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A SCIENTOMETRIC MACROANALYSIS OF CORAL REEF RESEARCH IN THE WORLD

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Abstract

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Marine and coastal biodiversity is crucial to the planet's functioning and offers ecosystem services that guarantee the health, wealth, and well-being of the entire humanity. This is why, evaluating the current body of research on coral reefs is essential for understanding the unprecedented growth of this field, which covers many topics including climate change, biotic interactions, bioresources, future bioprospecting, and biodiversity in general. Such an evaluation requires both descriptive summaries and co-citation analyses to understand the expansive nature of this particular research and identify research gaps. Given the importance of the topic and the fact that it is insufficiently addressed, this study fills in a gap regarding coral reefs studies. We analyzed coral reef research published in the Web of Science Core Collection database between 1970 and 2021, using the CiteSpace software. This gave a total of 20,362 records, focusing on variables including the list of contributors (author, affiliation, and country), total publications over time, dual map overlay, co-citation analysis (co-cited author and documents), cluster networks, and popular keywords and their burstness. We found that coral reef publications increased over time, with coastal countries (the USA, Australia, and Japan) being among the highest contributors. Researchers from Australia, New Zealand, and the USA are the top producers of coral reef research worldwide. Unsurprisingly, the journal Coral Reefs was the most productive journal. Interestingly, we found that keywords such as "great barrier reef," "climate change," and "predation" were among the top cited and most influential in coral reef science. To our knowledge, this is the first study to identify trends in coral reef research using scientometric analyses based on the CiteSpace software.

Key words: aquatic environment, coral bleach, coastal ecosystem, fish community, tropical reef.

Introduction

The oceans contain over 96.5% of the planet's total water, covering about 71% of its surface. Consequently, coastal and marine environments can harbor an extremely rich biodiversity (Chorfi et al., 2022; Vincevica-Gaile et al., 2022). Among the specific habitats, coral reefs play a vital role in sustaining coastal ecosystems; however, more than 50% of the coral reefs worldwide are already degraded (Díaz et al., 2019; Eddy et al., 2021). Current evidence suggests that global climatic changes and increasing human activities could increase the stress toward the future collapse of coral reefs (Johnson et al., 2022; Obura et al., 2022). Coral reefs are not only useful indicators of ocean health through the measurement of live coral cover (Castro-Sanguino et al., 2021; Hughes et al., 2017), but also support more than 500 million people in the world who depend on coral reef ecosystems (Hoegh-Guldberg et al., 2019). This research issue is crucial because coral reefs are important ecologically and economically. Nevertheless, despite the outmost importance of the subject, there is a lack of studies, specifically recent ones, dealing with

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coral reef literature. In addition, studies that identify the current literature using bibliometric analyses could be important for understanding the contribution of coral reef research within global scientific communities. There has been unprecedented growth in scientific literature on coral reefs, which has attracted the authors to conduct interdisciplinary or multidisciplinary research (Martindale et al., 2021). Topics include larval dispersal of coral reef fishes (Counsell et al., 2022), nutrient enrichment on coral reefs (D'Angelo, Wiedenmann, 2014), marine protected areas (Pelletier et al., 2005), and hydrodynamic perspectives of sediments on coral reefs (Schlaefer et al., 2021). Previous reviews on coral reefs have also focused on research fields such as conservation science (Boakes et al., 2022; Platz et al., 2022), management science (Camp, 2022; Razak et al., 2022), and computer science (Burns et al., 2022; Pavoni et al., 2022).

Bibliometric studies or scientometric analyses could be useful for identifying current research and development trends in many fields (Ianoş, Petrişor, 2020)), including global coral reef science. Such studies can help to know the current status of research through citation analysis, covering correlation between journals and literature, as well as important keywords and cluster analysis, and can ultimately help researchers grasp a global perspective and reveal research hotspot and knowledge gaps in certain research areas (Zhang, Zou, 2022). Any research gaps and/or potential future studies can be identified through in-depth bibliometric analysis such as document burstness, co-citation comparison, dual map overlay, keywords' distribution, and contributors' analysis (Aryadoust et al., 2019; Azra et al., 2022; Chen, 2017; Chen, Song, 2019; Noor et al., 2022). Scientometric reviews of literature have been conducted on themes ranging from specific issues, for example, carbon emissions (see Udara Willhelm Abeydeera et al. 2019), to researchers, for example, Professor Wolfgang Glanzel (Gholampour, Noruzi, 2021), taxa, for example, zebrafish (see Kinth et al. 2013), or organizations, for example, Iranian Orthopedics Academic Departments (see Ebrahimpour et al. 2021). The CiteSpace software is used to identify bibliometric data and to find relatively new or insufficiently known connections.

