Int Aquat Res (2021) 13:271-288
https://doi.org/10.22034/IAR.2021.1932503.1166

ORIGINAL RESEARCH

Aquaculture research in Southeast Asia - A scientometric analysis (1990-2019)

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Received: 05 June 2021 / Accepted: 09 December 2021 / Published online: 14 December 2021

Abstract The volume of the aquaculture industry has tripled since 2000 and recent data showed that 47% of the total global fish production and 10.34% of it comes from the Southeast Asia region. Thus, the purpose of this study is to synthesise the available literature of aquaculture research in Southeast Asia from 1990 to 2019 using the scientometric method. This article found that a total of 1662 publications with 230,221 total citations were retrieved from Web of Sciences on 10th November 2020. The aquaculture research's landscape from Southeast Asia showed that the year of 2018 resulted in the highest number of total publications in terms of the year. The study reveals that "aquaculture" is the top publication title used, and the author of Qiwei Qin is the most prolific author in the aquaculture research in Southeast Asia (author's affiliation was not among the Southeast Asia countries). The study also reveals that Vietnam and Can Tho University is the leading country and organisation, respectively within Southeast Asia in this research area (i.e. Aquaculture Research) in terms of the highest publication. The key topic and development showed that "Ecology, Earth, Marine" discipline dominate the study in this area. There are six clusters that emerged as key topics with high silhouette scores ranging from 0.649 to 0.988. Surprisingly, keyword with largest magnitude was "climate change" (strength = 10.9997), with a burst span of 2 years and the strongest burst strength for an article by Richards and Friess. Overall, this study shows a diversity trend with the continuous development of cross disciplinary integration.

Keywords Climate change . Document citation analysis . Network analysis . Research trend . Web of science

Introduction

The seafood industry had grown exponentially over the past decade (end of 2000s) with an increment of over 350% of total production since the 1970s and significantly contributed to an average of 0.5 – 2.5% of Gross Domestic Product (GDP) for the world economy (World Bank 2013; FAO 2016). Furthermore, the value of the global fish trade exceeded the value of international trade for other animals as food resources

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combined (FAO 2020; Knowler et al. 2020; Nor et al. 2020). However, the global production of fisheries were decreasing over the past years due to continuous pressures from overfishing activities as a result of catering the increasing demand of seafood from the expanding global population as well as climate change (Cochrane et al. 2009; FAO 2012; Brander et al. 2017). With the world population estimated to reach 10 billion by 2025, many countries have shifted towards developing aquaculture industry to meet the global seafood demand (FAO 2013; Brander et al. 2017).

Aquaculture is among one of the rapidly growing animal-based food producing sectors in the world (Naylor et al. 2000; Bostock et al. 2010; FAO 2020; Azra et al. 2021). It represents 47% of the total global fish production in 2016 with 10.34% from Southeast Asia (FAO 2020). Since 1996, the total production and its values of Southeast Asia's aquaculture had tripled with focus in mariculture and cage culture (Hishamunda et al. 2009; Kobayashi et al. 2015), which had enhanced the food security as well as contributed to poverty reduction and national economy in the region (Bostock et al. 2010; World Bank 2013; FAO 2020). Multiple aquaculture programs have been initiated by the Government in this region to boost the aquaculture industry such as Aquaculture Industry Zone, Permanent Food Production Parks and Agropolitan (FAO 2013; Wayne and Vun 2016).

To support the aquaculture industry, there has been increasing aquaculture-related research in Southeast Asia which focused on environment (World Bank 2013; Nor et al. 2020), health and food security (Clausen et al. 2015; Golden et al. 2016; Pandey et al. 2016; Binh et al. 2018). In addition, several reviews had synthesised aquaculture in specific topics such as food science (Pandey et al. 2016; Bird et al. 2019), environment sustainability (Golden et al. 2016; Richards and Friess 2016) and engineering related topics (Järviö et al. 2018). However, the importance and significance of existing reviews related to the aquaculture research remain to be explored as many of the existing reviews and studies focusing on aquaculture were conducted in isolated and separate research domains.

By focusing on the dynamics and relationships between articles, authors, and journals for studies in Southeast Asia's aquaculture, the following information would be beneficial for identifying research avenue: (i) the intellectual turning points within a specialty, (ii) the links between different specialties and (iii) the progress of knowledge over time (Chen 2016; Chen et al. 2009; Chen and Leydesdorff 2014). One way to examine this is to utilise scientometrics, which is a study on a class of measurement for scientific performance and has been applied in evaluation of various research areas. Aryadoust et al. (2019) had use scientometric to review the eye tracking technology, Castillo Vergara et al. (2018), used it to examine the landscape of creativity research in the scope of business economics while Wang et al. (2018) provided insights of current research progress of atomic power in the advancement on nuclear power. Furthermore, scientometric involves quantitative approaches, from descriptive statistics and data visualisation to advanced econometric methods (e.g., network science, machine-learning algorithms, mathematical analysis and computer simulation) (Chen 2004; Chen et al. 2009; Chen and Leydesdorff 2014).

Here, this study aimed to synthesise the published research of aquaculture in Southeast Asia from the year 1990 to 2019, using the Web of Science database through the scientometric method, specifically the CiteSpace. The specific objectives were (1) to determine the research landscape of aquaculture in Southeast Asia in terms of the year, journals, co-cited journals, authors, countries, institutions, keywords, and references; and (2) to explore the key topics and developments of research focus over time.

Materials and methods

Scientometric method was used to analyse the journal articles published between year 1990 and 2019 focusing on aquaculture research in Southeast Asia. This method was chosen due to (i) the availability of large bibliographic corpora such as Web of Science, Scopus and Pubmed (Bar-Ilan 2008; Adriaanse and Rensleigh 2013), and (2) the availability of text-mining and visualisation software packages such as CiteSpace (Chen 2016; Chen et al. 2009; Chen and Leydesdorff 2014).

Database search

Web of Science (WoS) core collection database by Clarivate Analytics was chosen as a main source of data mining as it has been extensively used as data source for review articles besides being reputable

and comprehensive for covering many areas of knowledge (Aryadoust and Ang 2021). Furthermore, WoS provides details of ranking for countries, journals, scientists, papers, and institutions by field of research. WoS registered more than 6650 major journals across 150 scientific disciplines and included cited references captured from indexed articles (Bar-Ilan 2008; Adriaanse and Rensleigh 2013).

The method of database search here followed (Azzeri et al. 2020; Aryadoust et al. 2019). The field "TS" was checked to include the title of manuscript, its abstract, keywords, author, and Keywords Plus in the search (Bar-Ilan 2008; Adriaanse and Rensleigh 2013). The search in WoS was made using keywords (search code) commonly used to refer to aquaculture (Dong et al. 2012; Du et al. 2014). The Boolean "OR" was used to capture at least one of the specified terms used to describe aquaculture. Asterisk "*" was used at the end of some search code to identify variations, thereby broadening the search (Kitchenham 2004; Denyer and Tranfield 2009; O'Connor et al. 2017). The following search code was used based on Barrett et al. (2019)'s systematic review study on impacts of aquaculture on wildlife:

TS= (((Cambodia) OR (Myanmar) OR ("Vietnam") OR ("Thailand") OR ("Laos") OR ("Indonesia") OR ("Malaysia") OR ("Philippines") OR ("Brunei") OR ("East Timor") OR ("Singapore") OR (ASEAN) OR ("South Asia") OR ("South$east Asia")) AND ((aquaculture) OR (mariculture) OR ("fish farm*") OR ("shellfish farm*") OR ("mussel farm*") OR ("oyster farm*") OR ("sea cage*") OR ("net pen*") OR ("fish pond*") OR ("seaweed farm*") OR ("macroalgal farm*") OR ("algal farm*")))

The search terms in the WOS databases were restricted to the publication between the start of 1990 until at the end of 2019. It also means that the abstracts of publications before 1990 were not included in the WOS database, especially in the WOS's core collection section, and only those published from 1990 onwards were considered for this analysis (Ho et al. 2010). Only original research articles were considered whereas commentaries, short communications, books and book chapters, protocol papers, theoretical papers and editorials were excluded. All research designs (i.e., quantitative, qualitative, and mixed methods) were included. The search was conducted on 10th November 2020.

