frontiers | Frontiers in Earth Science

TYPE Review
PUBLISHED 08 September 2022
DOI 10.3389/feart.2022.988710

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Interdisciplinary Climate Studies, a section of the journal Frontiers in Earth Science

RECEIVED 07 July 2022
ACCEPTED 01 August 2022
PUBLISHED 08 September 2022

CITATION
Nor Azra M, Mohd Noor MI, Pau Tan M, Dawood M, Amin M, Zekker I, Fuad Abdullah M, Abd Latif Z and Pardi F (2022), Zebrafish and Medaka as model organisms for climate change research: Global literature scientometric analysis. *Front. Earth Sci.* 10:988710. doi: 10.3389/feart.2022.988710

Zebrafish and Medaka as model organisms for climate change research: Global literature scientometric analysis

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Determining how climate change affects aquatic organisms, such as fish is vital, since this could directly or indirectly impact food and protein sources that are important for human nutrition. Thus, identifying suitable organisms for studying the impacts of climate change on aquatic species is essential. It is most effective to select model organisms for climate change study and determine how each organism might adapt within the diversity of organisms present. This study aimed to review the current development and frontiers of climate change's model organism based on the literature. We conducted a scientometric analysis by differentiating between publications on different model species, the number and origin of authors and affiliations involved, the citation analysis, and the most common keywords used. Increased publication numbers for Zebrafish and Medaka were detected during the analysis of the networks. Our results showed that both species are among the most important aquatic model organisms for climate change related research. Furthermore, we found that these model organisms, especially the Zebrafish are becoming increasingly important towards climate change related studies, because of their simple anatomy and established biological studies. Our analysis could be on the forefront for disseminating and communicating scientific knowledge and impactful discoveries to researchers, academics, policymakers, and to the public worldwide for future contribution to the community resources preservation.

KEYWORDS

bibliometrics, Citespace, environmental sciences, global warming, hypoxia number of articles affiliations

1 Introduction

Fish are vital sources for human protein and are a basic necessity for a large percentage of the world, especially who lived in the coastal area (Braña et al., 2021; Mamun et al., 2021; Maulu et al., 2021). The future sustainability of aquatic products, such as seafood, is partly related to the human response to climate change. For example, sea surface temperature is changing the distribution of fish stock (Sunday et al., 2012), thus altering where fish can sustainably be caught (Free et al., 2022). Due to the diversity of aquatic organisms, it is more effective to select a few aquatic organisms as model species, and assess how they might adapt to climate change rather than trying to assess many species at once The concept of model organism research started in the early 1960s and 1970s due to the increasing number of techniques available in the molecular biological field (Dietrich et al., 2014). Research organisms or model organisms are also frequently used for laboratory research for specific characterization experiments. This type of research helps to inform on the fundamental mechanisms in other organisms and their behaviour. Some examples of classic model species in biology include mice and chickens (Müller and Grossniklaus, 2010; Tregaskes and Kaufman, 2021); Zebrafish and Medaka can also be considered as model organisms, especially among aquatic species.

There are a few traits which make a species a good candidate for being a model species, including: short generation times or short life cycle and rapid development (Silvertown et al., 2011), anatomically simple and clearly defined biological system, tolerance to various environmental conditions (Morgan et al., 2019), capability for breeding or inbreeding, established domestication (Joubert and Bijlsma, 2010) and complete reference genomic studies (Waldvogel et al., 2020). Zebrafish and Medaka are species living in freshwater and marine water environments (Hsu et al., 2014), thus making them suitable organisms for understanding organism function changes within climate change-related studies in either environment. Zebrafish and Medaka's ecology and evaluation are well established as natural model organisms, and knowledge of how they should best be managed is vital for various research (Marx, 2021; Chowdhury et al., 2022). In addition, Zebrafish and Medaka also share the same anatomy, genetic, and physiological elements (Hsu et al., 2014; Chowdhury et al., 2022).

Publication trends on model organisms have been assessed by previous authors, however, these authors only focused on a few species, mostly terrestrial (e.g., rat, mouse, common fruit flies, chicken, and frogs) rather than aquatic species (Dietrich et al., 2014). Therefore, comprehensive bibliographic analysis on aquatic model organisms, such as author and affiliation network or citation analysis is needed. Scientometrics is known as the idea of measuring the networks of scientists, institutions and ideas from a large database or number of sources. The fields of scientometrics and bibliometrics are growing, and there is an increased appreciation for their importance in many scientific fields. Previous scientometric analysis also has been done on the global mapping of zebrafish species (Kinth et al., 2013), however, their relationship with climate change was not assessed. There are no available scientometric-based studies for the Medaka species and this study is among the first to identify the different scientometrics for this species. Previous studies showed that various model organisms can be useful for researching climate change related studies, such as climate-induced water temperature changes (Morgan et al., 2019), acidification, and eutrophication (Altshuler et al., 2011) as well as pollution (Vilas-Boas et al., 2020). However, still missing is an analysis that broadly assesses how model organisms can improve our understanding of climate change.

Thus, the goal of this study was to examine the impact of climate change on two select aquatic model organisms. By employing bibliometric analyses and scientific techniques, we aimed to answer questions about the structure and dynamics of Zebrafish and Medaka as model organisms for climate change related studies. The questions were divided in two different categories, which were 1) the descriptive dataset and 2) the scientometrics-based analysis. The descriptive dataset includes the number of articles published, the citation counts of the articles, the distribution of the countries involved, and the active authors. Meanwhile, for the scientometrics data, the distribution of the cited authors and articles as well as the most abundant keywords used were generated from Citespace software.

The type of bibliometric based studies are also expected to increase the visibility of the field of research and future collaboration between authors and institutions involved. The study is also expected to contribute to the bioclimatology, policymakers, philanthropic and the public worldwide on how to invest limited resources in policies, programs, and research on the impacts of climate change on aquatic species.

2 Methods

2.1 Data sources

Methodological framework for the current study is shown in Figure 1. Web of Science (WOS) Core Collection (WOSCC) was the only database used for the study because it is the general standard for scientometric-based analysis for identifying and

