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Global Research Climate Change and Whale Domain: A Scientometric Review

Nur Fakhzan Marwan[1*], Mohd Faizal Azrul Azwan Muhamed Che Harun[2], Azeni Abu Bakar[1], Jolin Norshyme Hashim[1], Ratha Krishnan Suppiah[1]

[1]Faculty of Business and Management, Universiti Teknologi MARA, Pahang Branch, Raub Campus, 27600 Raub, Pahang Darul Makmur, Malaysia.
[2]Faculty of Business and Management Universiti Teknologi MARA, Pahang Branch, Jengka Campus ,26400 Bandar Tun Abdul Razak Jengka, Pahang Darul Makmur, Malaysia.

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ABSTRACT. This study analyzed the research and development landscape in the domain of climate change and whale studies through descriptive metadata and scientometric analysis. Using the Web of Science Core Collection (WoS), we compiled a total of 824 relevant articles and analyzed publication trends, authors and affiliations, countries involved, references, impactful articles, and significant keywords. One notable finding was the involvement of 74 different countries or states with relevant publications in the field of climate change and whale studies, with the USA leading in terms of publication count, followed by Canada and Australia. A total of 3,229 active authors in whale studies were identified, with Canadian researchers having the highest citation count in climate change and whale studies. Surprisingly, the most impactful keywords identified were “climate change” and “marine mammals.” Additionally, the emergence of new keyword burst trends such as “marine” and “management” highlights the need for increased funding or the application of innovative methodologies to encourage more scientifically original research articles in the field of climate change and whale studies. These growing trends emphasize the ongoing importance of sustained inquiry and exploration to effectively address the challenges and opportunities in this evolving field.

Keywords: Bowhead, Climate change, Humpback, Scientometrics, Whales,.

INTRODUCTION

The global effects of climate change are being seen on a widespread scale as unprecedented biophysical changes that exceed most predictions are becoming more apparent. Insufficient study has been conducted on the examination of marine ecosystems in the context of climate change, revealing a noticeable gap in knowledge. It is evident that distinct and rapid impacts are taking place in diverse geographical areas worldwide (Gissi et al., 2021; IPCC, 2021). Whales play a significant role within these ecosystems as top predators, making them valuable indicators of ecosystem shifts in reaction to biophysical changes caused by the shifting climate (Tulloch et al., 2019). Alterations in ocean temperature, the dilution of seawater, acidification, elevations in sea levels, the depletion of polar ice habitats, and the reduction of food resources are among the numerous hazards that climate change presents for whales and dolphins (Malinauskaite et al., 2021). Furthermore, the rapid global warming phenomenon is causing a reduction in suitable habitats for whales and dolphins, leading to heightened competition for diminishing prey species. This environmental shift is influencing the timing and geographic extent of their migratory patterns, altering their distribution and adversely affecting their reproductive capacities (Cook et al., 2020; Riisager-Simonsen et al., 2020).

*Corresponding author: Tel.: +60 93512102; fax: +60 93515555.
E-mail address: *nurfakhzan@uitm.edu.my*

In addition to the numerous biological and biochemical roles whales play, they possess inherent cultural and biodiversity significance. Consequently, they can contribute to the economic stability of coastal regions by serving as attractions for ecotourism (Lambert et al., 2010). Approximately 15 million individuals engage in whale-watching activities annually and the economic impact of this industry has been substantial, with an estimated annual revenue surpassing 2.1 billion dollars (US) and creating approximately 13,000 jobs as of 2009 (Hoyt and Parsons, 2014). The introduction of whale-watching tourism has notably transformed several coastal communities. For instance, in Kaikoura, New Zealand, the annual number of visitors surged from 3,400 to an estimated 873,000 within a span of approximately 10 years (Lundquist, 2014; Simmons, 2014). This form of tourism also exhibits substantial and enduring contributions to employment and the economy in regions like Scotland (Parsons, 2014) and numerous other coastal communities globally, where whale watching is experiencing faster growth compared to other tourism sectors (Castro et al., 2015). Also, in the region of Macaronesia, encompassing the volcanic archipelagos of Azores and Madeira (Portugal) and the Canary Islands (Spain) in the North Atlantic Ocean, the whale-watching industry has experienced substantial growth in recent decades (Bentz et al., 2016; Sequeira et al., 2009). Despite variations in the nature of the activity among the distinct archipelagos and even within islands of the same archipelago, recent assessments reveal that the industry has generated more than 35 million euros in direct income for the region (IWC, 2022; Krasovskaya, 2018; Suárez-Rojas et al., 2021).

Examining the impact of climate change on whale ecology, their ecosystem services (ES), and human well-being requires an interdisciplinary research methodology that bridges various perspectives within the scientific inquiry. This approach is a common feature of many environmental and sustainability challenges, as these issues are too intricate to be effectively addressed by a single field of study, given their complex connections between the natural and human realms (Annan-Diab and Molinari, 2017; Guerrero et al., 2018). Remarkably, a comprehensive scientometric analysis of research pertaining to climate change and whales remains conspicuously absent from the scholarly landscape. Hence, the focus of this study is to delve into the aforementioned subject. This study explores the use of scientometric analysis, a method that systematically gathers, arranges, and examines scientific literature and publications. This approach offers a comprehensive comprehension of the evolving terrain, uncovering valuable observations, patterns, and advancements that may otherwise be overlooked (Azra et al., 2022). To facilitate the examination of climate change and whale studies through scientometrics, various software tools such as CiteSpace, VOSviewer, ScientoPia, and HistCite have been utilized (Li et al., 2022).

METHODOLOGY

The methodology employed in this study adheres to the established procedures outlined in prior scientometric literature (Lim et al., 2023; Neoh et al., 2023). For our study, we accessed the Web of Science Core Collection (WOSCC) database to locate relevant literature on climate change and whales. The search was conducted on August 14th, 2023, and can be accessed at the following URL: (https://www-webofscience-com.ezaccess.library.uitm.edu.my/wos/woscc/summary/6d7f991b-8c60-44c7-bb7d-0ee1511ef98c-

9d9b88e8/relevance/1) .We employed CiteSpace, a scientometric analysis tool, along with Microsoft Excel 2019, to analyze and organize the collected dataset. The methodology utilized in our literature search is visually summarized in Figure 1. During the process, various CiteSpace techniques, such as centrality, burst detection, co-citation, and sigma score, were employed. Comprehensive definitions and detailed explanations of these concepts are available on the official CiteSpace webpage, accessible at the following link: (https://citespace.podia.com/glossary) . Data were retrieved using the search string TITLE-ABS-KEY ((“climat* chang*”)) AND (“whale*”)).

