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Text mining and topic modeling insights on fish welfare and antimicrobial use in aquaculture

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Abstract

Antimicrobial use (AMU) and antibiotic resistance (AR) in aquaculture present growing concerns for public health. Furthermore, there exists a correlation between fishes' welfare and AMU. This systematic review aims to analyze the scientific literature on fishes' welfare and AMU/AR over the last 32 years, identifing the main research topics, and the fields where investigation has been imitated. A comprehensive search was conducted using Scopus, employing specific keywords related to AMU/AR and welfare and preselected filters. The study employed a systematic approach following the PRISMA guidelines, and machine learning techniques were used. From 2,019 records retrieved, only those focused-on fishes welfare and AMU/AR were retained. Ultimately, 185 records showing a connection between these topics were included in the qualitative analysis. Text mining analysis revealed terms with the highest weighted frequency in the data corpus, while topic analysis identified the top five core areas: Topic 1 (Antibiotic resistance and strain genetic isolation), Topic 2 (Aquaculture and Human Health, environment, and food), Topic 3 (Fish response to stress and indicators), Topic 4 (Control of water and fish growth), and Topic 5 (Aquaculture research and current farming methods). The results indicate a growing interest in fish welfare and AMU/AR, while also highlighting areas that require further investigation, such as the link between these research fields. Improving fish welfare can reduce AR, aligning with the One Health policy.

Keywords Aquaculture, Fish, Welfare, Antimicrobial use, Antibiotic resistance, Text mining, Topic analysis

Introduction

The global aquaculture industry has seen a significant increase in production, reaching a record of 184.6 million metric tons in 2022 [1] (https://www.statista.com/statistics/264577/total-world-fish-production-since-2002). This intensification has led to growing attention towards fish welfare. Due to higher production demands, fish production industries are encouraged to maintain high growth densities and so, fishes in farm are stressed and prone to possible infectious bacterial diseases, thus maximizing the need for antimicrobials [1–2].As a result of antimicrobial use (AMU) for the control of bacterial diseases, antibiotic resistance (AR) may occur in fish farming [3–4]

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which poses significant risks to both fish health and welfare and can potentially impact human health [5–8]. The development of resistant bacteria is driven not only by AMU but also by the co-selection of resistance genes and cross-resistance mechanisms [9–10]. These resistant bacteria in aquaculture present a serious public health risk, as they can be transmitted to humans through handling or consumption of affected fish [11–12].

Improve animal welfare by reducing stress can, therefore, reduce the frequency of infection and, consequently AMU/AR [4], an issue considered a growing threat within the "One Health" framework [5–8]. Attention to fish welfare is relatively recent, with recognition of their capacity to experience pain beyond basic nociception emerging less than 20 years ago [13–14]. Fishes are now considered intelligent, sentient beings with complex cognitive abilities [15–16] and improving their welfare could have positive effects on public health [8].

This study applies text mining (TM) and topic analysis to systematically review the existing literature, identifying prominent topics and trends related to fish welfare and AMU also considering this correlation into the One-Health context. The TM approach is a valuable tool for analyzing large volumes of text data and its potential applications in the assessment of fish welfare and AMU/AR are explained. The method allows for the efficient handling of unstructured textual data found in scientific literature, eliminating errors and saving time while providing precise insights [17]. TM uses word indexing techniques to extract meaningful information from large sets of text documents [17].

Materials and methods

Data sources and search strategy

A systematic scientific literature review was conducted to identify peer-reviewed papers with at least an English abstract that covered the topic of AMU/AR and welfare in aquaculture. We utilized Scopus® (i.e., the abstracts and citation database of Elsevier©), a widely accessibility database with broad coverage of peer-reviewed academic literature [18].

The search - performed in June 2023 – focused on papers published between 1990 and 2022, limiting results to subjects within Veterinary and Agricultural and Biological Sciences. We included only English-language publications, with an abstract available for quantitative analysis and full text availability for qualitative evaluation. If full texts were inaccessible online, authors were contacted directly. Papers lacking both an abstract and full text were excluded due to the necessity of these elements for screening and analysis. The records were stored in a Microsoft Office Excel® file, with rows representing individual documents and columns detailing various attributes such as author, affiliations, abstracts, publication year, document type (e.g., article or review), journal, and topic.

The literature search followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [19]. The search queries consisted of combinations of keywords related to AMU, AR, and welfare in aquaculture, using the TITLE-ABS-KEY function in Scopus. Keywords were connected by the 'AND' operator:

- Antibiotic resistance AND aquaculture (ARQ) [Title/Abstract/Keywords] (850 records);
- Welfare AND aquaculture (WA) [Title/Abstract/Keywords] (660 records);
- Aquaculture AND sustainable AND farming AND One AND Health (ASFOH) [Title/Abstract/Keywords] (17 records);
- Antimicrobial use AND aquaculture (AUA) [Title/Abstract/Keywords] (818 records);
- Antibiotic resistance AND fish farm (ARFF) [Title/Abstract/Keywords] (190 records);
- Aquaculture AND one AND welfare (AOW) [Title/Abstract/Keywords] (116 records);
- Aquaculture AND food AND safety AND legislation (AFSL) [Title/Abstract/Keywords] (27 records).

A total of 2,678 records were retrieved.

Eligibility criteria, selection process and data collection process

After downloading 2,678 records from Scopus, 637 duplicate entries were removed. Additionally, 22 records (16 without abstract and 6 presenting errors) were excluded. This left 2,019 records for further screening, during which three reviewers (APas-APr-VB) independently assessed titles and abstracts based on predefined inclusion and exclusion criteria. Any disputes during the screening process were resolved by an expert in animal welfare (APas). Documents were included if they focused on the following topics:

- Fish welfare in aquaculture;
- Aspects on welfare/AMU/AR linked to aquaculture technologies;
- AR in aquaculture;
- Ethical issues on the topic;
- Legislation about aquaculture, fish farming, welfare, and antimicrobics' use in aquaculture;
- Alternative solutions to combat AR in aquaculture.

Inclusion and exclusion labels' criteria defined for screening titles and abstracts are reported in Table 1.

A total of 1,574 articles ($n = 274$ topics related to drugs, diseases, and vaccines; $n = 4$ generic welfare;

Table 1 Inclusion and exclusion labels' criteria

Inclusion criteria (labels)	**Reasons**
Welfare	Reports relating to fishes' welfare in aquaculture
Aquaculture technologies	Reports relating to any aspects on welfare/antibiotic resistance linked to aquaculture technologies
Antibiotic resistance	Reports on antibiotic resistance in aquaculture
Ethics on the topic	Reports on ethics aspects on the topic
Legislation	Legislation about aquaculture, fish farming, welfare, and antimicrobics' use in aquaculture)
Proposed alternative to AR	Reports that indicate alternative solutions to antibiotic resistance
Exclusion criteria (labels)	**Reasons**
Other/many species	Other species than fishes or other aspect not relating on aquaculture, welfare, legislation, antibiotic resistance, antimicrobial use.
Disease, drugs, vaccines	All articles about viral, bacterial, parasitic, or fungal diseases that no interesting antibiotic resistance
Humans	Articles related to human perceptions, structured from a human point of view, or on animal abuse or on relinquishment reasons, animal hoarding
Generic Welfare	Generic protocols to assess stress and welfare on pets or to reduce/improve them, generic welfare legislation, fishes' welfare related to other phases of production such as transport, slaughter, etc.
Others	Articles on drugs' pharmacokinetics, toxic, genetics, effectiveness, side/adverse effects, flower extracts, essential oils, others fishes' aspects, biofilm, behaviour not related to welfare, others substances with antimicrobial effects, withdrawal, fishery export refusals time, diet.

