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*Research Article*

# Mangrove Literature from 2000 to 2019 – A Scientometric Analysis of Scopus Records

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**ABSTRACT**
Mangrove forests are incredibly important ecosystems. They are biodiversity hotspots, provide livelihood for the coastal communities, maintain the water quality, stabilize shorelines by slowing erosion and capture massive amounts of carbon dioxide emissions and other greenhouse gases from the atmosphere. Mangroves thus offer a wide area of research to the scientific community of the world and hence it may be interesting to know the growth of literature in the field of mangrove research. In this context, we present a scientiometric analysis of literature for 7603 Scopus articles published globally in the area of mangrove research during the period 2000–2019. No such study has been done on mangroves after 2012 and hence this study has got its own relevance in scientometrics to highlight the recent developments in the field of mangrove ecosystem and associated research. To accomplish the research Microsoft Excel and Bibexcel were used for the bibliometric analyses and Pajek and CiteSpace were used for mapping and visualization. The results indicate that 90% of work were peer-reviewed articles and a doubling time obtained is 8 years. China leads the rest of the countries by a big margin in the number of publications on mangroves followed by India, and the USA. 'Remote sensing', 'Avicennia marina', 'salinity', 'sediment' and 'climate change' are the major areas under which the research is progressing in a fast pace. This research study will help the researchers about the direction of evolution of research and upcoming research trends.

**Keywords:** Mangrove, Mangroves, Mangrove literature, Scientometrics, Scientometric Analysis, Scopus.

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## INTRODUCTION

Mangroves are salt-tolerant plant species mostly prevalent in the fringing and intertidal zones of tropical and subtropical coastlines between 24 °N and 38 °S latitudes.[1] They are not obligate halophytes but show optimum growth in the presence of an ideal quantity of sodium chloride concentrations.[2-3] Thus the presence of salt becomes an essential component in mangrove development. Mangroves are one of the most productive ecosystems on the planet with rich biodiversity and an economic resource for the coastal environment.

Genomic and fossil evidence suggest the evolution of mangroves 75 million years ago.[4] Though the exact distribution of mangroves during Holocene is still not clear, shreds of evidence suggest that relative sea-level rise and climate change contributed the most.[2]



According to the World Atlas of Mangroves, mangroves are distributed over 123 countries in about 1,50,000 sq. km.[5] They are most extensive in South East Asia (33.5%) followed by South America (15.6%) and North Central America (14.7%). The least cover is reported in East Asia with around 0.1% of total mangrove cover.[6] 10344 sq. km of total global mangrove cover is found in South Asia (6.8% of the total world's mangrove cover).[7-8]

Longitudinal mangrove distribution is usually divided into an Eastern group and a Western group. The Indo-West Pacific (IWP) region harbours more species diversity compared to the Atlantic-East Pacific (AEP) region. About 70 mangrove species are identified across 40 genera across the world.[6] Mangroves are classified into three types based on topographic features as riverine forest, fringe forest and basin forest.[9]

The exploitation of mangroves for economic purposes can be dated back to the eighteenth century. They form a valuable resource for the people living in the tropical and subtropical coastlines of the world. Humans discovered the economic and ecological prominence of mangroves long back and the goods and services from mangroves are generally categorized

into four viz. provisioning, regulating, supporting, and cultural.[10] The overexploitation of mangrove forests led to mangrove deforestation. Myanmar experienced the highest rate of deforestation during the period 2000–2012 (0.70%) followed by Malaysia (0.41%) and India (0.27%).[11]

Research in mangroves is progressing in various areas such as the geographical impact of mangrove forest in an ecosystem, role of mangroves in climate change, mitigation, adaptation and climate modelling, studies related to flora, fauna and microbial diversities of mangrove habitat, the extent of distribution and diversity of mangroves, antibacterial, anti-inflammatory and antioxidant potential of mangroves, phenotypic and genotypic studies, and mangrove mapping and monitoring using GIS and remote sensing. Furthermore, due to the multiple benefits and range of ecosystem services they provide, sustainable management and conservation of mangroves aligns with several of the United Nation's Sustainable Development Goals, especially Goal 13: "Take urgent action to combat climate change and its impacts", Goal 14: "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" and Goal 15: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss".[12] It is therefore of utmost importance to keep track of such multidisciplinary research conducted on this particular area and to monitor the patterns and trends occurring in the research area with the help of bibliometrics.

Pritchard defines bibliometrics as "the application of mathematics and statistical methods to books and other media of communication".[13] Bibliometry has its root in library science and its definition has undergone numerous modifications according to the research community of different periods. However, the primary objective of this study is to establish the fundamental bibliometric characteristics of scientific literature focused on mangroves as the topic of research from 2000 to 2019, a span of 20 years. Further objectives are to determine the growth pattern of mangrove literature around the world from 2000 to 2019, to explore the pattern of authorship and collaborative trend, to analyse the citation pattern of mangrove research papers and to study the evolution of co-authorship network. The objectives stated are achieved by the determination of basic bibliometric parameters such as distribution by publication type, number of authors, country, institution, journal, Relative Growth Rate (RGR), Doubling time (DT), activity index, most cited publications and keyword analysis. Network analysis is done for the determination of collaborative research, co-citation clusters and major subject areas in mangrove literature.