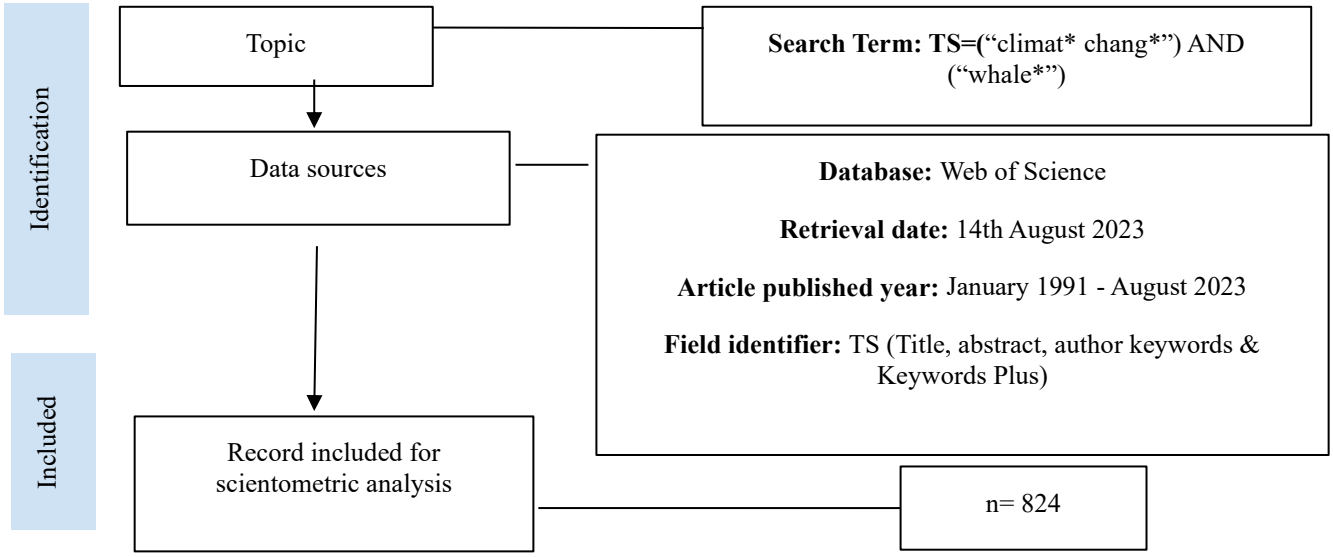

Figure 1. The methodological framework of the present study on climate change and whale.

RESULTS AND DISCUSSION

Descriptive statistics

Number of publications

The scope of our investigation was limited to scholarly articles published from January 1991 to August 2023, as seen in Figure 2. During the designated time frame, a cumulative sum of 824 articles was gathered. Significantly, there was a consistent upward trend seen in the number of publications commencing in 2007, resulting in a total of 802 articles created over the timeframe spanning from 2007 to 2023. The observed phenomenon exemplifies an increasing inclination and heightened focus within the scientific community on the complex connection between climate change and whales.

Top productive authors

Starting from 1991, a substantial volume of publications addressing climate change and whales has emerged, as depicted in Figure 3. Among the authors, 17 have made noteworthy contributions, each authoring more than 10

publications. Out of a total of 3,229 authors, 686 (21.24%) have contributed more than one article to this field. Steven Ferguson stands out with the highest number of publications, having contributed 40 papers. Following closely are Kit M. Kovacs with 30 publications and Mads Peter Heide-Jørgensen with 29 publications. These prolific authors have made significant strides in enhancing our understanding of the intricate relationship between climate change and whales.

Top institutions

Figure 4 showcases the leading ten institutions based on their cumulative publications in the domain of climate change and whales. Among the 1244 institutions contributing to this subject area, the National Oceanic and Atmospheric Administration (NOAA) emerges as the most prolific, with a contribution of 121 publications. It is closely followed by Fisheries and Oceans Canada (DFO) with 118 publications and the University of Washington with 75 publications. Collectively, the top ten institutions, with an average of 672 publications, play a substantial role in enriching the collective knowledge within this field.

Top productive journals

In Figure 5, the leading ten journals are highlighted based on their publication volume within the climate change and whale field, encompassing a review of 305 journals. Frontiers in Marine Science stands out as the premier journal with the highest publication count, encompassing 55 articles. Directly trailing behind are PLOS One and Polar Biology, with 31 and 29 publications, respectively. Over the span from 1993 to 2023, these top ten journals collectively published 266 articles, underscoring their prominence as influential avenues for disseminating research within this domain. These journals play a pivotal role in shaping and disseminating knowledge relating to the intersection of climate change and whales.

Top regional distribution

Figure 6 presents an analysis of the published articles on the topic of climate change and whale research across 74 nations. Significantly, the collective contribution of the top 10 periodicals amounts to a noteworthy 70.91%. The United States of America is at the forefront in terms of publication output, with a notable total of 411 articles. Canada is ranked second in terms of the number of publications, with a significant margin of 222 publications. Australia, on the other hand, secures the third position with 127 publications. These countries have significantly influenced research in this field, highlighting their importance and active involvement in addressing climate change and concerns linked to whales.

Top publishers

Among the 87 publishers evaluated, the top 10 are notably distinguished, collectively contributing to 75.3% of the total publications (Figure 7). This highlights their substantial involvement in addressing the critical issue of climate change's impact on whales. Noteworthy among them is Elsevier, leading the list with 158 publications, followed closely by Wiley with 135 publications and Springer Nature with 110 publications. This underscores a pronounced

dedication from these publishers to disseminate research concerning the interplay between climate change and whale dynamics. This collective commitment to publishing such articles plays a significant role in disseminating knowledge and has the potential to influence policy decisions.

Top research area and citation topic micro

A total of 63 distinct research domains have been identified, with their top ten categories outlined in Table 1. Among these, the prominent fields of study are Environmental Sciences, Ecology, and Marine Freshwater Biology, along with Oceanography. Remarkably, Environmental Sciences contribute to 462 scholarly works, while Ecology and Marine Freshwater Biology account for 214 and 134 research publications, respectively. These leading ten research areas collectively constitute 83.7% of the entire body of work, underlining their notable scholarly interest and engagement. This statistical prominence highlights the allure of these specific research domains, captivating researchers' attention.