Descriptive analysis (method for 1st specific objectives)

R version 4.0.2 (R Core Team, 2019) was used to visualise the data and perform the basic statistical analyses. The data included annual number of publications, the journals where the papers were published, and the most productive authors as well as the universities/institutes, and countries where the authors were affiliated with and residing when the papers were published.

Scientometric analysis (method for 2nd specific objectives)

CiteSpace V version 5.2.R 2.3.26.2018 for 64-bit windows was used to conduct visualisation and knowledge graph analysis here as it allows the generation of multiple bibliometric networks and conduct of multiple methods of analysis (Chen 2004; Chen and Leydesdorff 2014). To investigate the inter-domain specialty to specialty trends that link aquaculture research, this study used dual-map overlay. The dual maps overlay is also the trajectory of the citation in which it is the connection and relationship between various fields of study. A connection in trajectory from one trajectory to another indicates that certain literature's discipline was influenced by other literature from another discipline. The ovals form found in the CiteSpace V represent the total of authors involved in certain field and the total number of papers was being published. The author-to-author ratio is denoted by the width of the oval, while the height of the oval indicates the number of papers published. Dual map overlay also categorised the retrieved literature into (1) cited journals and (2) citing journals (i.e., the latter cited its references from the former) (Chen and Leydesdorff 2014). The strength of relationships between these two were visualised and measured using CiteSpace (Chen and Leydesdorff 2014). CiteSpace were also used to perform (i) keyword analysis to analyse the instances of two keywords appearing together, and (ii) Document Co-citation Analysis (DCA) to get the cluster of co-citing journals, where a co-citation instance occurred when two sources are cited together in one paper (Chen 2004; Chen and Leydesdorff 2014; Aryadoust and Ang 2021).

The input data for CiteSpace were retrieved from Web of Sciences as mentioned above. To generate an individual network, threshold setting was required to enable article selection. For this study, the threshold

setting was "*Top N*" per slice, which allowed the selection of most cited items from each slice to form a network based on the choice of input value (i.e., 50) and multiple node types. Consequently, the top 50 most cited were displayed and ranked accordingly by CiteSpace. The "Time Slicing" was set to 1990-2019 and "Years per slice" at 1 year. The "Pruning" parameter was selected to prune the generated network. For text processing, all term sources in Web of Science, including title, abstract, author keywords and keywords plus were chosen.

Multidimensional clustering was used to identify clusters of research in focus areas. Log-likelihood ratio (LLR) could provide the best results in terms of uniqueness and coverage and hence was used to extract the cluster label automatically. The "timeline view" and "cluster view" of DCA were used to visualise the shape and the form of the network. The "timeline view" comprised a vertical range of chronological time period from left to right, whereas the "cluster view" produced a spatial network of representations that were colour-coded and automatically labelled in a landscape format.

Quality control and impact

The quality and the homogeneity of the analyses as well as the detected clusters were measured using modularity Q index, average silhouette metric and centrality (Chen et al. 2009; Chen Ibekwe-Sanjuan and Hou 2010; Chen 2016). The modularity Q index ranges between 0 and 1, with larger index indicating higher reliability. The average silhouette metric ranges between -1 and 1, where values above 0 indicate better homogeneity. Centrality is a measure of influence that shows the degree to which publications or journals stand between each other, where publications with higher betweenness would have higher influence on the network as they connect more publications or journals and therefore, more information and paths pass through them.

Influential publications and top keywords were determined by computing citation burstiness and sigma, of which both are temporal metrics. Burst detection is a sudden surge of citations for a specific article or 'an abrupt elevation of the frequencies [of citations] over a specific time interval', as indicated by a red ring around the node (Chen et al. 2009; Chen et al. 2010; Chen 2014). Sigma is the combination of centrality and burstiness score, ranging from 0 to 1 where the highest value of sigma is associated with high value research articles (Chen et al. 2009; Chen et al. 2010; Chen 2016).

Results and discussion

Overall, the search in the Web of Science database generated 1960 publications which were further filtered by selecting only "articles", resulting in the final total of 1662 publications for the scientometric analysis in this study. These publications boasted an h-index of 68, 18.22 citations per item and a sum of 30,221 times cited. There were 27,185 articles without self-citations.

Publication and citation trends

Between the year 1990 and 2019, there were 1662 published articles focusing on aquaculture research in Southeast Asia, where there was a higher proportion of publication in recent years from 2015 to 2019 with 2018 having the highest number of total publications (Fig. 1). The highest Total Publication in the research of aquaculture in Southeast Asia is 10.95% which is in 2018 (Fig. 1(a)). Overall publications from 2015 had the highest number of cited publications, though a decline trend in citation per publication was evident from 2015 onwards. The highest publication without self-citation is in 2015 with a total citation of 1988 citations (Fig. 1(b)). The decline could be attributed to the unavailable open access article due to the embargo period of the published paper(s). Usually, articles that have been published have hardly been cited between 3 to 5 years after fully published (Council of Canadian Academies 2012). Article published in 2011 had the highest *h*-index, and it's referred to the article published within the year of 1990 to 2019, also known as the most influential year. The mean number of citations per cited publication is between 0.9 to 1 citations per article (Fig. 1(c)). The rapid growth in the number of publications pertaining to aquaculture research