$n = 6$ humans; $n = 87$ others/many species; $n = 1{,}203$ other issues) were excluded, leaving 445 for descriptive analysis, and TM and TA. Furthermore, 185 records that addressed the connection between fish welfare and AMU/AR were selected for qualitative analysis. The flowchart in Fig. 1 reports the systematic literature search protocol and the manual screening of records.

Descriptive statistics

Descriptive statistics were applied to the selected records, generating an overview of the data, including the number of publications per year, top journals, and the most frequently cited articles related to AMU/AR and welfare in aquaculture. Pivot tables were used to analyze publication trends. Variables were tested for normality using the Shapiro-Wilk test, and Student's t-test was applied where appropriate. Results were considered statistically significant at a P-value ≤ 0.05.

Text mining

TM was performed using RStudio (Version 1.3.1093, Free Software Foundation, Boston, MA, USA) after downloading the dataset. An Excel sheet was prepared with two specific columns: "doc_id" (document number), with the progressive numeration of the 445 documents, and "text" (abstract of each paper). Preprocessing [20] included converting text to lowercase, removing punctuation, numbers, stop words (e.g. "the", "a", "and", "on", etc.), and unnecessary symbols (such as "@", "/" or "*"). Text tokenization was carried out to reduce words to their root form.

A document-term matrix (DTM) that contains the documents along the rows and the terms along the columns was built. A term frequency-inverse document frequency technique (TF-IDF) was calculated to assign weight to words based on their relevance across documents [21]. Words with a TF-IDF ≥ 3 were visualized as histogram, and a word cloud was generated using "https://www.wordclouds.com/" to represent frequently occurring terms. Associations between the most relevant words (TF-IDF ≥ 3) and all the document terms in the corpus were identified, considering a correlation threshold of ≥ 0.2.

Statistical analysis was performed with R package (2017) using functions from the package's "tm", "SnowballC", "ggplot2", "dplyr", and "tidyverse".

Topic modelling analysis

Latent Dirichlet Allocation (LDA), a probabilistic model for discovering the main topics from the substantial text content, was applied for the TA. LDA assumes that documents contain a mixture of words regarding potential topics, and each topic can be considered as a multinomial distribution of words [22–23]. We used "topic models" package in R [24] with the Gibbs sampling to identify five key topics from the corpus.

The cumulative probability of top 15 words in each topic was calculated, and topics were visualized using bar histogram. Topics were named based their most significant words (beta value = coefficient measuring the importance/weight of the word in the topic), following the approach of Nalon et al. (2021) [25]. This process helped uncover thematic patterns in the literature, providing insight into the relationship between fish welfare and AMU/AR.

Results

Descriptive analysis

Figure 2 provides a general overview of the number of publications per year. Between 1990 and 2022, 445 records were selected for this study. Before 2015, fewer than 20 articles were published annually, but since 2005, there was a significant increase in publications ($P < 0.001$). Over half of the articles have been published since 2019 ($n = 62$) with a peak in 2021 ($n = 108$).

Aquaculture Research ($n = 29$) and Aquaculture ($n = 27$) were the leading journals publishing these articles,

