Fisheries Research 263 (2023) 106676

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Application of the frontier approach in capture fisheries efficiency and productivity studies: A bibliometric analysis

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ARTICLE INFO

Handled by Cameron Speir

Keywords:
Fisheries efficiency
Frontier approach
Bibliometric analysis

ABSTRACT

A vast body of literature on fisheries efficiency, productivity and fisheries efficiency-related topics exists. This study applies a bibliometric analysis to review a sample of 183 scientific articles based on the Scopus database from 1995 to 2021. The results show that from 1995 to 2021, there was a significant increase in the number of publications. Most of the productive authors' institutions were from developed countries, and the productive authors tend to produce influential works. The topic of efficiency and productivity in fisheries has attracted scholars from geographically diverse regions (48 countries). The findings indicate that *Marine Resource Economics, Marine Policy, and Fisheries Research* were the top three journals for publication during 1995–2021 in this area. Data envelopment analysis, stochastic frontier analysis and stochastic distance function have been the most prevalent approaches used in the field of research over the past decades. Studies that are relevant to small-scale fisheries, artisanal fisheries, socioeconomic factors, management, economic performance, and total factor productivity have become increasingly of interest to researchers in recent years. The findings from this study can provide deeper insight to understand the publication trend, hotspots and future research directions in this research field.

1. Introduction

It is widely accepted that the wild capture fisheries sector plays an important role for many countries worldwide, ranging from high-income countries to low-income countries. The capture fisheries industry can serve as a prominent contributor to economic growth and development, a source of income and wealth, food security, employment, cultural identity and livelihoods, especially in coastal areas. Renewable fisheries resources might provide long-lasting benefits to fishers, fishing communities, society and those who ultimately own the resources if such resources are well managed. Given the importance of effective fisheries management, information about the relationship between inputs used in fishing and resultant catches is essential for effective management (Pascoe et al., 2001; Tingley et al., 2003). Efficiency and productivity analyses are important for evaluating the performance of a decision-making unit (e.g., fisher, fleets) and indicating its potential improvement (Daraio et al., 2020). Such analyses help track the economic well-being of participants in capture fisheries. Information on efficiency, productivity and its drivers can help fishers improve economic performance (e.g., saving input resources and/or expanding outputs) and earnings, while policymakers could use the information to design appropriate and effective policies for sustainable fisheries management in the future (Sharma and Leung, 1998; Tingley et al., 2005). Over the past decades, research on efficiency and productivity in

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https://doi.org/10.1016/j.fishres.2023.106676
Received 8 June 2022; Received in revised form 20 February 2023; Accepted 21 February 2023
Available online 15 March 2023
0165-7836/

fisheries has thus expanded and a number of aspects related to efficiency and productivity in fisheries have been analyzed.

A number of approaches have been used for fisheries efficiency and productivity analyses. Data envelopment analysis (DEA) and stochastic frontier analysis (SFA) are two common frontier approaches.[1] The frontier approach evaluates the performance of individual firms relative to the best practice frontier in the industry. Data Envelopment Analysis, a non-parametric approach first proposed by Charnes et al. (1978), uses mathematical programming techniques to construct a frontier that envelopes the observed data and thus defines best practice. Efficiency measures are then calculated relative to this frontier. Stochastic Frontier Analysis, independently proposed by Aigner et al. (1977), and Meeusen and van den Broeck (1977), is a parametric approach. The method assumes that output is a function of a set of inputs, random noise and inefficiency. SFA has, thus two error terms: one representing normal random error and the other a one-sided error term representing technical inefficiency in production. Both DEA and SFA approaches have advantages and disadvantages (Chen et al., 2016; Thøgersen and Pascoe, 2014). The primary benefits of the DEA method are that this approach can easily handle the case of a production process using multiple inputs to produce multiple outputs, and no functional form needs to be predetermined. However, the major drawback of DEA is that random error is not taken into account. In contrast, the SFA method enables the inclusion of a measure of random error, making this approach more readily accepted in fisheries efficiency analysis due to random variation in fisheries (e.g., environmental factors, weather) (Tingley et al. 2005). The drawback of SFA is that the functional form needs to be specified in advance (Herrero, 2005). Other approaches, such as the stochastic distance function (SDF) and bootstrapped DEA models, have also been applied in fewer cases. The application of these approaches mainly depends on the main objective of the study, data, types of production processes, and number of outputs, among others (Herrero, 2005; Pascoe and Tingley, 2007; Quang et al., 2021).

A large number of scientific studies that analyze efficiency, productivity and other efficiency-related topics in fisheries exist, but few studies have been conducted to provide comprehensive surveys and/or reviews of the literature. An exception is Quang (2019), who applied a meta-regression model to examine the variation in mean technical efficiency and study-specific characteristics from 1995 to 2018. To fill this gap, this paper conducts a bibliometric analysis of the literature on fisheries efficiency and productivity from 1995 to 2021. This analysis is restricted to only studies that use a frontier approach because the frontier approach has been applied in most previous efficiency and productivity studies (Daraio et al., 2020). Furthermore, index numbers cannot be used to decompose productivity change into several components, e.g., technical efficiency change, technical change and scale change. Therefore, any efficiency studies that apply index numbers are excluded from our study. Bibliometric analysis is a common tool that is used to analyze scientific data and to generate research impact considering the large amount of literature in the field. Bibliometric analysis has been widely conducted to examine the literature in many fields, including aquaculture (See et al., 2021), airline (Yakath Ali et al., 2021), airport (See et al., 2023), water utility (Goh and See, 2021), business and marketing research (Baker et al., 2020), and others (Jing et al., 2021; Kokol et al., 2021; Palomo et al., 2017).

The remainder of this paper is structured as follows: Section 2 describes the methodology, including data collection and a brief overview of the bibliometric technique. The results and discussion are presented in Section 3. Section 4 outlines the conclusion.

2. Data and methods

2.1. Data collection

A broad review of the literature is important to identify knowledge gaps and provide a comprehensive overview of the topic (Briner and Denyer, 2012; Daraio et al., 2020; Tranfield et al., 2003). We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method to select the articles to include in the analysis (see e.g., Boloy et al., 2021; Jing et al., 2021; See et al., 2023; Yakath Ali et al., 2021). Fig. 1 presents the process of PRISMA, which includes several phases: identification, screening, eligibility and inclusion. The first step is to search and identify relevant articles using the Scopus database of abstract and citations of peer-reviewed papers that cover a wide range of research fields (Daraio et al., 2020; Md Khudzari et al., 2018; Palomo et al., 2017).

A number of key terms, such as "efficiency of fisheries", "marine

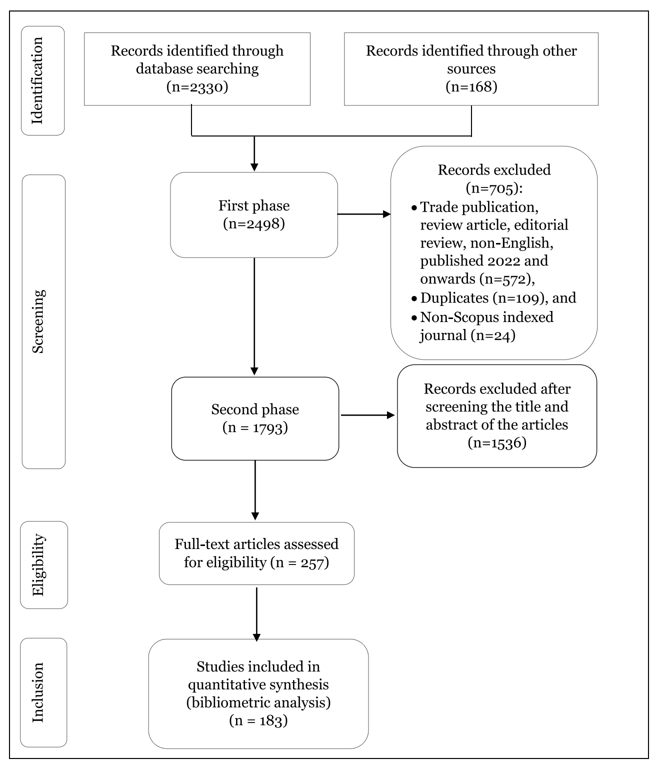

Fig. 1. PRISMA flow diagram.

