 7 and 30 documents per year. Entering the period of 2001-2010, there was a significant increase. At the beginning of this period (2001) there were 21 documents and the number continued to increase until it reached 71 documents in 2010. The increase in the number of documents published in this period indicates that there is an increase in research interest in the field of integrated aquaculture in this period. The increase in the number of publications is seen to be very significant in the period 2011-2024. In this period, it was recorded that as many as 98 documents published in 2011 then continued to experience a very significant increase until 2024 which reached 396 documents. The significant increase in the number of publications during this period illustrates the growing importance of globally integrated aquaculture topics and is a major focus for all global researchers in the field.

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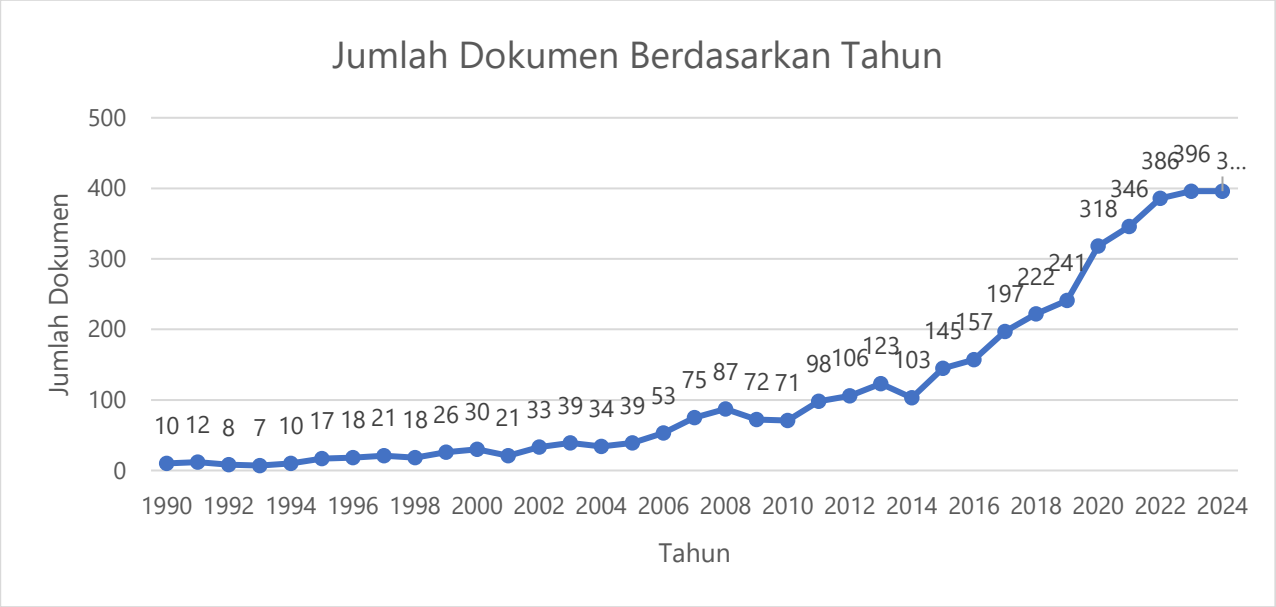
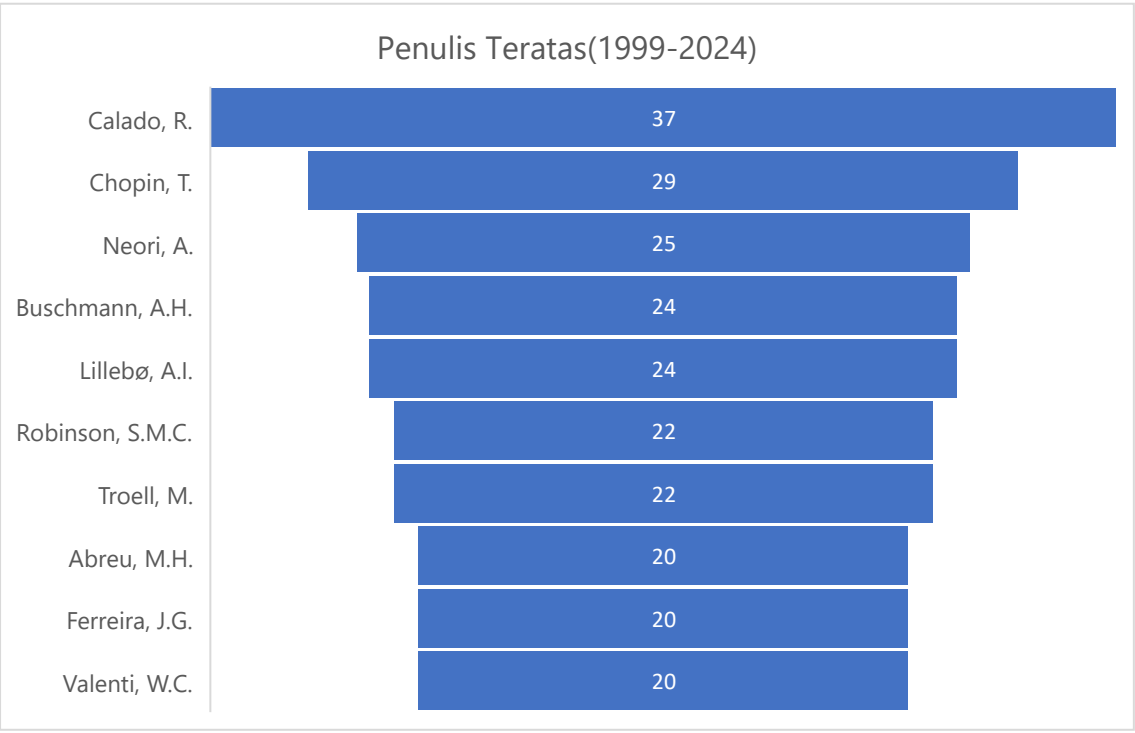