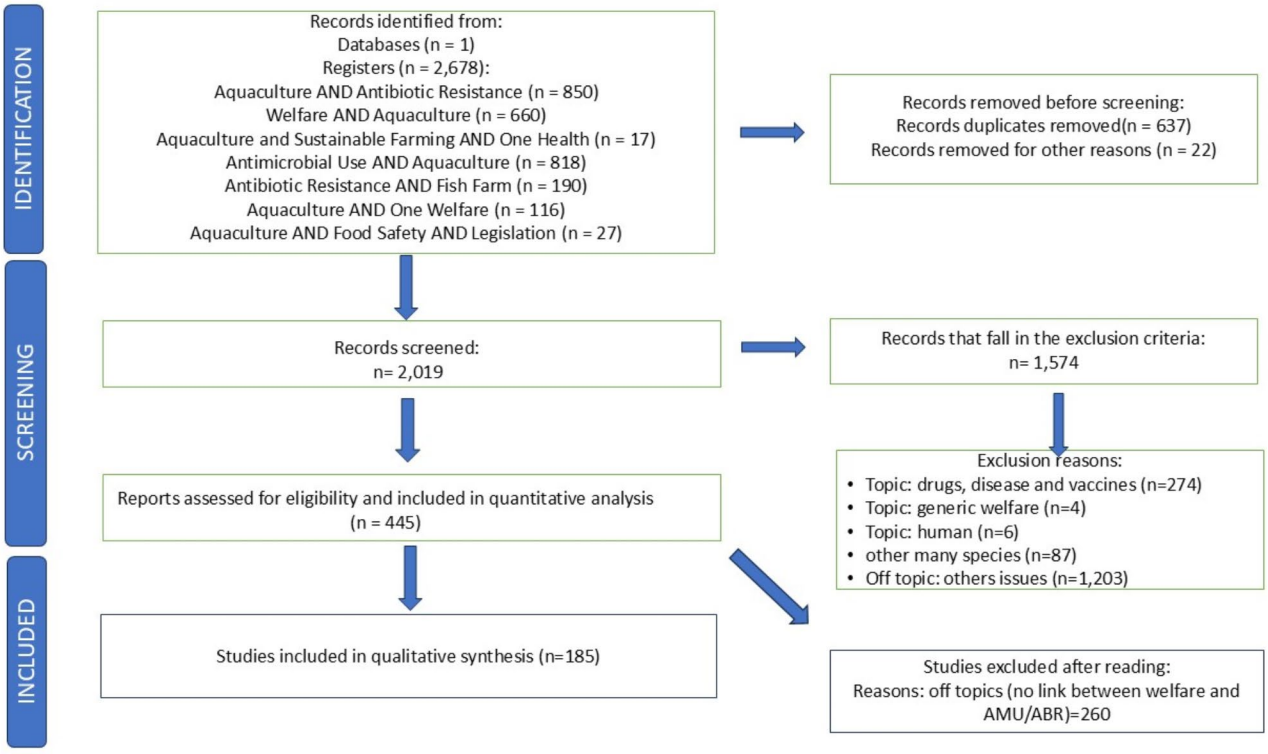

Fig. 1 Flow-chart represents graphically the search protocol

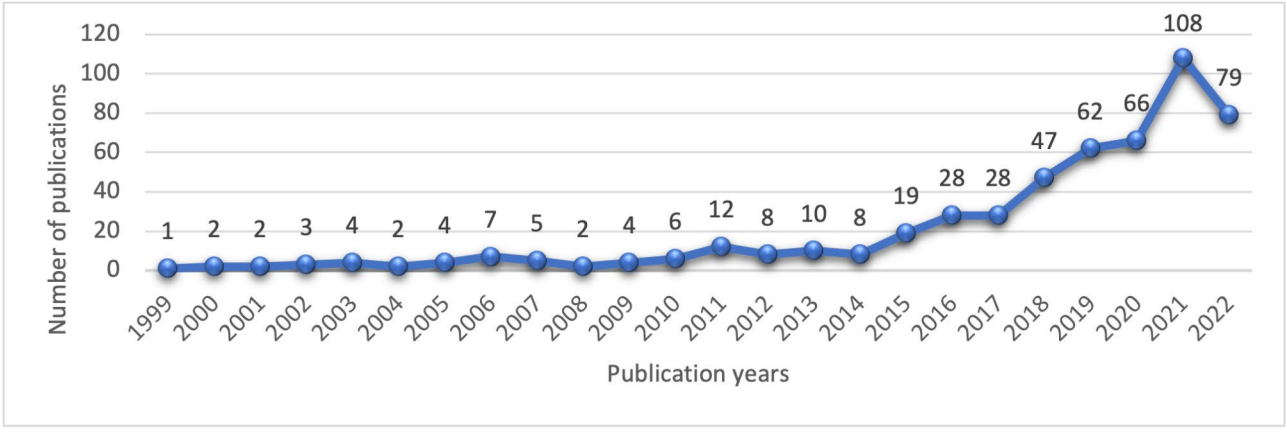

Fig. 2 The number of peer-reviewed articles regarding the AMU/AR and welfare in aquaculture published per year within the period 1990–2022

followed by Animals ($n = 18$), Antibiotics ($n = 16$), and Reviews in Aquaculture ($n = 16$).

Table 2 lists the ten most-cited papers, including the title and citations count.

The most cited publication was Verschuere et al. (2000) [26] with 1,507 citations. It discussed the role of probiotic bacteria as biological control agents in aquaculture, highlighting their mechanisms like inhibiting pathogens, competing for resources, enhancing immune response, and improving water quality. The second most cited paper was by Hong et al. (2005) [27], with 737 citations, focusing on probiotics as an alternative to AMU. Seiler and Berendonk (2012) [28] came in third with 649 citations, empathizing metal-driven co-selection of ABR in aquaculture and agriculture. The other highly cited papers cover a range of topics fromfish welfare to AMU's impact on resistance in the environment, and AR in Vibrio specie. Huntingford et al. (2006) [29] received 586 citations. Their article provided a broad overview of the current understanding of several issues relating to fish welfare. The review of Cabello et al. (2013) [30] examining AMU in aquaculture (especially on salmon) and its impact on the molecular genetics and evolution of AR in the environment have 518 citations. The sixth most

Table 2 The top ten most-cited documents. GC: global citations

No.	Authors/Year/Journal	Title of the publication	GC
1	Verschuere et al., 2000, Applied and Environmental Microbiology	Probiotic bacteria as biological control agents in aquaculture	1,507
2	Hong et al., 2005, FEMS Microbiology Reviews	The use of bacterial spore formers as probiotics	737
3	Seiler and Berendonk, 2012, Frontiers in Microbiology	Heavy metal driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture	649
4	Huntingford et al., 2006, Journal of Fish Biology	Current issues in fish welfare	586
5	Cabello et al., 2013, Environmental Microbiology	Antimicrobial use in aquaculture re-examined: Its relevance to antimicrobial resistance and to animal and human health	518
6	Watts et al., 2017, Marine Drugs	The rising tide of antimicrobial resistance in aquaculture: Sources, sinks and solutions	362
7	Schmidt et al., 2000, Applied and Environmental Microbiology	Occurrence of antimicrobial resistance in fish-pathogenic and environmental bacteria associated with four danish rainbow trout farms	307
8	Martins et al., 2012, Fish Physiology and Biochemistry	Behavioural indicators of welfare in farmed fish	257
9	Elmahdi et al., 2016, Food Microbiology	Antibiotic resistance of Vibrio parahaemolyticus and Vibrio vulnificus in various countries: A review	246
10	Jajere S.M. et al., 2019, Veterinary World	A review of Salmonella enterica with particular focus on the pathogenicity and virulence factors, host specificity and adaptation and antimicrobial resistance including multidrug resistance	240

cited document (362 citations) analyzed the transfer of AR between the microbial community, the environment, and the aquaculture product, to better understand the implications to human and environmental health [31]. The seventh document in citations (307) was research published by Schmidt et al. (2000) [32] regarding bacterial susceptibility to five antimicrobial agents in and around fish farms situated along a stream in western Denmark. The eighth article was published in 2012 and has been cited 257 times in the Scopus database. It relates to behavioral changes used to assess welfare in farmed fish, using both functional and feeling-based approaches [33]. The ninth most cited document (246 citations) was a review on antibiotic resistance of Vibrio [34]. Finally, the tenth article with 240 citations was published in Veterinary World in which Jajere (2019) [35] discussed AR focusing on *Salmonella enterica*.

Text mining

TM was conducted using the inverse document frequency to calculate the importance of specific terms. Words like "isol", "resist", "gene","antimicrobi", "antibiot" "salmon" "bacteria" "stress", "farm", "water", "strain" "anim" and "environ" and "density", "product", "health", "group", "system", "human", "level", "growth", "treatment", "speci", "feed", "increa", "aeromonad", "pathogen", "bacteri", "shrimp", "aquat", "indic","respon", "differ" (TD-IDF ≥ 3) were identified as the most relevant and frequent (Fig. 3).

To visualize the most frequently occurring terms, a word cloud was generated with a font size proportional to the TF-IDF value of each word, as shown in Fig. 4.

The Table 3 provides the associations between the most relevant words (with a TF-IDF ≥ 3) and the other words in the dataset, with correlations of ≥ 0.2).

Noteworthy associations include "Aquat" linked to "invertebrate" (0.45); "bacteria" with "plasmid" (0.46), and "gene" with "tetracyclin" (0.43). Additionally, words like "strain" showed correlations with "rifampicin (0.58)", "novobiocin (0.50), and chloramphenicol (0.42); "feed" with "intellig" (0.49) and "tradit" (0.41); "density" is significantly associated with "stock" (0.65) and "rear" (0.42); water" is often associated (0.45) with word "quality"; "cortisol" with "stress"(0.62) and plasma (0.60).

Finally, among the 445 articles screened, 58 included the word "salmo" in the title and 82 included this word in the abstract.

Topic analysis

LDA was applied to categorize the content into five topics in according to Nalon et al. (2021) [25]. The name and number of records for each topic are summarized in Table 4.

The most represented topics were Topic 1 ("Antibiotic resistance and strain genetic isolation"), Topic 2 ("Aquaculture and Human Health, environment and food"), and Topic 3 ("Fishes' response to stress and indicator"), with 141, 92, and 75 records, respectively.

Figure 5 illustrates the most relevant words for the five topics in LDA analysis, with each topic visualized by the cumulative probabilities (cp.) of the top 10 words.