Table 1
Search strings.

Database	search string
Scopus	TITLE-ABS-KEY(("efficienc*" OR "productivit*" OR "inefficienc*" OR "capacit*" OR "technical efficiency*") AND ("fish*" OR "fisherie*" OR "fishing" OR "marine capture*" OR "harvest*" OR "buyout*") AND ("SFA" OR "DEA" OR "stochastic" OR "envelopment" OR "parametric" OR "nonparametric" OR "non parametric" OR "nonparametric" OR "distance function"))

[1] Apart from the frontier method, index numbers can be used to measure productivity without any assumptions of efficiency or an efficient frontier. These are constructed using prices as weights to aggregate outputs and inputs. See Coelli et al. (2005) or O'Donnell, 2018 for a thorough discussion of index numbers used to measure productivity. Several fishery productivity studies have used index numbers over the past 30 years including Eggert and Tveterås (2013), Ekerhovd and Gordon (2020), Jin et al. (2002), Pan and Walden (2015), Squires (1992), Thunberg et al. (2015), and Wang and Walden (2021). Index numbers are also used in different research areas (e.g., See and Coelli, 2014 for energy; See and Abdul Rashid, 2016 for airlines).

capture fisheries", "capacity", "data envelopment analysis", "stochastic frontier analysis", "distance function", "productivity of fisheries", and "buyout", were used to search relevant papers. The query string used to search the Scopus database is given in Table 1. In the first phase, a total of 2498 publications were obtained through the search of the Scopus database (2330) and other sources (168).[2] These records were screened for duplicates and for inclusion and exclusion using the criteria for inclusion illustrated Table 2. Specifically, all books, book chapters, reviews, conference proceedings, non-English articles, and articles published in non-Scopus journals were excluded. Furthermore, only publications with a time span from 1995 to 2021 were retained for further phase. This is because the seminal paper in the field of productive efficiency of capture fishery using stochastic frontier analysis was published by Kirkley, Squires, & Strand in 1995 (Lampe and Hilgers, 2015). After applying these criteria, the number of publications was reduced from 2498 to 1793. In the second phase, the 1793 articles were manually screened based on their titles and abstracts. Publications were also excluded if the field of research was not capture fishery.[3] As a result, 1536 articles were removed from the list, leaving 257 publications for the next step of analysis. In the eligibility phase, two authors served as reviewers to examine the articles for inclusion and exclusion based on their titles, abstracts and full-text eligibility. Finally, 183 articles that met all the criteria for inclusion were retained for final bibliometric analysis.

2.2. Bibliometric approach

Bibliometrics is considered to have started in research performance evaluation in the 1950s (Thelwall, 2008; Wallin, 2005) and has recently been increasingly applied to a wide range of research fields (Bhatt et al., 2020; Kokol et al., 2021; See et al., 2023). This approach is a useful tool that provides significant benefits for scholars to *(i)* identify knowledge gaps, *(ii)* have a comprehensive overview, *(iii)* obtain ideas for conducting research, and *(iv)* position their contributions to the field (Donthu et al., 2021).

Bibliometric analysis is a quantitative approach that applies mathematical and statistical analysis to assess the published literature in a particular research area and to evaluate the quality and impact of research output (Yakath Ali et al., 2021). Other quantitative review methods, such as meta-analysis, can possibly handle these data. Unlike meta-analysis, bibliometric analysis demonstrates the relationship between studies through networks and cluster analysis. Accordingly, it is able to capture the latest research topics in diverse fields. To conduct bibliometric analysis, this study involves performance analysis and science mapping. The subsequent subsections describe the properties of bibliometric analysis.

Table 2
Inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Literature type	Journal article, book chapter, book, book series	Trade publications, review article, editorial review, conference proceeding
Database	Scopus	Non-Scopus
Language	English	Non-English
Timeline	≤2021	>2021
Date of search	18 September 2022	>18 September 2022

2.2.1. Performance analysis

Performance analysis is a descriptive and simple statistical way to evaluate publication and citation metrics. These metrics include the number of publications and the number of citations (for authors, institutions, and countries) as proxies for productivity and the influence of publications in this area, respectively. Full counting and fractional counting in publications and citations are often used to calculate performance metrics in many bibliometric studies (See et al., 2023). Waltman and van Eck (2015) suggested that the use of the fractional counting method is preferable over the full counting method, as each study is assigned a fair weight in publications and citations. In the case of productive authors, fractional publication assigns co-authored publications to a single author with a fractional weight count. For instance, each author will be given an equal weight of $1/5 = 0.2$ if there are five co-authors of a single publication. A similar counting method is applied for fractional citations. This study uses the fractional counting method to calculate the number of publications and the number of citations to determine productive authors, institutions, and author countries.

2.2.2. Science mapping

Science mapping involves identifying the linkages between research elements in terms of intellectual interactions and structural connections in the research area (Baker et al., 2020). The strength of the relationship among the attributed studies is illustrated by the size of nodes and the thickness of edges. For instance, in the case of author collaboration, the size of nodes corresponds to the number of papers co-authored with other authors. The thickness of edges is used in collaborative maps, where a higher density of edge thickness between nodes can be clearly observed if there is a highly collaborative relationship between two authors. The value of edge thickness can be determined through the direct connections between two authors for the number of publications. There are more than 30 analysis tools available for science mapping (Li et al., 2020). Co-authorship analysis and co-citation analysis are popular tools used for science mapping. VOSviewer software (Van Eck and Waltman, 2010) and the "bibliometrix" package in R (Aria and Cuccurullo, 2017) have been widely used in many bibliometric studies to create and visualize networks (e.g., co-authorship, co-occurrence, and co-citation networks). These tools efficiently determine the similarities of the studies collected within the parameters and produce significant research themes through clusters (Nobanee et al., 2021).

3. Results and discussion

3.1. Overview of publication trends

The number of research articles published from 1995 to 2021 is presented in Fig. 2. The oldest research article on the theme of productive efficiency of fisheries using the frontier approach was published in 1995 by Kirkley et al. (1995). For a period of 36 years, a total of 183 research articles were published, and the annual growth rate of publications was 10.03%. In the late 1990s, only a few research articles were published, but the research interest in fisheries efficiency and productivity began to grow considerably from 2000 to 2021. Prior to 2000, a relatively limited number of studies of fisheries efficiency (e.g., technical, allocative and economic efficiencies) were conducted. The papers in this period mainly focused on fishing in high-income countries such as the United States (Kirkley et al., 1995; Kirkley et al., 1998; Sharma and Leung, 1998), Canada (Grafton et al., 2000) and the United Kingdom (Pascoe and Coglan, 2000). Furthermore, the stochastic frontier analysis approach was mostly used in these papers.