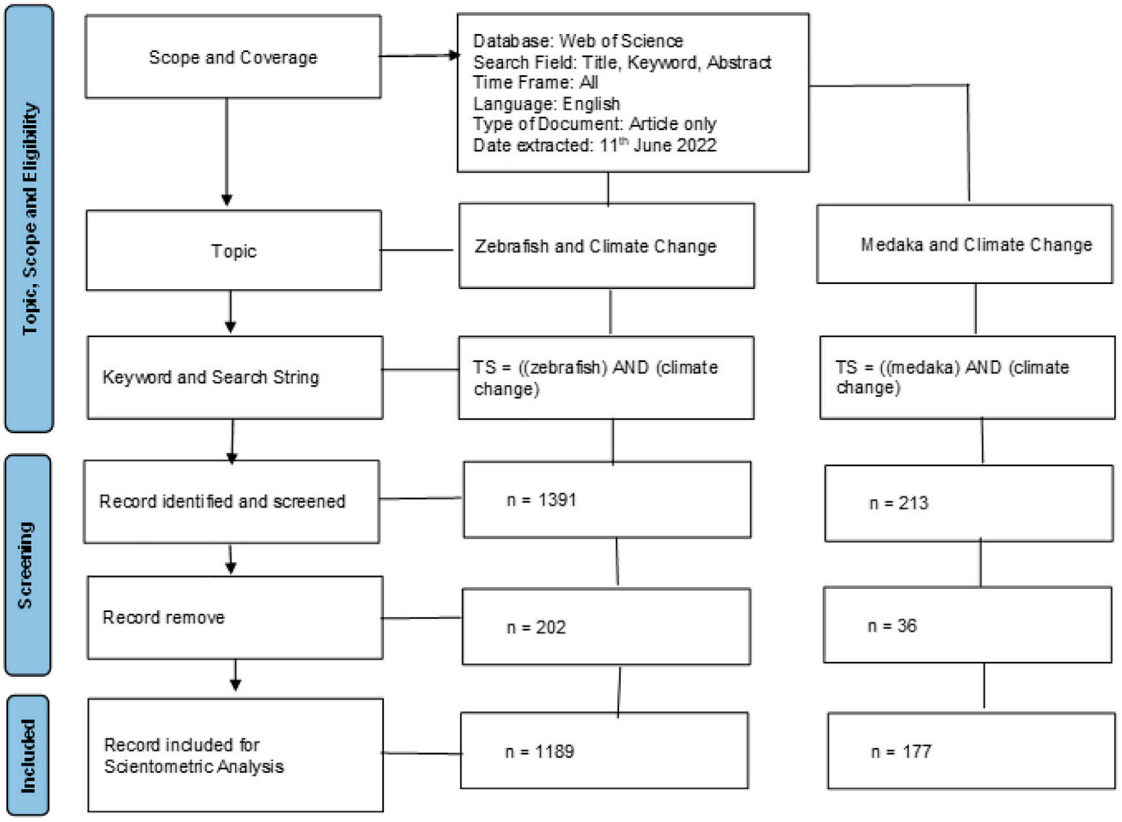

FIGURE 1
Flowchart indicating methodological framework where two separate searches were done focusing on: (i) Zebrafish and (ii) Medaka relation with climate change.

monitoring research trends and development. The WOSCC searching index and database includes the "topic" (TS) field (i.e., article titles, abstracts, keywords, KeyWords Plus). There are few steps applied in the review process of the data, including selection of the database, identification of the articles that relate to our study, screening and eligibility criteria, and included documents. The various qualifying and exclusion criteria were considered, the article type, the language used and the source type of the article. Figure 1 shows that there were various types of methods employed in the systematic review process such as scope and coverage (i.e., database, keywords, etc.), topic identification, screening eligibility, merging, duplicate removal and included documents for the scientometric analysis.

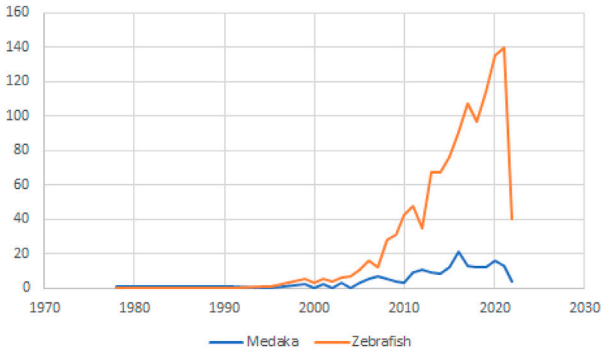

FIGURE 2
Number of research articles related to climate change effects on Medaka and/or Zebrafish published annually since 1978.

The common name as well as the scientific name for both fish species were collected from FishBase, where the current correct information on fishes is provided by various experts and with the support of the European Commission. The climate change related keywords were similar as in Azra et al. (2022). As such, our search strings included the following:

1st searches

Zebrafish:

TS = ((*zebrafish*) OR ("*Danio rerio*") OR ("*Girella* zebra") OR ("*Pterois russelii*") OR ("*Pterois volitans*") OR ("*D. rerio*") OR ("*G. zebra*") OR ("*P. russelii*") OR ("*P. volitans*"))

AND

Climate change:

TS= (("climat* chang*") OR ("global warm*") OR ("seasonal* variat*") OR ("extrem* event*") OR

("environment* variab*") OR ("anthropogenic effect*") OR ("greenhouse effect*") OR ("sea level ris*") OR (erosio*) OR ("agricult* runoff") OR ("weather* variab*") OR ("weather* extrem*") OR ("extreme* climat*") OR ("environment* impact*") OR ("environment* chang*") OR ("anthropogenic stres*") OR ("temperature ris*") OR ("temperature effect*") OR ("warm* ocean") OR ("sea surface* temperat*") OR (heatwav*) OR (acidific*) OR (hurrican*) OR ("el nino") OR ("el-nino") OR ("la nina") OR (la-nina) OR (drought*) OR (flood*) OR ("high precipit*") OR ("heavy rainfall*") OR ("CO_2 concentrat*") OR ("melt* of the glacier*") OR ("melt* ice*") OR ("therm* stress*") OR (drought) OR (hypoxia))

2nd searches

Medaka:

TS = [(medaka) OR ("Oryzias latipes") OR ("*Aphyocypris* kikuchii") OR ("*O. latipes*") OR ("A. kikuchii")]

AND

Climate change:

TS = ((climat* chang*) OR ("global warm*") OR ("seasonal* variat*") OR ("extrem* event*") OR ("environment* variab*") OR ("anthropogenic effect*") OR ("greenhouse effect*") OR ("sea level ris*") OR (erosio*) OR ("agricult* runoff") OR ("weather* variab*") OR ("weather* extrem*") OR ("extreme* climat*") OR ("environment* impact*") OR ("environment* chang*") OR ("anthropogenic stres*") OR ("temperature ris*") OR ("temperature effect*") OR ("warm* ocean") OR ("sea surface* temperat*") OR (heatwav*) OR (acidific*) OR (hurrican*) OR (el nino) OR ("el-nino") OR ("la nina") OR (la-nina) OR (drought*) OR (flood*) OR ("high precipit*") OR ("heavy rainfall*") OR ("CO_2 concentrat*") OR ("melt* of the glacier*") OR ("melt* ice*") OR ("therm* stress*") OR (drought) OR (hypoxia)).

2.2 Analysis tool

2.2.1 Software tool

Data from WOSCC were imported directly to the CiteSpace software as a text file (*.txt). The CiteSpace version 6.1.R2 on 64-bit was used for the analysis. CiteSpace is among one of the popular software to analyze scientometric based results (Noor et al., 2021; Feng et al., 2022; Shi et al., 2022). It also shows various types of interactive visualization (i.e., network analysis and visualization), such as most active areas, major related areas, key papers for a given area, critical transitions in the history of the development of the field and its turning points.

The data were divided into the number of authors, number of institutions, countries involved, terminologies used, consistent and most common keywords, cited authors as well as cited references in the field. The threshold setting for CiteSpace was set at "*Top 50 N*" *per* slice, which allows the selection of most cited items from each slice to form a network based on the input value and node types. "Pruning" parameter was chosen to prune the network. All term sources in Web of Science, including title, abstract, author keywords, and keywords plus, were chosen for text processing. Three types of scientometric analysis were used in this study, namely; 1) cluster analysis, 2) co-citation analysis and 3) burstness analysis. The explanation for each analysis is given below.

2.2.2 Cluster analysis

Cluster analysis was used to identify research clusters in focus areas. For this study, variable use for cluster analysis is based on the Articles Cluster. Log-likelihood ratio was used to provide the cluster label as it gives the best results in terms of uniqueness and coverage (Hiekkalinna et al., 2012). The "timeline view" and "cluster view" were used to visualize the articles cluster network's shape and form. The "timeline view" displayed a vertical range of chronological time periods from left to right, whereas the "cluster view" displayed a spatial network of colour-coded and automatically labeled representations in a landscape format (Chen 2004; Chen and Leydesdorff 2014).