This study aims to investigate coral reef research in terms of current publication quality and productivity, literature impacts, research networks, and potential research gaps. Specifically, there are two types of analysis: (A) descriptive and (B) sciento based, which include (i) number of publications, (ii) author, affiliation, journal, and listed country, (iii) dual map overlay, (iv) co-cited author and documents, (v) cluster analysis of documents, and (vi) keywords' distribution and its burstness. The study can offer a valuable perspective and in-depth understanding to researchers and authorities who wish to promote coral reef science.

Methods

Data source, collection, and processing

The present study retrieved data from one of the vast scientific databases, Web of Science (WOS), which has a new interface and is functionality available from the summer of 2021 (Chang, 2021). We focused on the WOS Core Collection (WOS CC), which currently contains more than 21,100 peer-reviewed journals with high-quality publications and comprehensively covers 250 multidisciplinary fields of science, social science, and arts & humanities. WOS also offers various complete cited reference searching activities and is connected to the Google Scholar database. The link can be referred at: https://www.webofscience.com/wos/woscc/summary/a0b8cf79-0535-4a4a-b088-f47170e20db1-4455096b/date-descending/1.

WOS was chosen for two main reasons. The first one concerns CiteSpace, a software limited to only one database that can be incorporated in a one-time process. The second one is the fact that WOS offers more details on citation data compared to other databases, such as Scopus or PubMed.

We conducted our search on July 19, 2022. The search terms included only one keyword ("coral reef*"). We excluded articles published in 2022, non-research articles, and those that were not written in English. The text files downloaded from the WOSCC were exported to CiteSpace software for subsequent analysis. All 29 fields in WOSCC database were selected (i.e., custom selection) to generate the bibliographic records. Also, Pro Word Cloud, an add-on in Microsoft Office PowerPoint 2019, was used to generate the keywords' distribution in coral reef research.

Scientometric analysis

CiteSpace software was used to analyze the sciento-based data of coral reef research. The updated version of 6.1. (R2) in the basic mode was used (version built on June 20, 2022 and expiring on December 31, 2022). Certain terms were used in CiteSpace, such as centrality, burst detection, co-citations, modularity and silhouette scores, pathfinder network scaling, and sigma (Chen, 2015).

Results

Descriptive statistics

All top descriptive statistics in the figures can be referred to in Supplementary Materials, including the number of articles published, list of authors, list of affiliations, and contributing journals as well list of the top countries involved in the field. Briefly, a total of 20,362 publications were found in coral reef science. A total of 36,204 authors, 7398 affiliation entries, 1602 different journals, and 166 countries or regions were found through the descriptive analysis. Countries including the USA, Australia, France, England, and Japan contributed to about 88% of the total publications in this field. Affiliations from Australia, such as James Cook University, Australian Institute of Marine Science, and University of Queensland, and the University of California System, USA, as well as the Centre National De La Recherche Scientifique, France, were among the top five institutions publishing research about coral reefs. Authors such as David R. Bellwood from James Cook University, Australia, Mark Ian Mccormick from University of Waikato, New Zealand, Peter J. Mumby from University of Queensland, Australia, Geoffrey P. Jones from James Cook University, Australia, and Timothy R. Mcclanahan from Wildlife Conservation Society (a nongovernmental organization based in the USA) were among the top producers of coral reef studies. Coral Reefs, Marine Ecology Progress Series, and Plos One were among the top three journals, based on the WOSCC database.