Picture 3 Number of Integrated Aquaculture Documents from 1999-2024.

Top and Most Cited Authors on Integrated Aquaculture Research

This section will explain the top ten authors and the five authors with the most citations on integrated aquaculture research in the period from 1990 to 2024. Figure 4 provides information on the top 10 most prolific authors from 1990 to 2024 who conducted research on integrated aquaculture. Calado, R has the highest number of publications and research in the field of integrated aquaculture, which is 37 documents from the period from 1990 to 2024. During this period, Abreu, M.H., Ferreira, J.G., and Valenti, W.C. published 20 documents each in the field of integrated aquaculture. For researcher publications in the field of integrated aquaculture, the top three most cited authors from the period from 1990 to 2024 are Pretty et al. (2011) A total of 774 citations, then followed by Streftaris and Zenetos (2006) a total of 523 citations, Goddek et al. (2015) A total of 336 citations. In detail, the top ten authors whose publications in the field of integrated aquaculture have the most citations can be seen in table 2.



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Picture 4 Top Author on Integrated Aquaculture Research (1990-2024).

Table 2. Most Cited Articles from 1990 to 2024.

Writer	Source Documents	ΣCitations
Pretty et al. (2011)	Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability, 9(1), 5-24. https://doi.org/10.3763/ijas.2010.0583	774
Streftaris and Zenetos (2006)	Alien Marine Species in the Mediterranean - the 100 'Worst Invasives' and their Impact. Mediterranean Marine Science, 7, 87-118.	523
Goddek et al. (2015)	Challenges of Sustainable and Commercial Aquaponics. Sustainability, 7(4), 4199-4224. https://www.mdpi.com/2071-1050/7/4/4199	336
Dumont et al. (2013)	Prospects from agroecology and industrial ecology for animal production in the 21st century. Animal : an international journal of animal bioscience, 7(6), 1028–1043. https://doi.org/10.1017/S1751731112002418	251
Schmidt Anja et al. (2001)	Incidence, distribution, and spread of tetracycline resistance determinants and integron-associated antibiotic resistance genes among motile aeromonads from a fish farming environment. Applied and environmental microbiology, 67(12), 5675–5682. https://doi.org/10.1128/AEM.67.12.5675-5682.2001	250

Publication Pattern of Integrated Aquaculture Research from 1990-2024 : Based on Sources

The following Table 3 provides information on the top five in the number of documents or publications on integrated aquaculture from the 1990s to 2024. In the table, it is known that the *journal Aquaculture* during the period from 1990 to 2024 recorded a total of 329 related documents about research in the field of integrated aquaculture. The Science *Of The Total Environment Journal* was recorded as the fifth rank by publishing research publications in the field of integrated aquaculture as many as 69 documents.

Table 3. Number of Integrated Aquaculture Documents in 1990-2024. By Source.