This scientiometric paper helps to identify the knowledge base, hotspots, key points as well as emerging trends of the area of research in mangroves. The evolution of subject areas and keyword analysis helps to identify the gaps in mangrove research and thereby draws attention of the research community to address those gaps in future.

To the knowledge of the authors, no such study has been done on mangroves after 2012, and overall, very few bibliometric studies have been done on mangrove literature and hence this work extends the boundaries of bibliometric research on mangroves. Additionally, this paper maps existing literature to explore the trends in mangrove research and networks the cooperation among various researchers.

## LITERATURE REVIEW

This bibliometric analysis is focused on peer-reviewed literature on mangroves from 2000 to 2019 (20 years). This particular time frame was chosen because of the explosion of mangrove research at the beginning of this century and due to the lack of bibliometric analysis on mangroves for more than a decade. The data were collected from Scopus database using the keyword "mangrove*" in the title and the keyword sections. The Scopus database was considered so that only peer-reviewed records would be included in the study. The total number of files downloaded was 7644. The downloaded data were checked for duplicates and the accuracy is ascertained by manual screening of the downloaded documents and deleting the irrelevant records. Besides the duplicates have been removed from the data set by searching for the exact title in excel. The records were compared and 41 duplicates were removed. There was no source classification for 638 items and they were cleaned manually and wrong entries were corrected. The final number of articles considered for analysis was 7603. Microsoft Excel and Bibexcel[14] were used for the bibliometric analyses and Pajek[14-15] and CiteSpace[16] were used for mapping and visualization.

### Data Analysis and Interpretation

#### *Distribution by publication type*

Peer-reviewed articles were by far the most occurring type of publication, 6853 or 90%. Review papers constituted 201 (~3%), books/book chapters 96 (~1%), and conference papers/workshops 441 (~6%).

#### *Relative Growth Rate (RGR) and Doubling time (DT)*

RGR (Relative Growth Rate) is "the increase in the number of articles or publications or pages per unit of time". Hunt modified an equation that was earlier used for growth analysis studies in plants and is analogous to the rate of compound interest earned on capital.[17] Thus mean RGR over the specific period of an interval can be calculated as:

$$\text{Mean RGR} = 1 - 2^{R} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

where,

$1\text{-}2^R$ is the mean relative growth rate over the specific period of interval;

$\log_e W_1$ is the log of initial number of articles;

$\log_e W_2$ is the log of final number of articles after a specific period of interval; and

$T_2\text{-}T_1$ is the unit difference between the initial time and the final time. The unit of time considered here is a year.

Therefore, $1 - 2^R$ ($aa^{-1}$ $year^{-1}$) represents the mean relative growth rate per unit of articles per year over a specific period of interval.

The time taken by any population or sample that grows exponentially to become double is called doubling time (Dt).[18] The formula for doubling time is derived from the compound growth equation that is used to project the population size of any quantity that is growing exponentially. Thus Dt can be approximately calculated as

$$\text{Doubling time (Dt)} = \frac{0.693}{1 - 2^{R}} = \frac{0.693}{R}$$

In this study, the average number of articles per year was 380. The growth of the literature is shown in Figure 1.

There were only 136 articles on mangroves in 2000 but there was a steady increase through the years, culminating in 803 articles in 2019. There are pronounced peaks in research seen in 2002, 2008, 2014 and 2018. An exponential curve of the form $y=128.62\ e^{0.09x}$ was fitted to the growth curve, which led to a doubling time of 8 years for the publication. The relative growth rate and doubling time were calculated and plotted (Figure 2).

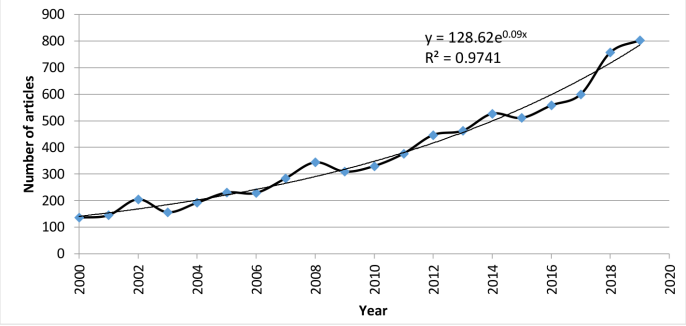


**Figure 1:** Growth of mangrove literature from 2000 to 2019 (20 years). The dotted line shows the exponentially fitted curve.

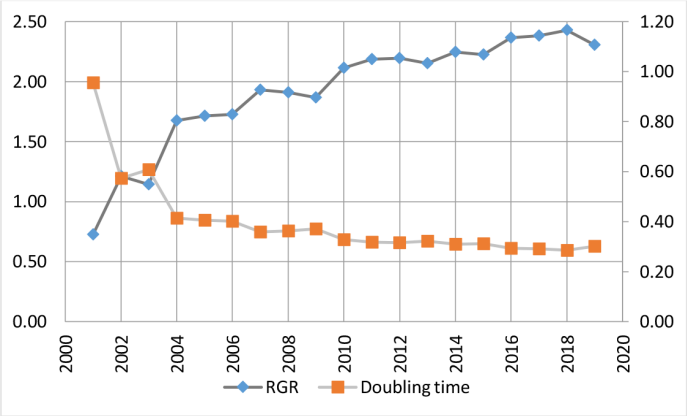


**Figure 2:** Relative growth rate and doubling time for mangrove literature from 2000 to 2019.

Figure 2 shows that as the RGR increased over time, the doubling time decreased from 0.95 in 2000 to 0.30 in 2019, and it remained almost steady in the last decade.