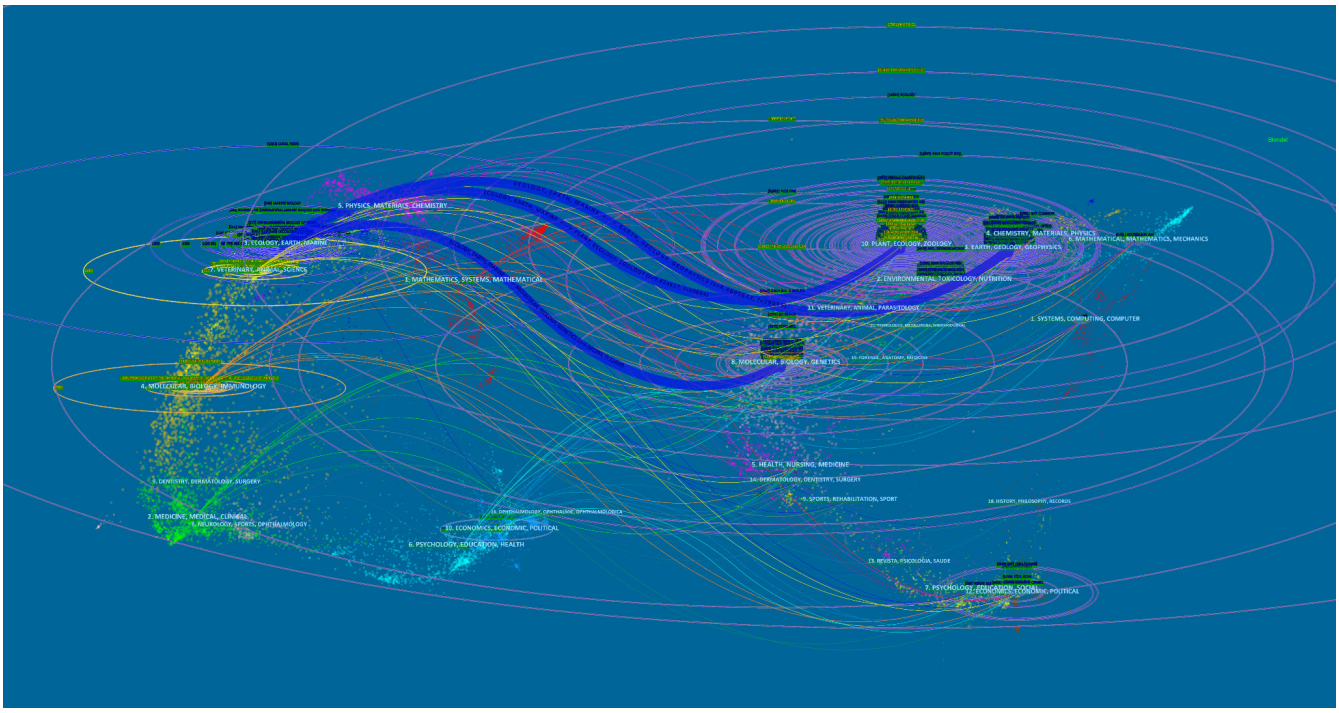


Fig. 1. Dual map overlay on coral reef research in the world, based on data generated from the Web of Science Core Collection, through CiteSpace analysis. Each different color indicates a field of study. The image points out "Plant, Ecology, and Zoology" as the main anchor for coral reef science, as indicated by the total number of ellipses in the figure and marked by the purple oval.

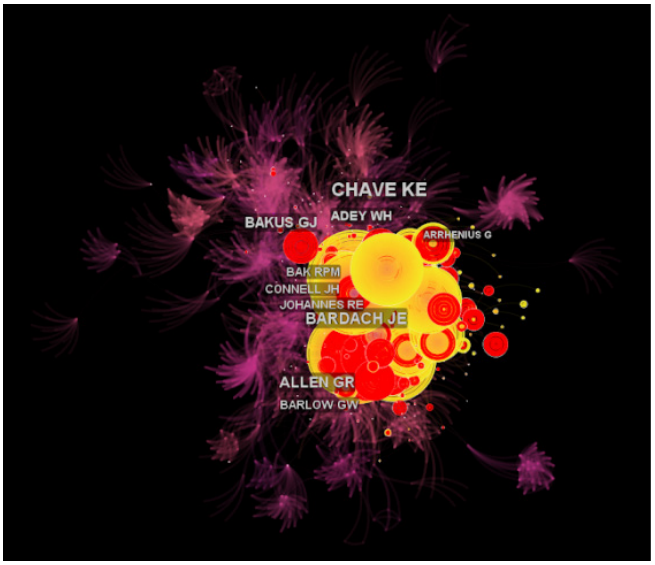


Fig. 2. Author co-citation analysis in coral reef science. The size of the author name font indicates their influence over the knowledge domain.