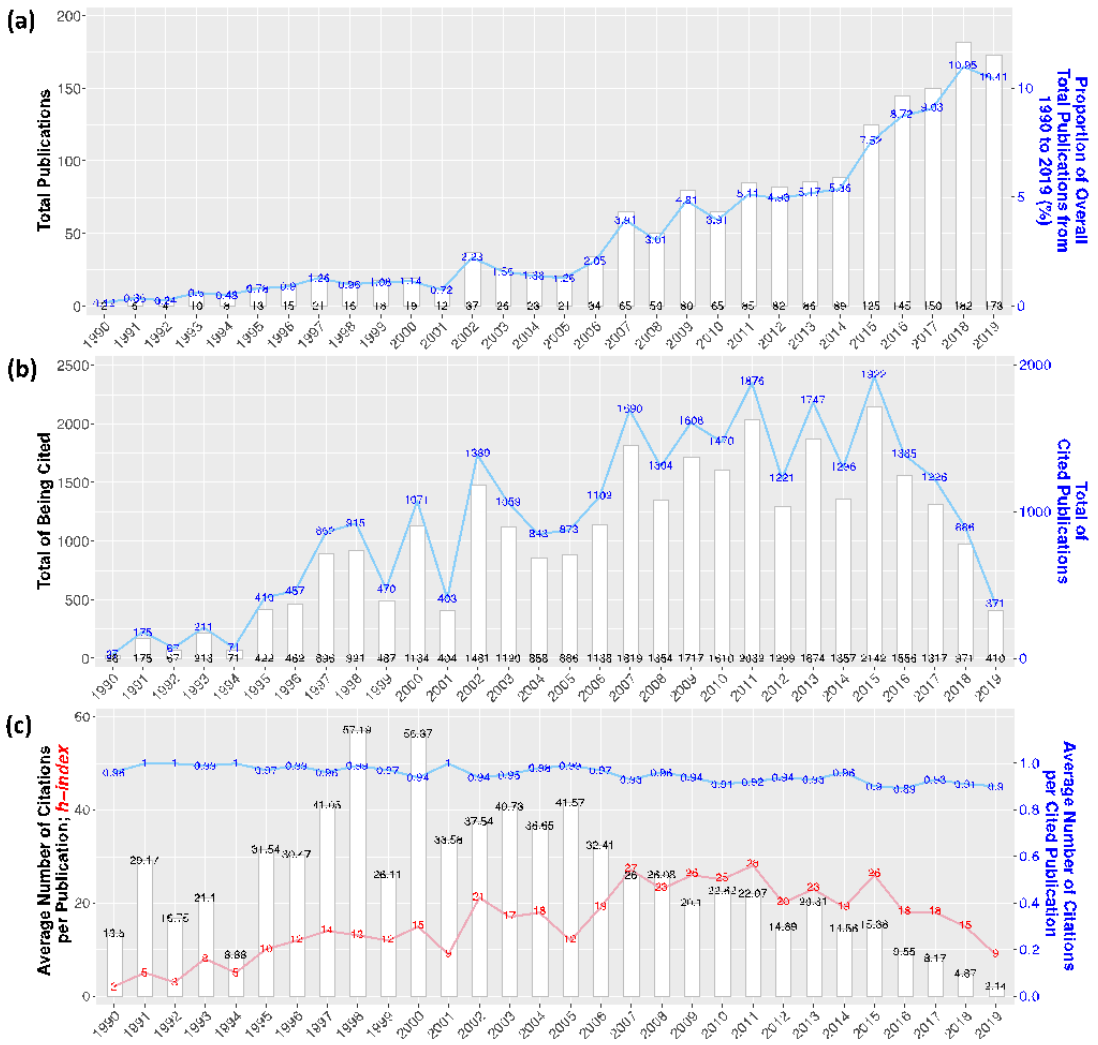

Fig. 1 Publication and citation trend on Aquaculture Research in Southeast Asia between year 1990 and 2019

in Southeast Asia could be explained by the rapid growth of aquaculture industry in this region (Barrett et al. 2019; Nong 2019), which is crucial for boosting the local, nationwide and global economy (Ahmed and Lorica 2002; Tran et al. 2013; Grainger 2016). Aquaculture had been promoted by governments around the world as a means to reduce the reliance on the declining wild fishery resources while still catering the global demand for fishery products (Bess 2006; Llorente and Luna 2013; Nong 2019).

Top countries and institutions distribution

The papers featured in the sample come from 76 countries around the world. Vietnam was the most frequent publisher (352 publications), followed by Thailand, Malaysia, United States of America, Philippines, Australia, Japan, Indonesia, Netherlands, and China, as among the top 10 countries had published in this research areas (i.e. Aquaculture research in Southeast Asia) (Table 1).

There are a total of ten institutions which was contributed to the 31.85% (529 publications) of total publication between 1990-2019 (Fig. 2). Can Tho University which is based in Vietnam contributed the highest number of articles retrieved for this study with proportion of 5.05% of total number of publications, followed by Wageningen University in Netherlands (3.79%), University of the Philippines (3.61%), Kasetsart University in Thailand (3.13%), National University of Singapore (3.01%), University Copenhagen in Denmark (3.01%), Mahidol University in Thailand (2.83%), Universiti Putra Malaysia (2.838%), Universiti Malaya in Malaysia (2.41%), and the autonomous intergovernmental body Southeast

Table 1 Top ten highest publication countries

Countries	TP	%
Vietnam	352	21.18
Thailand	278	16.73
Malaysia	218	13.12
USA	202	12.15
Philippines	195	11.73
Australia	172	10.35
Japan	140	8.42
Indonesia	116	6.98
Netherlands	108	6.50
China	100	6.02

Notes: TP=total number of publications

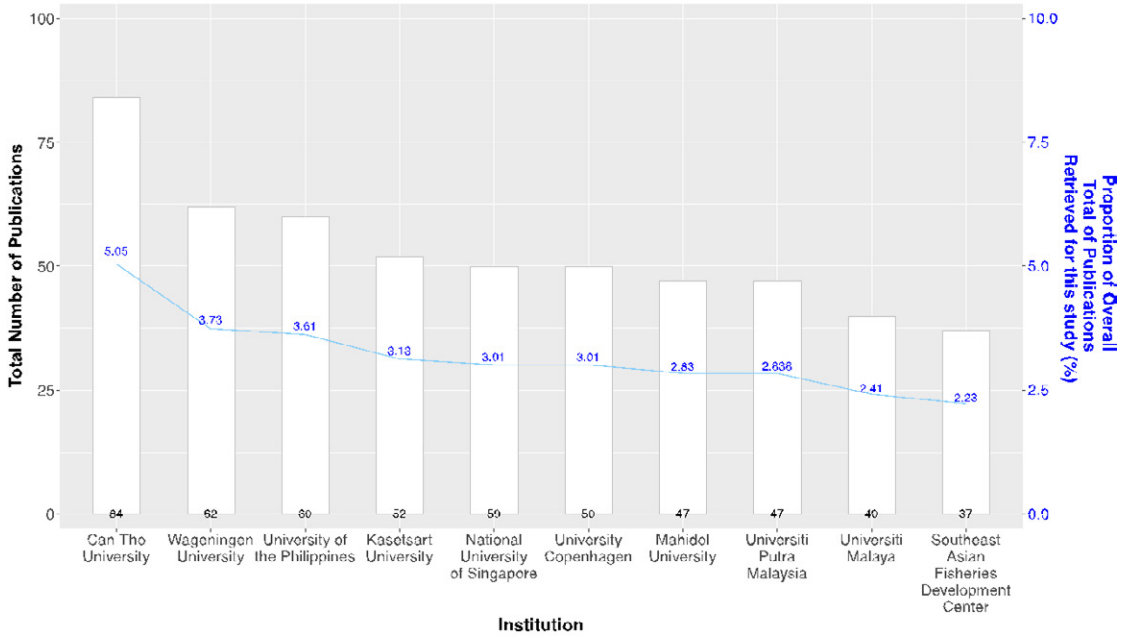

Fig. 2 Top ten institutions that had published substantial research articles focusing on aquaculture

Asian Fisheries Development Centre (2.23%) (Fig. 2).