Finally, the temporal trend of topics across 32-years period is presented in Fig. 6. Each topics exhibited a significant rise in publications post-2019, with most papers being published between 2019 and 2022.

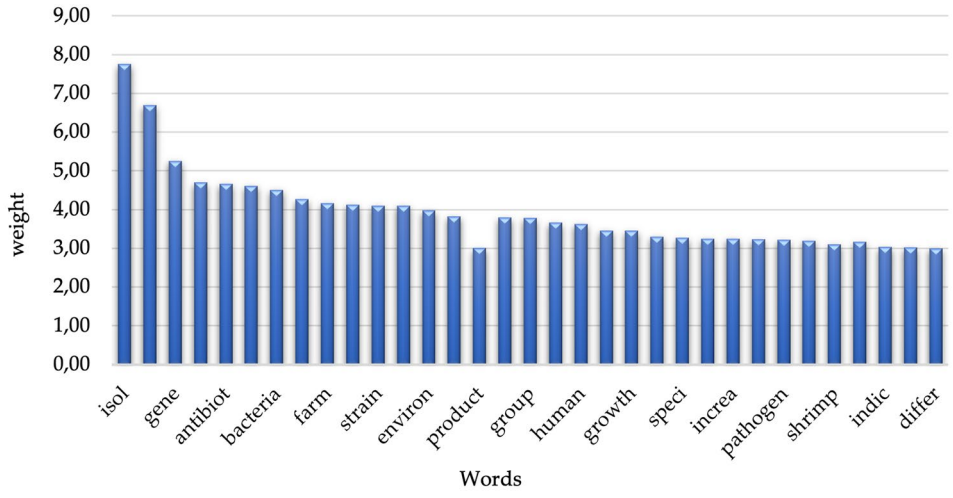

Fig. 3 The most frequent words with a TFIDF ≥ 3 and their weight across the studied records

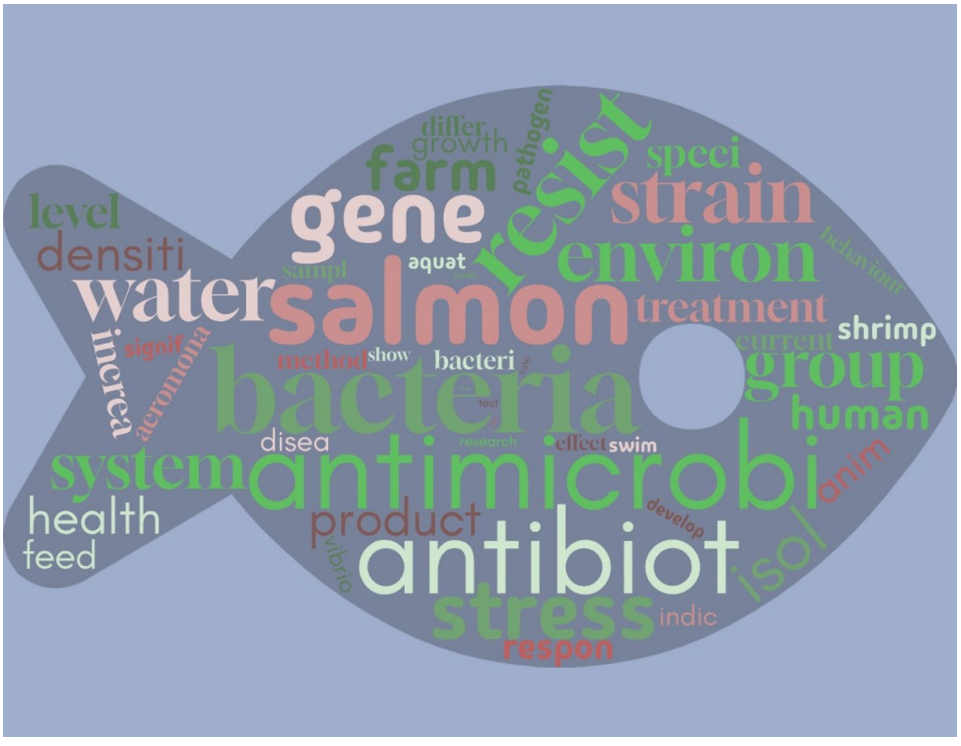

Fig. 4 Word cloud depicting the most frequent words, with larger fonts indicating higher TF-IDF values

Discussion

This study systematically examined scientific research on fish welfare and AMU/AR in the Scopus database, a widely accepted resource in the scientific community [9–10–11–12]. Using TM and TA, we were able to identify significant trends and gaps in current research, which can guide future investigations in the field of aquaculture. A key contribution of this study is its systematic approach to recognizing underexplored areas, particularly in relation to the pressing issue of AMU and AR, with potential applications in improving aquaculture practices.

The results of the TA largely aligned with expectations, with a particular focus on antibiotic resistance, strain genetic isolation, fish stress responses, and farming methodologies. These topics have been widely researched within aquaculture, indicating their importance.

Although concept extraction and trend analyses have been conducted in other areas of veterinary science, such

Table 3 Significant correlation (≥ 0.2) between the most relevant words (TF-IDF ≥ 3) and the remaining words in the matrix

Words (TF-IDF≥3)	Associated words (correlation ≥ 0.2)
Aeromona	cavia (0.51); aeromonad (0.42); sobria (0.40).
Aquat	invertebrat (0.45)
Bacteria	plasmidimedi (0.46)
Density	stock (0.65); rear (0.42)
Feed	intellig (0.49); tradit (0.41)
Gene	teta (0.46); tetracyclin (0.43)
Health	compon (0.43)
Water	quality (0.45)
salmon	atlant (0.61); lice (0.55); attach (0.42); salar (0.42); infest (0.40)
Growth	perform (0.43)
resistance	ampicillin (0.46); chloramphenicol (0.40)
respon	cortisol (0.43); acut (0.41)
Strain	rifampicin (0.58); novobiocin (0.50); chloramphenicol (0.42)
Stress	cortisol (0.62); plasma (0.40)
Treatment	failure (0.48)

Table 4 Label and number of papers per topic, along with the first year of publication

Topic number	Label of the topic	Papers (n)/from year
1	Antibiotic resistance and strain genetic isolation	141/1999
2	Aquaculture and Human Health, environment, and food	92/2005
3	Fishes' response to stress and indicators	75/2006
4	Control of water and fishes' growth	69/2003
5	Current aquaculture research on farming method	68/2000

as the farm animal welfare [25, 36–37], there appears to be a notable absence of similar studies focusing specifically on fish welfare and AR. Interestingly, the number of publications on this topic has been risen significantly since 2019, coinciding with the COVID-19 pandemic, which emphasized the fragile nature of global food systems and highlighted the importance of reevaluating food consumption legislation [38].

One of the most researched topics in the context of AR concern the isolation of genes responsible for the transmission. Salmon is notably the most frequently studied species, but research is expanding to include invertebrates like decapods which are sentient and thus deserve ethical and legislative consideration [39].

Fish welfare, especially in relation to diet, also plays a role in influencing AMU and AR in aquaculture. As evidenced by the correlation study, there is a significative association between the words "diet" and "intelligent"/"traditional" the words.

