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Mapping the global network of fisheries science collaboration

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Abstract

As socio-environmental problems have proliferated over the past decades, one narrative which has captured the attention of policymakers and scientists has been the need for collaborative research that spans traditional boundaries. Collaboration, it is argued, is imperative for solving these problems. Understanding how collaboration is occurring in practice is important, however, and may help explain the idea space across a field. In an effort to make sense of the shape of fisheries science, here we construct a co-authorship network of the field, from a data set comprising 73,240 scientific articles, drawn from 50 journals and published between 2000 and 2017. Using a combination of social network analysis and machine learning, the work first maps the global structure of scientific collaboration amongst fisheries scientists at the author, country and institutional levels. Second, it uncovers the hidden subgroups—here country clusters and communities of authors—within the network, detailing also the topical focus, publication outlets and relative impact of the largest fisheries science communities. We find that whilst the fisheries science network is becoming more geographically extensive, it is simultaneously becoming more intensive. The uncovered network exhibits characteristics suggestive of a thin style of collaboration, and groupings that are more regional than they are global. Although likely shaped by an array of overlapping micro- and macro-level factors, the analysis reveals a number of political–economic patterns that merit reflection by both fisheries scientists and policymakers.

KEYWORDS
communities, fisheries science, machine learning, social network analysis, sociology of science, topic modelling

1 | INTRODUCTION

Over the past number of decades, as socio-environmental crises have multiplied, the question of research collaboration has captured the attention of policymakers and scientists alike (Katz & Martin, 1997), with calls for "intensive cooperation" and a widening of perspectives becoming commonplace (Palsson et al., 2013, p. 4). The underlying assumption driving these calls is that solutions to the complex—social, ecological and socio-ecological—problems facing humanity today are in many instances not going to be found within the confines of traditional disciplinary, thematic, sectoral or territorial boundaries (European Commission, 2008). In this respect,

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fisheries have not been an exception. Amidst ongoing dissatisfaction with the outcomes of traditional fisheries science and management—for example, in terms of the increasingly precarious status of fish stocks and the communities that depend upon them (Symes, Phillipson, & Salmi, 2015)—policymakers and scientists have shifted their gaze to the production of knowledge within this space, and actively sought to broaden collaborative efforts in this area (European Commission, 2008, 2016; IOC-UNESCO, 2017; Rozwadowski, 2002; Smith & Link, 2005; Symes & Hoefnagel, 2010).

It is unsurprising then, if not entirely consequential, that research collaboration has increased exponentially over the past decades (Wuchty, Jones, & Uzzi, 2007). Further, given the significant amount of empirical research suggesting that social relationships and the networks these relationships constitute are important in explaining processes of knowledge production (Bourdieu, 1975, 1991; Forsyth, 2003; Granovetter, 1983; Law, 1987; Moody, 2004; Phelps, Heidl, & Wadhwa, 2012; Schott, 1991, 1993), it is of no surprise that this shifting character of science (Adams, 2013) has drawn the attention of scholars. Patterns of co-authorship amongst scientists—long recognised as providing a window into collaboration within the academic community (Newman, 2004)—have proven a particularly fruitful line of inquiry in this respect (Adams, 2012, 2013; Azoulay, Zivin, & Wang, 2010; Ding, 2011; Katz, 1994; Katz & Martin, 1997; Leydesdorff & Wagner, 2008; Liu & Xia, 2015; Martin, Ball, Karrer, & Newman, 2013; Newman, 2001; Wagner, Bornmann, & Leydesdorff, 2015). Regarding the field of fisheries, however, whilst scholars have directed their attention towards characterising the direction and content of fisheries science publications (Aksnes & Browman, 2016; Jarić, Cvijanović, Knežević-Jarić, & Lenhardt, 2012; Natale, Fiore, & Hofherr, 2012; Nikolic et al., 2011; Syed, Borit, & Spruit, 2018; Syed & Weber, 2018), and studies have highlighted that collaboration is increasing within this space (Jarić et al., 2012), we know comparatively little about the structure these collaborations are taking. The small body of work that has analysed co-authorship networks in fisheries science has been narrowly confined in terms of time span and journal inclusion (Elango & Rajendran, 2012), or a particular type of fishing (Oliveira Júnior et al., 2016).

Given the applied nature of fisheries science, with science playing a critical role in informing fisheries management decisions (Campling, Havice, & McCall Howard, 2012), and hence having practical consequences for fish and people, understanding how knowledge is produced in this area is especially pertinent. Thus, with an eye to making sense of the shape of fisheries science, here we take scientific collaboration, measured as co-authorship amongst scientists in this field, as our analytical vantage point. Using a combination of social network analysis and topic modelling (a variant of unsupervised machine learning), alongside theoretical insights from the sociology of science, we map the co-authorship network that characterises this applied domain, and investigate the collaborative entanglements within this space. In doing so, we pose questions with respect to how patterns of collaboration differ between subjects and how these have changed over time (Newman, 2004). Our analysis provides a dynamic portrait (Newman, 2004) of the fisheries science community and an avenue through which the social dynamics underpinning fisheries science collaborations and consequently the production of knowledge within this space may be explored (Bourdieu, 1975; Ding, 2011; Forsyth, 2003; Latour, 1993; Liu & Xia, 2015; Martin et al., 2013).