Furthermore, Table 1 outlines primary micro-level citation topics, with *Tursiops truncatus* (common bottlenose dolphin or Atlantic bottlenose dolphin) as the most prevalent, featuring in 457 publications. In contrast, the topic of fisheries is represented by 53 publications, while copepods follow with 42 publications. These citation preference patterns unveil the enduring significance of dolphin-related matters, especially concerning their vulnerabilities induced by climate change. The dominance of studies related to dolphins underscores the pressing necessity to examine and conserve these creatures due to their heightened susceptibility to evolving environmental conditions.

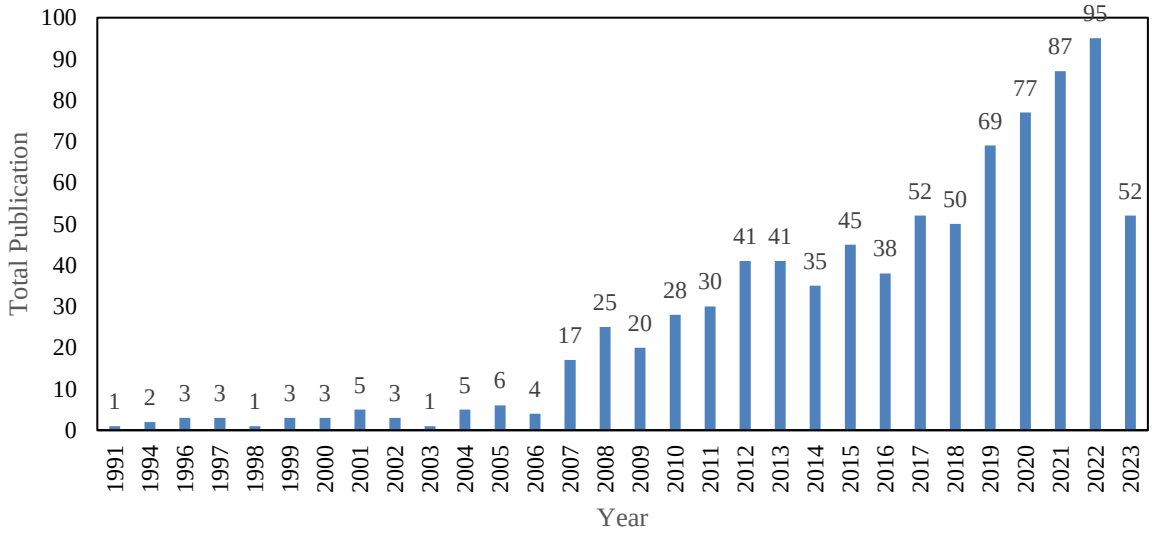

Figure 2. Number of research articles published annually between 1991 to 2023.

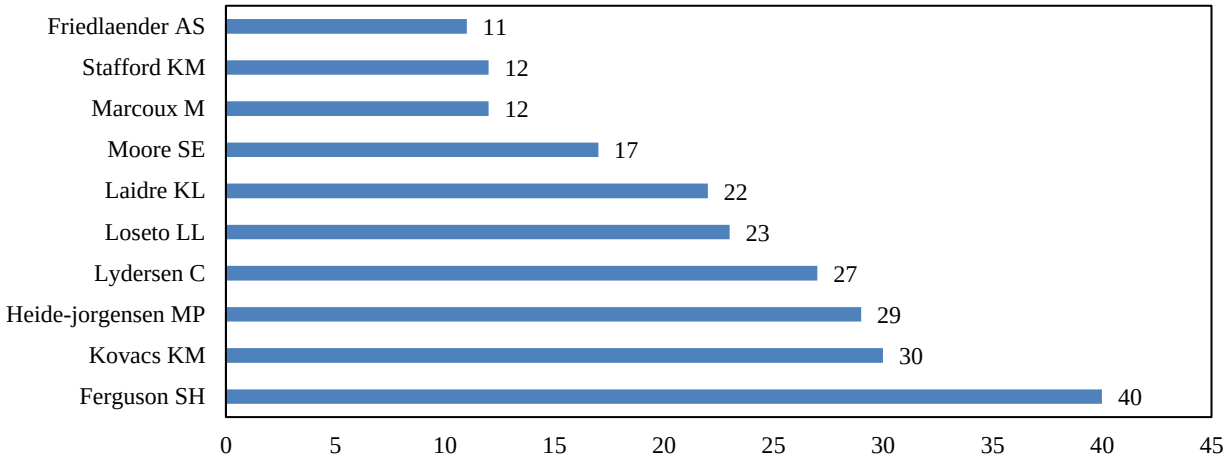

Figure 3. Top ten most productive authors for the period 1991 to 2023.

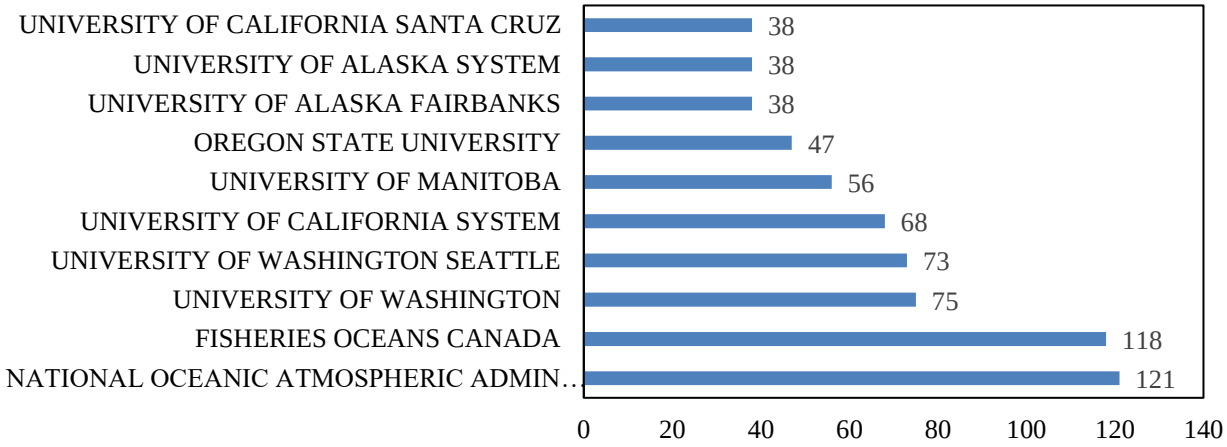

Figure 4. Number of publications from the top ten of 1244 institutions.