One of the most pressing concerns identified is the inappropriate use of antibiotics, which creates selective pressure and promotes the survival of resistant bacteria by means of adaptive mechanisms involving transferable nucleotide sequences (i.e., plasmids) (Topic 1, Antibiotic resistance and strain genetic isolation, with 141 records). As above mentioned, also the text mining analysis highlights that the terms "isol," "resist," "gene," "antimicrobi," and "antibiot" are among the most relevant. Phylogenetic analysis suggests that the genomic origin of resistant bacteria is often identical, reinforcing the idea that antibiotic resistance (AR) genes are exchanged across animal and environmental microbiomes via horizontal gene transfer [2]. Research has identified tetracycline, rifampicin, novobiocin, and chloramphenicol as the most studied antibiotics. The associations between "strain" and "rifampicin" (0.58), "novobiocin" (0.50), and "chloramphenicol" (0.42) support this statement [2]. Regarding the antimicrobial class, aquaculture farms commonly rely on tetracyclines for the treatment and prevention of infectious disease, given that they are considered a cost-effective and highly effective class of antibiotics [2]. Furthermore, the inappropriate use of antibiotics creates selective pressure that promotes the survival of resistant bacteria through adaptive mechanisms involving transferable nucleotide sequences (i.e., plasmids).

The topic 2 (Aquaculture and Human Health, Environment, and Food) emerges as crucial in aquaculture research, as it highlights the interconnection between farming practices and the broader consequences for human health, the environment, and food safety, reinforcing their relevance of the "One Health" concept, which advocates for a holistic approach to health across species and ecosystem. These findings support the notion that research on fish welfare can reduce AMU, which in turn has positive implications for human health. Text analysis reveals that terms such as "health," "human," "product," and "environ" are among those with the highest weighted frequency. Studies in this area focus on the need for responsible management of antibiotics in aquaculture, given the possible transmission of resistant bacteria to humans through the handling or consumption of contaminated fish. Environmental conditions, as welfare conditions, also play a significant role in AMU and AR, with factors like nutrient levels and the presence of pollutants in water influencing the distribution of antibiotic resistance genes (ARGs). Heavy metals (mainly the As, Cu, Cr and Se), antibiotics, and others water parameters (Total Phosphorusand Electrical Conductivity, etc.) have all been linked to the maintenance and spread of ARGs in aquatic environments [44]. Several studies have used specific water quality indicators (i.e. nitrate nitrogen and dissolved potassium; total ammonia nitrogen and total vibrio) to assess fish health and welfare [45–47].

Attention to legislation and regulation on the use of antibiotics in aquaculture is therefore fundamental,

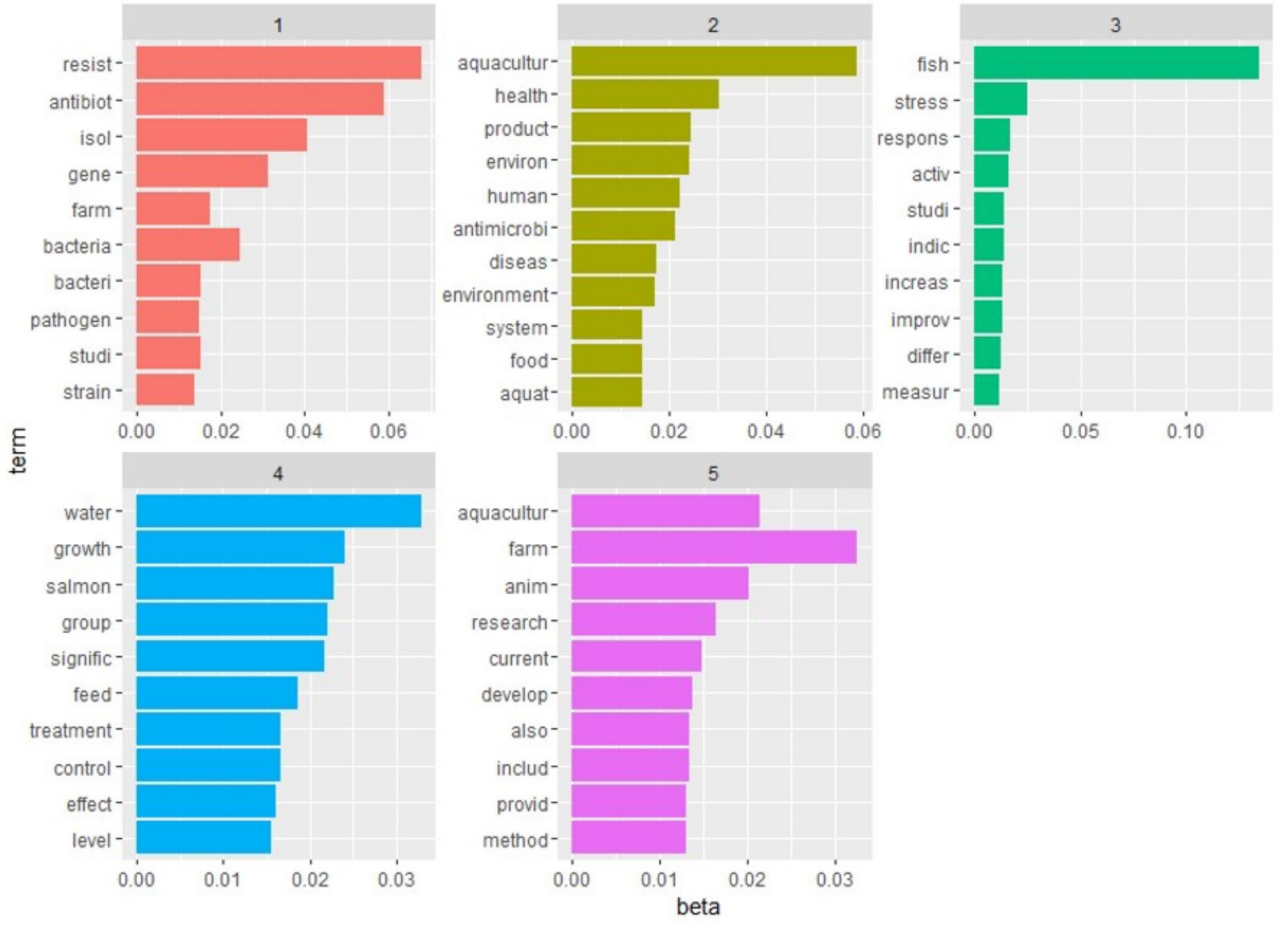

Fig. 5 Bar histograms illustrating the most relevant words for five main topics based on their relative probability where "beta" indicates the relative probability of each word belonging to each topic