Our study builds upon the important groundwork that has been laid out by previous scholars within this domain (Aksnes & Browman, 2016; Elango & Rajendran, 2012; Jarić et al., 2012; Natale et al., 2012; Nikolic et al., 2011; Oliveira Júnior et al., 2016; Syed et al., 2018) in a number of ways. First, by focusing our attention on the networks of production, we expand upon existing analysis that has focused on the content of fisheries science (Aksnes & Browman, 2016; Jarić et al., 2012; Natale et al., 2012;

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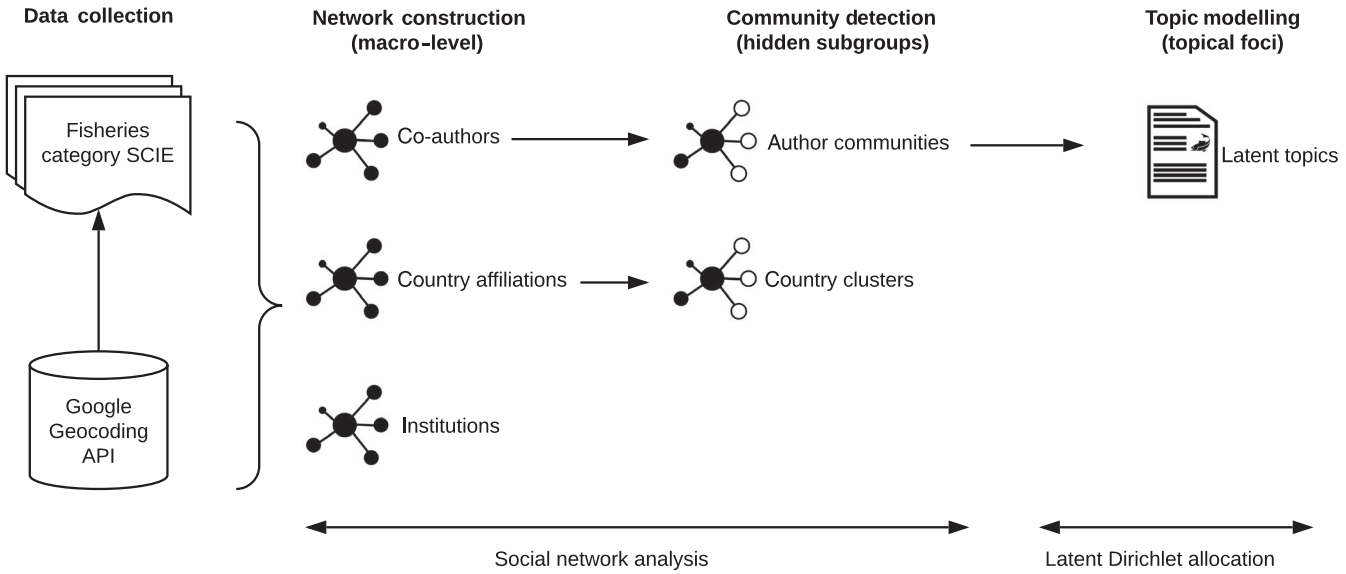

FIGURE 1 Schematic overview of employed analyses and used methods

Nikolic et al., 2011; Syed et al., 2018), by characterising the structure of the community of scientists that produce that output, in a manner that may help us understand its content (Bourdieu, 1975; Forsyth, 2003). Second, as detailed, the work that has previously taken a network approach to the production of fisheries-related knowledge (Elango & Rajendran, 2012; Oliveira Júnior et al., 2016), though illuminating, has been hitherto narrowly bounded either by time or specific knowledge communities. Here, our analysis is based upon an extensive data set of fisheries publications, which has been cited elsewhere as containing the core journals within the field (Aksnes & Browman, 2016). Consequently, the network we construct is expansive and traverses a broad spectrum of fisheries-related research relating to both capture and culture fisheries. This large network is subsequently analysed at progressively finer levels of granularity (Ding, 2011), across a number of different planes (e.g., spatial, temporal, topical), in a manner which broadens the bounds of the analysis and provides for a multidimensional overview of the field.

2 | MATERIALS AND METHODS

We examined our data set at two time intervals: 2000–2008 and 2009–2017. Figure 1 provides a schematic overview of the method process employed—the steps of which are explicated in more detail in the following sections.