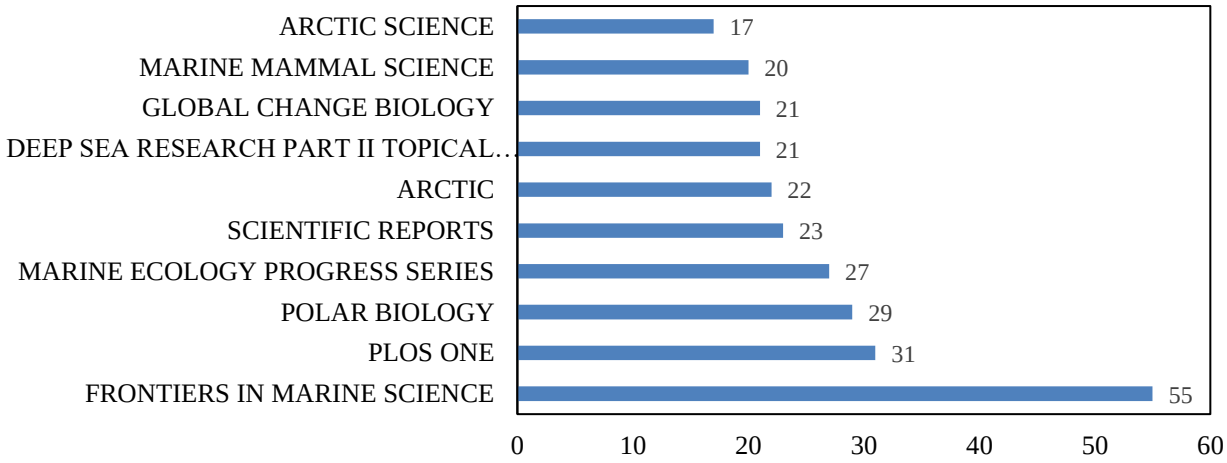

Figure 5. Number of publications published between 1991 and 2023 from the top ten journals.

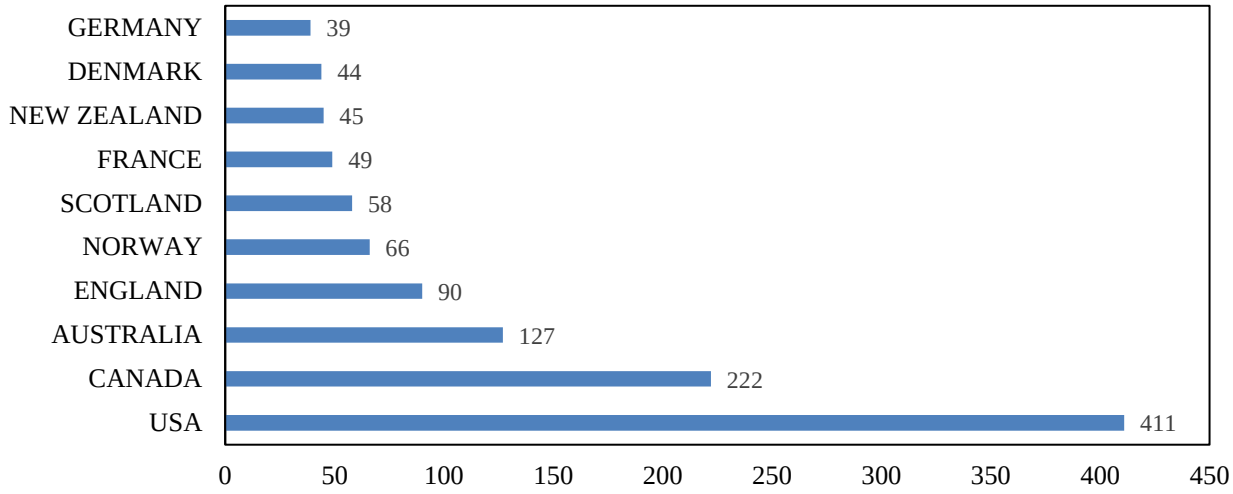

Figure 6. Number of publications published from 1991 to 2023 from the top ten country/region.

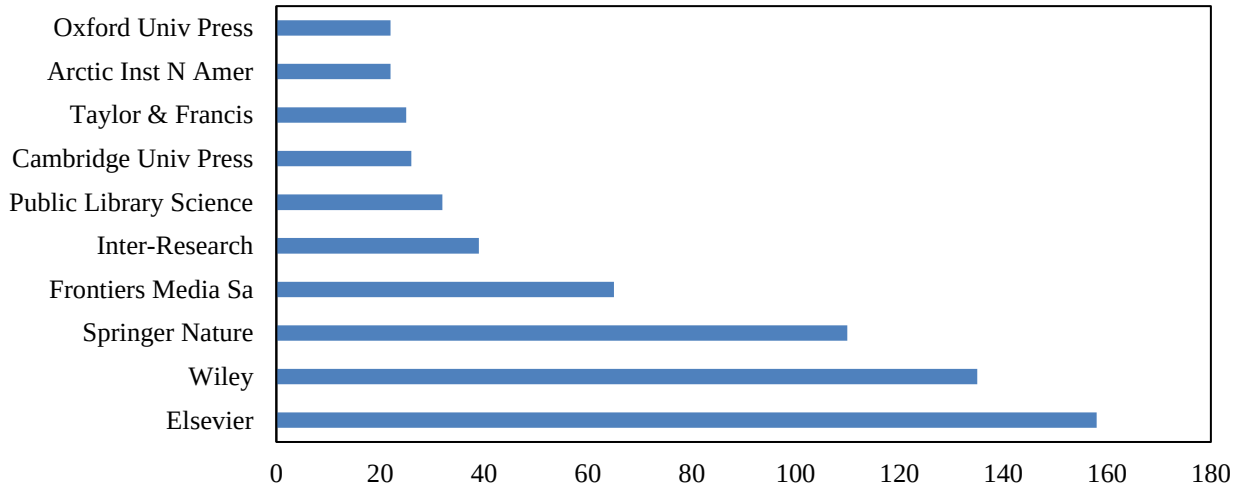

Figure 7. Number of publications published between 1991 and 2023 from the top ten publishers.