The study of mangroves is a niche area and there are only a handful of scientists doing long-term studies as compared to other popular fields of study. As such, the relatively smaller number of publications is to be expected. However, the importance of mangroves was pushed into prominence after the 2004 Indian Ocean tsunami when it was found that mangroves in some parts protected the coastline behind them.[19-20] The research conducted about the role of mangroves as a bioshield revealed its ability to attenuate the wave impact and storm surges effectively. There were emerging studies that highlighted the capability of mangrove forests to capture sediments and build soils.[21-22] The ability of mangroves for carbon sequestration is approximately fifty times more than that of tropical forests and the quantity of carbon fixed is estimated at up to 25.5 million tonnes annually, making them carbon-rich forests.[23] Thus the role of mangroves in coastal protection and climate change mitigation has increased the research on mangroves in the last two decades.[24]

### *Distribution by number of authors*

The distribution of single-author and multiple-author publications is shown in Table 1. Excluding anonymous and/or missing authors, 7585 publications were considered for analysis.

A quarter of the publications was by single authors, indicating the influence of collaborative research in mangroves. A reason could be that most mangroves are found in tropical regions, and scientists from developed countries who are interested in mangrove research have to collaborate with the respective local institutions. Also, it is interesting to note that half of the publications are by two or three-author teams, indicating that though collaboration is needed, it is not done in big teams as is usually seen in climate studies.

**Table 1: Distribution of authorship for mangrove literature from 2000 to 2019.**

| Number of authors | Number of papers | Percentage of authorship |
|---|---|---|
| 1 | 1958 | 25.8 |
| 2 | 2242 | 29.6 |
| 3 | 1681 | 22.2 |
| 4+ | 1704 | 22.5 |

**Table 2: Publication volume and citation numbers for countries in mangrove research (2000–2019).**

| Country | Number of publications | Number of citations | Relative Citation Index |
|---|---|---|---|
| China | 1366 | 16128 | 11.81 |
| India | 978 | 11732 | 12.00 |
| United States | 749 | 23976 | 32.01 |
| Brazil | 521 | 7578 | 14.55 |
| Australia | 481 | 16042 | 33.35 |
| Indonesia | 361 | 815 | 2.26 |
| Japan | 337 | 5622 | 16.68 |
| Malaysia | 328 | 2805 | 8.55 |
| Germany | 204 | 5378 | 26.36 |
| Thailand | 146 | 1649 | 11.29 |
| Mexico | 144 | 2501 | 17.37 |
| United Kingdom | 138 | 4160 | 30.14 |
| France | 135 | 2645 | 19.59 |
| Belgium | 127 | 4341 | 34.18 |
| Netherlands | 102 | 4672 | 45.80 |
| Philippines | 98 | 907 | 9.26 |
| Hong Kong | 94 | 3534 | 37.60 |
| Taiwan | 78 | 1203 | 15.42 |
| Colombia | 76 | 538 | 7.08 |
| Nigeria | 72 | 492 | 6.83 |

The degree of collaboration is defined as "the ratio of the number of collaborative research papers to the total number of research papers in the discipline during a certain period of time". The formula suggested by Subramanium[25] is used. It is expressed as , where *C* is the degree of collaboration in a discipline, *Nm* is the number of multi-authored research papers in the discipline published during a year and *Ns* is the number of single-authored papers in the discipline published during the same year. The degree of collaboration was calculated for the current study as 0.74.

### *Distribution by country*

The top 20 countries leading by the overall number of publications in mangrove research in the period 2000–2019 are shown in Table 2. The country-wise number of citations in the same time period and the Relative Citation Index (RCI) for these 20 countries are also shown in Table 2.

Relative Citation Index is used to determine the impact of research output. The Institute of Scientific Information developed RCI to calculate the science and engineering indicators. According to Kumari,[26] "RCI is a measure of both the influence and visibility of a nation's research in a global perspective". It is defined as the ratio of a country's share of world citations to the country's share of world publications.

$$\text{Relative Citation Index (RCI)} = \frac{\text{Citation \%}}{\text{Publication \%}}$$

RCI > 1 indicates that country's citation rate is higher than the world's citation rate,

RCI = 1 indicates that country's citation rate is equal to the world citation rate; and

RCI < 1 indicates that country's citation rate is less than the world's citation rate.

China, India, and the USA lead the rest of the countries by a big margin in the number of publications on mangroves. They contribute around 41% of the total publications. The graph of countries with 10 or more publications is shown in Figure 3.

Though China has only 0.1% of the world's mangroves,[27-28] it leads in the number of publications, which shows the emphasis placed on publication output in the country. A look at the number of citations and the RCI, however, throws a different picture (Table 2). USA leads in the number of citations followed by China, Australia and India. The Netherlands has the highest RCI of 45.80 indicating that one or more of the papers published there have been cited the most, followed by Hong Kong and Belgium. Denmark has the highest RCI (55) of all the countries but it is not in the top 20 list (34 publications).