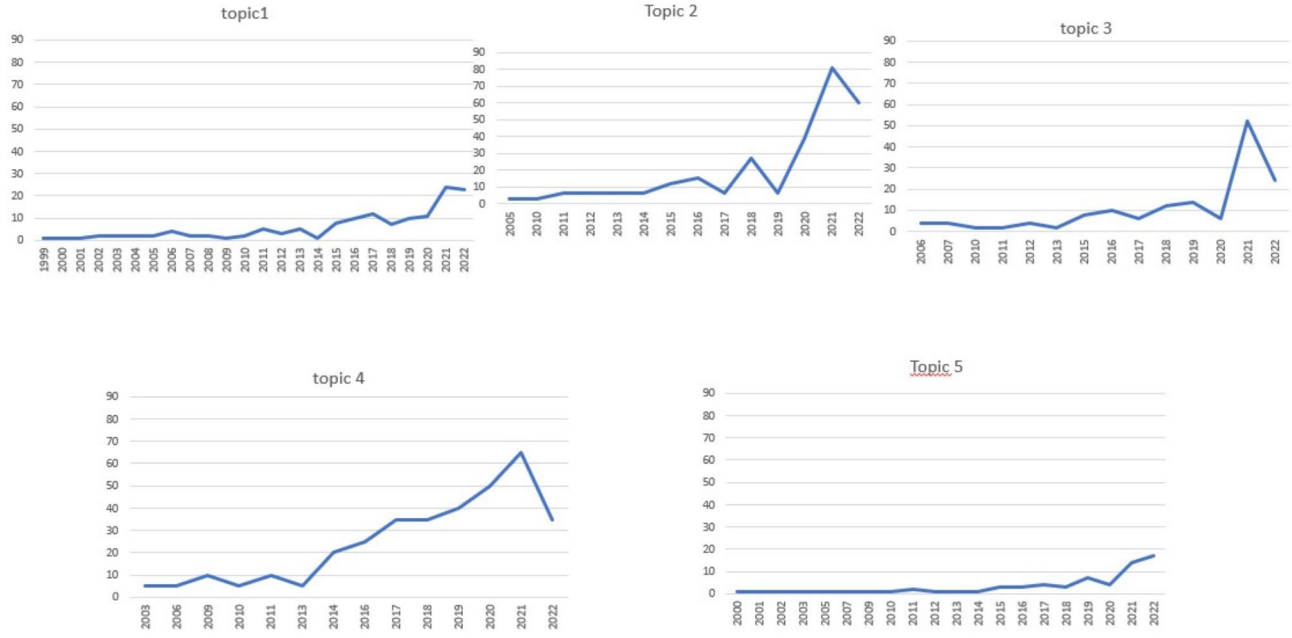

Fig. 6 Time-trend analysis of topics distributions from 1990 to 2022

particularly to harmonize the lists of antibiotics that can be used to treat fish diseases, taking into account the environmental impact.

Research in this field is essential to ensure that aquaculture practices are sustainable and do not compromise public and environmental health. Efforts to regulate the use of antibiotics in aquaculture have been made by the Food and Drug Administration (FDA) (2023) [49–50] and the United States Department of Agriculture (USDA) (2018). European legislation (European Commission, 2009) [51] provides more detailed and species-specific (including finfish and shellfish) limits for an extensive range of xenobiotics. For the export of finfish products, the legislators of the developing countries (Brazil, Vietnam, Chile, China, India, Philippines, and Thailand) have adopted parameters like those of the European Union and the United States [2]. In response to the AMR phenomenon, many regulatory agencies are working together on improvement of antimicrobial stewardship. For example, the FDA continues to detect nitrofurans and chloramphenicol in collaboration with Malaysian aquaculture producers, and as a result this country has banned them. China has implemented innovative and specific "Applicative Guidelines", specifying the use of sulfonamides, tetracycline, and enrofloxacin, which have been adopted in other Asian countries such as Vietnam. It is imperative to harmonize the lists of antibiotics that can be used to treat finfish diseases (see topic 3 -Aquaculture and Human Health, environment, and food) due to the environmental impact that poses a risk to human and animal health.

The emerged topics identified through TA are closely interconnected, particularly those relating to fish stress responses (topic 3), which directly affect susceptibility to antimicrobials. In fact, i.e., Karvonen et al. (2021) [48] investigated how the amount and type of aquaculture enrichment (few versus many stones; clean versus seawater-treated stones) affected bacterial infection severity in salmonids. Stone conditioning significantly increased the survival rate of hosts in rearing tanks with few stones and increased host survival was also observed with more unconditioned stones. Heterogeneity of aquaculture environments can significantly reduce disease impact by reducing the transmission of pathogen (quantity of stones) and by establishing beneficial microbial communities (quality of stones). This supports enrichment as an ecological and economical method of preventing bacterial infections by minimizing use of antimicrobial agents.

Regarding "Control of Water and Fish Growth" (Topic 4), it concerns the practices of water and feed management used to optimize fish growth, also taking into account the impact on their welfare. Intelligent feeding systems, for example, have been shown to improve fish growth performance and reduce feeding costs [40]. However, these systems can also increase stress levels and suppress innate immunity.

Stocking density is another critical factor influencing welfare, with both overcrowding and understocking causing adverse physiological and immune responses in fish, especially in trout, thus impacting AMU in aquaculture (Table 3, words "density" and "rear"/ "stock") [41].

Other Authors [42–43] have investigated stocking density effects on growth performance and welfare in different species such as Atlantic salmon. Similarly, another study looked at the welfare implications of stocking density for juvenile tilapia evaluating the overall stress reaction, considering the first (cortisol), second (physiological) and thirst (growth) reactions or, different stocking densities and their influence on the metabolic stress on growth performance [1].

Water quality is a determining factor for fish health, and its appropriate management is fundamental for a sustainable aquaculture system. Research in this area is important for developing aquaculture practices that promote efficient fish growth while ensuring their welfare.

Topic 5 (Aquaculture Research and Current Farming Methods) focuses on the evolution of farming practices in aquaculture and the continuous search for innovative solutions to improve fish welfare and minimize the environmental and human health impact. Farming technologies and management methods play a fundamental role in ensuring fish welfare and reducing the need for antibiotics. This theme also includes the analysis of ethical and legislative implications related to fish welfare, the use of antimicrobials, and sustainable farming practices.

Finally, improve animal welfare reducing stress can reduce AMU and consequently AR [4] contributing to excellent results in terms of One Health. The concept of One Health, as defined by the One Health High Level Expert Panel (OHHLEP), recognizes the interconnectedness of human, animal, and environmental health (https://www.fao.org/one-health/background/ohhlep/en). It emphasizes the need to balance and optimize the health of all these components, mobilizing various sectors and disciplines to work together towards well-being and addressing threats to health and ecosystems. This approach encompasses the collective need for clean water, energy, and air, safe and nutritious food, action on climate change, and sustainable development. However, despite the comprehensive nature of One Health, there is currently a lack of legislation specifically addressing fish welfare in the context of sustainable aquaculture. This gap highlights the need for further studies and research on fish welfare to ensure that the principles of One Health and One Welfare are applied to all aspects of animal welfare, including fish. Addressing this gap will be crucial for promoting sustainable aquaculture practices that prioritize fish welfare while safeguarding human and

environmental health under the One Health-One Welfare paradigm.

Nevertheless, this study has some limitations. Although the search strings for entry into the Scopus search were discussed in detail, certain synonyms may not have been included and therefore fewer records might have been retrieved. Additionally, the reliance on the Scopus® database may have excluded relevant studies published in other sources. Finally, it is possible that other adverbs or conjunctions have appeared in the elaboration that have not been recruited as stop words.