The period from 2001 onward witnessed a significant increase in the

[2] Other sources refer to the backward search process. A list of references based on previous systematic literature reviews in the field was included as other sources. The reason is that we were trying to capture as many relevant studies as possible that may not appear in our initial database search process. However, some of these records were removed in the first phase due to duplication, not being indexed in Scopus, etc.

[3] The term "fishery" used for inclusion and exclusion criteria means capture fishery and does not mean aquaculture. Thus, all productive efficiency studies related to aquaculture or cultured fish were excluded.

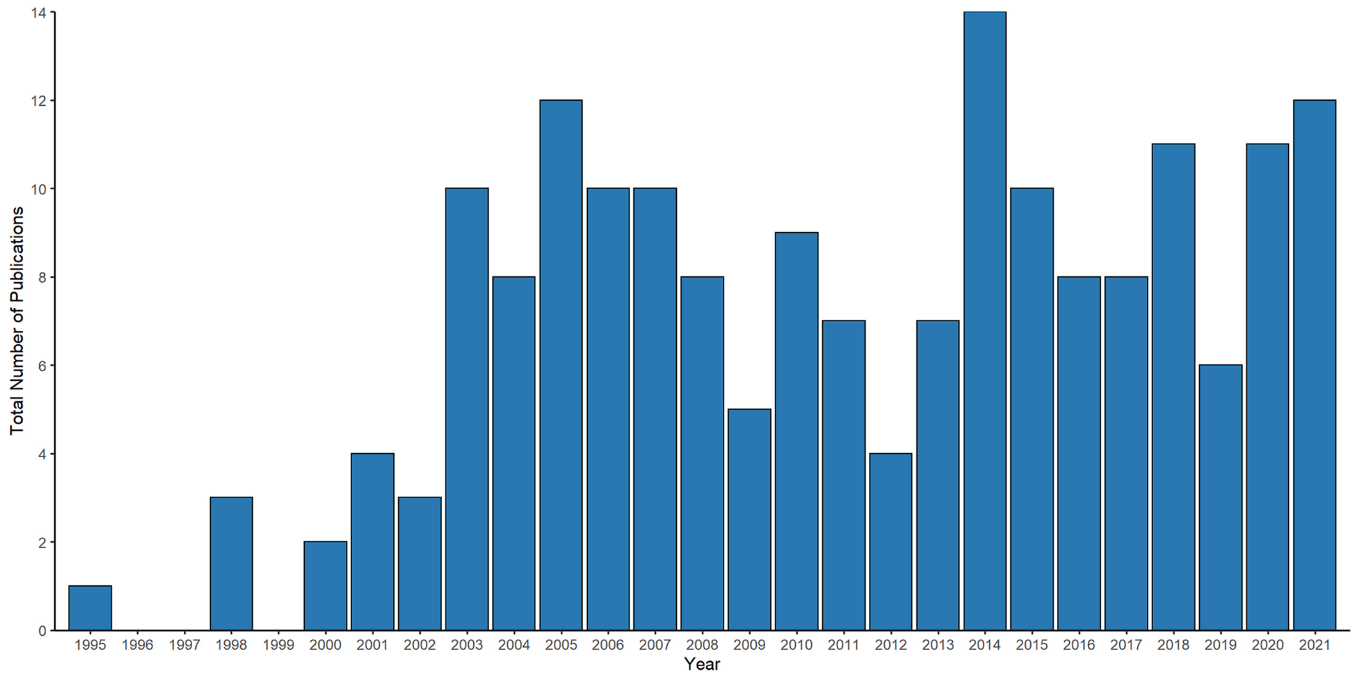

Fig. 2. Total Number of Publications in the Field.

number of publications, although there was a decrease in the number of research articles in 2012 and 2019. From 2001–2021, both SFA and DEA models were widely used to estimate efficiency and its determinants and to evaluate capacity utilization in fishing[4] (Kirkley et al., 2003; Pascoe et al., 2001; Tingley and Pascoe, 2005a, 2005b). Studies using SDF model, which can simultaneously handle multioutput technology and allow for noise in the efficiency model were also published in increasing numbers during this period. (see e.g., Fousekis, 2002; Herrero, 2005; Orea et al., 2005; Pascoe et al., 2010; Pascoe et al., 2012).

The application of SFA and DEA in the field of fisheries has not only been applied in developed countries such as the United States, the United Kingdom and Canada but has also been used in a wide range of countries, especially in Asia, Africa, and South America. These countries mainly include Malaysia (Kirkley et al., 2003; Squires et al., 2003; Viswanathan et al., 2001), Indonesia (Jeon et al., 2006; Susilowati et al., 2005), Vietnam (Duy and Flaaten, 2016; Quang et al., 2019; Thanh et al., 2014), Iran (Esmaeili, 2006), Tanzania (Lokina, 2009), Korea (Kim et al., 2011), Fiji (Reddy, 2008), Nigeria (Akanni and Akinwymi, 2008), Chile (Dresdner et al., 2010) and others.

The number of papers published shows that throughout the last three decades, fisheries efficiency, productivity analysis, and the use of frontier approaches in fisheries have expanded and attracted interest from scholars worldwide.

3.2. Most productive and influential authors

In general, a total of 334 authors were involved in 183 published articles during 1995–2021. In this section, we analyze authors in terms of productivity and influence. The term “productive” refers to number of publications by an author while the term “influential” indicates the total number of citations of the author. Table 3 shows the top ten productive authors and their total citations during 1995–2021. Regarding the number of scientific outputs, the results indicate that S. Pascoe (10.39 publications or 5.68% of the total publications) ranked first regarding both indicators, including the number of publications and the number of first-author publications in the field. At the same time, I. Herrero (3.33 publications or 1.82% of the total publications) ranked second in terms of the number of publications and the number of first-author publications, followed by D. Squires, with 3.32 research articles.

Table 3 shows that five productive authors had more than one hundred citations. A. Hoff was the most-cited author (360.33 citations) during 1995–2021, followed by S. Pascoe (239.70 citations), D. Squires (235.83 citations), JE. Kirkley (168.83 citations), and RG Felthoven (104 citations). The results from Table 3 also show that there is a significant change in the ranking of the most productive authors. For example, A. Hoff had a noticeable impact on the research on fisheries efficiency and productivity and the application of benchmarking in fisheries despite having limited publications in this field. The change in the ranking of the most productive authors might come from the fact that the literature in this field largely falls into several categories: *(i)* studies in which efficiency, productivity and capacity utilization in fisheries are the primal objectives of the research (see e.g., Kirkley et al., 1995; Sharma and Leung, 1998; Tingley and Pascoe, 2005b; Tingley et al., 2005); *(ii)* studies that take fisheries as application examples for new proposed approaches or methodologies (e.g., Färe et al., 2006; Hoff, 2007; Pascoe and Herrero, 2004; Vázquez-Rowe et al., 2010), these types of research seemed to receive more citations than others; and *(iii)* studies that examine the change in efficiency performance of fishing fleets and productivity change of fishing due to fisheries management and/or policy change (e.g., Pascoe et al., 2012; Pascoe et al., 2017; Solís et al., 2015; Solis et al., 2014).

To better understand the collaboration pattern among the authors in this field of research, we present the authors’ collaboration networks during the period 1995–2021 (Fig. 3). Different color shaded nodes in Fig. 3 indicate different author collaboration groups, and the size of the node represents the degree of publication of authors. The collaboration intensity between two authors is constructed by the edge linked between two nodes. A total of 334 authors (nodes) are involved in fisheries productivity and efficiency research. There are three distinct groups that appear in the network. S. Pascoe has contributed to the most

[4] Apart from SFA and DEA methods, which are widely used to estimate fishing capacity and capacity utilization, free disposal hull (FDH) and “order-m” frontier methods are also used as alternative methods and considered to be promising approaches to estimate fishing capacity. For further information about these approaches, potential readers can refer to article by Walden and Tomberlin (2010).