### *Activity index*

Activity Index (AI) is the measure of the productivity of individual countries against the world contribution.[29] The AI can be used to relate the contribution of mangrove research in India to that of the mangrove research in the whole world.

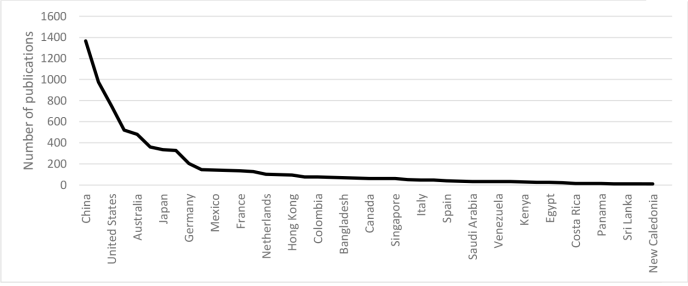


**Figure 3:** Countries with 10 or more publications on mangroves in the period 2000–2019.

This common and useful bibliometric indicator was first proposed by Frame[30] and is given by the formula

$$AI = \frac{\text{Given field's share in the country's publication output}}{\text{Given field's share in the world's publication output}}$$

If

AI=1, the country's research output in the given field corresponds exactly to the world's average

AI>1, reflects an average higher than the world average

AI<1, reflects an average lower than the world average.

The AI for the top 10 countries by the number of publications was calculated to analyse the growth of publications and is presented in Figure 4. The index of most countries increased slowly; for example, for India, it went from 0.92 in 2000 to 4.15 in 2019. Colombia had a sudden increase in activity in 2018 and 2019, and Indonesia showed a startling rise from 2.5 in 2016 to 7.6, 16.7 and 22.7 in 2016, 2017 and 2018, respectively. An analysis of the records shows a sudden increase in publications in the last few years leading to the rise in AI for Indonesia. However, a closer scrutiny shows that out of 298 publications in the years 2017–2019, 162 (54%) were conference papers. Even then, it is quite a remarkable increase from the earlier years.

### *Distribution by institution*

Table 3 shows the leading institutes within each of the five most published countries. These data were taken from the affiliations of the first authors. The list is dominated by institutions in China; Xiamen University led with 196 publications followed by the Chinese Academy of Sciences (185) and Sun Yat-Sen University (175).

Apart from the above, some of the other leading institutes are Universiti Putra Malaysia, Vrije Universiteit Brussels, Belgium, Leibniz Center for Tropical Marine Ecology, Germany, Griffith University, Australia, James Cook University, Australia, and National University of Singapore.

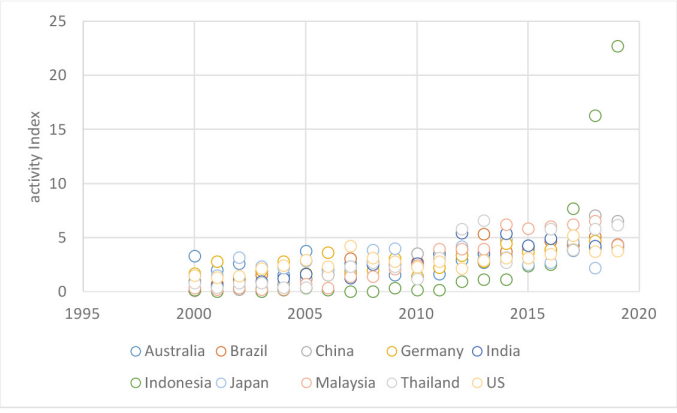


**Figure 4:** Activity index of top ten countries in mangrove research (2000–2019) (by publication volume).

**Table 3: Leading institutes within each of the five most published countries in mangrove research (2000–2019).**

| Institution | Country | Number of publications |
|---|---|---|
| Xiamen University | China | 196 |
| Chinese Academy of Sciences | China | 185 |
| Sun Yat-Sen University | China | 175 |
| Annamalai University | India | 105 |
| University of Calcutta | India | 73 |
| United States Geological Survey | USA | 66 |
| Smithsonian Institution | USA | 38 |
| Federal University of Pará | Brazil | 56 |
| Universidade Federal Do Rio de Janeiro | Brazil | 42 |
| University of Queensland | Australia | 75 |
| Australian Institute of Marine Science | Australia | 46 |

Care should be taken, however, to place much weight on this ranking because of the confusion prevalent in the institute names. Even established institutes are not reflected in the same way in the affiliations and it was extremely confusing and difficult to extract the institute names for countries such as China or Brazil. The list provided here was extracted to the best of the authors' knowledge. The information provided can thus at best be taken as a general indicator of where institutions stand in mangrove research.

### *Cities where authors live*

Data extracted from Bibexcel were submitted in the website GPSVisualizer.com to create the map of cities indicated by the first authors in their affiliations (Figure 5). Authors having five or more papers to their credit as the first authors were selected for this analysis. It is seen that most of them are situated along the coast, probably many of them near their study areas to facilitate data collection. Africa and South America are poorly represented.