The modularity Q index, average silhouette metric, and centrality metric were used to assess the quality and homogeneity of the document cluster analyses, as well as the detected clusters (Chen et al., 2009; Chen, 2020). The modularity Q index ranges between 0 and 1, where larger index values indicate higher reliability. The average silhouette metric has a value between −1 and 1, where values greater than 0 indicate greater homogeneity. Centrality is a measure of influence that shows the degree to which publications or journals stand between each other, where publications with high centrality would have higher influence on the network as they connect more publications or journals and therefore, more information and paths pass through them.

2.2.3 Co-citation analysis

Co-citation analyses generate a research network consisting of nodes and link and density values to show the main structure of selected variables. For this study, selected variables included 1) Cited Articles analysis and 2) Cited Author analysis. Co-citation analysis will allow us to obtain the cluster of co-citing variables, where a co-citation instance occurs when two articles/authors are cited together in one paper (Boyack and Klavans, 2010). The analysis quality was assessed using degree, betweenness, and sigma (Chen and Song, 2019). The degree value represents the number of citations an article/author receives from another article/author, with a higher degree indicating more citations. Betweenness is a measure of influence that shows the influence to which the same article/author has on others. High betweenness means the article/author has a greater influence on the research areas because it connects other articles/authors, and thus more information and paths pass through them. Centrality is the

TABLE 1 The articles with the highest citations for research on medaka and climate change.

No	Title	Source title	Publication year	Total citations	Average per year
1	Evaluation of the toxic impact of silver nanoparticles on Japanese medaka (oryzias latipes)	Aquatic Toxicology	2009	210	15
2	Evolutionary dynamics of olfactory receptor genes in fishes and tetrapods	Proceedings of the National Academy of Sciences of the United States of America	2005	200	11.11
3	Zinc oxide nanoparticles induce oxidative DNA damage and ROS-triggered mitochondria-mediated apoptosis in zebrafish embryos	Aquatic Toxicology	2016	137	19.57
4	2,3,7,8-Tetrachlorodibenzo-p-dioxin alters cardiovascular and craniofacial development and function in sac fry of rainbow trout (Oncorhynchus mykiss)	Toxicological Sciences	1999	104	4.33
5	Cumulative ecological impacts of two successive annual treatments of imidacloprid and fipronil on aquatic communities of paddy mesocosms	Ecotoxicology and Environmental Safety	2012	97	8.82
6	Development of a marine fish model for studying *in vivo* molecular responses in ecotoxicology	Aquatic Toxicology	2008	97	6.47
7	Leptins and leptin receptor expression in the goldfish (*Carassius auratus*). Regulation by food intake and fasting/overfeeding conditions	Peptides	2012	87	7.91
8	Hypoxia causes transgenerational impairments in reproduction of fish	Nature Communications	2016	80	11.43
9	Molecular cloning, characterization and expression profiles of multiple leptin genes and a leptin receptor gene in orange-spotted grouper (*Epinephelus coioides*)	General and Comparative Endocrinology	2013	75	7.5
10	Comprehensive Transcriptome Analysis Reveals Accelerated Genic Evolution in a Tibet Fish, *Gymnodiptychus pachycheilus*	Genome Biology and Evolution	2015	64	8

combination value based on betweenness and burstiness scores (described below), ranging from 0 to 1 where the highest value is associated with high value research articles (Aryadoust et al., 2019).

2.2.4 Burstiness analysis

Citation burstiness were used to determine top keywords related to research areas. Burst detection is defined as a sudden increase in the number of citations for a specific article, or "an abrupt elevation of the frequencies (of citations) over a specific time interval," as indicated by a red ring around the node (Hou et al., 2018).

3 Results

3.1 Trends in literature

This study focused on scientific publications related to climate change and its relationship with zebrafish and medaka species. Research on medaka and climate change started in 1978 (Figure 2), where a total of 177 original articles have been published since then, with an average of 10 publications per year since 2011. On the other hand, the first scientific publication on zebrafish and climate change was only published in Web of Science in 1994. However, zebrafish publications rapidly outnumbered medaka publications, with a total of 1189 papers published since 1994.

Article citation is an indicator that shows the impact of a study in its research field. Based on previous studies, the direction of a research field is associated with the articles that are most frequently cited (Chen et al., 2010; Chen, 2020). The top three articles with the highest number of total citations for medaka and climate changes were, 1) "Evaluation of the toxic impact of silver nanoparticles on Japanese medaka (Oryzias latipes)" (210 citations); 2) "Evolutionary dynamics of olfactory receptor genes in fishes and tetrapods" (200 citations); and 3) "Zinc oxide nanoparticles induce oxidative DNA damage and ROS-triggered mitochondria-mediated apoptosis in zebrafish embryos" (137 citations). Tables 1, 2 show the highest citations for climate change research associated with Medaka and Zebrafish, respectively.

For research focusing on Zebrafish and Climate Change, the top 3 most cited publications were: 1) "Toxicity of silver nanoparticles in zebrafish models" (681 citations); 2) "The Oxygen-Rich Postnatal Environment Induces Cardiomyocyte Cell-Cycle Arrest through DNA Damage Response" (437 citations) and 3) "The Serine Protease Matriptase-2 (TMPRSS6) Inhibits Hepcidin Activation by Cleaving Membrane Hemojuvelin" (405 citations).

TABLE 2 The top ten articles with the highest number of citations for research on Zebrafish and climate change.

No	Title	Source title	Publication year	Total citations	Average per year
1	Toxicity of silver nanoparticles in zebrafish models	Nanotechnology	2008	681	45.4
2	The Oxygen-Rich Postnatal Environment Induces Cardiomyocyte Cell-Cycle Arrest through DNA Damage Response	Cell	2014	437	48.56
3	The Serine Protease Matriptase-2 (TMPRSS6) Inhibits Hepcidin Activation by Cleaving Membrane Hemojuvelin	Cell Metabolism	2008	405	27
4	Live imaging of neuronal degradation by microglia reveals a role for v0-ATPase a1 in phagosomal fusion *in vivo*	Cell	2008	380	25.33
5	Hypoxia induces heart regeneration in adult mice	Nature	2017	347	57.83
6	Comparison of the toxicity of silver, gold and platinum nanoparticles in developing zebrafish embryos	Nanotoxicology	2011	315	26.25
7	The composition of the zebrafish intestinal microbial community varies across development	Isme Journal	2016	290	41.43
8	Assessing the toxicity of Pb- and Sn-based perovskite solar cells in model organism *Danio rerio*	Scientific Reports	2016	275	39.29
9	Acute toxicities of six manufactured nanomaterial suspensions to *Daphnia* magna	Journal of Nanoparticle Research	2009	263	18.79
10	A horizon scan of global conservation issues for 2010	Trends In Ecology Evolution	2010	249	19.15

3.2 Trends in countries

Research papers in the sample for medaka and climate change research came from 65 countries around the world. Figure 3 shows the distribution of countries working on the Medaka and Zebrafish as a model organism in climate change research and development. China was the most frequent publisher (56 publications), followed by the United States, Japan, Canada, France, Germany, Norway, South Korea, Taiwan and Australia as the top 10 countries that have published in this research area. In the research areas focusing on zebrafish and climate changes, a total of 74 countries contributed between 1994–2022. The United States of America contributed the highest number of articles (342 publications), followed by China, Canada, England, Germany, Australia, France, Italy, Brazil, and Taiwan.