Table 3
The 10 most contributions in publications of authors.

Author	Publications number	First author publications	Weighted publications (%)	Citations number
S. Pascoe	10.39 (1)	5.81 (1)	5.68	239.70 (2)
I. Herrero	3.33 (2)	2.83 (2)	1.82	89.00 (6)
D. Squires	3.32 (3)	0.58 (9)	1.81	235.83 (3)
JE. Kirkley	3.25 (4 =)	1.50 (8)	1.78	168.83 (4)
JB. Walden	3.25 (4 =)	1.83 (6 =)	1.78	49.33 (9)
RG. Felthoven	3.08 (6)	1.83 (6 =)	1.68	104.00 (5)
L. Coglan	2.75 (7)	0.50 (10)	1.50	77.42 (7)
A. Hoff	2.67 (8)	2.33 (5)	1.46	360.33 (1)
Q. Weninger	2.50 (9 =)	2.50 (3 =)	1.37	55.00 (8)
AK. Akanni	2.50 (9 =)	2.50 (3 =)	1.37	8.00 (10)

Notes: Weighted publications are the weighted of fractional total publications for an author to all authors for all publications during 1995–2021. Numbers in parentheses indicate rank order.

publications, followed by D. Squires and JE. Kirkley. Furthermore, S. Pascoe and L. Coglan showed the greatest number of links in collaboration as they collaborated to produce eight studies, followed by JE. Kirkley and D. Squires with 6 studies, and D. Solis and JJ. Agar with 5 studies. More specifically, publications between S. Pascoe and L. Coglan mostly focused on efficiency and its determinants, capacity utilization, and evaluation of fisheries management changes on the efficiency and productivity of fisheries in Australia and the United Kingdom. Main research areas between JE. Kirkley and D. Squires were productive efficiency and its determinants and capacity utilization of fishing fleets in the United States and some Asian countries, such as Indonesia and Malaysia. Most of the publications between D. Solis and JJ. Agar in the field was the productivity of fishing fleets in the United States.

A number of the productive authors presented in Table 3 also appear in distinctive clusters in Fig. 3, such as S. Pascoe, JE. Kirkley and D. Squires. Additionally, a number of publications have been carried out through international collaborative work. For instance, the research article published by Viswanathan et al. (2001) included authors from the United States, Malaysia and Indonesia. Similarly, the authors of the paper entitled “Decomposing productivity and efficiency changes in the Alaska head and gut factory trawl fleet” (Fissel et al., 2015) were from the United States and Australia, and the authors of Herrero et al. (2006) came from Spain and the United Kingdom.

3.3. Most productive and influential institutions

To locate the affiliation of the most productive authors, the number of publications and total number of citations of their institutions were analyzed and are presented in Table 4. In total, 196 institutions published publications in this field of research from 1995 to 2021. Table 4 also presents the ten most productive institutions. These institutions produced 42.99 publications, accounting for 23.48% of the total publications. The University of Portsmouth contributed the largest number of publications, with 9.67 publications (5.28%), and ranked second in terms of the number of citations. The CSIRO Marine and Atmospheric Research (2.91% of publications) and NOAA Southwest Fisheries Science Center (2.52% of publications) ranked second and third, respectively, followed by University of Copenhagen with 2.37% of the total published papers in the field. Notably, if NOAA Southwest Fisheries Science Center, NOAA Alaska Fisheries Science Center, NOAA Northeast Fisheries Science Center in the United States were combined, which are subbodies of NOAA Fisheries, they would contribute the largest number

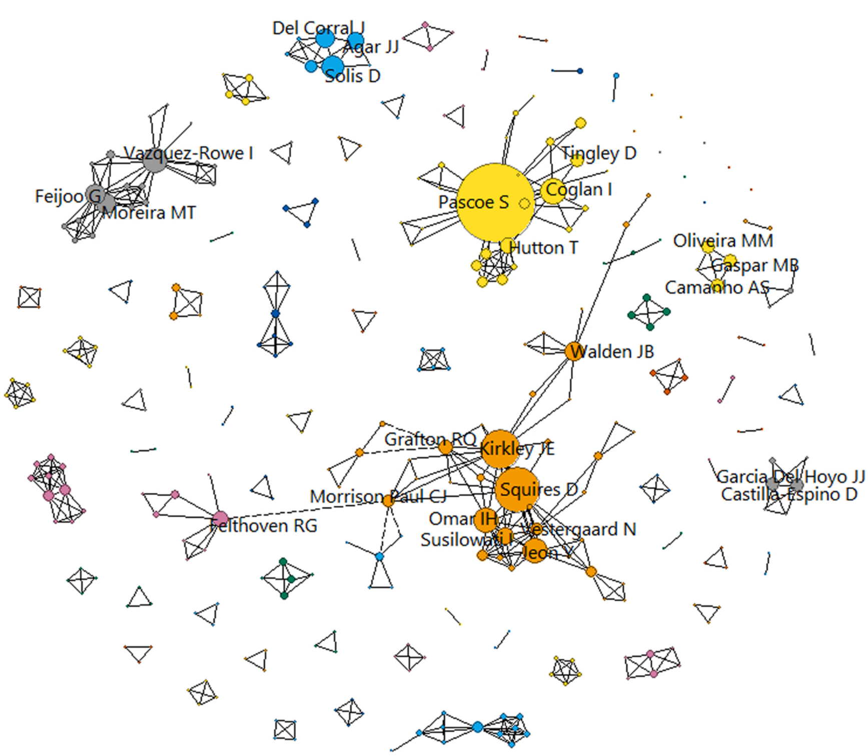

Fig. 3. Author collaboration network.

Table 4
The top productive institutions.

Institution	Publications number	Weighted publications (%)	Citations number
University of Portsmouth	9.67 (1)	5.28	350.00 (2)
CSIRO Marine and Atmospheric Research	5.33 (2)	2.91	75.67 (7)
NOAA Southwest Fisheries Science Center	4.62 (3)	2.52	155.07 (4)
University of Copenhagen	4.33 (4)	2.37	378.17 (1)
NOAA Alaska Fisheries Science Center	3.67 (5)	2.00	110.50 (5)
University Pablo De Olavide	3.50 (6)	1.91	91.50 (6)
University of Santiago De Compostela	3.17 (7)	1.73	171.17 (3)
Universiti Putra Malaysia	3.03 (8)	1.66	42.90 (9)
IOWA State University	3.00 (9)	1.64	77.00 (8)
NOAA Northeast Fisheries Science Center	2.67 (10)	1.46	32.33 (10)

Notes: Weighted publications are the weighted of fractional total publications for an institution to all institutions for all publications during 1995–2021. Numbers in parentheses indicate rank order.

of publications (10.96 publications, 5.98%).

The results from Table 4 also show that there are five institutions have more than 150 total citations, including the University of Copenhagen (378.17), University of Portsmouth (350), University of Santiago De Compostela (171.17), NOAA Southwest Fisheries Science Center (155.07), and NOAA Alaska Fisheries Science Center (110.50). Furthermore, the ranking of institutions in terms of publications differs from the ranking in terms of citations. For instance, the University of Copenhagen had only the fourth most publications, but ranked first in total citations. Additionally, we observe that almost all productive institutions are from Europe, the United States, and Australia, while Universiti Putra Malaysia was the only institution in the Asian area (Malaysia) listed on the top 10 most productive institutions. This finding is reasonable, as most productive authors came from European, the United States, and Australian regions.