Journal Name	Number of Documents
Aquaculture	329
Aquaculture Research	83
Aquaculture International	79
Journal Of Applied Phycology	78
Science Of The Total Environment	69

The following figure 5 provides detailed information on the number of publications from the top five journals that published documents or publications in the field of integrated aquaculture from the period 1990 to 2024. In general, it can be seen that the publication on integrated aquaculture from the top five journals from 1990 to 2024 is fluctuating. For more details, you can see in the following figure 5.

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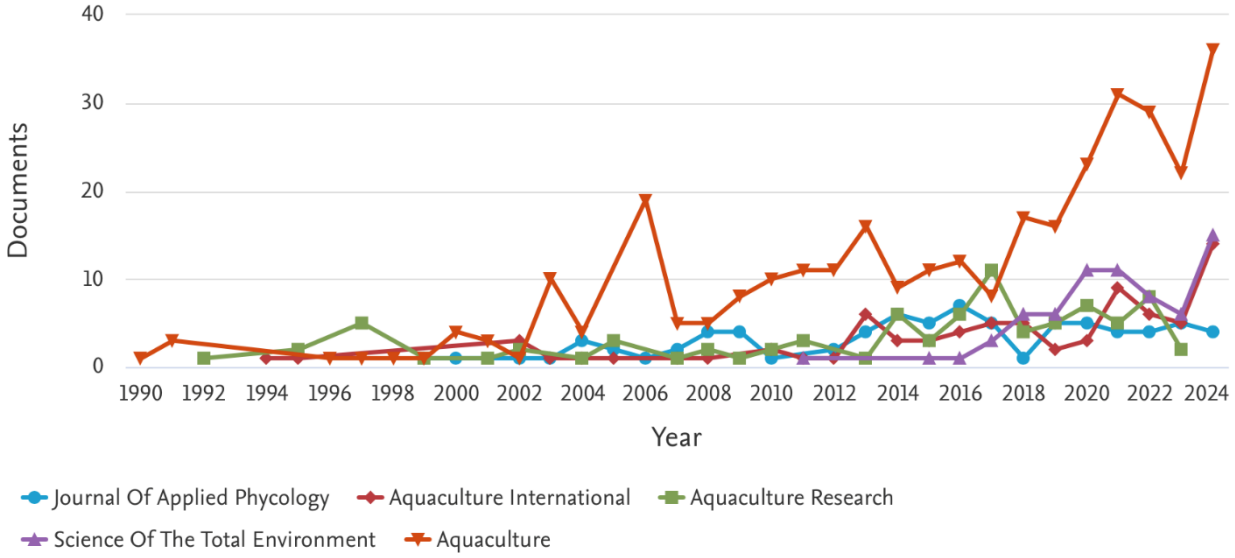

Picture 5 Publications in the Top five Journals.

Research in the Field of Integrated Aquaculture Based on Disciplines

The following Table 4 provides detailed information about research in the field of integrated aquaculture from 1990 to 2024. During this time span, the majority of research in the field of integrated aquaculture was carried out in scientific disciplines *Agricultural and Biological Sciences*, *Environmental Science*, *Engineering*, *Earth and Planetary Sciences*and *Social Sciences*. This indicates that research in the field of integrated aquaculture from this time span shows the involvement of several disciplines. In other words, research trends in the field of aquaculture science have received focus or attention in other fields. In detail, the distribution of research in the field of integrated aquaculture can be seen in table 4 and the percentage of distribution by field of science can be seen in figure 6.

Table 1 Distribution of Integrated Aquaculture Research by Discipline.

Disciplines	Number of Documents
Agricultural and Biological Sciences	2212
Environmental Science	1644
Engineering	626
Earth and Planetary Sciences	509
Social Sciences	366
Biochemistry, Genetics and Molecular Biology	338
Computer Science	266
Energy	223
Immunology and Microbiology	147
Medicine	143
Physics and Astronomy	126
Chemical Engineering	123
Chemistry	106
Economics, Econometrics and Finance	102
Multidisciplinary	86
Veterinary	80
Materials Science	79
Mathematics	78
Business, Management and Accounting	73
Pharmacology, Toxicology and Pharmaceutics	51