### *Distribution by journal*

A total of 160 journals have published 10 or more articles on mangroves, and account for 4572 records between them, which amounts to 60%. The total number of journals, conference proceedings etc. that have published all the records is 1582. The leading journal in the subject is Estuarine, Coastal and Shelf Science with 244 publications followed by Marine Pollution Bulletin (217) and Wetlands Ecology and Management (192). The journal Estuarine, Coastal and Shelf Science also topped the list in publishing mangrove studies in another bibliometric analysis of mangrove literature (Saravanan and Dominic, 2013) based on the online database

**Figure 5:** Spatial distribution of cities indicated by the first authors (having five or more papers to their credit) in their affiliations.

**Table 4: Top 20 journals by the number of publications in mangrove research (2000–2019).**

| Journal | Number of publications |
|---|---|
| Estuarine, Coastal and Shelf Science | 244 |
| Marine Pollution Bulletin | 217 |
| Wetlands Ecology and Management | 192 |
| IOP Conference Series: Earth and Environmental Science | 128 |
| Marine Ecology Progress Series | 128 |
| Hydrobiologia | 102 |
| International Journal of Systematic and Evolutionary Microbiology | 91 |
| Aquatic Botany | 84 |
| Journal of Coastal Research | 79 |
| PLoS ONE | 78 |
| Ocean and Coastal Management | 77 |
| Science of the Total Environment | 68 |
| Journal of Experimental Marine Biology and Ecology | 63 |
| Estuaries and Coasts | 61 |
| Marine Drugs | 56 |
| Wetlands | 56 |
| Remote Sensing | 53 |
| Environmental Monitoring and Assessment | 51 |
| Indian Journal of Geo-Marine Sciences | 50 |
| Journal of Natural Products | 48 |

Web of Science with 132 records. Table 4 shows the top 20 journals by the number of publications.

### *(Most cited publications*

Citation counts play an important role in determining the quality of research work. Highly Cited Papers (HCPs), excluding self-citations, throw light on the integrity of research as well as the author's scientific impact. Giri *et al*. (2011)[31] with 862 citations for their research on "Status and distribution of mangrove forests of the world using earth observation satellite data" and Alongi (2002)[32] with the paper on "Present state and future of the world's mangrove forests" with 861 citations topped the list. The top 20 publications in order of citations are displayed in Table 5.

The results of the top publications in order of citations share a similarity between the list of maximum co-citations occurring in the mangrove literature. The two papers "Status and distribution of mangrove forests of the world using earth observation satellite data" by Giri *et al*. (2011)[31] and "Present state and future of the world's mangrove forests" by Alongi (2002)[32] in the above list have also found their way in the list of documents with a maximum number of co-citations (Table 6). The third record in the above list by Donato *et al*. (2011),[33] on the other hand, secured the second and third positions in the list of co-cited documents with 22 and 19 co-citations, respectively. The above results indicate that the research focus in the mangrove area is towards the distribution of mangroves, its present and future status and species diversity. This inference can be correlated to the results obtained further such as keyword frequency analysis where the terms 'remote sensing', 'climate change', 'conservation' and 'diversity' came within the first ten keywords used most.

### *Collaborative research*

Amabile *et al*.[34] describe collaboration as "individuals who differ in notable ways sharing information and working toward a particular purpose". It is the practice in which researchers with varied interests work by exchanging and sharing data, information or resources to achieve a common goal. Research collaboration can be viewed in three to five dimensions. They are profession of collaborating researchers, their institutional affiliations, the organisational collaborations, various disciplines of the participants, and varied geographical environments. Collaborations in research are operated by co-authorship and acknowledgements. Thus co-authorship studies pave the way to understanding the extent of collaborative research undergone in the concerned area.[35]

As indicated earlier, almost 74% of research on mangroves is collaborative in nature. One of the objectives of this study was to analyse the author and institutional networks to gain an idea on which subfields were more likely to need collaborations. The co-author network of the top 20 collaborations is shown in Figure 6.

The maximum collaboration was among Dahdouh-Guebas and Koedam (mangrove dynamics and diversity in Africa), between Tam and Wong (pollution studies), and between Kairo and Koedam (mangrove replantation and growth). There was also high collaboration within and among the Chinese authors.