Productive journal

A total of 250 journals had published articles which focused on aquaculture research in Southeast Asia with the Top 10 most productive journals is shown in Fig. 3. The journal of (i) Aquaculture (150 publication (9.15% from overall publications)), (ii) Aquaculture Research (66 publication; 4.09%), (iii) Ocean Coastal Management (36 publications;2.7%), (iv) Marine Pollution Bulletin (32 publications; 1.83%), (v) Journal of Applied Phycology (31 publications; 1.3%), (vi) Aquaculture International (25 publications; 1.3%), (vii) Fisheries Science (21 publications; 1.26%), (viii) Diseases of Aquatic Organisms, (ix) Hydrobiologia and (x) Marine Policy (20 publication; 1.9%) is among the top ten journal within this research domains with at least a total of 20 article being published (Fig. 3(a)). Aquaculture journal from the Elsevier received the highest number of citations (3504 citations) followed by Aquaculture Research (1104 citations) and Ocean Coastal Management (1022 citations). The highest journal without self-citation is also Aquaculture with a total of 3220 citations (Fig. 3(b)). Although Aquaculture had the most highest number of publications and citations overall, the journal of Ocean Coastal Management is the journal received the highest citation per

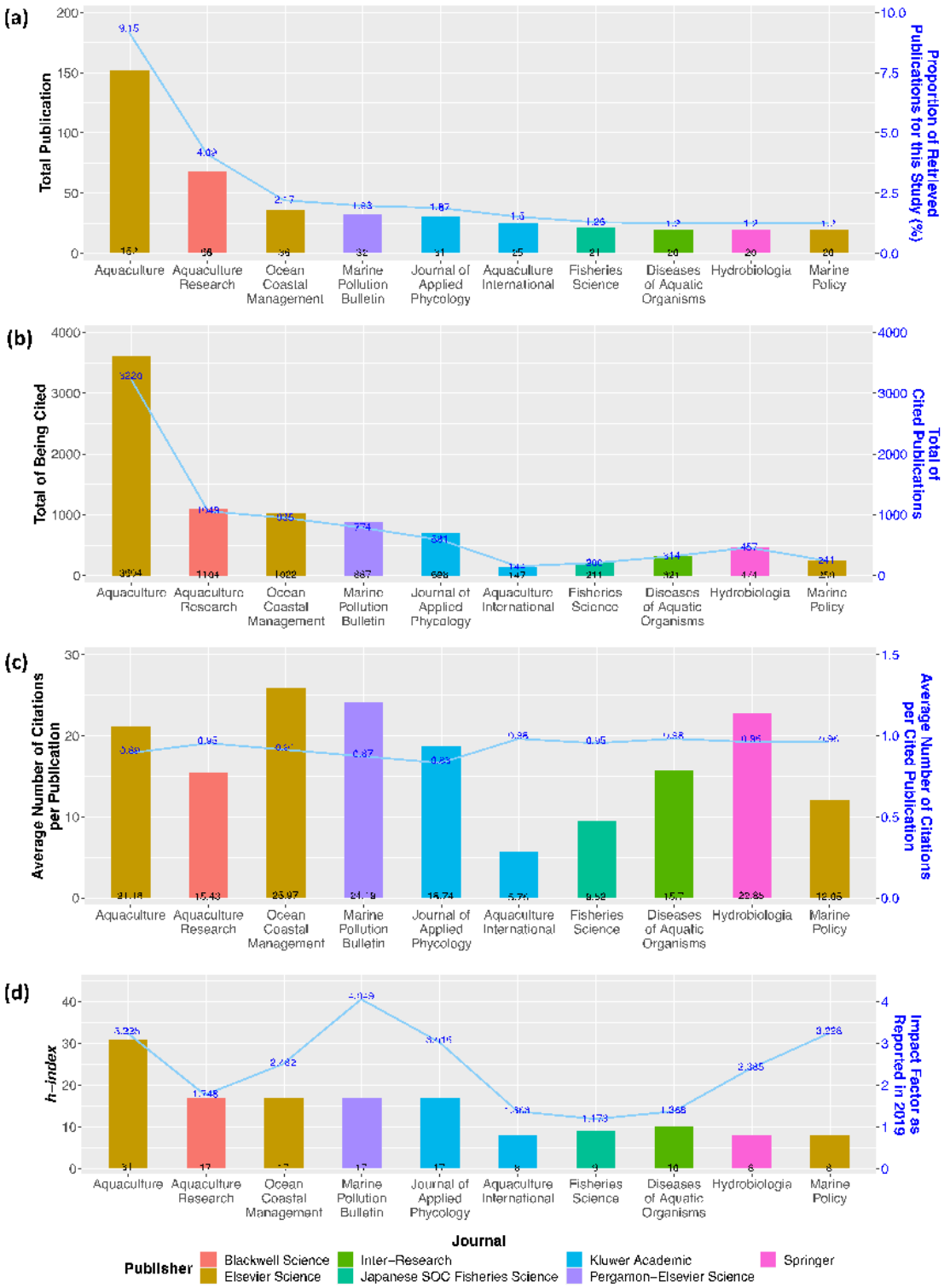

Fig. 3 Top ten productive journal

article (Fig. 3(c)), which may be explained by the journals' credibility as indicated by the high impact factor (Fig. 3(d)).

Productive author

The results showed that a total of 5202 authors have been published in the aquaculture field in Southeast