3.3 Trends of authors

For the zebrafish subsample, there were 842 authors who published an article related to climate change and zebrafish, but only two authors published more than 10 articles (Figure 3). Rudolf S.S Wu from Education University of Hong Kong contributed the most with 12 articles, followed by Keng Po Lai (10 articles), and Doris Wai Ting Au/Ting Fung Chan (9 articles). Tables 3, 4 indicate the list of top ten most productive authors regarding research on medaka and zebrafish, respectively, and climate change. Within the zebrafish subsample, out of a total of 6015 authors, Steve F. Perry published the most articles (34 articles), followed by Michael G. Jonz (16 articles), and Bernd Pelster (15 articles).

3.4 Scientometric analysis

3.4.1 Author co-citation analysis

Figure 4 depicts authors in the zebrafish subsample that have a betweenness score greater than 0.05.

There were 886 nodes and 3010 connections in the author co-citation network for the zebrafish subsample. The co-citation network density value was 0.0077. Figure 4 depicts authors that have a centrality score greater than 0.1. Pamela A. Padilla from Fred Hutchinson *Cancer* Research Center was the most interconnected author, with a degree connection of 30, betweenness score of 0.07, and a sigma of 1.81. Andrew Y. Gracey was the second most influential author, with a degree connection of 56, betweenness score 0.11 and Sigma score of 1.65. Even though Andrew Y. Gracey's degree connection and betweenness score are higher than Pamela A. Padilla's, his sigma score is lower. This shows that Pamela A. Padilla is located more central in the network and is cited by authors with higher betweenness and degree than Andrew Y. Gracey, making him less influential. Christopher Ton was the third most influential author (Degree Connection: 30; Betweenness: 0.05, Sigma: 1.45). Table 5 shows the details for the top ten authors with the most influence in zebrafish and climate change research.

The author's co-citation network for medaka and climate changes had 679 nodes, 2200 connections, and a density of

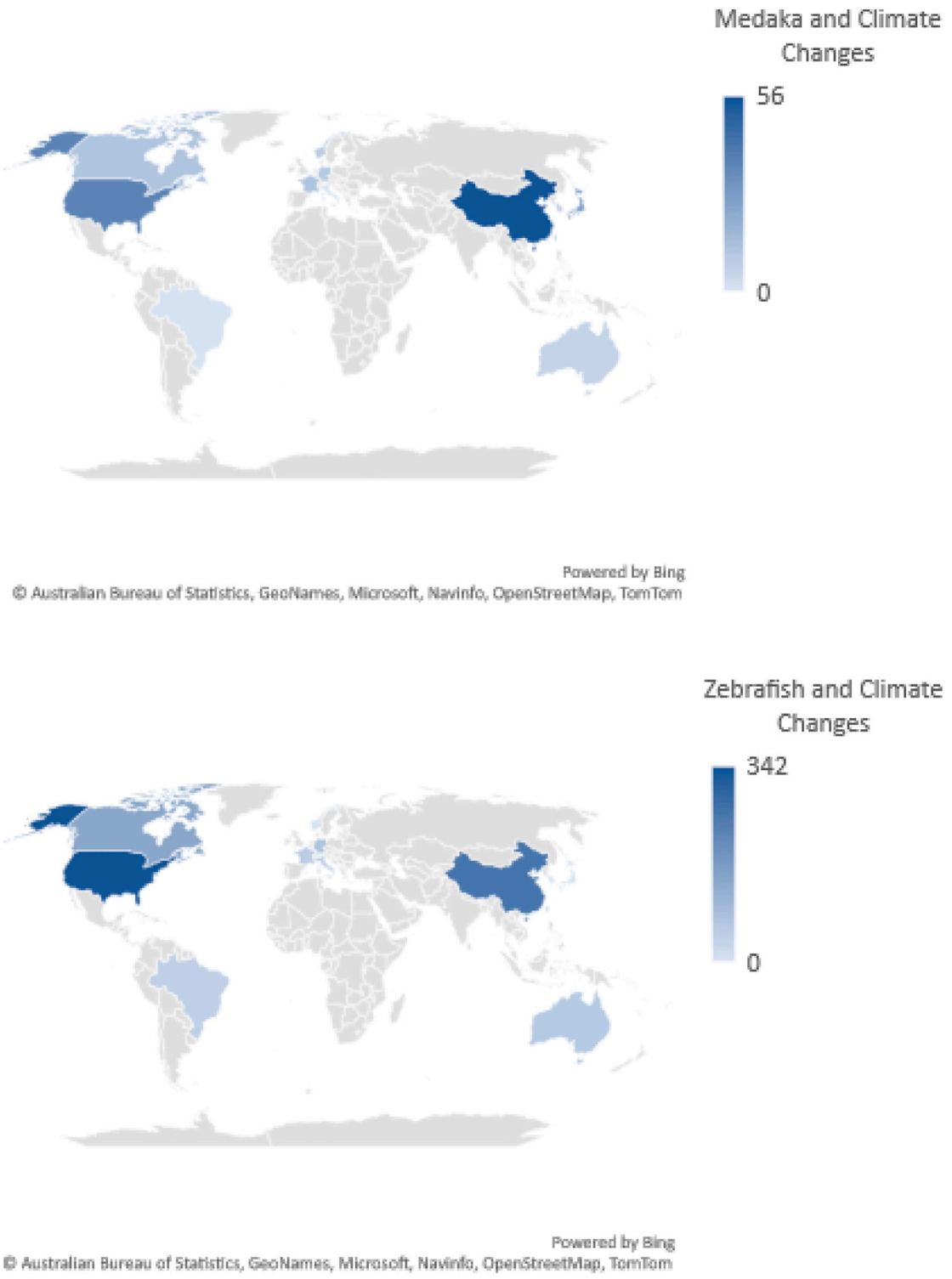

FIGURE 3
The distribution of countries that work on Medaka and Zebrafish as a model organism in climate change research and development.

TABLE 3 Top ten most productive authors regarding research on medaka and climate change.

Top authors for on medaka and climate changes	Number of articles	Affiliations
Rudolf S.S. Wu	12	Education university of Hong Kong
Keng Po Lai	10	Guilin Medical University
Doris Wai Ting Au	9	City University of Hong Kong
Ting Fung Chan	9	Chinese University of Hong Kong
Richard Yuen Chong Kong	8	City University of Hong Kong
Jing-Woei Li	8	Chinese University of Hong Kong
Anna Chung Kwan Tse	7	University of Hong Kong
Pei-Jen Chen	6	National Taiwan University
Daniel Schlenk	6	University of California Riverside
Simon Yuan Wang	5	Boston Children's Hospital

TABLE 4 Top ten most productive authors regarding research on zebrafish and climate change.

Top authors for on zebrafish and climate changes	Number of articles	Affiliations
Steve F. Perry	34	University of ottawa
Michael G. Jonz	16	University of Ottawa
Bernd Pelster	15	University of Innsbruck
Yuan Li	13	China Agricultural University
Warren W. Burggren	12	University of North Texas Denton
Cunming Duan	12	University of Michigan
Rudolf S.S. Wu	12	Education University of Hong Kong
Michael Lardelli	11	University of Adelaide
Thorsten Schwerte	11	University of Innsbruck
Yihai Cao	10	Karolinska Institutet

0.0096. Figure 5 illustrates the knowledge map for the author co-citation analysis, including only authors with betweenness scores greater than 0.05. Table 6 shows the details for the top ten authors involved in the Medaka subsample with the highest influence based on the authors degree, centrality, and sigma score.

Kinoshita Masato from Kyoto University was the most influential author with degree connection = 27, betweenness score = 0.15 and sigma score 1.72. The second and third most influential authors were Angel Amores (degree: 9, centrality: 0.05 and sigma: 1) and Philip L. Munday (degree: 6, centrality: 0.01 and sigma: 1).