Table 1. Top 10 research areas and citation topics micro in the fields of climate change and whale for the period 1991-2023.

Research Areas	Record Count	Citation Topics Micro	Record Count
Environmental Sciences Ecology	462	Tursiops Truncatus	457
Marine Freshwater Biology	214	Fisheries	53
Oceanography	134	Copepods	42
Biodiversity Conservation	113	Climate Change Adaptation	24
Science Technology Other Topics	113	Stable Isotopes	19
Geology	52	Breeding Success	17
Zoology	49	Pcbs	15
Physical Geography	43	Phytoplankton	14
Evolutionary Biology	37	Holocene	11
Water Resources	32	Polychaeta	9

Scientometric analysis

Co-citation analysis

Co-citation analysis is a powerful method that creates a scientific map with nodes, links, and density values. This approach helps us understand the core structure and changes over time. In the context of climate change and whales, co-citation analysis reveals connections and influential relationships among variables like authors, journals, regions, institutions, topics, and articles. Visualizing these networks uncovers key authors, significant publications, and emerging research areas in climate change and whale studies. Here are the co-citation results for authors, journals, regions, institutions, domains, and articles.

Author co-citation analysis.

The analysis of the author's co-citation network revealed 1,014 nodes and 6,208 connections, illustrated in Figure 8. The network's density, calculated at 0.021, indicates substantial interconnectedness among authors. To identify the most influential authors, three parameters were considered: (i) degree, (ii) centrality, and (iii) sigma. With a centrality score of 0.17, a connection degree of 87, and a sigma score of 3.27, David Ainley emerged as the most connected author, showcasing notable impact and influence within the network. Cynthia T. Tynan, the second most significant author, achieved a sigma score of 2.18, a centrality score of 0.06, and a degree score of 55. Knut Aagaard secured the third position with a connection degree of 69, a centrality score of 0.13, and a sigma score of 1.61. Table 2 highlights the top ten authors with the most substantial impact on climate change and whale research, as measured by their degree, centrality, and sigma values. These authors have made noteworthy contributions and wield significant influence in their respective fields.

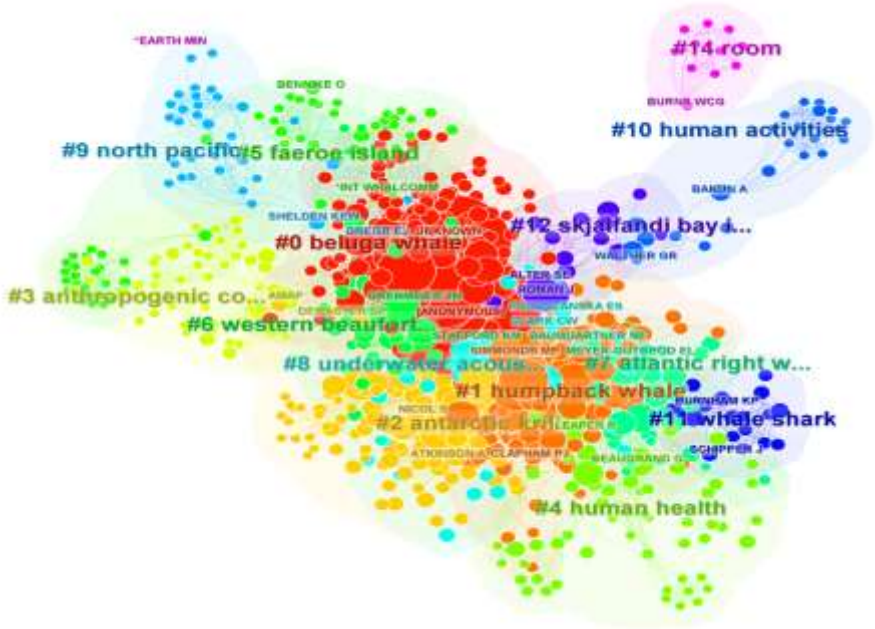

Figure 8. Network of authors co-citation.

Table 2. Top 10 Authors co-citation score

Author	Degree	Centrality	Sigma
Ainley DG	87	0.17	3.27
Tynan CT	55	0.06	2.18
Aagaard K	69	0.13	1.61
Simmonds MP	55	0.06	1.36
Stirling I	70	0.03	1.31
Bakun A	14	0.06	1.26
Derocher AE	49	0.03	1.24
Grebmeier IM	59	0.04	1.23
Finley KJ	52	0.05	1.22
Kovacs KITM	53	0.03	1.21

Journal co-citation analysis.

The journal co-citation network analysis revealed a presence of 832 nodes and 6,487 connections and a density of 0.1877. The knowledge map derived from the journal co-citation study is displayed in Figure 9, showcasing journals with centrality ratings exceeding 0.1. Table 3 provides degree, centrality, and sigma ratings for the top 10 influential journals in the field. Topping the list, the publication "Arctic" boasts a degree score of 651, a centrality score of 0.19, and a sigma score of 16.82, showcasing its substantial influence and frequent references in the co-citation network. The "Canadian Journal of Zoology," with a degree score of 635, a centrality score of 0.09, and a sigma score of 2.27, secured the second-most influential position. Similarly, the "Canadian Journal of Fisheries and Aquatic Sciences" claimed third place with a degree score of 583, a centrality score of 0.05, and a sigma score of 1.75.