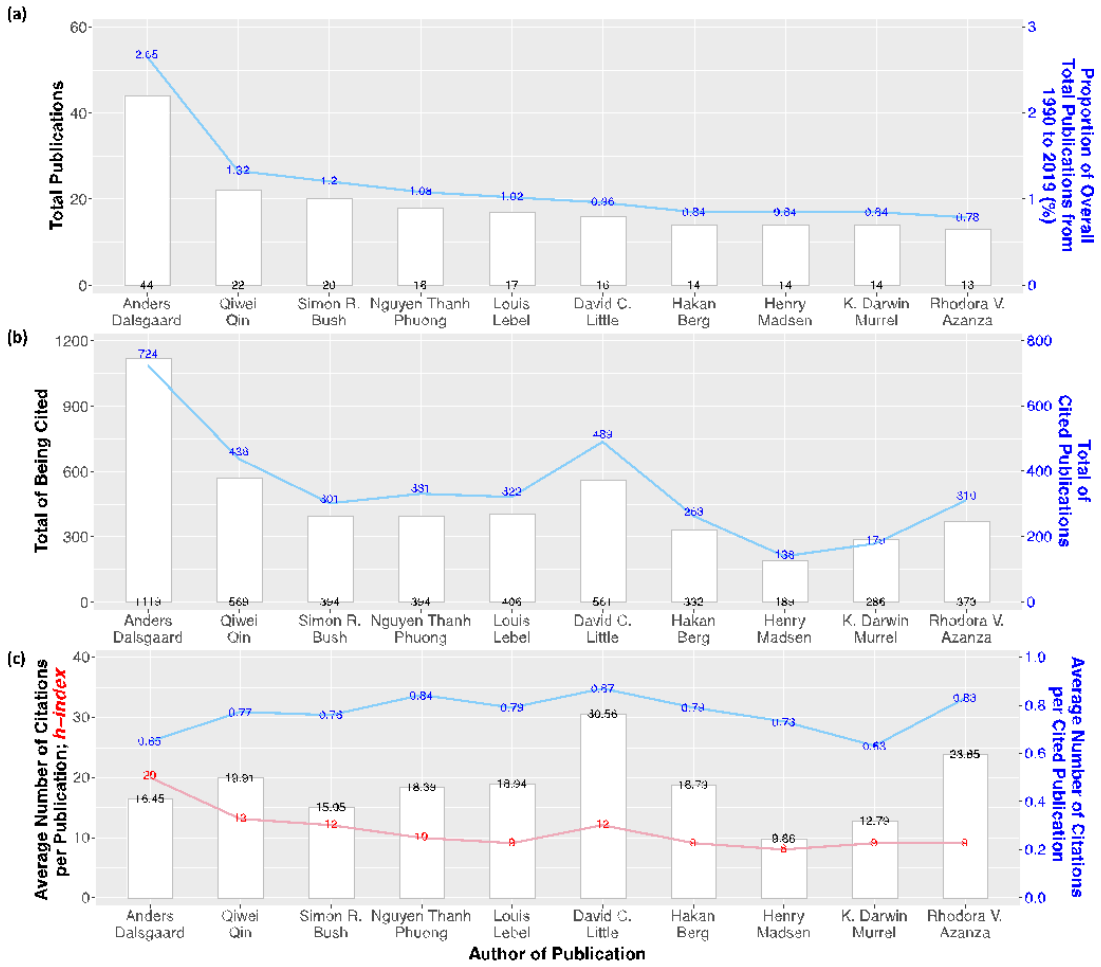

Fig. 4 Top ten most productive author

Asia, with only an active of 1684 authors have published more than one article in this research area. Authors such as Anders Dalsgaard (44 publications; 2.65%) Qiwei Qin (22 publications; 1.32%), Simon R. Bush (20 publications; 1.2%), Nguyen Thanh Phuong (18 publications; 1.08%), Louis Lebel (17 publications; 1.02%), David C. Little (17 publications; 0.96%), Haken Berg; Henry Madsen; K. Darwin Murrel (14 publications; 0.84%) and Rhodora V. Azanza (13 publications; 0.78%) is the top 10 authors from this area (Fig. 4). The author with the highest article about Southeast Asia's aquaculture was Anders Dalsgaard with a total of 44 articles, however the author's affiliation was not among the Southeast Asia countries (Fig. 4(a)). Although Anders Dalsgaard had the highest number of total publications and being cited (Fig. 4 (a) (b)), David C. Little had the highest average number of citations per publication and average number of citations per cited publication (Fig. 4(c)). An author's number of publications and citations are an indication of experts in each field as well as the visibility of their research output (Chen 2016; Castillo-Vergara et al. 2018; Wang et al. 2018).

Influential paper

The top three articles with highest number of total citations were Keiser and Utzinger (2005); Moriarty (1998); Richards and Friess (2016), though the top three articles with the highest average number of citations per year were published Richards and Friess (2016), Barange et al. (2014); Sadovy de Mitcheson et al. (2013) (Fig. 5).

Article citation is an indicator that shows the impact of a study in its research field. Based on previous studies, the direction of one research field is associated with its frequently cited articles (Chen et al. 2010; Chen et al. 2020).

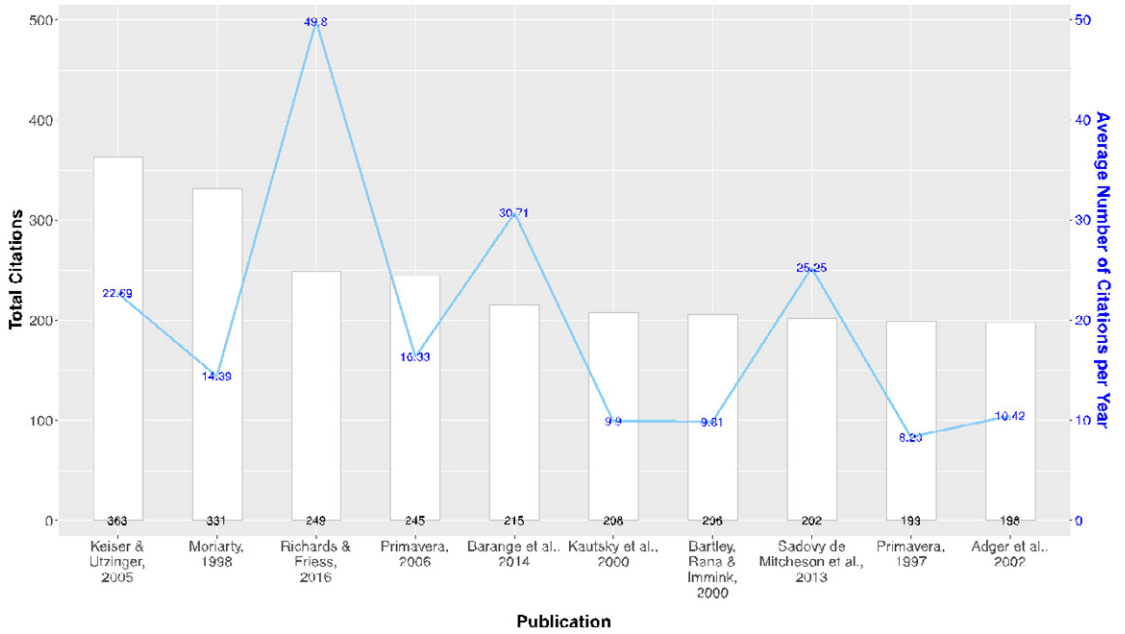

Fig. 5 Top ten most influential papers

Keiser and Utzinger (2005), studied the relationship between diseases caused by trematodes and proximity of human habitation. They found that the growth of the aquaculture industry may be the most important factor for the emergence of foodborne trematodiasis. Moriarty (1998), compared the prawn farm that used selected strains of *Bacillus* as probiotic bacteria and farms that did not use it. Both farms contained luminous *Vibrio* strains in its water. The results show that farms that used *Bacillus* as probiotic bacteria were culturing without problem while farms that did not use it experienced almost complete failure.

Richards and Friess (2016), quantifies the drivers of mangrove deforestation across Southeast Asia between 2000 and 2012. The result showed that aquaculture was the major driver of the loss, but its dominance was lower than what popular development narrative reports. Articles by Richards and Friess (2016), is also the article with highest citations per year. The second highest citation per year is Barange et al. (2014) and Sadovy de Mitcheson et al. (2013), which is the third highest current article that might not get a high number of citations but more on citation per year. Barange et al. (2014), found that with ongoing technological development in the aquaculture industry, the global fish demands in 2050 could be met thus challenging the prediction of inevitable shortfalls in fish supply by the mid-twenty-first century. Sadovy de Mitcheson et al. (2013), study groups and identify its major threats and mitigation taken by stakeholders. They found that if the current trend continues, grouper might face extinction and aquaculture might increase the fish production. However, as most operations of aquaculture depend on wild-caught juveniles, better management and conservation effort are needed.

Dual-Map overlay

Based on the generated dual-map overlay, aquaculture research in Southeast Asia was not only divided in many disciplines or research areas but also derived from various disciplines or research areas (Fig. 6). This suggested that this research topic was shifting towards more multidisciplinary and cross-disciplinary. In the citing site of the map, “Ecology, Earth, Marine” discipline was considered as prevailing for aquaculture research in Southeast Asia based on its thickness. Aquaculture journal was considered as the most prevailing journal focusing on this discipline with 152 publications. The discipline “Veterinary, Animal, Science” was also a prevailing area for the research topic with Marine Pollution Bulletin and Science of the Total Environment contributing the most to the discipline development. In the cited part of the map, “Plant, Ecology, Zoology” discipline was an important knowledge base or knowledge source, where Aquaculture Research journal had published 722 publications in this discipline and had been highly cited by related