3.4.2 Articles co-citation analysis

Figure 6 illustrates the articles' co-citation analysis for the zebrafish subsample. The network had 969 nodes and 2824 connections, with a density of 0.006. Only articles with a centrality score greater than 0.1 were listed.

Table 7 displays the top ten most influential scientific publications according to the degree, betweenness, and sigma score. "*Zebrafish mutants in the von Hippel-Lindau tumor suppressor display a hypoxic response and recapitulate key aspects of Chuvash polycythemia*" was the most influential article in zebrafish subsample, with a degree connection of 30, betweenness 0.19 and sigma score of 3.17. "*The zebrafish reference genome sequence and its relationship to the human genome*" was the second most influential article, with a degree connection of 12, betweenness 0.20 and sigma 2.14. The article "*Hypoxia-inducible factor-1 mediates adaptive developmental plasticity of hypoxia tolerance in zebrafish, Danio rerio*" was the third most influential article (degree = 21, centrality = 0.12 and sigma = 1.80).

Figure 7 shows the majority of highly influential articles based on the article co-citation analysis for the medaka subsample. The network contained 617 nodes and

TABLE 5 Top 10 authors co-citation score for Zebrafish and Climate Change Research Areas.

Author	Affiliation	Degree	Betweenness	Sigma
Pamela a. Padilla	Fred hutchinson cancer research center	30	0.07	1.81
Andrew Y. Gracey	Stanford University	56	0.11	1.65
Christopher Ton	University of Toronto	30	0.05	1.45
Shingo Kajimura	University of Michigan	29	0.05	1.44
Rudolf S.S. Wu	City University of Hong Kong	22	0.05	1.27
Ellen van Rooijen	University Medical Center Utrecht	19	0.03	1.26
Robert J Diaz	College of William and Mary	32	0.06	1.26
Douglas Bates	University of Wisconsin-Madison	11	0.07	1.25
Thorsten Schwerte	University of Innsbruck	22	0.02	1.17
Diego A. Rojas	Universidad de Chile	15	0.02	1.14

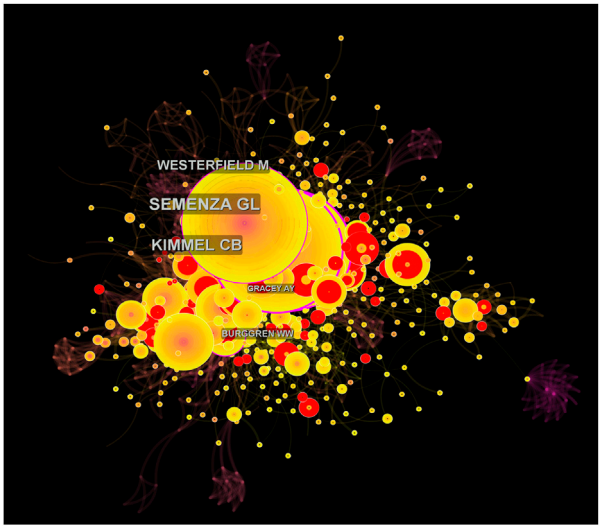

FIGURE 4
The distribution of cited authors for research on zebrafish and climate change. Node size and font size increase as centrality score increases.

1695 links. Each node represents an article with the first author's name and the publication year. The links between nodes represent co-citation relations between two articles. As there were no articles with a betweenness score >0.1, there are no names listed in the figure.

Table 8 shows the most influential publications (publications according to the degree, betweenness, and sigma score in the medaka subsample. The most influential article is "Epigenetics in teleost fish: From molecular mechanisms to physiological phenotypes" with degree connection of 109, betweenness score 0.04 and Sigma of 1. Interestingly, there are no articles with sigma more than 1, which might indicate there are no highly recognizable articles in this domain.

3.4.3 Articles cluster

The Modularity Q Index and the Mean Silhouette metric for the zebrafish subsample's article cluster analysis were 0.8963 and 0.9642 respectively, suggesting more than average reliability and homogeneity for the network. The analysis yielded a total of 17 co-citation clusters which are summarized in Table 9, where each cluster represents a different research topic. The cluster's size is equal to the number of publications it has. Each of the clusters has range between 4 and 80 publications, with Cluster #0 having the most (95 publications). Cluster silhouette score ranged from 0.927 to 1.000, indicating a high degree of homogeneity among publications in each cluster (silhouette score ranges from −1 to 1, with scores >0 seen as homogenous). This indicator measures the combined strength of structural and temporal properties of a node, namely, its betweeness centrality and citation burst. A composite metric sigma is defined in CiteSpace to measure the combined strength of structural and temporal properties of a node, namely, its betweenness centrality and citation burst. Sigma is computed as (centrality +1) burstness (50), with higher values indicating works with higher influential potential. (Chen et al., 2009).

Figure 8 depicts these 17 clusters summarized on a horizontal line, with the cluster label on the right side. The clusters were numbered and ranked in order of size, with #0 being the largest and #39 the smallest. The solid yellow line within each cluster represents the cluster's lifetime. Text mining and a keyword analysis algorithm in CiteSpace software were used to generate the cluster labels, then the log likelihood ratio was used to name these clusters (LLR).

The Modularity Q Index and the Mean Silhouette metric for the Medaka subsample's cluster analysis were 0.9645 and 0.9980 respectively, suggesting again more than average reliability and homogeneity for the network. The analysis yielded a total of 3 co-citation clusters which are summarized in Table 10. Each

TABLE 6 Top 10 Authors co-citation score for research on Medaka and Climate Change.

Author	Affiliation	Degree	Betweenness	Sigma
Kinoshita masato	Kyoto university	27	0.15	1.72
Angel Amores	University of Oregon	9	0.05	1
Philip L. Munday	James Cook University	6	0.01	1
Lianguo Chen	Chinese Academy of Sciences	16	0	1
Mark D. Robinson	The University of Melbourne	5	0.01	1
Serpil Aliriz	Yuzunzu Yil University	7	0	1
James C.W. Lam	City University of Hong Kong	16	0	1
Matthew M. Alloy	University of North Texas	2	0.01	1
Anneli Bohne-Kjersem	University of Bergen	12	0	1
Thaïs Aznar-Fernández	CICS	7	0	1

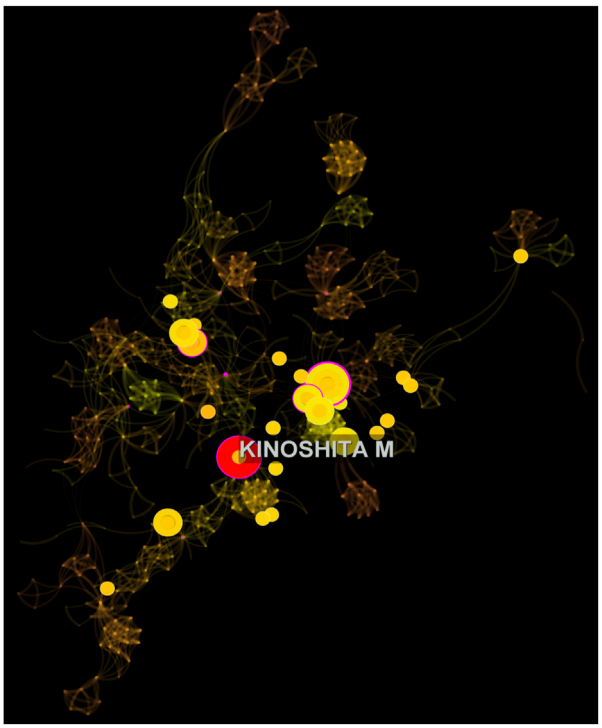

FIGURE 5
The distribution of cited authors for related to medaka and climate change.