2.1 | Data collection

With respect to the data set, fisheries science publications were selected based on the fisheries category as defined by the Science Citation Index Expanded (SCIE). This category spans a list of 50 journals covering all aspects of fisheries science, technology and industry. All 50 journals (Appendix 1) were included, and all articles published between 2000 and 2017 were selected. The Scopus developer API was subsequently utilised to extract article data such as abstracts, authors and affiliations. Specifically, the Scopus Abstract Retrieval API provides all (meta-) data associated with a particular article. The Scopus unique identifier for authors and affiliations was used to disambiguate authors and affiliations with identical names, and to merge the same author with different names. For affiliations without an affiliation ID, a surrogate key was constructed by concatenating all parts of the affiliation address. A filtering process was used to exclude non-English articles and those that did not constitute a research article (such as errata and comments) or contained no abstract. A total of 73,240 articles were deemed fit for further analysis, with a total of 106,137 authors and 100,175 affiliations. To obtain geographical coordinates (latitude–longitude) for affiliation addresses, the Google Geocoding API was used to enrich the data obtained from the Scopus developer API.

2.2 | Network construction

Following on from this, the co-author network was constructed by linking two authors (called nodes) on the basis of co-authorship (called edges). The frequency of collaborations between two authors defined the weight of the edge spanning the two nodes. The created network can formally be defined as a weighted undirected graph. The network of country affiliations was constructed in a similar manner, with the frequency of collaborations defining the edges, and the nodes representing the country affiliation (encoded with their 3-letter ISO 3166 representation). Authors with multiple country affiliations were fractionally credited. Two country affiliation networks were constructed: (a) looking only at international collaborations and excluding domestic collaborations, and (b) a mixture of international and domestic collaborations. A similar approach was performed when creating the network of institutions, with the frequency of collaborations between institutions defining the weight of the edges, and the

nodes representing the institutions (disambiguated by the Scopus affiliation ID or a constructed surrogate key in the absence of a key).

2.3 | Community detection

Most real networks contain groups within which the nodes are more tightly connected to each other than the rest of the network, oftentimes referred to as clusters or communities (Palla, Derényi, Farkas, & Vicsek, 2005). These groupings might be connected in various ways (e.g., topic, location, history), with studies indicating that links are often homophilous (i.e., made with similar others; McPherson, Smith-Lovin, & Cook, 2001). Uncovering these a priori unknown groups (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008) allows for the identification of functional units within a system, alongside their structural properties (Newman, 2012), which can vary widely and may—with respect to our interests here—be consequential in terms of knowledge creation (Granovetter, 1973; Lambiotte & Panzarasa, 2009). Indeed, many of the most important characteristics of a network only become apparent when analysing the hidden subgroups within that network (Girvan & Newman, 2002; Newman, 2012). Thus, in an effort to get a more nuanced understanding of the network, utilising community detection techniques, we decomposed the network into country clusters and communities of authors.

2.4 | Community detection algorithm

To detect author community structures, we used the Louvain algorithm (Blondel et al., 2008) that partitions a network into smaller subnetworks (i.e., communities) by optimising the density of edges within each community compared to the density of edges amongst communities. The Louvain algorithm was extended with a time parameter to allow for community detection at various resolutions (Lambiotte, Delvenne, & Barahona, 2014). The inclusion of a time parameter increases community stability and aims to ameliorate community size bias (Fortunato & Barthelemy, 2007). In a comparative study (Lancichinetti & Fortunato, 2009), the Louvain community detection algorithm was found to have "excellent performance" on several classes of benchmark graphs (Girvan & Newman, 2002; Lancichinetti & Fortunato, 2009), although benchmark performance may not necessarily align with broader real-world situations (Newman, 2012). We performed a grid search (Figure S1) on the hyper-parameter (i.e., resolution) space and, due to the heuristic nature of the Louvain algorithm, conducted 10 different random initialisations for each grid search. In doing so, we aimed to find the hyper-parameters that resulted in communities with high modularity (Newman, 2003; Newman & Girvan, 2004), a measure that quantifies the quality of the detected communities. A similar process was performed to detect country clusters (Figures S2 and S3) [here we have chosen the term country clusters which is analogous to the term country community]. The inter-community collaboration was measured by the (weighted) edges traversing communities within an induced community graph, where communities are represented as nodes themselves.