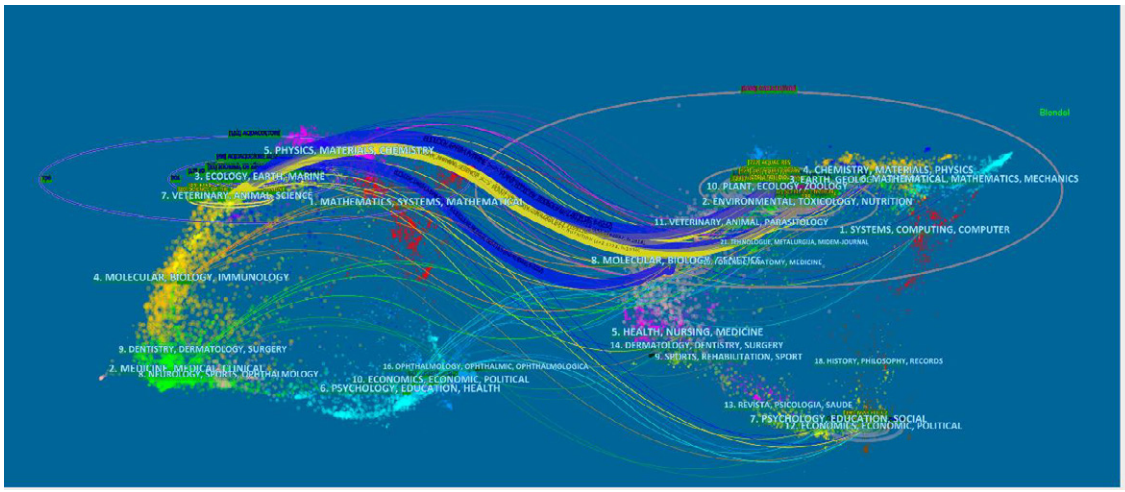

Fig. 6 Dual-map overlay on aquaculture research in Southeast Asia

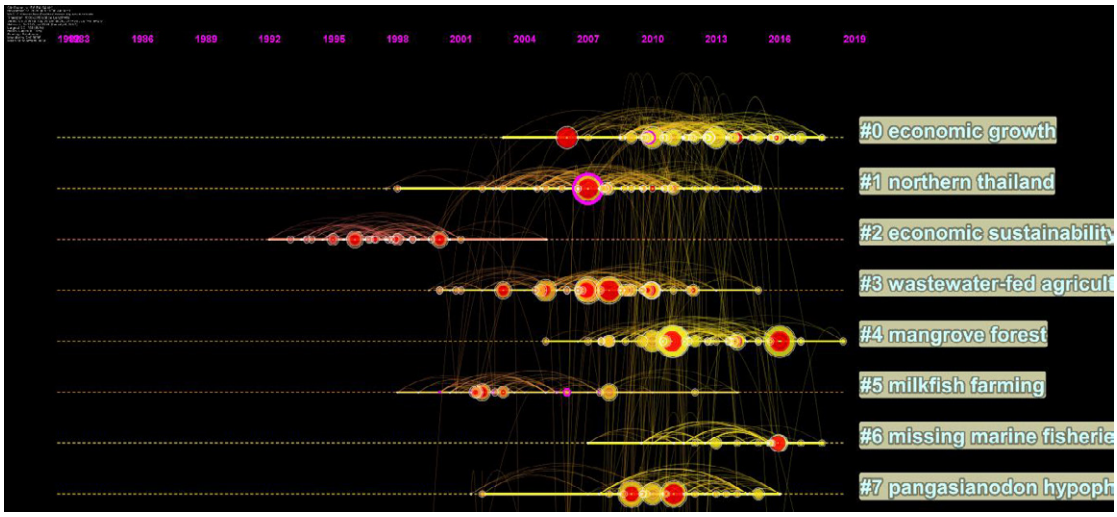

Fig. 7 Timeline view of the document co-citation network

frontier research on aquaculture research in Southeast Asia.

To determine the link research field focusing on aquaculture research in Southeast Asia had with each other, a dual-map overlay was generated (Fig. 6). The Figure represented the z-score function and the higher significance of the connections citing journal and cited journal was represented by thicker connecting lines. The citing journals were on the left, whereas the cited journals were on the right, while the citation links indicated which journal the citing journals were cited from. The citing journals were the most active journals in publishing studies of aquaculture research in Southeast Asia. Meanwhile, cited journals represent journals that provide research support in this area. The trajectory of the citation links provides an understanding of multi-disciplinary relationships.

Document co-citation analysis (DCA)

The modularity Q index and mean silhouette metric for DCA network were 0.9095 and 0.4068. The high modularity indicated that the clustering results of the network spectrum were excellent with a total of 20 co-citation clusters emerging from the analysis. Fig. 7 showed the timeline view of the DCA network and Fig. 8 showed the cluster view of DCA.

Fig. 7 shown the majority of highly centralise articles (red circle) is located at cluster #2 and cluster #3. Each cluster shown high connectivity, however cluster #2 seems to have peaked in 1992 and ended in 2001. Details of each cluster are explained at Table 2.

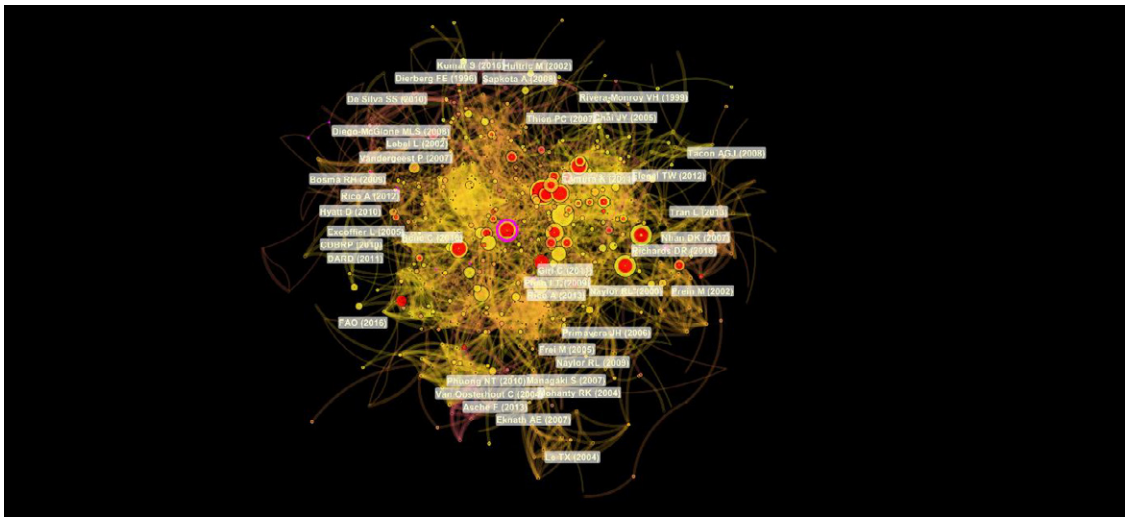

Fig. 8 Cluster view of document co-citation network

Table 2 Top six cluster and publications

Cluster ID	Size	Silhouette	Mean Year	Cluster Label	Most influential (centrality > 0.1)	Scientific novelty (sigma > 1)
0	103	0.649	2012	Economic Growth	(Bostock et al. 2010)	(Ottinger et al. 2016; Primavera 2006; Duncan et al. 2016)
1	81	0.845	2007	Northern Thailand	(Vandergeest 2007)	(Vandergeest 2007; Gräslund et al. 2003)
2	69	0.988	1997	Economic Sustainability	None	(Dierberg and Kiattisimkul 1996; Naylor et al. 2000; Sathirathai and Barbier 2001)
3	68	0.966	2007	Wastewater-Fed Agriculture	None	(van De et al. 2014; Chai et al. 2005; Thien et al. 2007)
4	65	0.944	2012	Mangrove Forest	None	(Donato et al. 2011)
5	51	0.932	2004	Milkfish Farming	None	(Holmer et al. 2003; Holmer et al. 2002)

The network contained 1,143 nodes and 3,334 links. Each node represents a publication with the first author's name and the publication year. The links between nodes represent co-citation relations between two documents. The label font size is proportional to the co-citations of a document. The cluster labels were turned off for clarity and the node documents with at least five co-citations are displayed in Fig. 8.