**Table 5: List of top 20 most cited documents in mangrove research (2000–2019).**

| Author(s) | Title of paper | Year | Journal name | Number of citations |
|---|---|---|---|---|
| Giri C., Ochieng E., Tieszen L.L., Zhu Z., Singh A., Loveland T., Masek J., Duke N. | Status and distribution of mangrove forests of the world using earth observation satellite data | 2011 | Global Ecology and Biogeography | 862 |
| Alongi D.M. | Present state and future of the world's mangrove forests | 2002 | Environmental Conservation | 861 |
| Donato D.C., Kauffman J.B., Murdiyarso D., Kurnianto S., Stidham M., Kanninen M. | Mangroves among the most carbon-rich forests in the tropics | 2011 | Nature Geoscience | 780 |
| Mumby P.J., Edwards A.J., Arias-González J.E., Lindeman K.C., Blackwell P.G., Gall A., Gorczynska M.I., Harborne A.R., Pescod C.L., Renken H., Wabnitz C.C.C., Llewenyn G. | Mangroves enhance the biomass of coral reef fish communities in the Caribbean | 2004 | Nature | 656 |
| Alongi D.M. | Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change | 2008 | Estuarine, Coastal and Shelf Science | 654 |
| Duke N.C., Meynecke J.-O., Dittmann S., Ellison A.M., Anger K., Berger U., Cannicci S., Diele K., Ewel K.C., Field C.D., Koedam N., Lee S.Y., Marchand C., Nordhaus I., Dahdouh-Guebas F. | A world without mangroves? | 2007 | Science | 619 |
| Nagelkerken I., Blaber S.J.M., Bouillon S., Green P., Haywood M., Kirton L.G., Meynecke J.-O., Pawlik J., Penrose H.M., Sasekumar A., Somerfield P.J. | The habitat function of mangroves for terrestrial and marine fauna: A review | 2008 | Aquatic Botany | 540 |
| Kristensen E., Bouillon S., Dittmar T., Marchand C. | Organic carbon dynamics in mangrove ecosystems: A review | 2008 | Aquatic Botany | 504 |
| Gilman E.L., Ellison J., Duke N.C., Field C. | Threats to mangroves from climate change and adaptation options: A review | 2008 | Aquatic Botany | 453 |
| Bouillon S., Borges A.V., Castañeda-Moya E., Diele K., Dittmar T., Duke N.C., Kristensen E., Lee S.Y., Marchand C., Middelburg J.J., Rivera-Monroy V.H., Smith III T.J., Twilley R.R. | Mangrove production and carbon sinks: A revision of global budget estimates | 2008 | Global Biogeochemical Cycles | 445 |
| Tam N.F.Y., Wong Y.S. | Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps | 2000 | Environmental Pollution | 424 |
| Polidoro B.A., Carpenter K.E., Collins L., Duke N.C., Ellison A.M., Ellison J.C., Farnsworth E.J., Fernando E.S., Kathiresan K., Koedam N.E., Livingstone S.R., Miyagi T., Moore G.E., Nam V.N., Ong J.E., Primavera J.H., Salmo III S.G., Sanciangco J.C., Sukardjo S., Wang Y., Yong J.W.H. | The loss of species: Mangrove extinction risk and geographic areas of global concern | 2010 | PLoS ONE | 406 |
| Kathiresan K., Rajendran N. | Coastal mangrove forests mitigated tsunami | 2005 | Estuarine, Coastal and Shelf Science | 359 |
| Walters B.B., Rönnbäck P., Kovacs J.M., Crona B., Hussain S.A., Badola R., Primavera J.H., Barbier E., Dahdouh-Guebas F. | Ethnobiology, socio-economics and management of mangrove forests: A review | 2008 | Aquatic Botany | 338 |
| Zhang F.-Q., Wang Y.-S., Lou Z.-P., Dong J.-D. | Effect of heavy metal stress on antioxidative enzymes and lipid peroxidation in leaves and roots of two mangrove plant seedlings (Kandelia candel and Bruguiera gymnorrhiza) | 2007 | Chemosphere | 334 |
| Laegdsgaard P., Johnson C. | Why do juvenile fish utilise mangrove habitats? | 2001 | Journal of Experimental Marine Biology and Ecology | 332 |
| Komiyama A., Ong J.E., Poungparn S. | Allometry, biomass, and productivity of mangrove forests: A review | 2008 | Aquatic Botany | 328 |
| Nagelkerken I., Van Der Velde G., Gorissen M.W., Meijer G.J., Van't Hof T., Den Hartog C. | Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique | 2000 | Estuarine, Coastal and Shelf Science | 320 |
| Lewis III R.R. | Ecological engineering for successful management and restoration of mangrove forests | 2005 | Ecological Engineering | 316 |
| Krauss K.W., Lovelock C.E., McKee K.L., López-Hoffman L., Ewe S.M.L., Sousa W.P. | Environmental drivers in mangrove establishment and early development: A review | 2008 | Aquatic Botany | 312 |

**Table 6: Top 15 co-citations occurring in mangrove literature (2000–2019).**

| Number of co-citations | Documents co-cited | |
|---|---|---|
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### *Co-citation clusters*

A co-citation is said to occur if two references to different authors appear in the same bibliography. It can be inferred as the extent of similarity of content inside two different references or authors. Co-citation analysis, therefore, indicates the frequency with which two documents are cited together.[36] Co-citation analysis can be done from two perspectives – author co-citation and document co-citation, of which the latter is considered as more dependable and effective.[37] The analysis commences with the selection of the co-citation object, which can be any author or document related to the concerned study. These are chosen based on their frequency of occurrence in a selected database. This is followed by the determination of co-citation counts. The highest absolute