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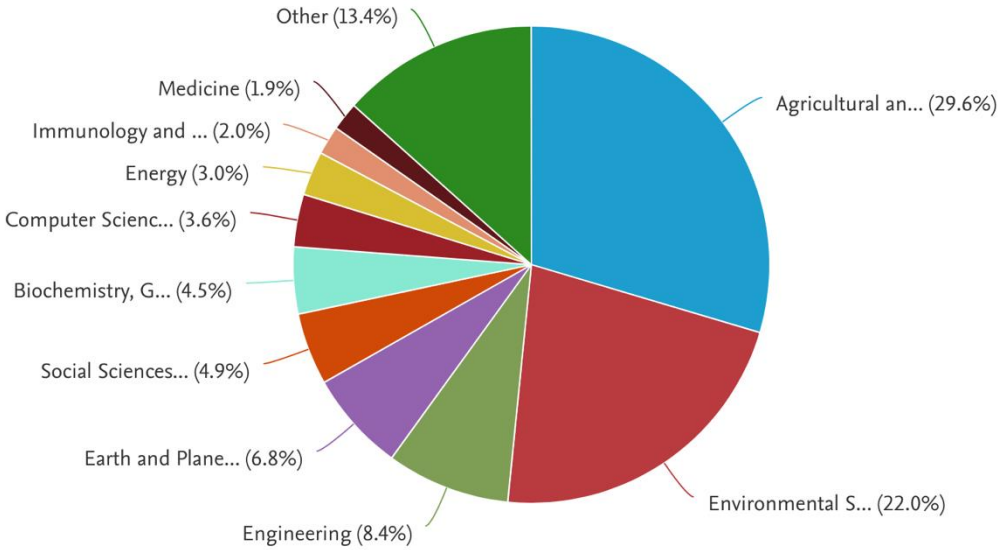
Disciplines	Number of Documents
Decision Sciences	46
Neuroscience	16
Arts and Humanities	13
Nursing	10
Health Professions	8
Psychology	2



Picture 6 Distribution of Documents by Discipline.

Distribution of Integrated Aquaculture Research by Country

The following diagram illustrates the distribution of integrated aquaculture research articles by country. *China* is the country that produces the most documents in the field of integrated aquaculture, accounting for more than 800 documents published in Scopus. Followed by the state *United States* which has nearly 500 documents in the field of integrated aquaculture. *United Kingdom*, *India*, *Australia*and *Canada* has more than 200 documents. While *Italy*, *Spain*, *Portugal*and *Norway* Each of them has nearly 200 documents. This shows that the distribution of research articles in the field of integrated aquaculture is dominated by developed countries.

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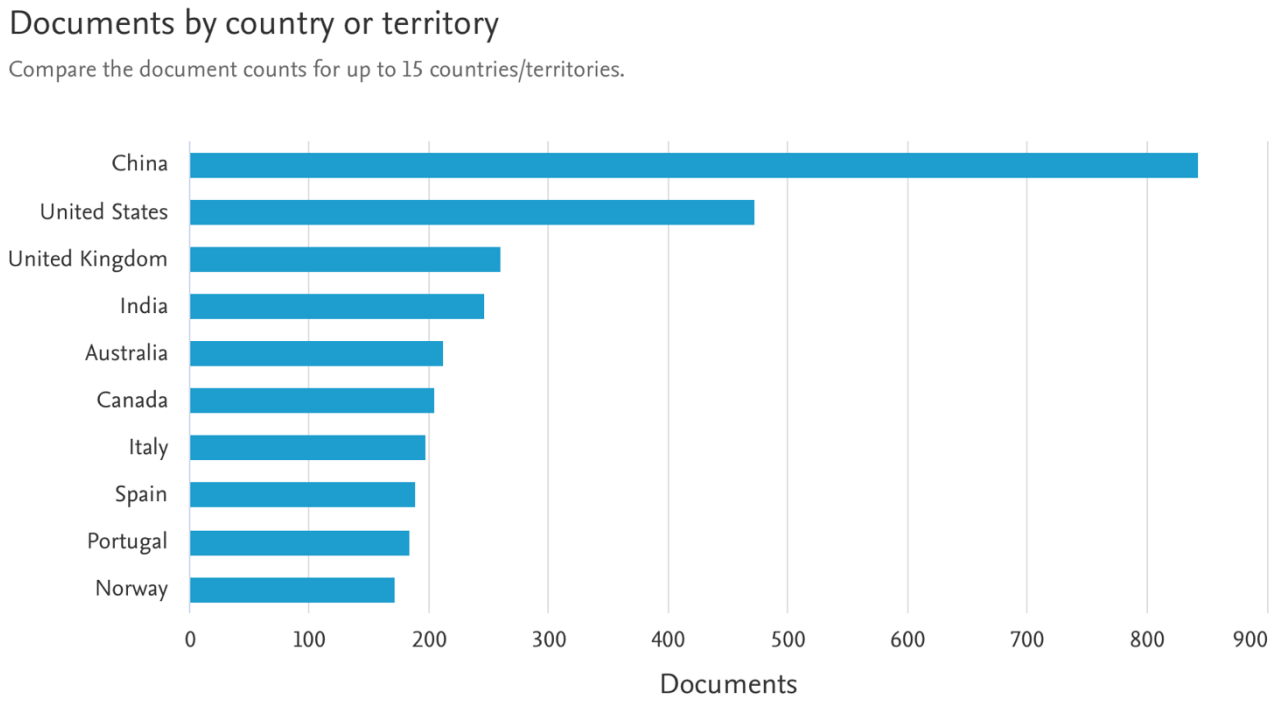