Conclusions

Through the application of machine learning techniques, this review has shed light on the growing concern of AMU/AR in aquaculture and its link to fish welfare. It also identified five key research areas that require further exploration. Given the rising importance of research-based policies to protect fish welfare, it is crucial to conduct additional studies that focus on reducing AM, which would in turn mitigate AR. Improving fish welfare is not only essential for the sustainability of aquaculture but also broader implication for food safety and public health within the One Health- One Welfare framework.

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The undersigned Michela Pugliese as the corresponding author of the manuscript declares to be an Editorial Board Member, therefore existing a competing interest, she must excluded from the peer review process.

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References

1. Costa AP, Roubach R, Dallago BSL, Bueno GW, McManus C, Bernal FEM. Influence of stocking density on growth performance and welfare of juvenile tilapia (Oreochromis niloticus) in cages. Arq Bras Med Vet Zootec. 2017;69(1):243–51. https://doi.org/10.1590/1678-4162-8939.
2. Ferri G, Lauteri C, Vergara A. Antibiotic Resistance in the Finfish Aquaculture Industry: a review. Antibiotics. 2022;11(11):1574. https://doi.org/10.3390/antibiotics11111574.
3. Chen J, Sun R, Pan C, Sun Y, Mai B, Li QX. Antibiotics and Food Safety in Aquaculture. J Agric Food Chem. 2020;68(43):11908–19. https://doi.org/10.1021/acs.jafc.0c03996.
4. Salamanca N, Giráldez I, Morales E, De La Rosa I, Herrera M. Phenylalanine and tyrosine as feed additives for reducing stress and Enhancing Welfare in Gilthead Seabream and Meagre. Animals. 2020;11(1):45. https://doi.org/10.3390/ani11010045.
5. Jani K, Srivastava V, Sharma P, Vir A, Sharma A. Easy Access to Antibiotics; spread of Antimicrobial Resistance and implementation of one Health Approach in India. J Epidemiol Glob Health. 2021;11(4):444–52. https://doi.org/10.1007/s44197-021-00008-2.
6. Bizzaro G, Vatland AK, Pampanin DM. The one-health approach in seaweed food production. Environ Int. 2022;158:106948. https://doi.org/10.1016/j.envint.2021.106948.
7. Miao L, Li H, Ding W, Lu S, Pan S, Guo X, Zhou XN, Wang D. Research priorities on One Health: a bibliometric analysis. Front Public Health. 2022;10:889854. https://doi.org/10.3389/fpubh.2022.889854.
8. Rømer Villumsen K, Bojesen AM. Addressing a rule of Thumb: modeling the effects of Meteorological conditions on prescription of antimicrobials in Aquaculture. Microbiol Spectr. 2022;10(5):e0175222. https://doi.org/10.1128/spectrum.01752-22.
9. Hossain A, Habibullah-Al-Mamun M, Nagano I, Masunaga S, Kitazawa D, Matsuda H. Antibiotics, antibiotic-resistant bacteria, and resistance genes in aquaculture: risks, current concern, and future thinking. Environ Sci Pollut Res Int. 2022;29(8):11054–75. https://doi.org/10.1007/s11356-021-17825-4.
10. Larsson DGJ, Flach CF. Antibiotic resistance in the environment. Nat Rev Microbiol. 2022;20:257–69. https://doi.org/10.1038/s41579-021-00649-x.
11. Okacha RC, Olatoye IO, Adedeji OB. Food safety impacts of antimicrobial use and their residues in aquaculture. Public Health Rev. 2018;39(21):1–22. https://doi.org/10.1186/s40985-018-0099-2.
12. De Souza GLE, De Brito KCT, Nakazato G, Cavalli LS, Otutumi LK, De Brito BG. Antimicrobials and resistant bacteria in global fish farming and the possible risk for public health. Arq Inst Biol. 2020;87:1–11. https://doi.org/10.1590/1808-1657000362019.
13. Sneddon LU, Braithwaite VA, Gentle MJ. Do fishes have nociceptors? Evidence for the evolution of a vertebrate sensory system. Proc. R. Soc. London Ser. B Biol. Sci. 2003;270:1115–1121.
14. Ashley PJ, Sneddon LU, McCrohan CR. Nociception in fish: stimulus-response properties of receptors on the head of trout Oncorhynchus mykiss. Brain Res. 2007;1166:47–54. https://doi.org/10.1016/j.brainres.2007.07.011.
15. De Pasquale C, Sturgill J, Braithwaite VA. A standardized protocol for preference testing to assess fish welfare. J Vis Exp. 2020;156:e60674. https://doi.org/10.3791/60674.
16. Fernö A, Folkedal O, Nilsson J, Kristiansen TS. Inside the fish brain: cognition, learning consciousness. In: Kristiansen T, Fernö A, Pavlidis M, van de Vis H, editors. The Welfare of Fish. Animal Welfare Cham. Springer, 2020;20.
17. Eroglu Y. Text Mining Approach for Trend Tracking in Scientific Research: a Case Study on Forest Fire. Fire. 2023;6:33. https://doi.org/10.3390/fire6010033.
18. Mongeon P, Paul-Hus A. The journal coverage of web of science and Scopus: a comparative analysis. Scientometrics. 2016;106(1):213–28.
19. Moher D, Liberati A, Tetzlaff J, Altman DG. PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;6(7):e1000097. https://doi.org/10.1371/journal.pmed.1000097.
20. Sebastiani F. Machine learning in automated text categorization. ACM-CSUR. 2002;34(1):1–47.
21. Salton G, Buckley C. Term-weighting approaches in automatic text retrieval. Inf Process Manage. 1988;24(5):513–23. https://doi.org/10.1016/0306-4573(88)90021-0.
22. Blei DM, Ng AY, Jordan MI. Latent Dirichlet Allocation. J Mach Learn Res. 2003;3:993–1022.
23. Jelodar H, Wang Y, Yuan C, Feng X, Jiang X, Li Y, Zhao L. Latent dirichlet allocation (LDA) and topic modeling: models, applications, a survey. Multimed Tools Appl. 2019;78(11):15169–211. https://doi.org/10.1007/s11042-018-6894-4.
24. Grün B, Hornik K. Topicmodels: an R Package for Fitting Topic models. J Stat Softw. 2011;40(13):1–30. https://doi.org/10.18637/jss.v040.i13.