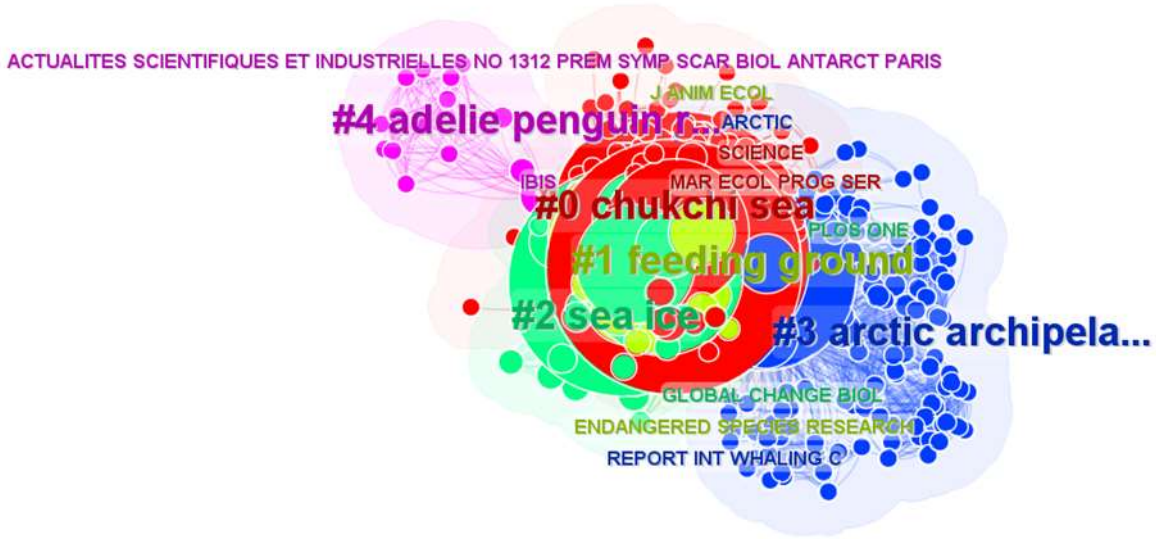

Figure 9. The knowledge maps for journal co-citation analysis.

Table 3. Top 10 Journal co-citation score.

Journal	Degree	Centrality	Sigma
Arctic	651	0.19	16.82
Canadian Journal of Zoology	635	0.09	2.27
Canadian Journal of Fisheries and Aquatic Sciences	583	0.05	1.75
Science	653	0.08	1.7
Nature	649	0.09	1.44
Scientific Reports	458	0.01	1.21
Report of the International Whaling Commission	330	0.03	1.18
Annals of Glaciology	238	0.01	1.16
Ambio	461	0.02	1.14
Frontiers in Marine Science	433	0.01	1.14

Countries/region co-citation analysis.

In the examination of the co-citation network pertaining to countries/regions, 73 nodes, 651 connections and a density of 0.2477 were identified. Figure 10 illustrates the co-citation network based on the countries/regions of the primary authors, where each node signifies a country and the connecting lines symbolize international collaborations. Only countries with a centrality score exceeding 0.1 are featured, and the size of the nodes corresponds to the country's centrality score, representing its influence. Table 4 highlights the top ten most influential countries in the climate change and whale domain based on their co-citation scores. Notably, Canada emerges as the most influential country, boasting a degree score of 35, a centrality score of 0.05, and a sigma score of 1.2. This underscores Canada's substantial influence and collaborative engagements within the co-citation network in this domain. The USA secures the second position, with a degree score of 60, a centrality score of 0.45, and a sigma score of 1. England ranks third, showcasing a degree score of 49, a centrality score of 0.16, and a sigma score of 1.

Figure 10. Network of country/region co-citation analysis.

Table 4. Top 10 country/region co-citation score.

Country	Degree	Centrality	Sigma
Canada	35	0.05	1.2
USA	60	0.45	1
England	49	0.16	1
Australia	44	0.18	1
Germany	39	0.12	1
Scotland	38	0.05	1
New Zealand	37	0.05	1
Brazil	36	0.04	1
France	35	0.05	1
Spain	32	0.09	1

Document cluster analysis

The Document Cluster Analysis showcased consistent and coherent network properties, demonstrated by the Modularity Q Index of 0.5627 and the Weighted Mean Silhouette measure of 0.8299. The analysis identified 12 co-citation clusters, with 10 notable clusters, as depicted in Figure 11. Each cluster is indicated by a solid yellow line, labelled on the right side, and ordered by size. The cluster labels were generated in the CiteSpace program using text mining and keyword analysis, employing the loglikelihood ratio (LLR) for cluster naming.

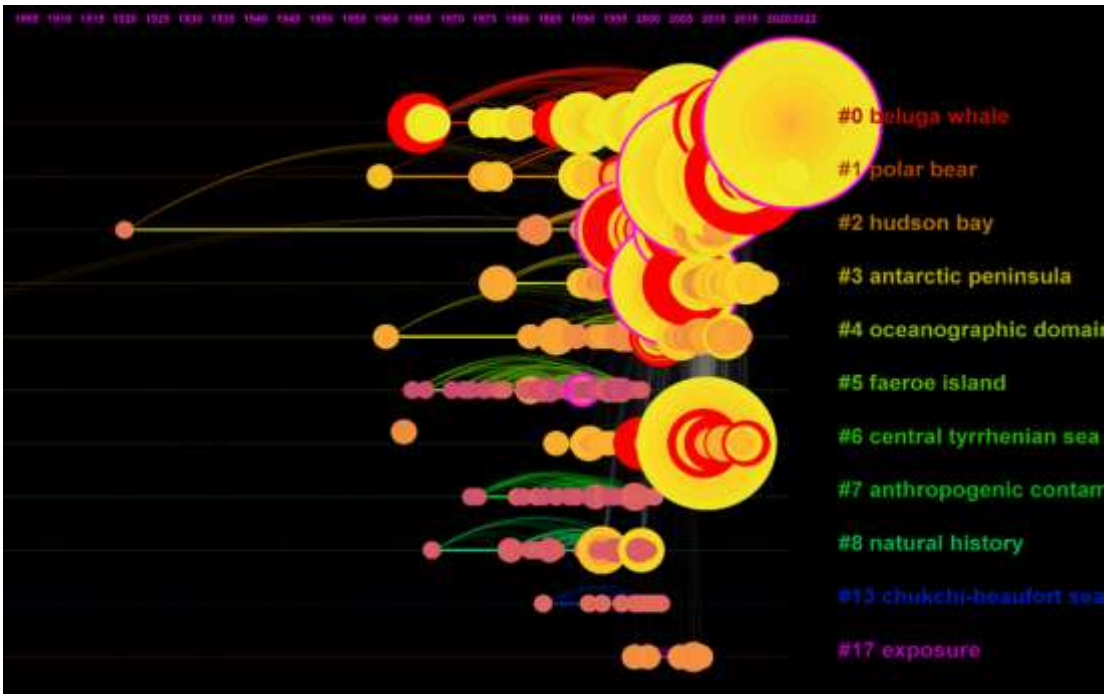

Figure 11. Summary of identified document cluster lifetimes (solid lines). Cluster labels were generated from CiteSpace.