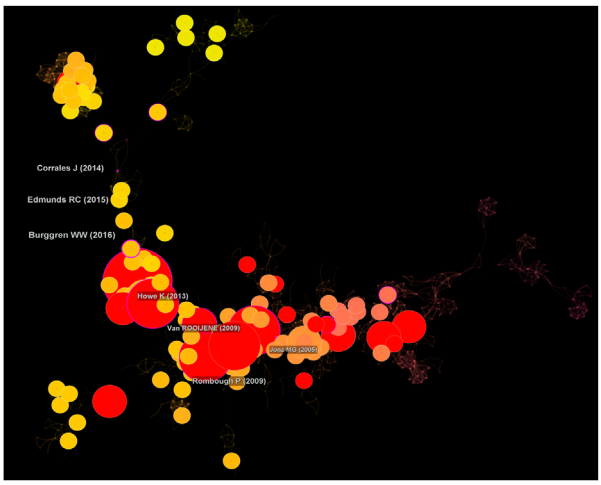

FIGURE 6
Network of Document Co-citation Analysis where articles with a centrality score greater than 0.1 are shown.

cluster ranged between 12 and 35 publications, with Cluster #0 having the most (35 publications). Cluster silhouette score ranged from 0.997 to 1.000, indicating a high degree of homogeneity among publications in each cluster.

Figure 9 depicts these 20 clusters summarized on a horizontal line, with the cluster label on the right side as well as with three major cluster summarized in Table 10. The clusters were numbered and ranked in order of size, with #0 being the largest and #16 the smallest. As before, text mining and keyword analysis algorithms in CiteSpace software was used to generate the cluster labels, and log likelihood ratio was used to name the clusters (LLR).

3.5 Keyword burst

Table 11 displays the keywords with the keyword citation burst for the zebrafish subsample. There were no burst keywords from the medaka subsample. Bursts reflect the emergence of a keyword within a subject area during a specific time period (the blue line), here from 1994 to 2022, while the red lines represent the burst period. Beginning in 2019 and ending in 2022, the word "temperature" had the highest burst strength (6.81). The following top keywords were "embryonic development"

TABLE 7 Top 10 (of 1189) most influential scientific publications related to research on zebrafish and climate change.

Title	Year	Degree	Betweenness	Sigma
Zebrafish mutants in the von hippel-lindau tumor suppressor display a hypoxic response and recapitulate key aspects of Chuvash polycythemia	2009	30	0.19	3.17
The zebrafish References genome sequence and its relationship to the human genome	2013	12	0.20	2.14
Hypoxia-inducible factor-1 mediates adaptive developmental plasticity of hypoxia tolerance in zebrafish, *Danio rerio*	2014	21	0.12	1.80
Development of oxygen sensing in the gills of zebrafish	2014	31	0.17	1.75
Gene expression profiling of the long-term adaptive response to hypoxia in the gills of adult zebrafish	2005	21	0.10	1.68
Serotonergic and cholinergic elements of the hypoxic ventilatory response in developing zebrafish	2005	12	0.10	1.51
Gene expression profile of zebrafish exposed to hypoxia during development	2013	33	0.07	1.50
HIF signaling and overall gene expression changes during hypoxia and prolonged exercise differ considerably	2003	27	0.07	1.50
Cloning of hif-1α and hif-2α and mRNA expression pattern during development in zebrafish	2011	26	0.08	1.43
Linking Oxygen to Time: The Bidirectional Interaction Between the Hypoxic Signaling Pathway and the Circadian Clock	2007	26	0.08	1.42

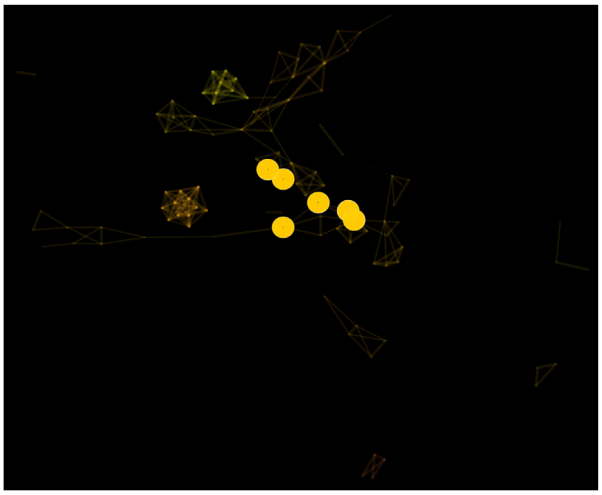

FIGURE 7
Medaka and Climate Change Network of Document Co-citation Analysis, where articles with a centrality score greater than 0.1 are shown.

(Strength = 5.5, 2016–2019) and "*in vivo*" (Strength = 4.78, 2009–2013).

4 Discussion

4.1 Descriptive analysis

Here, research related to climate change and either zebrafish or medaka was synthesized, revealing the research landscape in terms of the year, journals, authors, countries, keywords, and references. A descriptive analysis was performed on the number of publications, authors, and the countries/regions where authors were affiliated with when papers were published.

Both research domains saw the number of articles published increase annually, but the zebrafish subsample saw a higher increase in articles published, with a 10-years average of 92.9 publications per year; whereas medaka subsample only published a 10-years average of 12.7 articles per year. Consequently, the number of papers with high citation counts also differed, where zebrafish had 10 articles with >200 citations whereas medaka only had two articles with >200 citations. Both domains had China and the United States of America as the highest contributors for the number of papers published in the field. The top ten countries and authors varied in terms of region, but were dominated by developed countries and high-ranking institutions. As this result may be due to developed countries and high-ranking institutions having more resources to conduct scientific analyses, we strongly suggest that more international scientific research exchange and collaboration be conducted in the future. The difference in publication numbers and citations indicates that biology as a field has focused more on using zebrafish as a model species when it comes to climate change research, rather than medaka.

Tables 1, 2 showed that most of the top papers published were not related to climate change-related studies. Keywords related to environmental conditions, environmental change, and stress appeared to capture some articles that were not directly related to our objectives regarding climate change. Most of the articles on medaka discussed the ability and roles of the model organism towards various fields of study, such as nanotechnology (i.e., nanomaterials/nanoparticles) (Chae et al., 2009; Zhao et al., 2016) and genetics (Niimura and Nei, 2005). Similarly, articles on zebrafish discussed the species' ability and role in the fields of nanotechnology

TABLE 8 Top 10 (of 117) most influential publications related to research on medaka and climate change.

Title	Year	Degree	Betweenness	Sigma
Epigenetics in teleost fish: From molecular mechanisms to physiological phenotypes	2015	109	0.04	1
Hypoxia causes transgenerational impairments in reproduction of fish	2011	8	0.03	1
Early Dioxin Exposure Causes Toxic Effects in Adult Zebrafish	2007	40	0.02	1
Using Zebrafish as a Model System for Studying the Transgenerational Effects of Dioxin	2011	40	0.02	1
Hypoxia alters steroidogenesis in female marine medaka through miRNAs regulation	2016	9	0.02	1
Developmental exposure to a complex PAH mixture causes persistent behavioral effects in naive Fundulus heteroclitus (killifish) but not in a population of PAH-adapted killifish	2011	40	0.02	1
Sex in troubled waters: Widespread agricultural contaminant disrupts reproductive behaviour in fish	2009	25	0.02	1
Stress, novel sex genes, and epigenetic reprogramming orchestrate socially controlled sex change	2015	14	0.02	1
Genome Sequencing of the Perciform Fish Larimichthys crocea Provides Insights into Molecular and Genetic Mechanisms of Stress Adaptation	2009	107	0.02	1
Declining oxygen in the global ocean and coastal waters	2015	61	0.02	1

TABLE 9 Seventeen (17) major clusters from the article co-citation analysis for research on zebrafish and climate changes.