It is also not surprising that there has been a strong connection between the most productive (and influential) authors and the most productive (and influential) institutions. For example, the University of Portsmouth and CSIRO Marine and Atmospheric Research were associated with S. Pascoe and L. Coglan, whereas D. Squires and JB. Walden were represented by NOAA Southwest Fisheries Science Center and NOAA Northeast Fisheries Science Center. These results imply that influential and productive authors tend to significantly enhance the impact and productivity of their affiliated institutions.

Fig. 4 represents the collaborative connection among 196 institutions that had publications in this research area. As seen, several clusters are connected to each other to form a distinctive cluster, which appears at the center of the network. Discussing the individual institutions/universities in the network, based on the node size, the NOAA Southwest Fisheries Science Center contributed the most publications, followed by the Virginia Institute of Marine Sciences and Universiti Putra Malaysia. The NOAA Southwest Fisheries Science Center highly collaborates with the Virginia Institute of Marine Sciences, Worldfish Center, Universiti Putra Malaysia, and Florida Agricultural and Mechanical University, which contributed 5 studies to the field of research. The Worldfish Centre and Universiti Putra Malaysia also collaborated in contributing 5 studies. The results also indicate that some institutions in the Asian region, including the Worldfish Centre and Universiti Putra Malaysia, have had a strong international collaborative network during 1995–2021. More importantly, international collaboration to produce research outputs seems to be important to boost their institution's ranking. The Universiti Putra Malaysia is a prime example. Their ranking was likely attributed to international collaboration with productive and influential institutions (NOAA Southwest Fisheries Science

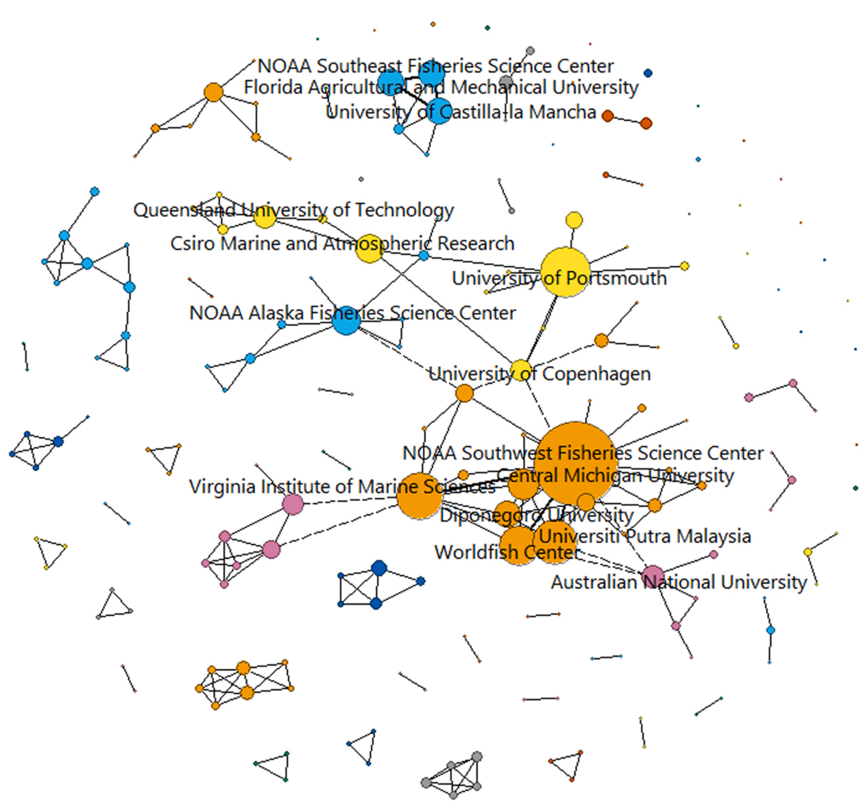

Fig. 4. Institution collaboration network.

Center, NOAA Northeast Fisheries Science Center) and productive and influential authors such as D. Squires and JE. Kirkley.

3.4. Countries of the most productive and influential authors

The present study also analyzed the most productive and influential countries in the field. The results found that a total of 48 countries (nodes) are involved in fisheries efficiency and productivity research during 1995–2021. The results from Table 5 show that the United States was both the most productive and influential country, contributing 39.62 publications to literature with a total of 1115.83 citations. The number of publications and citations of the United States are two times and three times higher than those of Australia, which ranks second in terms of publications (18.08) and citations (367.42). Australia was followed by Spain, with 16.67 articles and 406.67 citations. Scholars from Denmark produced only 7.92 articles (ranked fifth) during 1995–2021 but ranked second in terms of total citations (464.25) during the period. This was mostly due to the citation of A. Hoff (360.33 citations) or University of Copenhagen (378.17 citations).

Additionally, there is a collaboration among most high-income countries. For instance, the United States and Spain collaborated in publishing 6 studies, followed by the United States and Australia, and the United States and Malaysia contributed to 5 studies. Interestingly, the most productive countries are located not only in the European, Oceania, and American continents but also in the Asian and African regions. This means that researchers in developing countries (i.e., Indonesia, Malaysia, Nigeria) contributed significant numbers of publications to the literature. However, it is fairly noted that articles produced by scholars from these countries received very few citations. Taking Nigeria as an example, the country was one of the most productive countries, although articles produced by Nigerian scholars received few citations (i.e., 10 citations for KA. Akanni, and 12 citations for the country).

3.5. Most productive and influential journals

During the 1995–2021 period, research on fisheries efficiency and productivity and the application of frontier approaches in fisheries were published in 73 journals. However, the 10 journals listed on Table 6 attracted nearly 50% (89/183) of the total articles, especially the first three journals: *Marine Resource Economics, Marine Policy* and *Fisheries Research* accounted for more than 25% of the total publications. The scope of these ten journals mostly generally fell into marine science, fisheries economics and management, marine resource management and policy, productivity and efficiency, operational research, agriculture economics and development economics.

Marine Resource Economics was the most common outlet for publications in the field of research, with 21 publications, while the European Journal of Operational Research was the most influential journal (i.e., having greatest total number of citations), with 431 citations, even though this journal published only 4 papers in the field. Marine Policy ranked second with 18 publications and 286 citations, followed by Fisheries Research with 13 publications (380 citations). Among the 10 most common journals, two journals, Fisheries Science and Environment and Development Economics, received less than 100 citations. It is likely understandable that journals with the most cited papers published tend to receive higher citations (see Table 6 and Table 7).

Global citations indicate the frequency at which the publications were cited by all disciplines (without filtration), while local citations refer to citations cited by articles within the 183 articles used in the present study (Baker et al., 2020; Yakath Ali et al., 2021). The results from Table 7 reveal that articles written by Hoff (2007), Grafton et al. (2000) and Kirkley et al. (1995) were the most cited by other researchers from all disciplines.

Specifically, an article titled "Second stage DEA: Comparison of approaches for modelling the DEA score" by Hoff (2007) published in the European Journal of Operational Research was the most globally cited article (with 329 global citations). The objective of this study is mainly to compare different methods for modeling DEA scores against exogenous factors to examine which method is better than the Tobit model commonly used in second-stage DEA. To examine the author's proposed models, Hoff (2007) used the Danish fishery as a case study for empirical

Table 5
The 10 most productive author countries.