Results of the scientometric analysis

Dual map overlay

In scientometric analysis, especially when using CiteSpace software, one of the important indicators for a selected theme is the dual map overlay. This map objectively indicates if there are any interdisciplinary or multidisciplinary interactions or correlation trends between research areas (Chen, Leydesdorff, 2014). In the present study, a multidisciplinary relationship between citations or fields was found (Fig. 1). Figure 1 shows there are three different important indicators: (i) points referring to literature, (ii) ellipses indicating groups of subject matter, and (iii) directional lines showing the connection between subjects. "Plant, Ecology, and Zoology" was found to be the main anchor for coral reef science.

Co-cited author

Generally, the co-citation network "involves tracking pairs of papers (i.e., document) or authors that are cited together in the source articles" (Kademani, 2011). K. E. Chave, J. E. Bardach, G. R. Allen, G. J. Bakus, W. H. Adey, G. W. Barlow, J. H. Connell, R. E. Johannes, R. P. M. Bak, and G. Arrhenius were among the topmost influential authors in coral reef science (Fig. 2). All of them are authors from the 70s to 80s era (Supplementary Material).

Co-cited documents

Co-cited documents, also known as document co-citation analysis networks, refer to the most influential articles in the area of coral reef research. J.H. Zar, J. Zar, J.H. Connell, P.J. Doherty, N. Knowlton, M.A. Borowitzka, T.A. Gardner, and J.F. Bruno were among the most influential documents (referred to by author name in Fig. 3). This was based on the centrality score (min. 0.17, max. 0.25) through CiteSpace analysis (Supplementary Material).