Detecting communities in networks (e.g., social, biological, citation, metabolic networks) can generally be classified into discovering non-overlapping communities where each node belongs to a single community (Blondel et al., 2008; Clauset, Newman, & Moore, 2004; Decelle, Krzakala, Moore, & Zdeborová, 2011a, 2011b; Fortunato, 2010; Hofman & Wiggins, 2008; Newman & Girvan, 2004; Newman & Leicht, 2007; Nowicki & Snijders, 2001), or overlapping communities where nodes can belong to several communities (Ahn, Bagrow, & Lehmann, 2010; Airoldi, Blei, Fienberg, & Xing, 2008; Ball, Karrer, & Newman, 2011; Derényi, Palla, & Vicsek, 2005; Gopalan & Blei, 2013; Gregory, 2010; Lancichinetti, Radicchi, Ramasco, & Fortunato, 2011; Viamontes Esquivel & Rosvall, 2011). Increasingly, real-world networks can be characterised as overlapping (Palla et al., 2005), and the most general formulation of a community detection algorithm should ideally include both overlapping and non-overlapping communities (Ball et al., 2011). A major drawback, however, of overlapping community detection algorithms is that the number of communities within a network needs to be known in advance (Ball et al., 2011). Typically, this number is unknown, although recent studies have attempted to apply Bayesian inference and Monte Carlo methods to estimate this number (Newman & Reinert, 2016; Riolo, Cantwell, Reinert, & Newman, 2017). However, a successful application of such methods highly depends on the choice of an appropriate prior probability. Community detection algorithms based on modularity maximisation (a quality index for partitioning networks into communities) circumvent this drawback, but might result in a bias of the community sizes it uncovers (Ball et al., 2011; Bickel & Chen, 2009; Fortunato & Barthelemy, 2007). Typically, it fails to find very small communities. The Louvain algorithm (Blondel et al., 2008) used in this study uses such modularity maximisation, and the number of communities as well as the division into communities is performed automatically. However, the Louvain algorithm treats communities as disjoint (non-overlapping), forming a technical methodological limitation with respect to our study. Thus, explicitly identifying nodes that bridge communities could be an interesting direction for future research.

2.5 | Social network analysis

The constructed networks (i.e., both the macro-level and community-level networks) were subsequently analysed utilising social network analysis, which provides an array of statistics for doing so (Leydesdorff & Wagner, 2008; Newman, 2001). Here, for instance, we calculated the network density (i.e., the level of connectedness of the network), the degree (i.e., the average number of connections possessed by each node) and the average clustering (i.e., the extent to which a node's connections are also connected to one another) within the network. Additionally, seeking to identify central actors in the network (e.g., individuals, states or institutions that may be influential) and better characterise the uncovered author communities and country clusters, we calculated a variety of centrality measures. Such measures provide us with information relating to the quantity and quality of links a particular node has with respect to the other

TABLE 1 Description of the used social network analysis or graph theory metrics

Metric	Description
Density	The actual number of connections, divided by the total number of possible connections across the network
Degree	The average number of connections attached to each node
Weighted degree	The average number of connections attached to each node, accounting for the weight of each connection
Max cliques	The maximal complete subgraph of a given graph. In other words, the largest group of nodes where all the nodes are connected to one another
Average clustering	The extent to which the nodes connected to a particular node are also connected with each other
Degree centrality	Measures the number of links to other nodes a particular node has, thus allowing for the identification of central nodes within the network, in terms of the number of connections they have
Closeness centrality	Measures the distance of a node to all other nodes in the network, thus allowing for the identification of nodes that are most likely to receive information quickly in the network
Betweenness centrality	Measures the extent to which a particular node lies between the other nodes in the network, thus allowing for the identification of nodes that may otherwise look uninfluential, but that play important intermediary roles in the network in terms of information flow (e.g., brokers)
Eigenvector centrality	A centrality measure that has been adjusted on the assumption that the centrality of a node cannot be assessed in isolation from the centrality of all the other nodes to which it is connected, thus allowing for the identification of nodes that are well connected to others that are also well connected

nodes in the network, and therefore can be utilised to identify important nodes within the network (Bodin & Crona, 2009; Freeman, 1978; Newman, 2012). A full explication of the metrics we have calculated is provided in Table 1.

2.6 | Topic modelling

In order to gain a more substantive understanding of the manner in which the authors in the fisheries science network are grouping, we further uncovered the topical foci of the network, alongside the community-level and temporal variations therein. This involved coupling the social network analysis techniques we have been utilising thus far with topic modelling, thereby extending the inquiry beyond the spatial and temporal, and adding a topical dimension to the analysis. Topic modelling is a machine learning technique used to automatically (i.e., in an unsupervised manner) uncover what documents (e.g., publications) are about. In other words, what topics or themes are present within a single document, as well as a document collection (i.e., corpus).

Topic modelling typically uncovers latent or hidden topics, topics that are not explicitly stated within the documents. Such latent topics are described by groups of words that one would commonly use to describe something, and such words typically occur within the same linguistic context (DiMaggio, Nag, & Blei, 2013). More formally, the group of words tends to co-occur, and this phenomenon is rooted in the distributional hypothesis; namely, words with similar meaning tend to occur in similar contexts (Harris, 1954). For example, the words eggs, female, male, sex and larvae are words that can be found within the same linguistic context and can relate to the latent topic of reproduction. Topics are typically modelled as a probability distribution over words where the high probability words (i.e., the groups of words that co-occur) reveal the semantic meaning of the latent topic.