Picture 7 Distribution of Documents by Country.

Distribution of Research Sponsors in the Field of Integrated Aquaculture

The following table 5 provides detailed information about the sponsors who funded a number of research documents in the field of integrated aquaculture that focused on comparing 15 funding sponsors. It can be seen that *National Natural Science Foundation of China* dominated the funding that contributed as many as 306 documents. Followed by *European Commission* and *National Key Research and Development Program of China* a total of 209 and 157 documents respectively. The rest of the funding sponsors contributed less than 100 documents. Details can be seen in table 5.

Table 5. Documents Based on Funding Sponsor.

Sponsor	Number of Documents
National Natural Science Foundation of China	306
European Commission	209
National Key Research and Development Program of China	157
Ministry of Science and Technology of the People's Republic of China	130
Foundation for Science and Technology	94
Horizon 2020 Framework Programme	85
National Council for Scientific and Technological Development	82
European Regional Development Fund	82
Coordination for the Improvement of Higher Education Personnel	59
Natural Sciences and Engineering Research Council of Canada	53

Distribution of Documents by Affiliate

The distribution of documents based on affiliation is dominated by affiliates from the Chinese state. Compared to the total number of publication documents in integrated aquaculture, from the top 15 affiliates, it was recorded that there were 647 (66.76%) documents out of 969 publication documents whose affiliates came from China. Next from *Wageningen University & Research, Pilot National Laboratory for Marine Science and Technology, IFREMER French Research Institute for the*

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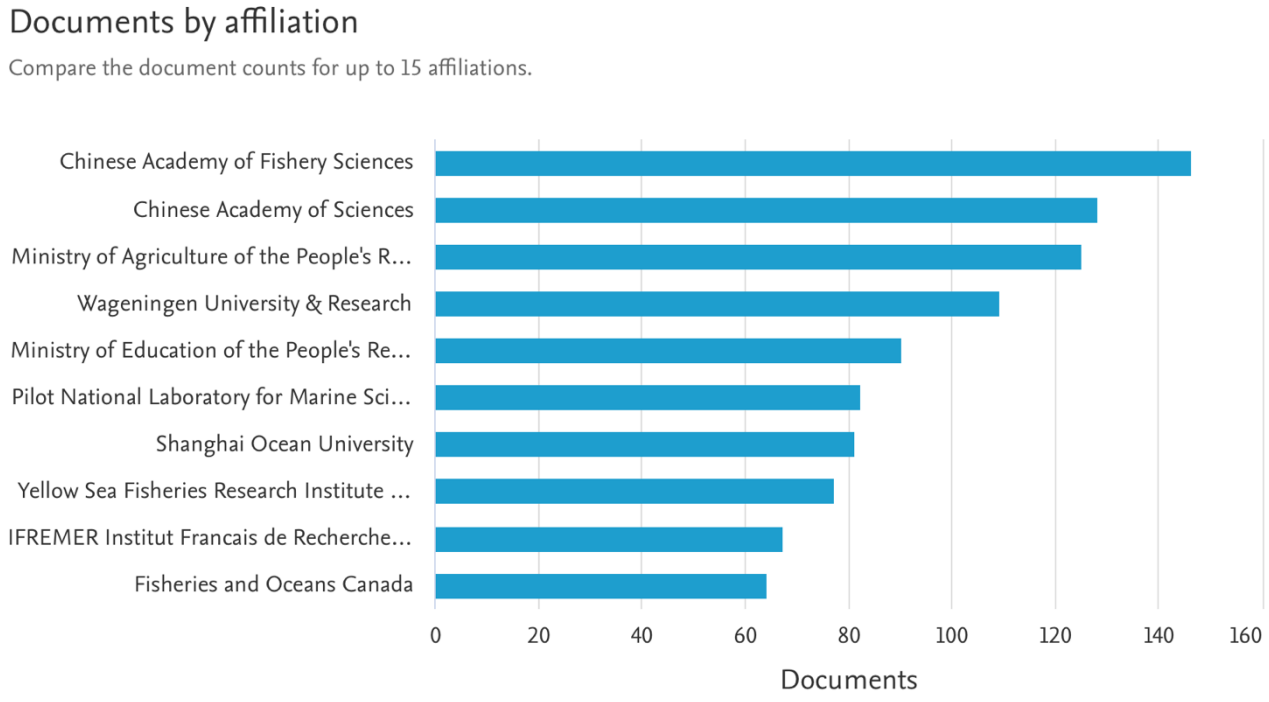
*Exploitation of the Sea*and *Fisheries and Oceans Canada* There were 109 documents (11.24%), 82 documents (8.46%), 67 documents (6.91%), and 64 documents (6.60%) respectively. This shows that China in research in the field of integrated aquaculture has a high research focus. In addition, it also indicates that research in the field of integrated aquaculture is getting serious attention from various affiliates in China.