Table 5 provides an overview of the ten primary clusters unveiled by the Document Cluster analysis, each representing a distinct research domain. The cluster's size is determined by the number of articles it encompasses. The largest

clusters include "beluga whale" with 248 publications, "beluga whale" with 192 publications, and "hudson bay" with 150 publications. Silhouette scores across the clusters range from 0.75 to 1, indicating a moderate level of similarity among articles within each cluster. These findings emphasize the clear research themes identified through the Document Cluster Analysis, with each cluster representing a different facet of climate change and its association with whales.

Table 5. Ten (10) major cluster emerged from document co-citation analysis.

ClusterID	Size	Silhouette	Label (LLR)	Average Year
0	248	0.75	beluga whale (486.26, 1.0E-4)	2011
1	192	0.752	beluga whale (789.41, 1.0E-4)	2009
2	150	0.824	hudson bay (476.75, 1.0E-4)	1995
3	93	0.887	antarctic peninsula (277.77, 1.0E-4)	2003
4	80	0.845	oceanographic domain (226.22, 1.0E-4)	2003
5	75	0.97	faeroe island (47.23, 1.0E-4)	1988
6	58	0.859	central tyrrhenian sea (327.9, 1.0E-4)	2006
7	37	1	anthropogenic contaminant (18.29, 1.0E-4)	1991
8	31	0.992	natural history (59.21, 1.0E-4)	1992
13	17	0.999	chukchi-beaufort seas bowhead whale (20.01, 1.0E-4)	199

Burst analysis

To pinpoint influential or pivotal publications and noteworthy keywords, a burst analysis was performed. This analysis aids in detecting emerging trends and significant advancements within the climate change and whale domain. The ensuing trends in studies and keywords were as below:

Document burst.

Table 6 outlines the top ten publications with the highest citation bursts, accompanied by the respective burst duration in the rightmost columns. A burst denotes the emergence of a keyword in a publication during a specific timeframe. The blue line illustrates the chronological span from 1991 to 2023, while the red line indicates the burst period. Notably, the most recent burst is associated with the article "Rapid Climate-Driven Circulation Changes Threaten Conservation of Endangered North Atlantic Right Whales," exhibiting a burst strength of 7.45. This burst commenced in 2019 and persisted until 2023. Published in the Oceanography journal in 2019, the research underscores its recent impact and pertinence in the field.

Table 6. Top ten references with strongest citation burst.

References	Year	Strength	Begin	End	1991 - 2023
Tynan CT, 1997, ARCTIC, V50, P308, DOI 10.14430/arctic1113, DOI	1997	9.91	2003	2015	
Ferguson SH, 2005, MAR MAMMAL SCI, V21, P121, DOI 10.1111/j.1748-7692.2005.tb01212.x, DOI	2005	9.6	2006	2010	
Stirling I, 2006, ARCTIC, V59, P261	2006	6.98	2008	2010	
Kovacs Kit M., 2011, MARINE BIODIVERSITY, V41, P181, DOI 10.1007/s12526-010-0061-0, DOI	2011	6.95	2014	2018	
Laidre KL, 2015, CONSERV BIOL, V29, P724, DOI 10.1111/cobi.12474, DOI	2015	6.98	2016	2023	
Reeves RR, 2014, MAR POLICY, V44, P375, DOI 10.1016/j.marpol.2013.10.005, DOI	2014	6.9	2017	2021	
Ramp C, 2015, PLOS ONE, V10, P0, DOI 10.1371/journal.pone.0121374, DOI	2015	9	2019	2023	
Meyer-Gutbrod EL, 2018, GLOBAL CHANGE BIOL, V24, P455, DOI 10.1111/gcb.13929, DOI	2018	7.2	2019	2023	
Tulloch VJD, 2019, GLOBAL CHANGE BIOL, V25, P1263, DOI 10.1111/gcb.14573, DOI	2019	9.06	2020	2023	
Record NR, 2019, OCEANOGRAPHY, V32, P162, DOI 10.5670/oceanog.2019.201, DOI	2019	7.45	2020	2023	

Moreover, the paper titled "Observations and Predictions of Arctic Climatic Change: Potential Effects on Marine Mammals" registered the highest burst strength at 9.91. Published in 1997, this influential publication underscores its extensive influence and prominence in the realms of climate change and whale studies.

Keyword burst.

Table 7 illustrates the keywords exhibiting the most citation bursts, signalling emerging trends and focal areas of research within the climate change and whale context. A burst indicates the prevalence of a term in publications related to a particular topic over a defined timeframe. The blue line traces the timeline from 1993 to 2023, while the red line represents the burst period. Among the keywords, "variation" registered the highest burst strength, scoring 6.53 during the interval from 2010 to 2014. Noteworthy keywords such as "polar bears" (burst strength: 4.44, 2008-2009) and "stable isotopes" (burst strength: 4.07, 2015-2018) also displayed robust bursts, indicating focused attention and burgeoning trends within their respective burst periods. These findings shed light on the evolving interests and prominent areas of exploration in the domain of climate change and whales.

Table 7. Top ten keywords with strongest citation burst.

Keywords	Year	Strength	Begin	End	1991 - 2023
variability	2008	6.53	2010	2014	
polar bears	2008	4.44	2008	2009	
stable isotopes	2009	4.07	2015	2018	
ursus maritimus	2017	3.94	2017	2020	
marine	2020	3.76	2020	2023	
management	2001	3.65	2021	2023	
diversity	2013	3.61	2013	2016	
evolution	2016	3.55	2016	2020	
bears ursus maritimus	2005	3.54	2005	2010	

Table 8, conversely, presents the frequently occurring terms in titles, abstracts, and keywords of publications. The term "climate change" stands out, recurring 384 times as the most prevalent keyword. Following closely, "climate-change" appears 144 times, and "marine mammal" follows with 138 occurrences. These keyword analyses offer valuable insights into prevailing research trends and crucial focal points within the realm of climate change and whale

studies. This emphasizes the spectrum from novel concerns to extensively researched concepts within the field.

The objective of our study was to perform a scientometric analysis of research within the climate change and whale domain. We conducted a descriptive investigation encompassing various critical attributes, such as the number of publications, the journals in which they were published, the authors involved, the universities or institutions affiliated with the authors, and the countries or regions associated with these authors. This comprehensive analysis aimed to provide insights into overarching publication trends.

Table 8. Top ten keywords with highest frequency.