Topic modelling is able to capture those groups of co-occurring words, the topics, and can additionally quantify the prevalence of the topics as a proportion of the document. Thus, a document might be for 30% about reproduction and for 70% about other uncovered topics. This is the topic probability distribution that can be inferred for each document. Technically, a document has some proportion for each of the latent topics found within the corpus, albeit that only a handful of topics make up for the largest part of the document—following the assumption that documents can be heterogeneous, but typically not every topic is present within every document.

To uncover latent topics, the topic model method latent Dirichlet allocation (LDA) (Blei, 2012; Blei, Ng, & Jordan, 2003) was used. All pre-processing steps to suitably prepare documents for statistical topical inference (Hoffman, Blei, & Bach, 2010) are described in our previous work (Syed et al., 2018), which are highly optimised for the fisheries domain (Syed & Spruit, 2017, 2018a, 2018b). With LDA, the number of topics needs to be specified in advance, analogous to most unsupervised methods such as k-means clustering or Gaussian mixture models. To find the number of topics that best describes the document collection, we created LDA models by ranging the number of topics from 2 to 30. In addition, we created different LDA models by exploring the various LDA hyper-parameters. This approach can be seen as a grid-search approach on the parameter and hyper-parameter space of the LDA algorithm (Figure S4). The highest quality LDA model is determined by utilising a topic coherence measure (Röder, Both, & Hinneburg, 2015), which is a quality measure of a topic model from the perspective of human interpretability, which is considered a more adequate measure than computational metrics such as perplexity (Chang, Gerrish, Wang, & Blei, 2009). For example, a hypothetical latent topic described by the words blue, red and green can be considered more coherent than the latent topic with the words blue, red and car, under the assumption that the latent topic is colour.

For readability, topics were labelled by fisheries domain experts via close inspection of the topic's top words, whilst simultaneously inspecting the publication titles (Table S1), abstracts and a visual representation of the topic model through multidimensional scaling (Sievert & Shirley, 2014). To calculate the similarity between two topic distributions (or cumulative topic distributions), the Hellinger distance was used (Hellinger, 1909). The Hellinger distance is a symmetrical measure to quantify how similar or dissimilar two probability distributions are.

3 | RESULTS

The results of our investigation are presented in two parts. First, the macro-level structure of the global fisheries science network is detailed and mapped at the author, country and institutional levels. Second, moving to a more fine-grained level of analysis, the hidden (i.e., a priori unknown) collaborative groupings within the network—referred to as country clusters and communities of authors, within which the nodes (i.e., countries, authors) are more tightly connected to each other than to the rest of the network (Palla et al., 2005)—are specified.

3.1 | Topology of the co-authorship network

In line with broader trends (Adams, 2012, 2013; Leydesdorff, Wagner, Park, & Adams, 2013), and previous work regarding fisheries (Aksnes & Browman, 2016; Jarić et al., 2012), the fisheries science collaboration network is expanding rapidly (Figure 2). The number of authors (i.e., nodes) participating in the network has increased steadily, whilst the number of collaborative ties (i.e., edges) via publication has increased almost exponentially, with a rapid increase visible since 2015. This has been fuelled, at least in part, by the volumetric rise in fisheries science publications, which has almost doubled since 2000. That said, as the network has expanded, the network degree (i.e., the average number of connections possessed by each scientist [Liu & Xia, 2015]) has increased, whilst the average clustering (i.e., the extent to which a scientist's co-authors also collaborate with each other [Liu & Xia, 2015; Newman, 2004]) has decreased, indicating that collaboration is indeed becoming more extensive. As it has expanded, however, the density of the network (i.e., the number of potential connections across the network that have been realised) has decreased, implying that over time the network has become less structurally cohesive.