The top three co-cited articles were published by Giri et al. (2011), Richards and Friess (2016) and Phan et al. (2009). Giri et al. (2011), determine the status of mangrove forest using earth observation satellite data. Richards and Friess (2016), focus on the driver of mangrove deforestation and Phan et al. (2009), study the aquaculture of catfish. The cluster were numbered and ranked in terms of its size starting with #0 being the largest cluster. The size of the circle reflected the magnitude of the publication's influence where a larger circle equal to high publication. The burstiness of one publication was indicated by the red tree rings while the outer purple rings indicate high centrality, which is an index to measure strategic positions and ability to connect different publications in the DCA network. The length of each line represents the lifetime of the cluster.

A total of 20 co-citation clusters of research emerged in the cluster analysis (Fig. 8), where each cluster represented a research topic of aquaculture in Southeast Asia. The size of a cluster equals the number of publications it has. The top six clusters with more than 20 publications were presented in Table 2. The six clusters have high silhouette scores ranging from 0.649 to 0.988, which indicates a good homogeneity of publications within each cluster.

These clusters were given names according to four methods: (i) Latent Semantic Indexing (LSI), Term Frequency * Inverted Document Frequency (TF*IDF), loglikelihood ratio (LLR), and, Mutual Information (MI). Based on study by Chen et al. (2000), this paper reports the cluster based on loglikelihood ratio (LLR) as the outputs of each method were not always sensical. Each cluster's most influential and scientific

novelty is shown. A short review of each cluster is done based on the most influential. The most influential publication is based on its centrality scores, where a value more than 0.1 indicates a central publication. Sigma scores show the novelty of a publication, where a high value sigma indicates a high novelty of publications.

Cluster #0 "Economic Growth" was the largest cluster and had 103 publications which were clustered, thus representing a co-citation relationship. Within this cluster, Bostock et al. (2010), was the only study with centrality value higher than 0.1. This study discusses the future of the aquaculture industry and its current key features and trends. There were three publications with sigma score more than 1 in this cluster; (i) Primavera (2006), (ii) Ottinger et al. (2016), and (iii) Duncan et al. (2016).

Primavera (2006), recommends an approach to mitigate the negative aspect of aquaculture in coastal areas. The study acknowledges the positive socio-economic impact of aquaculture in terms of employment, income and foreign exchange, but emphasises on the negative impact such as privatisation, loss of fisheries livelihoods and urban migration. The mitigation recommended is Integrated Coastal Zone Management based on stakeholder needs that act as mechanisms for conflict resolution, capacity building and rehabilitation. Ottinger et al. (2016), review the relevance, current status and distribution of aquaculture in global and regional scales. The article focuses on satellite remote sensing studies and it's used as a site monitoring method for better aquaculture management. Duncan et al. (2016), study the potential of abandoned aquaculture sites to turn to rehabilitation sites for mangrove. They find that in the Philippines, 96.7% of aquaculture ponds have high potential for effective greenbelt rehabilitation for reversion.

Cluster #1 was labelled "Northern Thailand" and had 81 publications. The most influential publication was Vandergeest (2007), which is also one of the two scientifically novel publications in this cluster. Vandergeest (2007), a study in Thailand found that local communities and local governments are the most effective regulators of shrimp aquaculture. The certification networks can be more effective if it borrowed the approaches from Community Based Natural Resource Management as it can be more open and flexible to be adapted by local communities. There are two articles with sigma >1 in this cluster which were Vandergesst (2007), and Gräslund et al. (2003). Gräslund et al. (2003), study the use of chemicals and biological products in marine and brackish water shrimp farming in Thailand. They found that many of the chemicals used could have negative effects on the ecosystems, food safety and occupational health. Based on their results, it shows that aquaculture farmers lack information regarding the chemical and the instructions of uses.

Cluster #3 "Economic Sustainability" had 69 publications, though there was no publication determined as influential (centrality score > 1) in this cluster. However, three publications had scientific novelty (sigma score > 1). Publications with sigma score > 1 were Dierberg and Kiattisimkul (1996), Naylor et al. (2000), and Sathirathai and Barbier (2001). Dierberg and Kiattisimkul (1996), discuss the importance of integrated aquaculture management based on the overexploitation of shrimp aquaculture industry in Thailand. Thailand is the biggest shrimp producer in the world, however without balanced policy and continued negative publicity it might bring negative impact toward the industry sustainability.

Naylor et al. (2000), paper also discusses the sustainability of the aquaculture industry focusing on shrimp for the long run. The paper argues that even though aquaculture relieves pressure faced by ocean fisheries, it still impacts it by requiring large input of wild fish for feed. Aquaculture industry must reduce the wild fish inputs in feed and adopt sustainable management practises. Sathirathai and Barbier (2001), calculate the economic value of mangrove forest conversion to shrimp aquaculture. The results state the economic value is lean more toward private benefits and not much on local communities. As the private sector gains income, locals might face externality in terms of mangrove destruction and water pollution.

Cluster #3 "Wastewater-Fed Agriculture" had 68 publications and 3 scientific novelty publications. The scientific publications (sigma > 1) were (i) Van De et al. (2014), (ii) Chai, Murrell and Lymbery (2005) and (iii) Thien et al. (2007). Van De et al. (2014), is doing a review on cysticercosis in Vietnam. This disease has become a serious health problem in Vietnam. Author suggests a national surveillance program in order to mitigate these issues. Chai et al. (2005) review the fish-borne parasitic zoonoses issues in low- and middle-income countries. Thien et al. (2007), also focuses on fishborne disease mainly on fishborne zoonotic trematodes (FZT) in Mekong Delta, Vietnam. They examined two types of fish aquaculture (poly culture

Table 3 Top ten references with strongest citation burst

References	Strength	Begin	End	1990 - 2019
(Richards and Friess 2016)	11.39	2017	2019	
(Naylor et al. 2000)	9.93	2002	2007	
(Dierberg and Kiattisimkul 1996)	8.81	2000	2004	
(FAO 2016)	7.41	2017	2019	
(Lebel et al. 2002)	7.12	2006	2010	
(Donato et al. 2011)	6.91	2015	2019	
(Dung et al. 2010)	6.79	2012	2015	
(Nhan et al. 2007)	6.56	2008	2012	
(Van Phan et al. 2010)	6.33	2012	2015	
(Chai et al. 2005)	6.27	2009	2013	

Table 4 Top ten keyword with strongest citation burst

Keywords	Strength	Begin	End	1990 - 2019
Climate Change	11.00	2017	2019	
Mangrove	10.24	2000	2005	
Thailand	9.74	1996	2004	
Ecology	7.65	1995	2010	
Livelihood	7.09	2017	2019	
Prevalence	5.80	2009	2015	
Growth	5.61	1996	2001	
Shrimp	5.29	2003	2004	
Adaptation	5.25	2015	2016	
Ecosystem Service	4.90	2016	2019	

and vegetable-aquaculture-animal husbandry farming) and its prevalence to FZT. The result shows no FZT were found in poly culture but a high prevalence infection in the other type of farming.