25. Nalon E, Contiero B, Gottardo F, Cozzi G. The Welfare of Beef Cattle in the scientific literature from 1990 to 2019: a text Mining Approach. Front Vet Sci. 2021;7:588749. https://doi.org/10.3389/fvets.2020.588749.
26. Verschuere L, Rombaut G, Sorgeloos P, Verstraete W. Probiotic bacteria as biological control agents in aquaculture. Microbiol Mol Biol Rev. 2000;64(4):655–71. https://doi.org/10.1128/MMBR.64.4.655-671.2000.
27. Hong HA, Duc LH, Cutting SM. The use of bacterial spore formers as probiotics. FEMS Microbiol Rev. 2005;29(4):813–35. https://doi.org/10.1016/j.femsre.2004.12.001.
28. Seiler C, Berendonk TU. Heavy metal driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture. Front Microbiol. 2012;3:399. https://doi.org/10.3389/fmicb.2012.00399.
29. Huntingford FA, Adams C, Braithwaite VA, Kadri S, Pottinger TG, Sandøe P, Turnbull JF. Current issues in fish welfare. J Fish Biol. 2006;68(2):332–72. https://doi.org/10.1111/j.0022-1112.2006.001046.
30. Cabello FC, Godfrey HP, Tomova A, Ivanova L, Dölz H, Millanao A, Buschmann AH. Antimicrobial use in aquaculture re-examined: its relevance to antimicrobial resistance and to animal and human health. Environ Microbiol. 2013;15(7):1917–42. https://doi.org/10.1111/1462-2920.12134.
31. Watts JEM, Schreier HJ, Lanska L, Hale MS. The Rising Tide of Antimicrobial Resistance in Aquaculture: sources, sinks and solutions. Mar Drugs. 2017;15(6):158. https://doi.org/10.3390/md15060158.
32. Schmidt AS, Bruun MS, Dalsgaard I, Pedersen K, Larsen JL. Occurrence of antimicrobial resistance in fish-pathogenic and environmental bacteria associated with four Danish rainbow trout farms. Appl Environ Microbiol. 2000;66(11):4908–15. https://doi.org/10.1128/AEM.66.11.4908-4915.2000.
33. Martins CI, Galhardo L, Noble C, Damsgård B, Spedicato MT, Zupa W, Beauchaud M, Kulczykowska E, Massabuau JC, Carter T, Planellas SR, Kristiansen T. Behavioural indicators of welfare in farmed fish. Fish Physiol Biochem. 2012;38(1):17–41. https://doi.org/10.1007/s10695-011-9518-8.
34. Elmahdi S, DaSilva LV, Parveen S. Antibiotic resistance of Vibrio parahaemolyticus and Vibrio vulnificus in various countries: a review. Food Microbiol. 2016;57:128–34. https://doi.org/10.1016/j.fm.2016.02.008.
35. Jajere SM. A review of Salmonella enterica with particular focus on the pathogenicity and virulence factors, host specificity and antimicrobial resistance including multidrug resistance. Vet World. 2019;12(4):504–21. https://doi.org/10.14202/vetworld.2019.504-521.
36. Brscic M, Contiero B, Magrin L, Riuzzi G, Gottardo F. The Use of the General Animal-based measures codified terms in the Scientific Literature on Farm Animal Welfare. Front Vet Sci. 2021;8:634498. https://doi.org/10.3389/fvets.2021.634498.
37. Zuliani A, Contiero B, Schneider MK, Arsenos G, Bernues A, Dovc P, Gauly M, Holand Ø, Martin B, Morgan-Davies C, Zollitsch W, Cozzi G. Show more topics and trends in Mountain Livestock Farming research: a text mining approach. Animal. 2021;15:100058.
38. Rathod NB, Elabed N, Özogul F, Regenstein JM, Galanakis CM, Aljaloud SO, Ibrahim SA. The impact of COVID-19 pandemic on Seafood Safety and Human Health. Front Microbiol. 2022;13:875164. https://doi.org/10.3389/fmicb.2022.875164.
39. Passantino A, Elwood RW, Coluccio P. Why protect Decapod crustaceans used as models in Biomedical Research and in Ecotoxicology? Ethical and legislative considerations. Animals. 2021;11(1):73. https://doi.org/10.3390/ani11010073.
40. Wei D, Zhang F, Ye Z, Zhu S, Ji D, Zhao J, Zhou F, Ding X. Effects of intelligent feeding method on the growth, immunity, and stress of juvenile Micropterus salmoides. Artif Intell Agric. 2021;5:118–24. https://doi.org/10.1016/j.aiia.2021.04.001.
41. Roy J, Terrier F, Marchand M, Herman A, Heraud C, Surget A, Lanuque A, Sandres F, Marandel L. Effects of low stocking densities on zootechnical parameters and physiological responses of Rainbow Trout (Oncorhynchus mykiss) juveniles. Biology. 2021;10(10):1040. https://doi.org/10.3390/biology10101040.
42. Calabrese S, Nilsen TO, Kolarevic J, Ebbesson LOE, Pedrosa C, Fivelstad S, Hosfeld C, Stefansson SO, Terjesen BF, Takle H, Martins CIM, Sveier H, Mathisen F, Imsland AK, Handeland SO. Stocking density limits for post-smolt Atlantic salmon (Salmo salar L.) with emphasis on production performance and welfare. Aquaculture. 2017;468(1):363–70. https://doi.org/10.1016/j.aquaculture.2016.10.041.
43. Liu B, Liu Y, Sun G. Effects of stocking density on growth performance and welfare-related physiological parameters of Atlantic salmon Salmo salar L. in recirculating aquaculture system. Aquac Res. 2017;48:2133–44.
44. Wang Q, Mao C, Lei L, Yan B, Yuan J, Guo Y, Li T, Xiong X, Cao X, Huang J, Jian Han J, Yu K, Zhou B. Antibiotic resistance genes and their links with bacteria and environmental factors in three predominant freshwater aquaculture modes. Ecotoxicol Environ Saf. 2022;241:113832. https://doi.org/10.1016/j.ecoenv.2022.113832.
45. Davidson J, Good C, Welsh C, Summerfelt ST. Abnormal swimming behavior and increased deformities in rainbow trout Oncorhynchus mykiss cultured in low exchange water recirculating aquaculture systems. Aquac Eng. 2011;3(45):109–17. https://doi.org/10.1016/j.aquaeng.2011.08.005.
46. Sun G, Liu L, Wang JJ, Liu Y. Effects of Flow Rate on Growth Performance and Welfare of Juvenile Turbot (scophthalmus Maximusl.) In recirculating Aquaculture systems. Aquac Res. 2014;4(47):1341–52. https://doi.org/10.1111/are.12597.
47. Yildiz HY, Robaina L, Pirhonen J, Mente E, Domínguez D, Parisi G. Fish Welfare in Aquaponic Systems: its relation to Water Quality with an emphasis on feed and faeces: a review. Water. 2017;9:13. https://doi.org/10.3390/w9010013.
48. Karvonen A, Räihä V, Klemme I, Ashrafi R, Hyvärinen P, Sundberg LR. Quantity and quality of aquaculture enrichments influence disease epidemics and provide Ecological Alternatives to Antibiotics. Antibiotics. 2021;10:335. https://doi.org/10.3390/antibiotics10030335.
49. U.S. Food and Drug Administration. Import Refusals Report. (2018). https://www.accessdata.fda.gov/scripts/importrefusals [accessed on 14 July 2023].
50. Food and Drug Administration. (2023). https://www.fda.gov/animal-veterinary/aquaculture/approved-aquaculture-drugs [accessed on October 5th, 2023].
51. European Commission. 2009. Commission Regulation 37/2010/EC of 22 December 2009 on pharmacologically active substances and their classification regarding maximum residue limits in foodstuffs of animal origin. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010R0037 [accessed on October 5th, 2023].

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