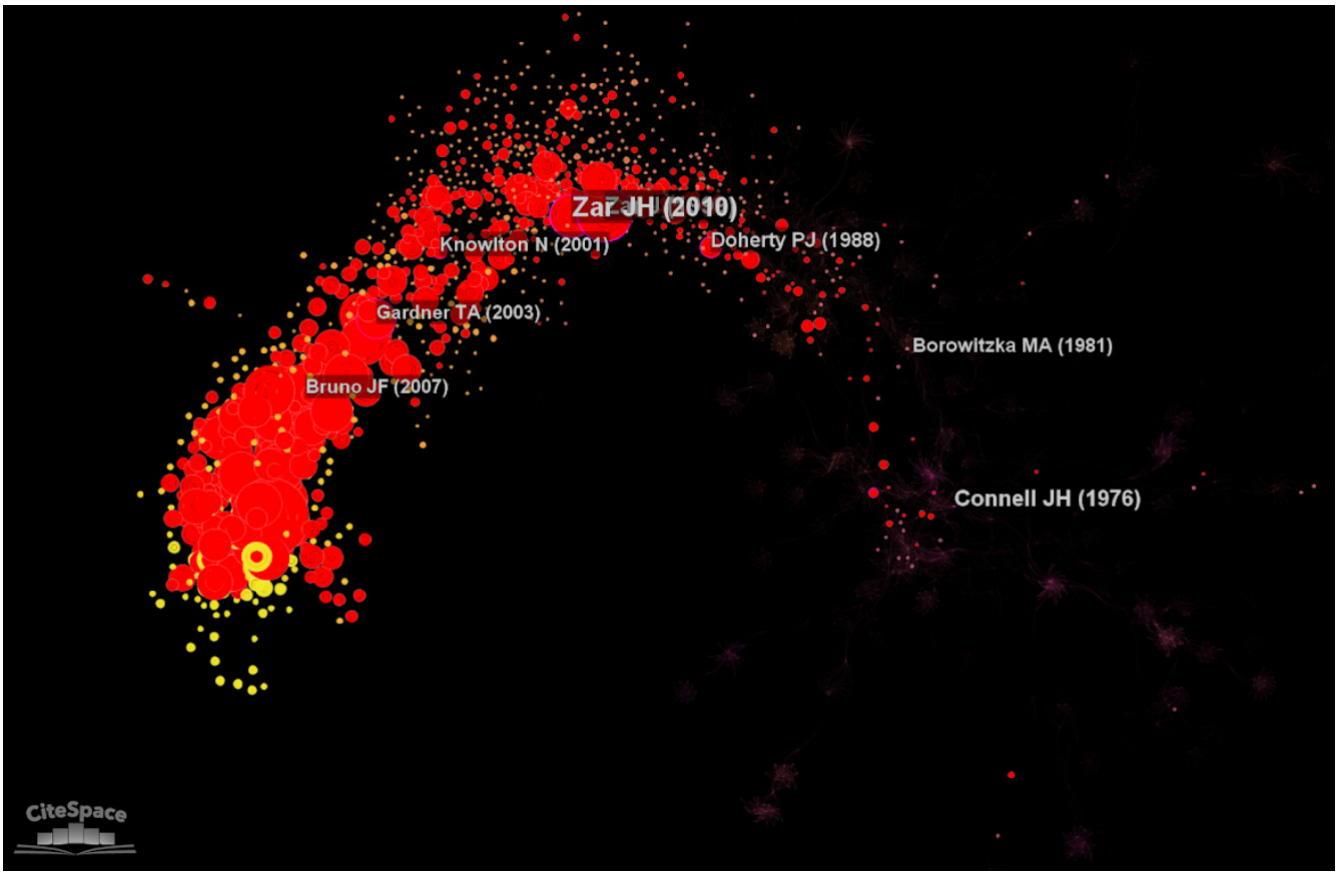


Fig. 3. Document co-citation analysis networks for coral reef in the world. The size of font indicates the influence of references over the knowledge domain.

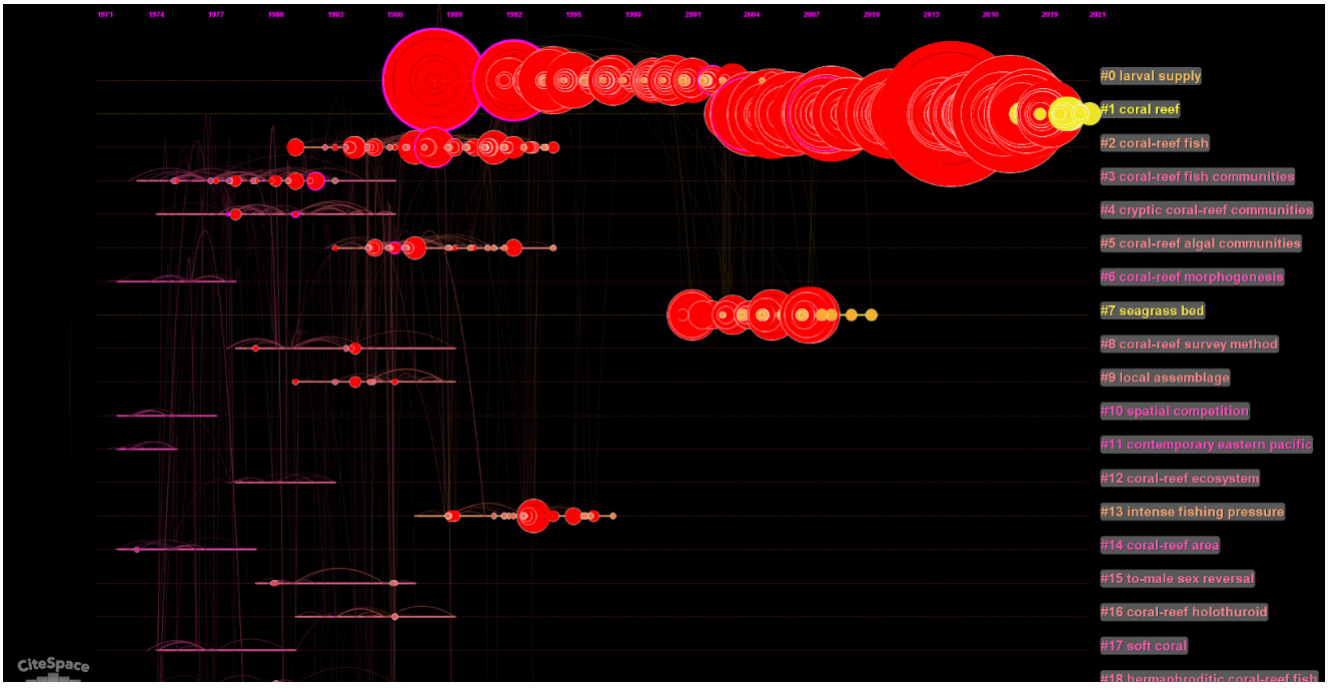


Fig. 4. Document clustering analysis for the coral reef research, based on the years between 1970 and 2021. #0 cluster has most articles, and bigger circles pinpoint the current cluster in a given time period.