Table 6. Documents by Affiliate.

Affiliate	Number of Documents
Chinese Academy of Fishery Sciences	146
Chinese Academy of Sciences	128
Ministry of Agriculture of the People's Republic of China	125
Wageningen University & Research	109
Ministry of Education of the People's Republic of China	90
Pilot National Laboratory for Marine Science and Technology	82
Shanghai Ocean University	81
Yellow Sea Fisheries Research Institute Chinese Academy of Fishery Science	77
IFREMER French Research Institute for the Exploitation of the Sea	67
Fisheries and Oceans Canada	64



Picture 8 Distribution of Document Count Based on Affiliate.

Collaboration Between Researchers in the Field of Integrated Aquaculture

The following figure 9 provides information about the collaboration network between authors in the field of integrated aquaculture. There are 9 inter-researcher network clusters. Researchers Øivind Strand and Ricardo Calado not only have an extensive network, but also connect various subgroups. This indicates that they have a very important role in terms of facilitating collaboration between researchers. On the other hand, Keesman and Goddek may have a significant influence in the field of integrated aquaculture research, but they focus more on specific areas or focus on their network groups.

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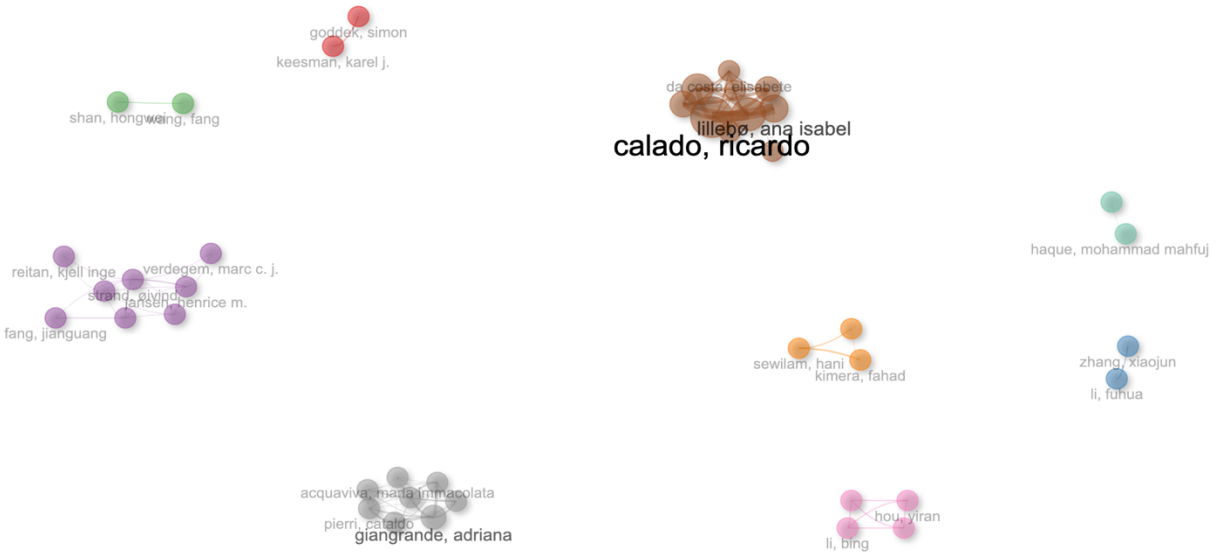
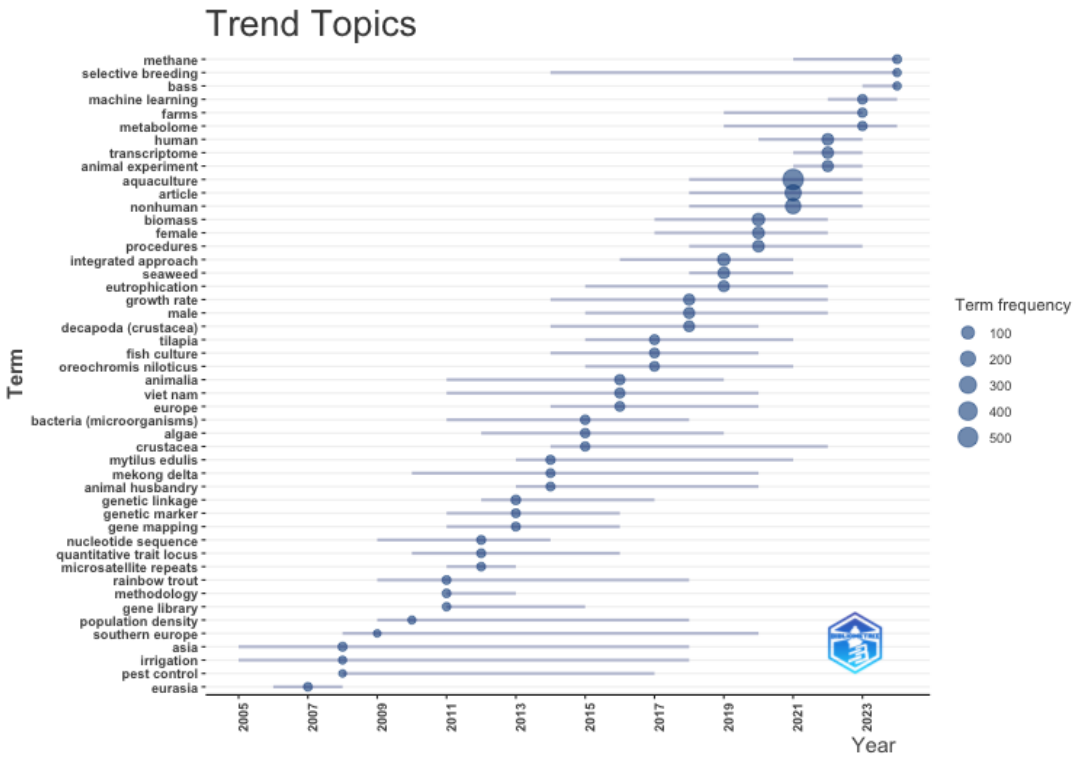


Picture 9 Network Between Researchers.

Visualization of Integrated Aquaculture Research Trends for the Period 1990-2024

Figure 10 provides information about the overview of integrated aquaculture research trends from various aspects. These various aspects are for example the organisms being researched and the approach from the technological side. Terms related to aquaculture, biotechnology, and sustainable have been on the rise in recent years. In general, research in the field of integrated aquaculture shows a diversification of topics focusing on sustainability, technology, and genetics issues.



Picture 10 Trends in Integrated Aquaculture Research Topics.

CONCLUSIONS

The results of this study show that there is an increasing trend of research in the field of integrated aquaculture. Research trends in the field of integrated aquaculture focus on sustainability

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and efficiency. For the direction of research in the field of integrated aquaculture, there are opportunities for further research on the aspects of new technology integration and socio-economic impacts. The results of this study recommend for further research, namely exploring the application of innovative technologies and evaluating sustainability issues from economic, social, and environmental perspectives. In addition, collaboration between countries needs to be strengthened to produce a more comprehensive approach to innovation and development of the integrated aquaculture sector in the future.

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