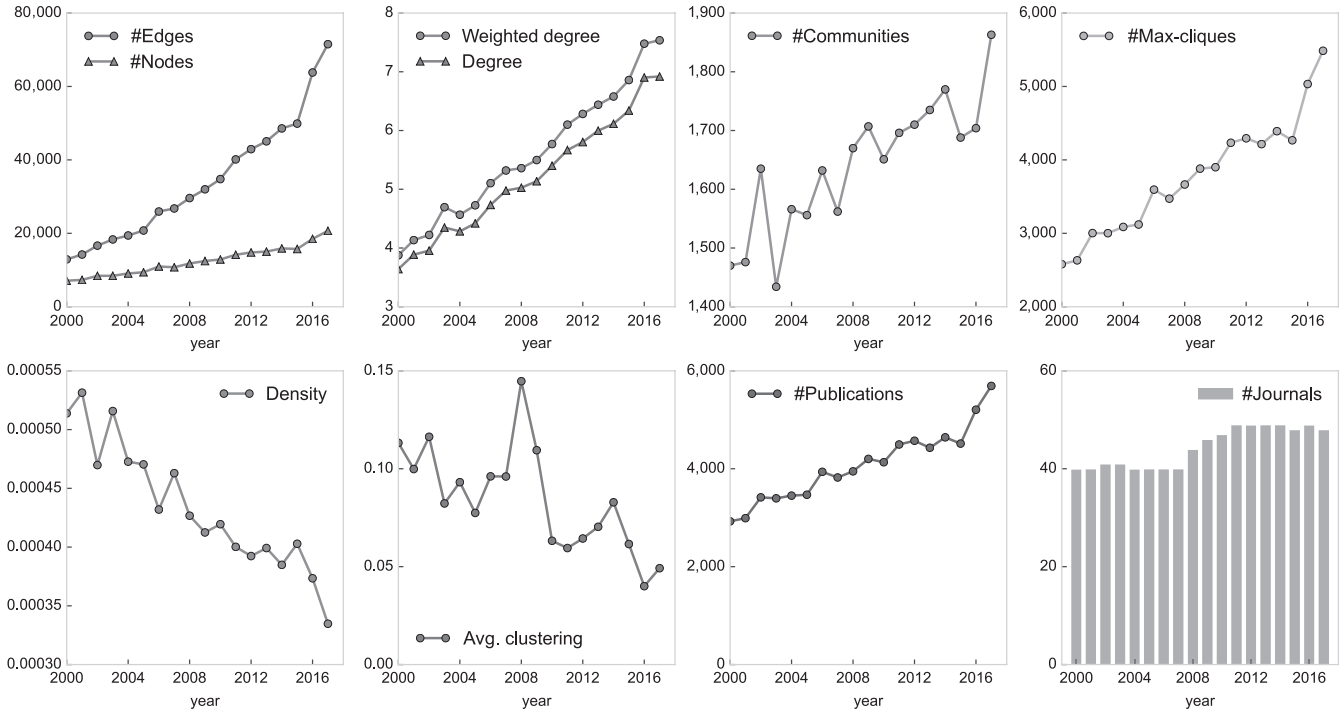

FIGURE 2 Social network analysis metrics obtained from the full network of 106,173 authors from 73,240 publications during the whole study period of 2000–2017, including the frequency counts of publications and journals included in the data set. Nodes: author in the network. Edges: co-authorship connections (i.e., collaborations). Degree: The average number of connections attached to each node. Weighted degree: The average number of connections attached to each node, accounting for the weight of each connection. Communities: Groups within which the nodes are more tightly connected to each other than the rest of the network. Max Cliques: The maximal complete subgraph of a given graph. In other words, the largest group of nodes where all the nodes are connected to one another. Density: The actual number of connections, divided by the total number of possible connections across the network. Average Clustering: The extent to which the nodes connected to a particular node are also connected with each other