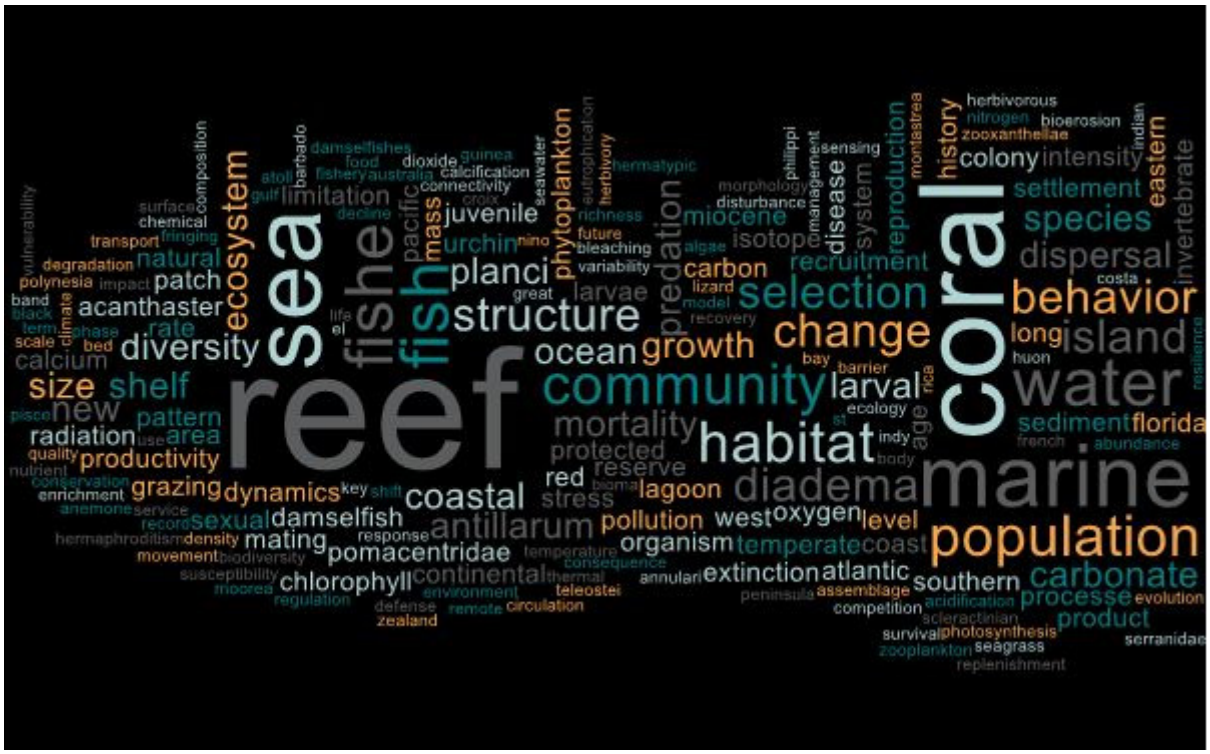


Fig. 5. Keywords' distribution in coral reef–related studies, as cited in the Web of Science Core Collection from 1970 until 2021.

Document cluster analysis

Document cluster analysis refers to the multi-perspective of characterizing and interpreting any trends of co-cited articles in terms of structure (i.e., visualize networks) and dynamics (i.e., clustering and summary) of the selected theme. Briefly, the network was divided into 39 co-citation clusters, and only the top 17 largest clusters are summarized in Figure 4. The top five clusters were #0 larval supply, followed by #cluster 1 coral reef, #2 coral-reef fish, #3 coral-reef fish communities, and #4 cryptic coral-reef communities.