Country	Publications number	Weighted publications (%)	Citations number
United States	39.62 (1)	21.65	1115.83 (1)
Australia	18.08 (2)	9.88	367.42 (4)
Spain	16.67 (3)	9.11	406.67 (3)
United Kingdom	11.87 (4)	6.48	367.00 (5)
Denmark	7.92 (5)	4.33	464.25 (2)
Nigeria	6.50 (6)	3.55	13.00 (10)
China	6.25 (7)	3.42	20.00 (9)
Greece	6.20 (8)	3.39	125.50 (6)
Norway	4.83 (9)	2.64	74.67 (7)
Portugal	4.33 (10)	2.37	61.67 (8)

Notes: Weighted publications are the weighted of fractional total publications for a country to all countries for all publications during 1995–2021. Numbers in parentheses indicate rank order.

Table 6
The 10 most relevant journals.

Journal	Publications number	Number of citations
Marine Resource Economics	21 (1)	425 (2)
Marine Policy	18 (2)	286 (4)
Fisheries Research	13 (3)	380 (3)
Journal of Productivity Analysis	7 (4 =)	238 (5)
ICES Journal of Marine Science	7 (4 =)	150 (6)
Applied Economics	6 (6 =)	119 (7)
Fisheries Science	5 (7 =)	49 (10)
European Journal of Operational Research	4 (8 =)	431 (1)
Journal of Agricultural Economics	4 (8 =)	107 (8)
Environment and Development Economics	4 (8 =)	51 (9)

Note: Numbers in parentheses indicate rank order.

Table 7
The 10 most cited articles.

Article	Journal	Total global citations	Total local citations
Hoff (2007)	European Journal of Operational Research	329 (1)	2 (10)
Grafton et al. (2000)	The Journal of Law and Economics	227 (2)	31 (5)
Kirkley et al. (1995)	American Journal of Agricultural Economics	124 (3)	51 (1)
Kirkley et al. (1998)	Journal of Productivity Analysis	114 (4)	43 (3)
Vázquez-Rowe et al. (2010)	The International Journal of Life Cycle Assessment	113 (5)	9 (8)
Tingley et al. (2005)	Fisheries Research	102 (6)	37 (4)
Sharma and Leung (1998)	Marine Resource Economics	98 (7)	45 (2)
Avadí et al. (2014)	Journal of Cleaner Production	91 (8)	3 (9)
Dupont et al. (2002)	Resource and Energy Economics	86 (9)	23 (7)
Felthoven (2002)	Marine Resources Economics	67 (10)	25 (6)

Note: Numbers in parentheses indicate rank order.

application. The author concluded that Tobit models can be sufficiently applied for second-stage DEA in most cases, and OLS might be used as alternative approaches for the Tobit model in a number of cases. However, this study has been cited by articles in disciplines other than fisheries, ranked in 10th place in terms of local citations. Second, the article titled "Private property and economic efficiency: a study of a common-pool resource" by Grafton et al. (2000) published in The Journal of Law and Economics was the second most globally cited article, with 227 citations. This article evaluates the changes in the technical, allocative and economic efficiency of the British Columbia halibut fishery in Canada using stochastic frontier analysis. The third most globally cited article is "Assessing Technical Efficiency in Commercial Fisheries: The Mid-Atlantic Sea Scallop Fishery", by Kirkley et al. (1995), published by the American Journal of Agricultural Economics and cited 124 times in all disciplines. The authors used stochastic frontier analysis to estimate the technical efficiency of sea scallop fishing vessels in the Mid-Atlantic. Thus, unlike the two most globally cited papers, Grafton et al. (2000) and Hoff (2007), which have been widely cited by studies in other fields, the study by Kirkley et al. (1995) has been the most influential article in terms of local citations (51 citations).

The majority of the most influential articles were published before 2005, when articles on fishery efficiency and the application of the frontier approach were published less frequently. Moreover, the results show that the most common and influential journals were associated with the most cited articles, and the most productive authors are likely to publish influential articles (see Table 3, Table 6, Table 7). For example, three out of the top ten most productive authors include RG. Felthoven, JE. Kirkley, A. Hoff listed in Table 3 produced the most influential articles (Table 7).

3.6. Citation network analysis

To identify important references associated with publications in this field, cocitation networks were analyzed and are presented in Fig. 5. For convenience, only articles with more than 25 global citations were analyzed herein. Three main clusters, represented by different colors, are identified:

Cluster 1 (red color) shows the evolution of the SFA concept and modeling to estimate technical efficiency. Cluster 1 formed with Aigner et al. (1977) consisted of the total link strength; its topics were mainly focused on the specification of the disturbance term, i.e., the sum of the symmetric normal and half-normal random variables, and considered the use of maximum likelihood for the estimation of the production function. At the same time, Meeusen and van Den Broeck (1977) introduced the composed error term from the Cobb—Douglas production function. Jondrow et al. (1982) suggested the computation of technical inefficiency by considering the expected value of technical inefficiency and conditional on the composed error term. Kodde and Palm (1986) proposed the Wald test for testing equality and inequality restricted of parameters of the model. Battese and Coelli (1988, 1995) extended the SFA model in the production function from cross-sectional to panel data for technical efficiency estimation. Squires and Kirkey (1999) applied fixed and random effects panel data models to examine the managerial ability in the Pacific Coast trawl fishery.

Cluster 2 (blue color) comprises six articles that concentrate on using the DEA model to calculate efficiency in fisheries. The DEA model, a nonparametric approach, was first proposed by Charnes et al. (1978), which is known as the CCR-1978 model, based on the seminal paper of Farrell (1957). The model is based on the assumption of constant return to scale. However, the CCR-1978 model was improved by Banker et al. (1984), also known as the BCC-1984 model, using the assumption of variable return to scale rather than constant return to scale. Vestergaard et al. (2003) applied a DEA model to examine the capacity utilization of the Danish gillnet fleet. Tingley et al. (2005) also used DEA and SFA models to measure efficiency and its determinants in English Channel fisheries.

Cluster 3 (green color) includes six papers in the network that estimate efficiency and its determinants. Specifically, Sharma and Leung