Cluster #4 “Mangrove Forest” had 65 publications. It has only one scientific novelty publication and no influential publications. The scientific novelty publication by Donato et al. (2011), discusses the importance of mangrove and the challenges and barriers faced to sustain the ecosystems. The last cluster with more than 20 publications was cluster #5 “Milkfish Farming”. The cluster had 51 publications and 2 scientific novelty publications by Holmer et al. (2003) and Holmer et al. (2002). Holmer et al. (2003), measured the sedimentation and sediment metabolism in milkfish farms in the Philippines to see the interactions between sediment and water in the coastal zone. They find that the sediment metabolism is significantly reduced after the site being abandoned by the sediment biogeochemical condition remains unaffected. Holmer et al. (2003), also measures the sediment-water interface in milkfish farms in the Philippines coastal zone. Their result suggests that milkfish farm practice in the Philippines leads to greater impact on benthic carbon and nutrient cycling than those doing suspended cage cultures.

Document citation burst

Citation bursts were detected in 52 publications and the top 10 publications with highest strength are shown in Table 2. The strongest burst strength was by Richards and Friess (2016), (strength= 11.3883, 2017-2019), which identified aquaculture as a major driver of mangrove deforestation, but its dominance was not severe as expected. The second highest bursting strength was Naylor et al. (2000), (Table 3) which focused on the positive and negative traits of marine aquaculture. They found that to sustain the growth of this industry, producer must reduce wild fish inputs in feed and adopt more ecologically management practices. The third burst was Dierbeg and Kiattisimkul (1996), (strength = 8.8138, 2000 – 2004) that reported the issues, challenges, barriers and opportunity of shrimp aquaculture in Thailand.

Keyword citation burst

Burst keywords can reflect the emergence of certain keywords in a short time. It can be used as a way to detect emerging trends and hotspots. The Modularity Q score is 0.4684 and the mean silhouette is 0.652, which suggests that network boundaries were not clear, but the heterogeneity is respectable. A total of 42 burst items were identified where a blue line depicted the time interval (1990 – 2019) and the burst period is depicted as a red line.

Keyword with largest magnitude was "climate change" (strength = 10.9997), with a burst span of 2 years (Table 4). Next keyword was "mangrove" (strength = 10.2399, 2000 – 2005) and followed by "Thailand" (strength 9.7367, 1996 – 2004). The longest burst span of 15 years was "ecology" (strength = 7.6451, 1995 – 2010). Based on the findings, the environment associated keywords (climate change, mangrove, ecology and ecosystem services) appeared to be prevailing, suggesting that the researchers focused on the impact of aquaculture on the environment. Nevertheless, the concentration of these keywords also suggested that the aquaculture research in Southeast Asia was not extensively done beyond the environmental aspect, but this hypothesis remained to be examined.

Limitations

There were several limitations of this study. Firstly, this study only used WoS database as source of publications which could have led to exclusion of other relevant studies that were not registered in WoS. Nevertheless, WoS had been recommended for and had been extensively employed in such scientometric studies as it covers hard science and social sciences compared to other available databases (Bar-Ilan 2008; Adriaanse and Rensleigh 2013; Chen et al. 2010; Chen 2014; Chen and Leydesdorff 2014). Future work could compare other databases such as Scopus, PubMed and EmBase with WoS to examine potential discrepancies in the data available.

Secondly, the data here were automatically retrieved using CiteSpace via WoS, without manual inspection. As a result, the data may have been subjected to inclusion of irrelevant subjects or articles by chance, though the decision to balance the stringent criteria and over-excluding certain studies remains a challenge. Using more stringent keyword searches, however, may reduce the likelihood of including irrelevant studies in the search. Also consider the use of wildcard "?" to account for different spelling and Boolean operators "AND" to account for both keywords in search strings to prevent exclusion of relevant articles.

Lastly, only the principal (first) authors were considered in the co-citation analyses in this study. Information of cited publications retrieved from WoS did not include the other contributing authors, though citing publications did not possess such restriction. Including the co-authors in the co-citation analyses may yield different results, hence providing further insights.

Implications for future research

According to the analysis, the socio-economic and environmental issues have the highest focus on research within these areas. However, most of the study is in silo and the cross disciplinary research between economic, environment and social are low. There is an urgency for researchers to develop a strategy toward improving economic sustainability and environmental resilience against this industry.

It is recommended that researchers focus on issues such as protecting both economic and environmental sustainability such as improving the resilience of aquaculture species and improving its health in Southeast Asia. One of the most popular mitigation solutions for big farmers is to produce in large areas and how to control the catch and size of aquaculture activities.

Researcher also need to focus on current engineering technology capacity and capability that might increase the use of advanced equipment and integrated approaches, such as the implementation of precision farmers, to reduce reliance on middle supply chain and focus on bottom-up policy prevention, which increases aquaculture species diversity, high added value species, and survival rate.

Future research or analysis can also focus on the topic of climate change's impact on the aquaculture industry in Southeast Asia as this topic has not enough literature and specific knowledge gaps. Research and

development on the ecosystems and fisheries for fish and shellfish species that are less sensitive to climate change, as well as assisting aquaculture ecosystems in preparing for change and becoming more resilient to the effects of climate change, are strongly encouraged.

As this scientometric analysis focuses more on overall aquaculture industry and activities, the future research can further this topic by focusing on some of the main species or groups in the aquaculture industry. This gap of study found in the analysis can help researchers develop their own topic and interest regarding these areas of study.

Conclusions

Here, the research of aquaculture in Southeast Asia from 1990 to 2019 was synthesised, revealing the research landscape of aquaculture in Southeast Asia in terms of the year, journals, co-cited journals, authors, countries, institutions, keywords, and references. Vietnam had produced the highest number of publications, of which mainly contributed by Can Tho University. Since 2005, there has been an increasing trend of aquaculture research in this region as supported by the increasing number of publications and citations. Based on the scientometric analysis, the aquaculture research in this region mostly fell under "Ecology, Earth, Marine" discipline, focusing on the impact of aquaculture on environment and food security. Nevertheless, the overall research of aquaculture in Southeast Asia appears to be shifting towards cross- and multi-disciplinary as suggested by the emerging research clusters and is expected to continuously diversify.

Acknowledgement This research has received funding in part from Internal State Funder grant (Dana Lestari Khas) via Universiti Teknologi Mara (UiTM) Pahang. A special thank you to everyone in UiTM Raub, Pahang for their generous support throughout the article write up.

Funding declaration This research has received funding in part from Internal State Funder grant (Dana Lestari Khas) Universiti Teknologi Mara (UiTM) Pahang.

Conflicts of Interest/ Competing Interests The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Authors' contributions Conceptualization, M.N.A, M.I. and A.M.A.; methodology, M.I, A.M.A and V.L; software, M.I, A.M.A and V.L.; validation, M.I, A.M.A, V.L, A.A.Z, F.D, I.M.H and H.C.H; formal analysis, M.I, A.M.A and V.L.; resources, M.I.; data curation, M.I,A.M.A.; writing—original draft preparation, M.N.A., M.I, A.M.A.; writing—review and editing, M.I, M.F.A, A.M.A, V.L, A.A.Z, F.D, I.M.H and H.C.H.; visualization, M.I, A.M.A and V.L.; supervision, M.I.; project administration, M.I.; funding acquisition, M.I.".

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