Key words' distribution

Based on the list of the keywords used by authors in the WOSCC database, we generated the keywords' distribution (Fig. 5) using Pro Word Cloud, an add-on in Microsoft Office PowerPoint 2019. Based on the generated keywords about coral reef, the keyword "coral reef" was used the highest number of times (a total of 7374 times), followed by Great Barrier Reef (total cited: 2400; year: 1987) and climate change (total cited: 2324; year: 2005).

Key word burstness

The most influential keywords are also known as keyword burstness. This refers to the keywords that frequently surged or appeared within a certain time or period (Table 1). The bursts are shown over the time period, where the blue line indicates when a keyword first appeared and the beginning of the red line shows a period where the keyword bursted (i.e., was used most frequently within the time period); the end of the red line marks the end of the burst period (Chen, 2015). The top five most influential keywords in coral reef science were "predation," "pisce," "French Polynesia," "bioma," and "settlement."

Discussion

Significance of the results

To the best of our knowledge, this was the first publication to identify trends in coral reef scientific literature using scientometric analysis based on CiteSpace software. Previous bibliometric analyses of coral reefs were focused on country-based analyses, rather than at the global level. Because coral reefs have an outmost importance for tourism (Spalding et al., 2017) and fishery (Teh et al., 2013), there is a need to ensure that current research helps understanding and maintaining these ecosystems of crucial worldwide importance.

The descriptive analysis showed that the most active contributors to coral reef research were mostly from Australia, at least based on the WOSCC database. Most top affiliations and active researchers who published about coral reef originated from Australia. This could be due to the fact that the world's largest coral reef is found in Australia, that is, the Great Barrier Reef. Similarly, top cited keywords in coral reef research included the Great Barrier Reef, which was used about 2400 times. This indicates that Australian research on the Great Barrier Reef dominates coral reef research worldwide (Pendleton et al., 2019; Ortiz et al., 2021).

Table 1. Top ten keywords with the strongest citation bursts in coral reef science, based on the WOSCC database, from 1970 until 2021.

Keywords	Year	Strength	Begin	End	1970 - 2021
predation	1970	**48.42**	1997	2008	
pisce	1970	**47.5**	1991	2007	
french polynesia	1970	**43.86**	1997	2006	
bioma	1970	**41.5**	1998	2008	
settlement	1970	**38.94**	1992	2007	
disturbance	1970	**37.47**	1995	2008	
Australia	1970	**36.84**	1993	2003	
population	1970	**35.88**	1993	2005	
mass mortality	1970	**35.84**	1991	2006	
population dynamics	1970	**33.93**	1992	2003	

In the dual map overlay, the multidisciplinary interaction between "Ecology, Earth, Marine" and "Plant, Ecology, Zoology" had a strong correlation (z = 9.424, f = 59664). This indicates that coral reef science relates to plants and the marine environment. In the author co-citation analysis, most influential authors were those from the 1970s, who probably wrote the fundamental principles of coral reef science. Also, simply by being older, there was more time for these papers to be cited and thus gain visibility. Ten articles were categorized as the most important publications for coral reef research in the co-citation analysis. For example, J. H. Zar is a researcher from Northern Illinois University, USA, and the fourth and fifth editions of his book (Zar, 1999, 2010) referred to the statistical analysis of biological data. Their citations were not directly associated with coral reef–related studies. However, the studies by Connell (1976), Knowlton (2001), Gardner et al. (2003), marked as Gardner TA 2003 in Figure 3, and Bruno, Selig, (2007), marked as Bruno JF 2007 in a co-cited document, were directly associated with coral reef research. These earlier studies mostly focused on the introduction of coral reefs in the world, their recent biodiversity and distribution, and other related bioresources within the coral reef ecosystem (Connell, 1976). However, later studies of co-cited documents indicated and summarized the current trends of coral reef decline in the Indo-Pacific and Caribbean regions (Gardner et al., 2003; Bruno, Selig, 2007). Knowlton (2001) mostly discussed the possibility of coral reef extinctions, especially with respect to what is known about the coral reef fossil record.