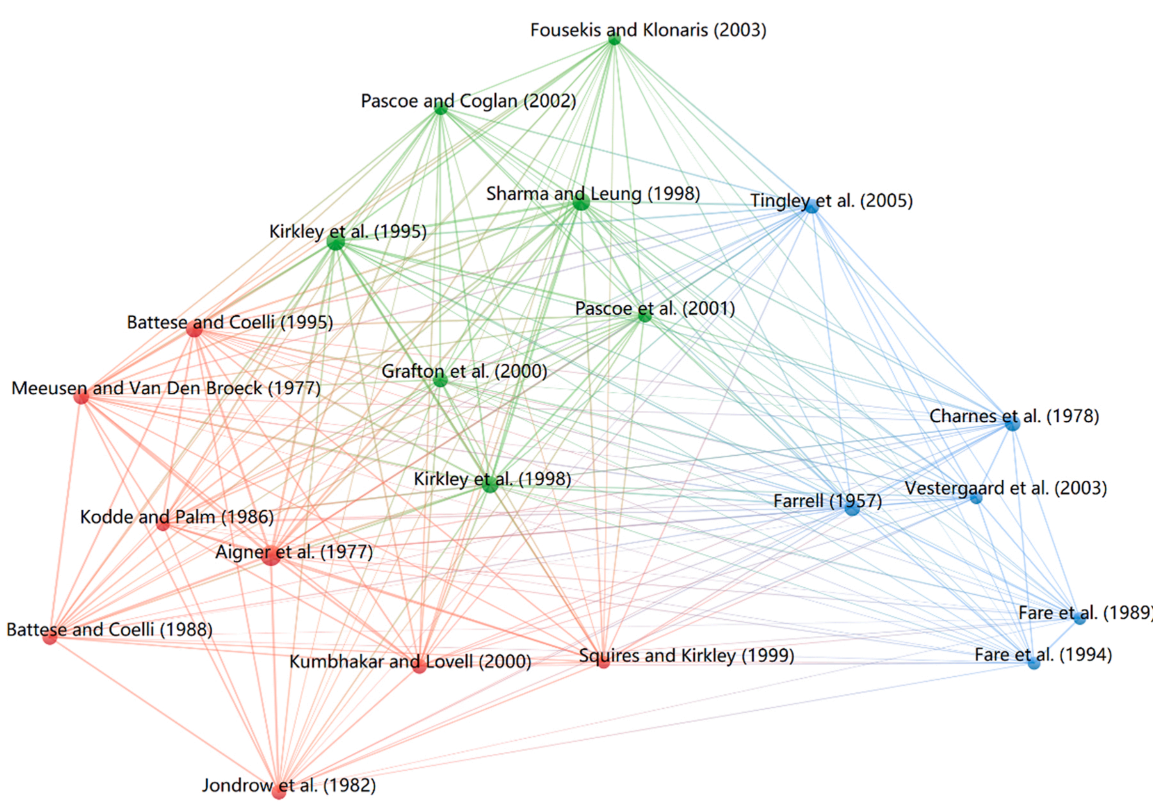

Fig. 5. Cocitation network.

(1998) analyzed technical efficiency and its determinants of longline fishing vessels operating in Hawaii using a translog stochastic production frontier. Pascoe and Coglan (2002) used the SFA model to examine the variation in efficiency and influencing factors of fishing vessels operating in the English Channel. Pascoe et al. (2001) also evaluated technical efficiency and its determinants in the Dutch beam trawl fleet. While Kirkley et al. (1995) applied a translog stochastic production frontier to estimate the technical efficiency of fishing vessels operating in the Mid-Atlantic Sea and then examined technical efficiency scores in relation to input levels, fish stocks and economic performance, Kirkley et al. (1998) used a stochastic production frontier model to examine the relationship between technical efficiency and skipper characteristics. Grafton et al. (2000) employed a stochastic frontier model to examine the changes in technical, allocative, and economic efficiency of the British Columbia halibut fishery after the introduction of private harvesting rights. The findings of the research provide valuable insights for fisheries management when the harvesting right mechanism is introduced.

3.7. Main research keywords and their temporal evolution

To identify research trends and research hotpots, we analyzed article titles, abstracts and author keywords, as shown in Fig. 6. Each keyword is represented by a node, and the size of the node represents the number of occurrences of the keyword. The color of the node and edge indicates the average publication year. The results from Fig. 6 show the six most widely used author keywords: DEA (69 occurrences), Technical efficiency (51), SFA (41), Fisheries (34), Efficiency (17), and Capacity utilization (14). The keywords "Technical efficiency", "DEA", and "SFA" are at the center of the network, implying that "DEA" and "SFA" were prevalent approaches in the field of research, and research on "Technical efficiency" was a common topic for worldwide researchers during 1995–2021. The recent keywords connecting to "SFA" are "small-scale fisheries", "artisanal fisheries", "socioeconomic factors", and "fisheries management", whereas the recent issues associated with "DEA" are "life cycle assessment", "artisanal fisheries", "small-scale fisheries", "purse seining", "economic performance", "management", and "TFP" (Total factor productivity).

Regarding methodology, earlier research tended to use the SFA approach to evaluate technical efficiency and its determinants (e.g., vessel characteristics, skipper's demographic characteristics, and fisheries management regulations) (Kirkley et al., 1995, 1998; Pascoe and Coglan, 2002; Pascoe et al., 2001; Pascoe et al., 2003; Sharma and Leung, 1998; Viswanathan et al., 2001). As presented in Fig. 6, the keyword DEA is mainly associated with (i) estimating efficiency and its determinants using Tobit models (Tingley et al., 2005); (ii) evaluating fishing capacity and capacity utilization (Maravelias and Tsitsika, 2008; Pascoe and Tingley, 2006; Thanh et al., 2014; Tingley and Pascoe, 2005a; Tingley et al., 2003); and (iii) the combined use of DEA with LCA (life cycle assessment) to evaluate eco-efficiency in fisheries (Avadí et al., 2014; Vázquez-Rowe et al., 2010).

The keywords "Bootstrap" and "SDF" were also the most frequently appearing as author keywords over the past three decades. This is because the use of DEA combined with the bootstrap technique and the application of the SDF to handle the case of multiple output production, which is characterized by multispecies fisheries in nature, have been used by scholars in a number of studies (Fousekis, 2002; Hoff, 2006; Orea et al., 2005; Pascoe et al., 2010; Walden, 2006). The use of these models allows scholars to overcome the limitations of DEA and SFA. Furthermore, "productivity" and "TFP" emerged as common author

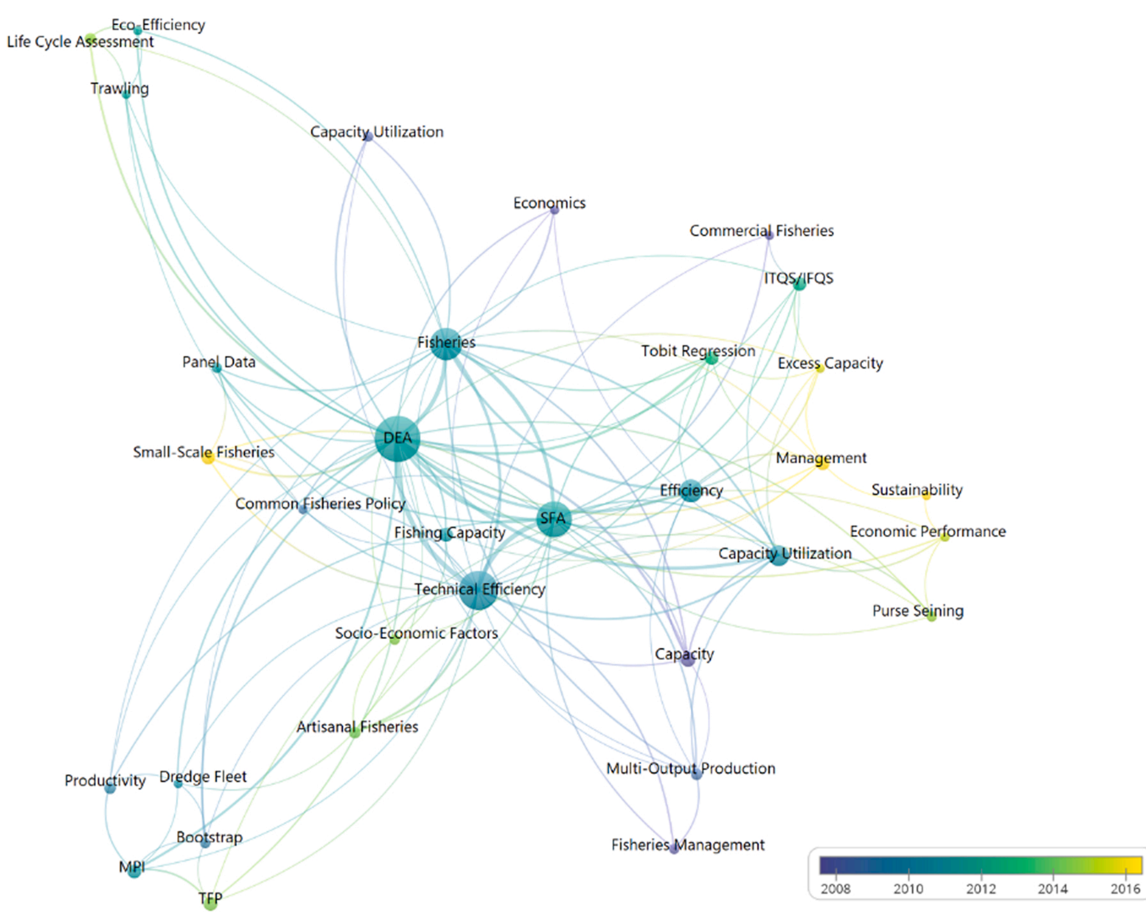

Fig. 6. Temporal evolution of author keywords based on average publication years.