ClusterID	Size	Silhouette	Label (LLR)	Average year
0	95	0.924	Hypoxia-inducible transcription factor	2014
1	81	0.927	Respiratory developmental plasticity	2009
2	56	0.978	Gene expression profiling	2004
3	55	0.996	Invasive lionfish	2015
5	46	0.979	Respiratory gasses	2015
6	44	1.000	Zebrafish larvae	2020
7	31	1.000	Toxicity	2000
8	28	0.955	Maladaptive larval phenotype	2018
9	27	0.964	Complex response	2004
10	26	0.936	Oxygen deprivation	2002
11	26	0.954	Ventilatory control	2006
12	25	0.976	Pathological hypoxia-driven angiogenesis	2009
13	24	1.000	Hypoxic cell	2017
15	12	1.000	Accelerated gene evolution	2015
28	7	1.000	Rainbow trout	2012
29	7	0.997	Marine medaka	2016
39	4	0.996	Drug-resistant gene expression	2015

(Asharani et al., 2008) and cell metabolism (Silvestri et al., 2008; Puente et al., 2014).

However, there were a few articles on Medaka and Zebrafish that were directly related to climate change issues and elements, such as environmental stress caused by hypoxia (Kong et al., 2008; Wang et al., 2016) and agricultural runoff (Hayasaka et al., 2012) and pollution (Babayigit et al., 2016). Basically, global warming can induce coastal hypoxia by decreasing oxygen solubility and resulting in an increase in the oxygen demand of the aquatic species. Adult marine medaka was used as a model organism for the determination of environmental stress of hypoxia, and the results showed that there were significant alterations in levels of cell proliferation marker and protein in liver conditions of the species, *Oryzias melastigma* (Kong et al., 2008). Sexually matrure marine medaka, *O. melastigma* were also affected by hypoxia, causing retarded gonad development, decrease in sperm count and sperm motility of the fish (Wang et al., 2016). Hayasaka et al. (2012) showed the effects of toxic agro-chemicals on the abundance of benthic organisms, such as Medaka, in aquatic paddy communities. They found that adult and juvenile medaka body size were smaller in the treated insecticide pools compared to the controls over the 2 year experiment. In the Zebrafish experiment, environmental pollution caused by the lead and tin impacted the fish embryonic development (Babayigit

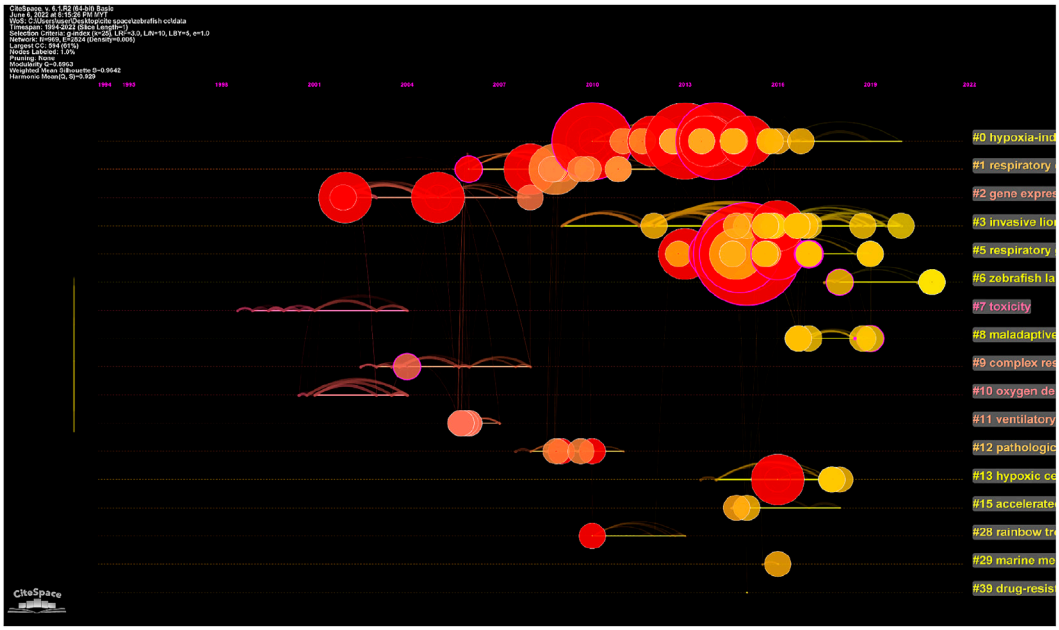

FIGURE 8
Summary of identified document cluster lifetimes (solid lines). Cluster labels were generated from CiteSpace.

TABLE 10 Three (3) major clusters that emerged from the article co-citation analysis for research on medaka and climate change.

ClusterID	Size	Silhouette	Label (LLR)	Average year
0	35	0.997	Transcriptomic responses	2014
5	20	1.000	Hypoxia alters steroidogenesis	2016
16	12	0.998	Multiple leptin gene	2012

et al., 2016). These results show that climate change research using medaka or zebrafish as models have largely focused on the effects of agriculture runoff and hypoxia. Specifically, research appears to have focused on how these effects change development and growth within these model species.

4.2 Scientometric based analysis

There is a huge difference between the most influential author analysis for the zebrafish subsample compared to the medaka subsample. The zebrafish subsample had >10 influential authors with a sigma score >1.0, while the medaka subsample only had one influential author. Even though the medaka subsample started earlier than the zebrafish subsample, the latter was more abundant and had higher influence in the scientific network than the former. From our results, the most influential authors in medaka research are clearly not active anymore as there is hardly any new research being published, indicating low scientific novelty for this domain. This demonstrates the need to change the current approach and introduce more disciplines in this domain. It is critical to start developing experts in these fields and build connections between sub-disciplines or the domain might cease to exist in the future. Our study also suggest that the domain (i.e., medaka and climate change) might not producing enough valuable research, and this could be shows less publication. This is also could be affected that the zebrafish are a better model organism for climate change related studies.