Keywords	Frequency
climate change	384
climate-change	144
marine mammals	138
abundance	75
sea ice	73
impacts	57
conservation	55
beaufort sea	53
variability	53
humpback whales	44

We observed a consistent upward trajectory in the number of publications each year over a span of three decades, averaging 27 papers per year. Notably, from 2008 onward, the publication output exceeded 25 papers per year, indicating a substantial surge in research activities in recent years. The increasing number of papers on the relationship between climate change and whales has additional importance due to the complex nature of this study topic and the related challenges and obstacles. The aforementioned trend is a strong indication of the growing curiosity, increased acknowledgement, and heightened scientific involvement in the field of climate change and whale research. Notwithstanding the inherent challenges associated with delving into this complex domain, the persistent increase in scholarly productivity highlights the resolve to comprehend the complicated connections between these two pivotal variables and their wider ramifications. The observed increased trend not only reflects the commitment of researchers and institutions but also underscores the urgent need to understand and tackle the intricate connection between climate change and the interests of whale populations.

A comprehensive co-citation analysis was undertaken to delve into the realms of authors, journals, countries, institutions, research domains, and publications within the context of climate change and whale studies. This extensive exploration aimed to pinpoint the key knowledge disseminators operating in these interconnected fields. The investigation yielded several influential figures, illuminating their pivotal roles. Notably, the investigation identified "Tynan CT" as the most influential author, underscoring their substantial presence and impact in the climate change and whale domains. Among the top 10 prominent authors identified, a significant proportion are actively

engaged in the climate change and whale arena. This observation serves to underscore their expertise, knowledge, and substantial contributions that have exerted a profound influence within this critical field of study.

Canada appears as the most dominant nation in terms of climate change and whales. This is shown by Canada's much higher sigma score when compared to other nations such as The USA and Canada. While the United States and England exhibit higher values in terms of degree and centrality compared to Canada, it is noteworthy that Canada demonstrates a superior sigma value. This elevated sigma value suggests that Canada is associated with a more substantial output of significant research on whales, implying its greater contribution to this field.

The fourth research question sought to identify the dominating subjects and clusters within the area of climate change and whales, as well as the temporal development of these topics and clusters. A total of 12 co-citation clusters were discovered using document cluster analysis. The most important clusters are “beluga whale (humpback whale)," "beluga whale (bowhead whale)," and "Hudson Bay (marine mammal)". These findings indicate a considerable portion of research is concentrated on examining the impact of climate change on specific whale species, particularly the humpback whale and bowhead whale. Moreover, it is noteworthy that a significant number of studies are centred around the geographical region of Hudson Bay, signifying its prominence as a focal area for research endeavours. The scrutiny of document bursts revealed a discernible pattern of expanding research topics, with contemporary publications progressively overtaking older ones. Interestingly, the burst analysis results exhibited some discrepancies from the document co-citation analysis. Notably, nine out of the top ten keyword burst scores were linked to older publications that were published before 2015. Nevertheless, spanning the timeframe from 1991 to 2023, terms such as "climate change" consistently held sway in both the burst and frequency analyses, highlighting their enduring prominence in the discourse.

The notable disparity between co-citation and burst scores underscores the pressing necessity to broaden the scope of the study focus. The occurrence of novel keyword burst patterns, namely "marine" and "management," in the domain of climate change and whale studies indicates the shifting research goals and regions of concentration. The increased frequency and significance assigned to these keywords emphasise the urgent need for more investigation and more comprehensive comprehension in these particular areas. Firstly, the use of the term "marine" indicates an increasing focus on marine ecosystems, underscoring the acknowledgment of the interdependence between climate change and the well-being of marine environments. This phenomenon highlights the pressing need for a comprehensive understanding of the effects of climate change on seas, marine organisms, and interconnected ecological systems. Comprehending these complex interconnections is crucial for formulating solutions that effectively address the impacts of climate change on marine ecosystems and organisms, such as whales.

Second, the use of the term "management" implies a growing acknowledgment of the imperative need for proficient management approaches in response to climate change and its consequences on marine ecosystems, specifically with regard to whales. This emerging phenomenon underscores the need for novel strategies in the realms of governance,

conservation, and sustainable resource management. The implementation of effective management techniques is crucial in safeguarding marine environments, regulating human activities, and enacting actions that support the welfare of marine animals, such as whales, in the face of a dynamic climate.

In order to promote an increased volume of scientifically novel research publications in these key domains, securing supplementary financing is vital. The provision of financial assistance is crucial for the implementation of comprehensive research initiatives, the facilitation of improved data-gathering methodologies, the facilitation of in-depth analyses, and the promotion of joint endeavours across various institutions and nations. Moreover, the use of novel procedures, such as cutting-edge technology and multidisciplinary approaches, will boost research capacity and provide more insightful discoveries.

CONCLUSION

This study offers a comprehensive overview of climate change's impact on whales, albeit with potential limitations, including publication bias stemming from the use of the Web of Science (WOS) database and the potential inclusion of unrelated subjects due to the CiteSpace software. The study accentuates the importance of interdisciplinary research and cooperation, pinpointing crucial research gaps and future directions. Notably, the outcomes of the study could contribute to addressing existing research limitations, particularly considering the constraints associated with the choice of database. To address this, further exploration and inclusion of a broader spectrum of literature sources are pivotal for bridging these gaps and enhancing comprehension in this pivotal realm of climate action and whale investigation.

AUTHOR CONTRIBUTIONS

Conceptualization: [Nur Fakhzan Marwan], Ideas; formulation or evolution of overarching research goals and aims; Methodology: [Nur Fakhzan Marwan], Development or design of methodology; creation of models; Investigation: [Azeni Abu Bakar], Conducting a research and investigation process, specifically performing the data/evidence collection; [Jolin Norshyme Hashim], Management and coordination responsibility for the research activity planning and execution; Writing-original draft: [Nur Fakhzan Marwan], Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation); Writing original- draft: [Mohd Faizal Azrul Azwan Muhamed Che Harun], Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation); Writing-review & editing: [Ratha Krishnan Suppiah], Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre- or post-publication stages.

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DATA AVAILABILITY

Data can be can be accessed at the following URL: (https://www-webofscience-com.ezaccess.library.uitm.edu.my/wos/woscc/summary/6d7f991b-8c60-44c7-bb7d-0ee1511ef98c-9d9b88e8/relevance/1)

COMPETING INTEREST

The authors declare that there are no competing interests.

COMPLIANCE WITH ETHICAL STANDARDS

Not applicable.

SUPPLEMENTARY MATERIAL

Supplementary material is available on the publisher's website along with the published article.

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