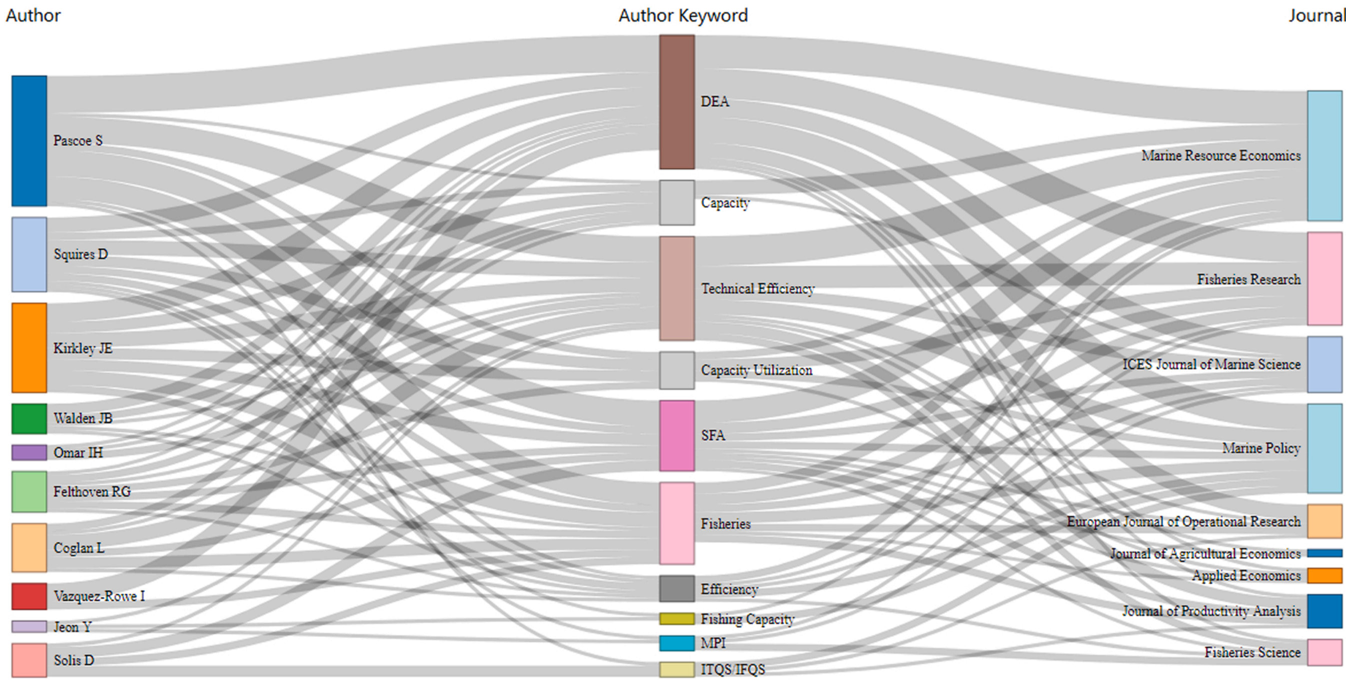

Fig. 7. Three-field plot of authors, authors, authors keywords, and sources.

keywords, and the Malmquist Productivity Index (MPI) was also adopted by researchers for productivity and TFP analysis along with parametric and nonparametric approaches (Fissel et al., 2015; Oliveira et al., 2009; Walden et al., 2012).

Our analysis indicates that "small fisheries", "artisanal fisheries" and "socioeconomic factors" also attracted the attention of fisheries researchers, especially in the Asia and Africa regions (Lokina, 2009; Quang et al., 2019; Squires et al., 2003). In addition, fisheries managed by ITQs (individual transferable quotas) and IFQs (individual fishing quotas) have also been interesting subjects of a number of studies over the past decades (Fissel et al., 2015; Fox et al., 2006).

The interconnections among authors, author keywords and journals can provide useful insights. Therefore, we construct a three-field plot as shown in Fig. 7 within the efficiency and productivity in fisheries research. For methodological comparison, we find that the keyword "DEA" is used by the majority of the most productive authors and that the majority of the studies are published in Marine Resources Economics, Marine Policy and Fisheries Research. Specifically, almost all the studies of S. Pascoe were published in the ten most common journals, and the author used a variety of approaches, including DEA, SFA and SDF, to evaluate the "Technical efficiency" and "Capacity utilization" of fisheries. JE. Kirkley and D. Squires tend to use "DEA" and "SFA" models to estimate "technical efficiency" and "capacity utilization" for their research, and journals publishing their research findings mainly include Marine Resources Economics, Marine Policy and Fisheries Research. Most studies of JB. Walden applied the "DEA" to estimate fishing capacity while research by RG. Felthoven used the SFA approach to evaluate capacity utilization. On the other hand, the SDF method was often adopted by D. Solis for ITQs/IFQs fisheries, and the research of the author was largely published in Marine Policy and Fisheries Research.

4. Conclusions

We employed a bibliometric analysis to review the literature on fisheries efficiency and productivity and the application of the frontier approach in fisheries from 1995 to 2021. We identified 334 individual authors involved in 183 publications in Scopus-indexed journals during the 1995–2021 period. The bibliometric analysis from this study found that there has been an increasing interest in the field of efficiency and productivity in fisheries over the past decades, corresponding to the growth rate of publications in this field at 10.03% from 1995 to 2021. Most publications in the early years likely focused on fisheries in the United States, Europe and Canada. Later, through international collaboration, to some extent, the topic of efficiency and productivity in fisheries gradually expanded to broader geographic areas, ranging from Asia to African regions.

This study identified some of the most common journals that were strongly preferred by scholars to publish their work. These journals included Marine Resource Economics, Marine Policy and Fisheries Research. Interestingly, there were strong correlations among the most productive authors and the most common and influential journals and the most influential articles. The most productive authors tend to have more citations and produce influential research as well as publish their work in the most common and influential journals. We also found that almost all the most cited papers were published before 2005 and in high-impact journals.

The results of author keyword analysis implies that research topics relevant to "small-scale fisheries", "artisanal fisheries", "TFP", "ITQs/IFQs", "socioeconomic factors" and "economic performance" were increasingly of interest to researchers, while the use of "SFA" and "DEA" appear to be the most common approaches used in fisheries efficiency and productivity. In addition, the application of DEA for fishing capacity and capacity utilization and eco-efficiency in the fishing industry have also been interesting areas for scholars in this field. More recently, the use of the SDF and bootstrapped DEA techniques for efficiency and productivity have been applied in a number of articles.

CRediT authorship contribution statement

Quang Van Nguyen: Conceptualization, Methodology, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Funding acquisition. **Kok Fong See:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgment

This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 502.01-2020.334. The authors would like to thank the Editor and the anonymous reviewer for useful comments that greatly improved the manuscript.

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