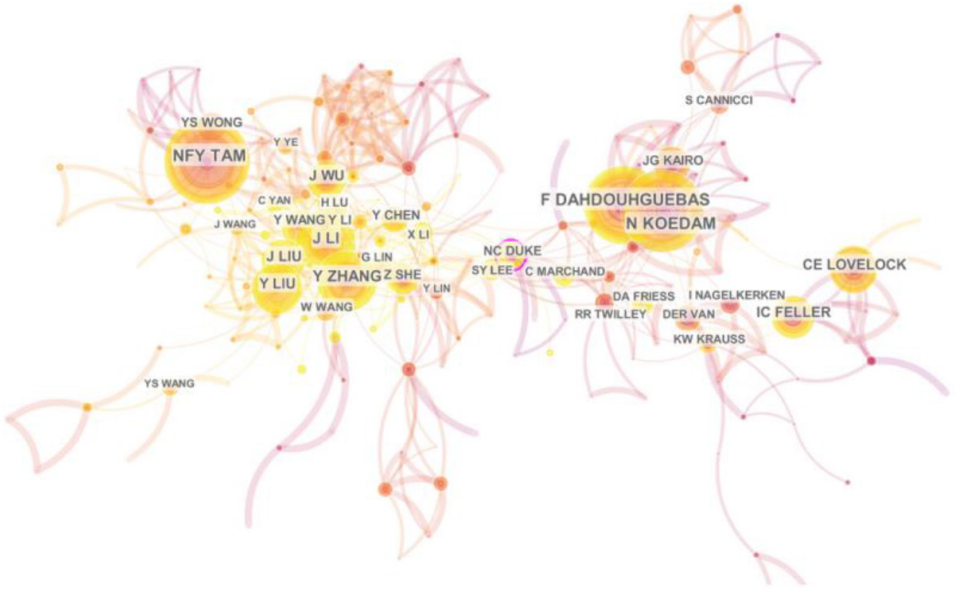


**Figure 6:** The co-author network of the top 30 collaborations in mangrove research (2000–2019).

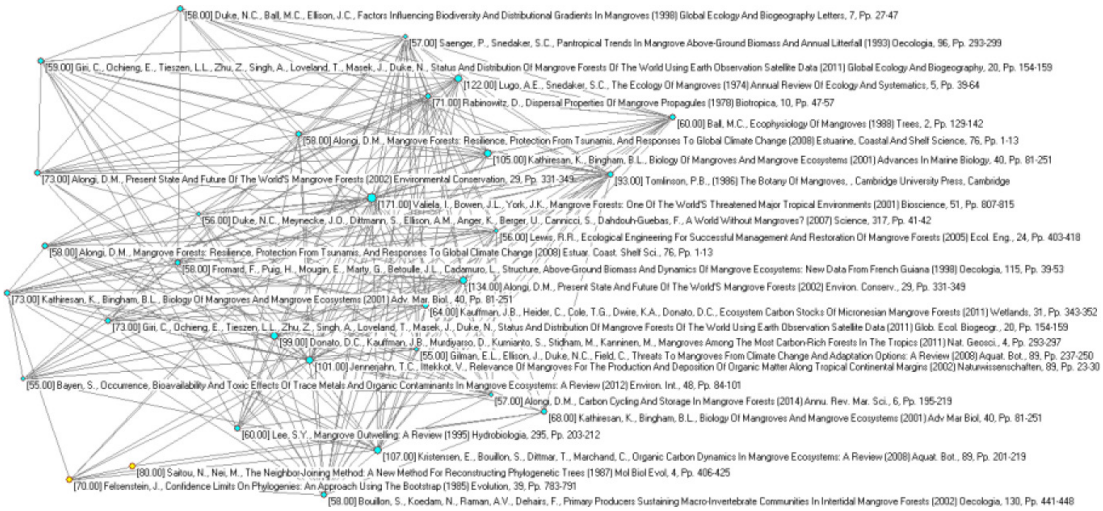


**Figure 7:** The co-citation network of mangrove literature from 2000 to 2019.

co-citation counts are considered for cluster formation. A group of references with multiple connections to each other is referred to as clusters. Complete cluster, star-shaped cluster, and chain- or ring-shaped cluster are the three basic types of co-citation clusters.[37]

Figure 7 shows the co-citation network. Felsenstein[38] and Saitou and Nei[39] had the maximum of 31 co-citations and their work dealt with phylogenetics. The next highest co-citation was for Donato *et al*. [33] and Kristensen *et al*.[40] with 25 co-citations and their works focused on carbon dynamics in mangrove ecosystems. Table 6 shows the top 15 co-citations in mangrove literature.

### *Major subject areas in mangrove literature*

As stated earlier, research in mangroves covers wide aspects such as mangrove ecosystem studies, distribution and mapping studies, conservation and management, climate change, adaptation and mitigation as well as threats developed by anthropogenic activities. The list is vast and this section focuses on the major areas in which mangrove research is extensively flourishing. The analysis is presented in the form of a Figure that indicates the major areas of research.[41] Figure 8 shows the prominent subject categories in mangrove literature.

Pollution and habitat use were important fields of study apart from the overall ecosystem studies. It is interesting to note that a lot of research focused on the two major species of mangroves, *Avicennia germinans* and *Rhizophora apiculata*, belonging to the black and red mangroves, respectively. These two species are also the most common mangrove species found over the world.[42-43]