In bibliometrics, co-citation analysis is one way to assess similar articles. Document or article co-citation analysis is a unique method for tracking similar papers that are cited together in journals by many authors; it will lastly identify clusters of research (Boyack and Klavans, 2010). Here, we only found a few articles for both species that fell into categories related to the current objectives of the paper (which is the use of model organisms in climate change

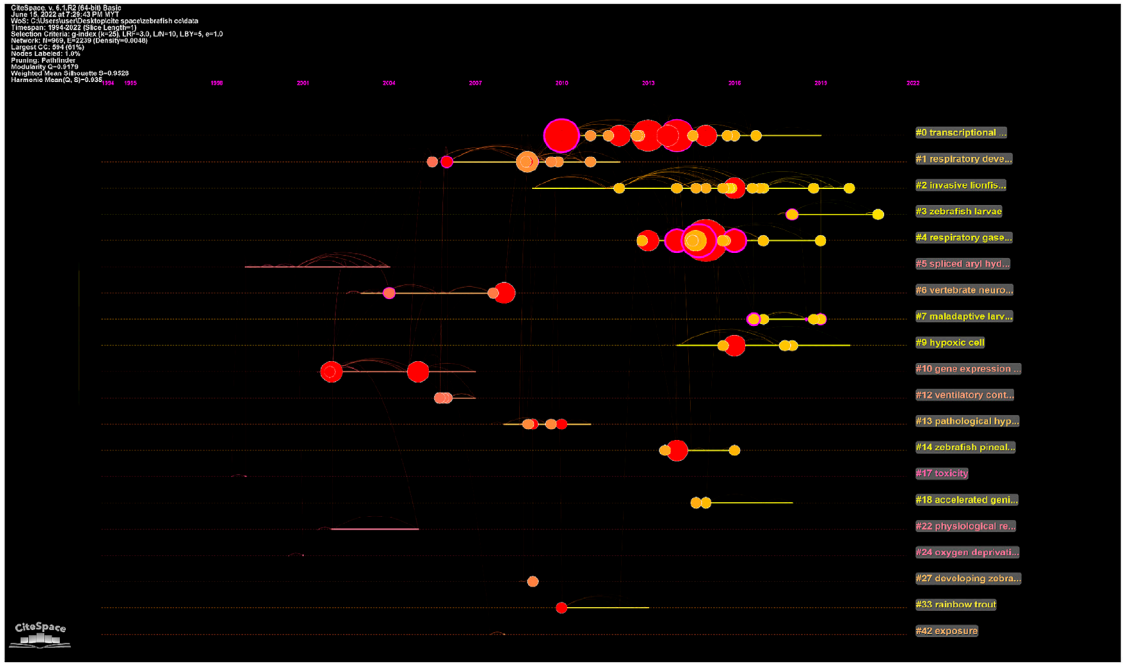

FIGURE 9
Summary of identified medaka and climate changes cluster lifetimes (solid lines). Cluster labels were generated from CiteSpace.

TABLE 11 Fifteen keywords with a citation burst for research on zebrafish and climate change.

Keywords	Year	Strength	Begin	End	1994–2022
Temperature	1994	**6.81**	2019	2022	
Embryonic development	1994	**5.5**	2016	2019	
In vivo	1994	**4.78**	2009	2013	
Danio rerio	1994	**4.74**	2002	2006	
Differentiation	1994	**4.61**	2013	2016	
Pharmaceutical	1994	**4.37**	2019	2020	
Neuroepithelial cell	1994	**4.02**	2014	2015	
Cancer	1994	**3.89**	2011	2012	
Nanoparticle	1994	**3.77**	2018	2020	
Angiogenesis	1994	**3.58**	2003	2011	
Aryl hydrocarbon receptor	1994	**3.49**	2000	2012	
Developmental toxicity	1994	**3.48**	2017	2022	
Messenger rna expression	1994	**3.43**	2011	2013	
Zebrafish embryo	1994	**3.43**	2018	2020	
Zebrafish danio rerio	1994	**3.42**	2015	2018	

The bold value refers to citation burst. The beginning of a blue line depicts when an article is published. The beginning of a red segment marks the beginning of a period of burst, whereas the end of the red segment marks the end of the burst period.

research). Instead most of the related studies were on hypoxia and agricultural runoff of chemical pollution (Robertson et al., 2014; Bertram et al., 2015; Lai et al., 2016; Wang et al., 2016). However, few articles have an impact in terms of documents co-citation analysis. For zebrafish species, there were only two articles with a sigma value higher than 2 (which indicates importance of the papers in the field), whereas no articles from the Medaka species reached a sigma value of 2. The studies by Rooijen et al. (2009) and Howe et al. (2013) had sigma values above 2.0. Rooijen et al. (2009) used zebrafish as a model organism to understand cellular response of tumors in humans by exposing fish to hypoxic conditions. Meanwhile, the study by Howe et al. (2013) showed the relationship between the zebrafish reference genome sequence with the human genome. This shows that the zebrafish was not only used for the climate change impacted the aquatic ecosystem or organism, it was also used for the human related studies. This could be impacted the number of researcher using this animals (i.e., zebrafish) rather than the Medaka species. Based on Table 11, there were a total of 15 top keywords generated from the scientometrics analysis. Surprisingly, the top keyword was temperature, in which it was the key driving force in climate change related studies, especially related to the aquatic organisms (Bozinovic and Pörtner, 2015). However, none of the papers or cluster was actually related to the temperature and climate change. This could be attributed to keywords used for researcher when conducted their related studies towards climate change, such as climate-induce water temperature changes or surface temperature (Borges et al., 2019; Azra et al., 2020). As mentioned above, the zebrafish subsample was the most related to climate change studies (Table 11), which indicates the importance of this species towards climate change related research.

Based on the previous scientometric results that was discussed in the present study, the authors found that the Zebrafish and Medaka have been widely used as one of the model species for ecotoxicological based studies. Agriculture runoff is categorized as one of the climate change elements (Azra et al., 2022), and this could directly or indirectly associated with many toxicological chemicals in the environment (Boxall et al., 2009). However, as both Zebrafish and Medaka can be found in the freshwater and seawater ecosystem, future insight into the potential of how these model species could be properly employed to improve our understanding of climate-driven changes are truly needed. For example, climate-induce water temperature changes could be one of the great example on how global warming could impacted the growth and development of both model species. Their results could be compared and future adaptation strategies could be proposed in the future.

5 Conclusions, strengths and limitations

Studying model organisms helps increase our understanding and knowledge on various types of systems as impacts can be applied to other species. The Zebrafish and Medaka are among one of the most popular aquatic model organisms for studies on climate change. However, our analysis has shown that zebrafish are the most versatile model organism compared to Medaka for climate change as well as in bioindication domain-related studies. Within climate change research, hypoxia and agriculture runoff were common examples for work using these species as models. While the number of publications on these species has increased rapidly, particularly for zebrafish, still missing are more specific studies related to climate change. To understand how other marine or freshwater species will be affected by climate change, particularly climate warming, zebrafish and medaka can be used in experimental studies as model species.

To our knowledge, this is the first study that systematically analyzes and differentiates the data of model-based organisms in climate change studies. However, this survey has some limitations. With respect to our search approach, we included only research articles that were published in English (excluding books, conference papers, abstract, notes, etc.). Additionally our keywords may have been too general, which may be why we saw a high percentage of research not directly related to climate change elements.

6 Recommendations

For future scientometric work, other databases such as Scopus, Directory of Open Access Journals etc. should be used for article searching and indexing in the future to include a wider array of articles. We also recommend including other alternative climate change species models, such as the *Artemia*. With respect to primary climate change research, our results indicate that work further investigating the effects of climate-induced hypoxia as well as chemical tolerance on model organisms would be beneficial. Further, we strongly suggest the use of model organisms in climate research to understand more climate induced effects, such as heatwaves, freshwater influx from flooding, or drought conditions that all may influence fish or other organism's development.

Author contributions

MN: Preliminary idea; First draft; Final draft MM: Preliminary idea; First draft; Final draft MP: Literature search; Critically revised; Software application; Final draft MD: Literature search; Critically revised; Second draft; Final draft MA: Literature search; Critically revised; Second draft; Final draft IZ: Literature search; Critically revised; Final draft MF: Literature search; Critically revised; Second draft; Final draft ZA: Literature

search; Critically revised; Supervision; Final draft FP: Preliminary idea; Critically revised; Funding Acquisition; Final draft.

Acknowledgments

The funding was received through PYPA Initiative managed by the Universiti Teknologi MARA (UiTM).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2022.988710/full#supplementary-material

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