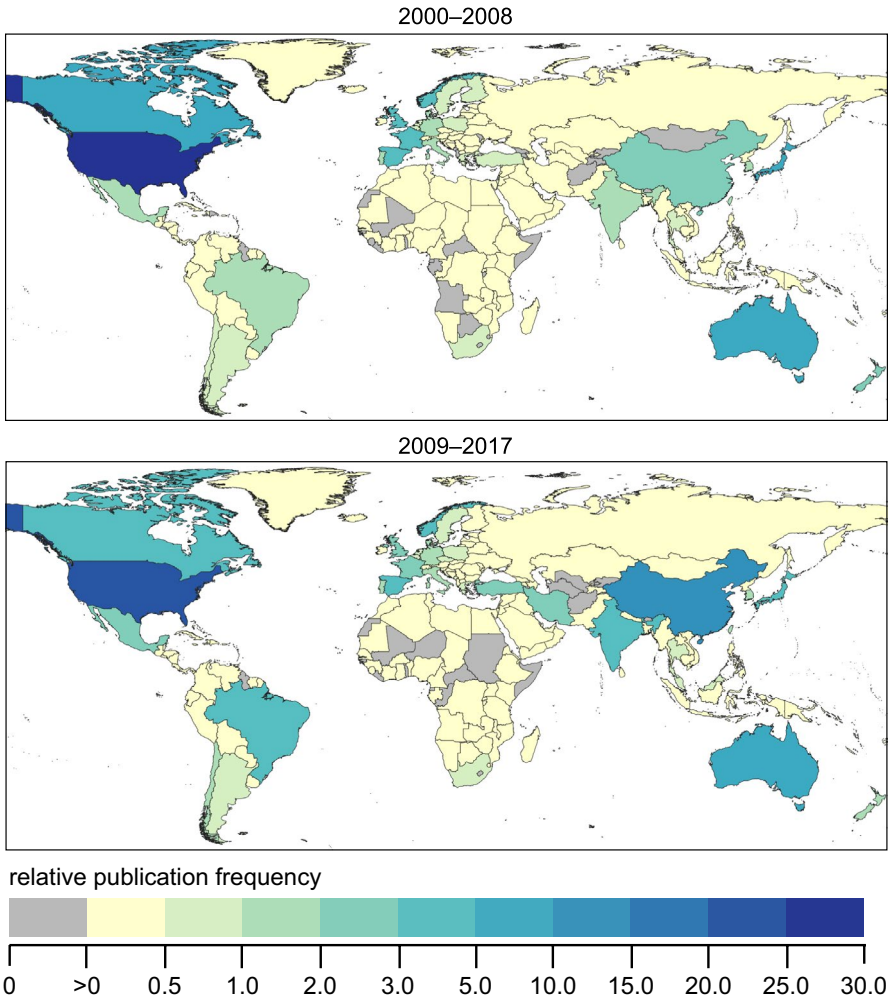

FIGURE 3 Publication percentage per country for the periods 2000–2008 and 2009–2017. Each publication is fractionally credited based on the number of authors and country affiliations. The actual values for the top-25 largest countries can be found in Table S2

3.2 | Country-level giants

As has been detailed elsewhere (Aksnes & Browman, 2016; Jarić et al., 2012; Oliveira Júnior et al., 2016), in terms of publication output, the fisheries science network is dominated by authors located in a few geographical regions. A large proportion of the publication volume in the field is produced by a small group of fisheries science powerhouses, comprising a number of traditional fisheries science producers (e.g., USA, Canada, Japan, Australia, UK, Norway), who over the past decade have been joined, and in some instances surpassed, by a number of large emerging economies (e.g., China, India, Brazil) (Figure 3 and Table S2). As one might expect, as the field has become increasingly collaborative, there has been a concomitant decline in the percentage of papers being published by single authors. Amongst the top 25 producers of fisheries science, the percentage of sole-authored papers has fallen to less than 10% in all cases. Interestingly, sole-authored papers command as low as 0.2% and 0.7% of the publication output of China and Brazil, respectively (Table S2). This figure remains closer to 5% amongst the traditional producers of fisheries science (e.g., USA, Canada, Norway, UK).

Although cross-border collaboration has increased over time, the patterns across the field are far from even, and the collaborative landscape—when viewed from the global level—is dominated by Western countries (Figures 4 and S5). In line with existing analysis (Jarić et al., 2012), the USA, UK and Canada are the most internationally collaborative countries in the network. As the field has become increasingly collaborative, historical links between European and North American countries have intensified, whilst a number of emerging economies have forged strong links with the USA. For example, mirroring the pattern in science more generally (Wagner et al., 2015), China has emerged as a prominent US collaborator, a relationship that is surpassed only by the collaborative relationship between the USA and Canada. Conversely, the traditionally strong—albeit at times unequal—relationship between the USA and Japan in this field (Finley, 2011; Hamblin, 2000) has dwindled.

3.3 | Institutional dynamics

Aggregating the network of authors at the institutional level (Figures 5 and 6) reveals a similar, albeit more complex, picture of the manner in which collaboration is occurring across the fisheries science network. Whilst there are technical difficulties posed to the analysis at this level—on account of different institutional IDs belonging to the same umbrella organisation, which consequently results in an