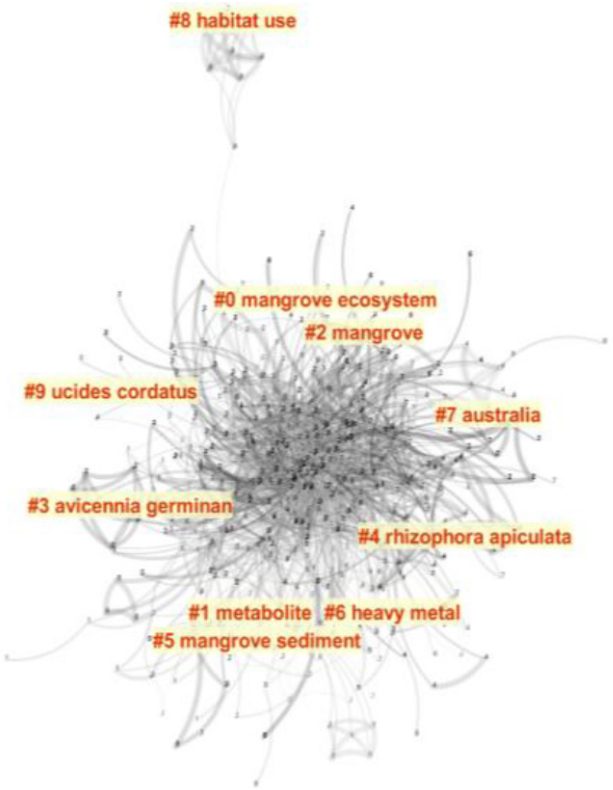


**Figure 8:** Prominent subject categories in mangrove literature from 2000 to 2019.

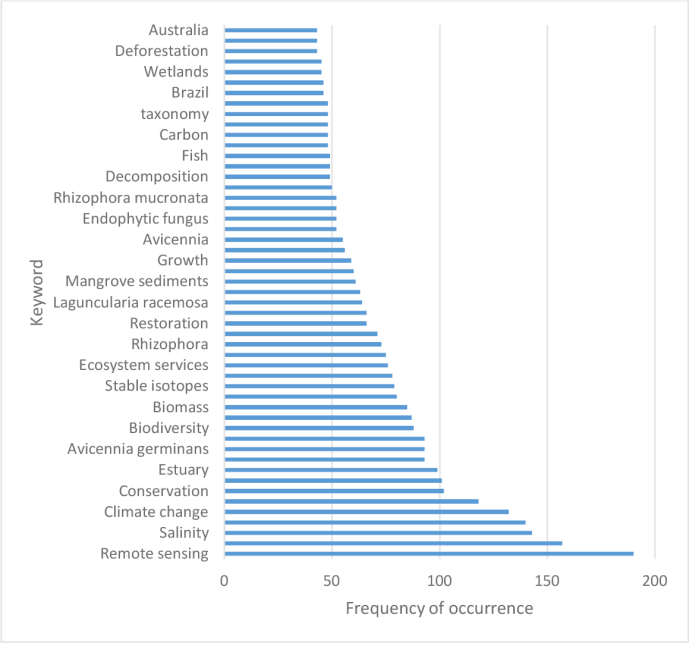


**Figure 9:** Top keywords used in mangrove literature (2000–2019) and their frequency of occurrence.

### *Keyword analysis*

Keywords are the terms or phrases that represent the essence of each publication, and which the authors are asked to provide to represent their scientific work.[44] Keyword analysis is widely used as a bibliometric tool to identify the most impacted fields of research and to identify the development of research in a certain area of study. The top 50 keywords are shown in Figure 9. Ignoring the common keywords 'mangrove' and 'mangroves', those most often used are "remote sensing", "Avicennia marina", "salinity", "sediment", "climate change", and "heavy metals". This indicates that the mapping, pollution and climate change are important directions going forward in mangrove research.

## CONCLUSION

This study examined the developments in mangrove research from a bibliometric perspective. The analysis of data retrieved from the Scopus database for a period of 20 years (2000–2019) revealed striking results. The volume of literature published shows a visible increase with a doubling time of 8 years, indicating the flourishing of research work in the field of mangroves.

China led in the number of publications globally followed by India and the United States. This provides the quantitative data relevant to the research in mangroves. The analysis of the number of citations and the RCI, which indicate the quality of the work, show that the United States led with the maximum number of citations followed by Australia. The authors from Denmark, the Netherlands and Hong Kong also had highly cited papers.

Analysis of Activity Index of the top 10 countries in terms of the number of publications showed a steady increase except for Nigeria. The surprising rise of Activity Index of Indonesia can probably be correlated to the technological progress, development and economic growth the country is achieving in recent years.

Xiamen University in China with 196 publications topped the list of leading institutes when the data of affiliations of the first authors were analysed. Estuarine, Coastal and Shelf Science was identified as the journal with maximum number of publications with 244 documents. Giri *et al*. (2011) was the most cited article with 862 citations.

The majority of research on mangroves was found to be collaborative in nature, but 2- and 3-author teams were preferred to larger teams. The co-author network and formation of co-citation clusters were studied to understand more about collaborative research in this field.

It was found that mangroves are extensively studied for their role in pollution control and climate change. Mapping of mangroves was also a favourite topic based on keyword analysis. These are the directions in which mangrove research is moving, and young researchers can focus on these areas. A drawback of this study was that journals such as Bioscience

that also focus on mangroves were not indexed in Scopus, which could have resulted in some discrepancies in the analysis. Future studies can address these issues.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

### Availability of Data and Material

The data for this study were collected from Scopus database.

### Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Deeptha Thattai, Sathyanathan Rangarajan, Rajitha J Rajan and Lakshmy J Rajan. The first draft of the manuscript was written by Deeptha Thattai and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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