Interestingly, the top coral reef science clusters are marked in Figure 4 as #0, larval supply. This could be due to the fact that most coral reefs act as nursery grounds for local reef species or species dispersing from other regions, such as coral reef damselfish, *Pomacentrus amboinensis* (Meekan et al., 1993), and Caribbean reef fishes, *Stegastes partitrus* (Sponaugle, Cowen, 1996). The CiteSpace analysis on this cluster shows that the most relevant citer to the cluster was Munday and Jones (1998). Their study found that it is important to identify and estimate the abundance of small aquatic species around the coral reef environment. Again, we anticipate this study being so well cited partially due to its age and also because it founded research on coral reef species monitoring. The second largest cluster with 381 publications was cluster #1, marked as "coral reef." Here, the most relevant and recent citer to the cluster was Cinner et al. (2009). Cinner et al. (2009) found that climate change was among the greatest threats for coral reefs due to climate-induced water temperature change, which causes coral bleaching and mortality, indirectly impacting coral reef fishes.

The present study also found that "climate change" was among the top three cited keywords, and it was first mentioned in 2005. We believe that during this time, climate change issues became more visible because worldwide climate change forums shifted

political priorities and reoriented research (Demekas, Grippa, 2021; Pattberg et al., 2022). Consequently, more researchers began drawing relationships to coral bleaching and climate change (Boonnam et al., 2022; Hannah, 2022; van Woesik et al., 2022). Also, 2005 was the hottest year on record for sea surface temperature, which impacted coral reef conditions through hurricanes in the Caribbean and Atlantic basin. Both increasing sea surface temperature and hurricane frequency are usually associated with anthropogenic climate change (Chand et al., 2022; Knutson et al., 2020). The most recent influential keywords appeared in 2008, including "predation," "bioma," and "disturbance." No focused keywords were detected after 2008. We believe that coral reef research has perhaps stagnated in terms of novel research terms. However, we were able to pinpoint the urgent and ongoing importance of climate change research for coral reefs.

Contribution to the field

The coral reefs have been identified as one of the vital ecosystems in coastal communities, contributing toward many economic activities such as marine recreation, jobs, tourism, and fishery. The total economic value of coral reefs worldwide was estimated to reach about 375 billion USD each year (Conservation International, 2008). This shows the importance of coral reef research. Thus, any studies aiming to identify current trends and development of coral reef science are necessary, as they can directly or indirectly affect the funding or further collaboration of parties interested in coral reef research and development.

Recommendation

We recommend any interested party to look at the correlations between certain interactive keywords, such as climate change and aquatic marine species. During the searching activities, authors need to find if there are any relationships between keywords. It would be beneficial to have easily accessible websites that identify big worldwide events that can be related with a certain keyword, facilitating correlations and offering a greater understanding. This would improve future studies.. For example, during the search for the interaction between the most cited and influential keywords on coral reef, climate change, and 2005, we found interesting evidence suggesting that during that period, there was a powerful hurricane that hit the Atlantic Ocean, which affected coral reef environments. It will be also interesting and useful to use a mixed methodology combining scientometric analyses with classical approaches based on classic text mining tools.

Perspectives

With no recent keyword surge in coral reef science, future directions should continue to focus on the impacts of climate change on coral communities. There is a need for more work on identifying any significant impacts of climate-driven changes on coastal environments, such as the impact of sea level rise and increasing sea surface temperature on coral reef bleaching. We also suggest to expand the research using additional databases with detailed article information (e.g., titles, authors, abstracts, citations, co-citations, etc.), such as SCOPUS, PubMed, China National Knowledge Infrastructure (CNKI), Chinese Social Sciences Citation Index (CSSCI), and Index Copernicus.

Conclusion

Our study focused on research in coral reef using a scientometric approach. We conclude that coral reefs play an important role in supporting reef larval supply, which ensures the stability of coral reefs over time, particularly in the face of climate change and coral bleaching. The top contributors to coral reef science were Australian researchers and institutions, geographically closest to the largest coral reef system worldwide, that is, the Great Barrier Reef. These findings could explain altogether why the most relevant keywords were "climate change" and "Great Barrier Reef."

Undoubtedly, further studies are necessary to better understand the dynamics of coral reef research and make the concerned authorities aware of the urgent need to curb climate change and any form of pollution and restore degraded coral reefs while protecting the healthy ones at the same time. In addition, the results of this study can be used to initiate further relevant research approaches concerning coral reefs in view of their ecological and economic importance.

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