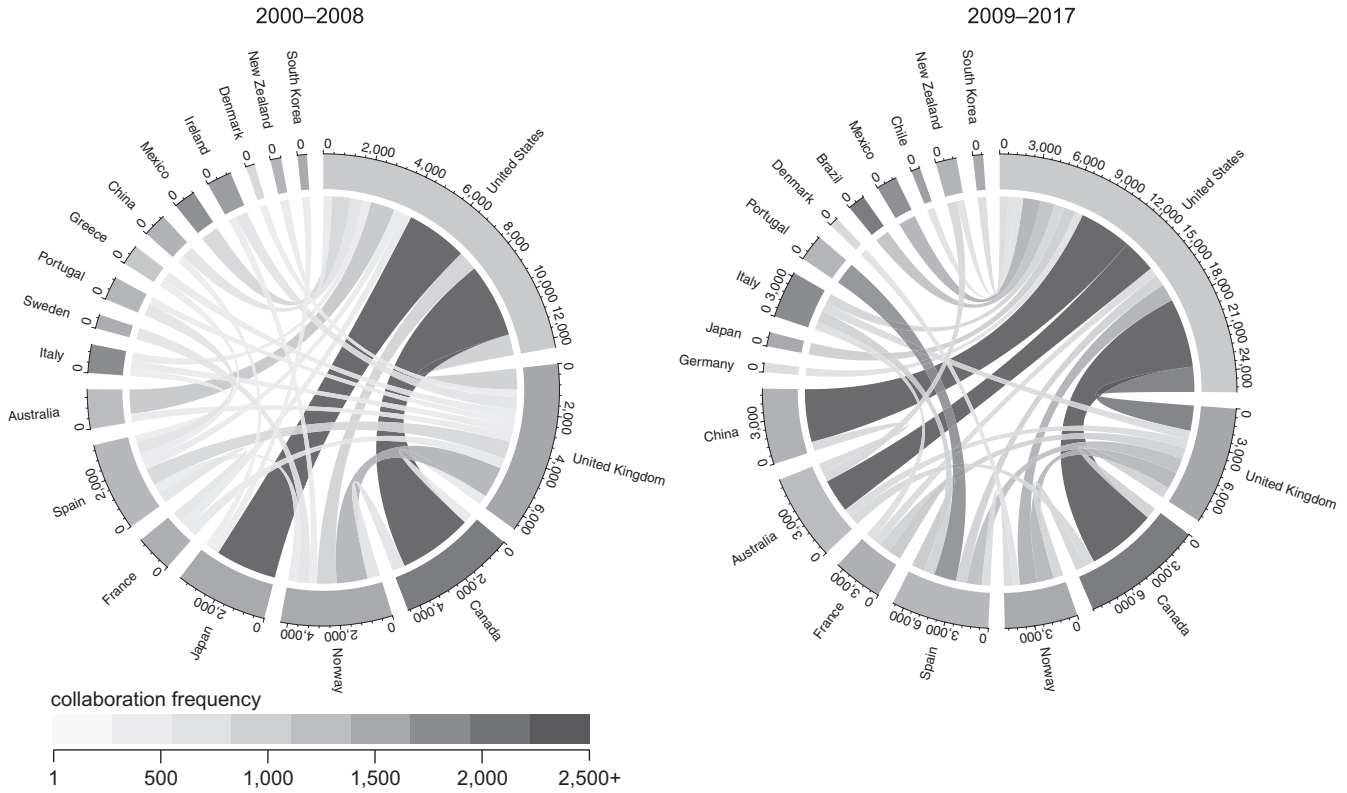

FIGURE 4 The collaboration frequency counts of international country collaborations for the time frame 2000–2008 and 2009–2017. Only the top-10% strongest links of the top-25 largest collaborating countries are shown, sorted clockwise. See Figure S5 for international and domestic collaborations

imperfect picture at the level of individual institutions (this limitation is explicated further in the Supporting Information)—we can see that, as with the country-level aggregation, the most active institutional collaborators are largely based in Western countries. Over time, however, a number of Chinese institutes have joined their ranks, whilst institutes based in Japan have become increasingly marginalised. Analysis at this level illuminates also a lack of typological diversity amongst the institutions producing the bulk of collaborative work within this field, with the most active institutional collaborators largely comprising of national research institutes and universities, many of which (perhaps unsurprisingly given our data set) display a leaning towards the natural sciences.

Alongside this, further divergences in terms of cross-border collaboration are visible, and the uncovered pattern suggests there is a spatial character to the manner in which collaboration is occurring, even when it traverses national borders. For instance, whilst there is a prevalence of European institutions amongst the top cross-border collaborators (Figure 5) when intra-national links are included US-based and increasingly Chinese institutes dominate the picture (Figure 6). Thus, implying that much US and Chinese institutional collaboration occurs within national borders, whilst amongst European institutes (though intra-national links remain important), international collaboration is more widespread. That said, it is worth noting, however, that amongst the top cross-border institutional collaborators there is a visible propensity to form strong links with institutions located in countries that are geographically proximate to their own, and this propensity does not appear to have diminished over time (Figure 5).

3.4 | Country clusters

Figure 7 presents the main country clusters within the collaboration network. As indicated by the colours, the network divides into distinct clusters, with spatial and temporal variation in clustering visible. Three large distinct country clusters are uncovered within the time period 2000–2008, all of which comprise northern and southern partners. Four clusters are visible in the 2009–2017 time period, three of which comprise a mixture of northern and southern partners, and one of southern partners only. Although the clusters are globally dispersed to varying degrees, elements of spatial clustering are visible in all of them. Whilst the countries within each of the clusters have changed over time, all have maintained this spatialised character.

In terms of quantity or quality of collaborative connections and location within the network (i.e., centrality metrics), the country clusters are centred on a small group of (mainly Western) countries (Tables S3 and S4). Many of the fisheries science powerhouses (as detailed in the previous section) have maintained central positions within the clusters, thus placing them in favourable positions with respect to control and dissemination of information. The most geographically expansive cluster is centred on the USA. The second on North European countries—with Norway, for example, positioned as

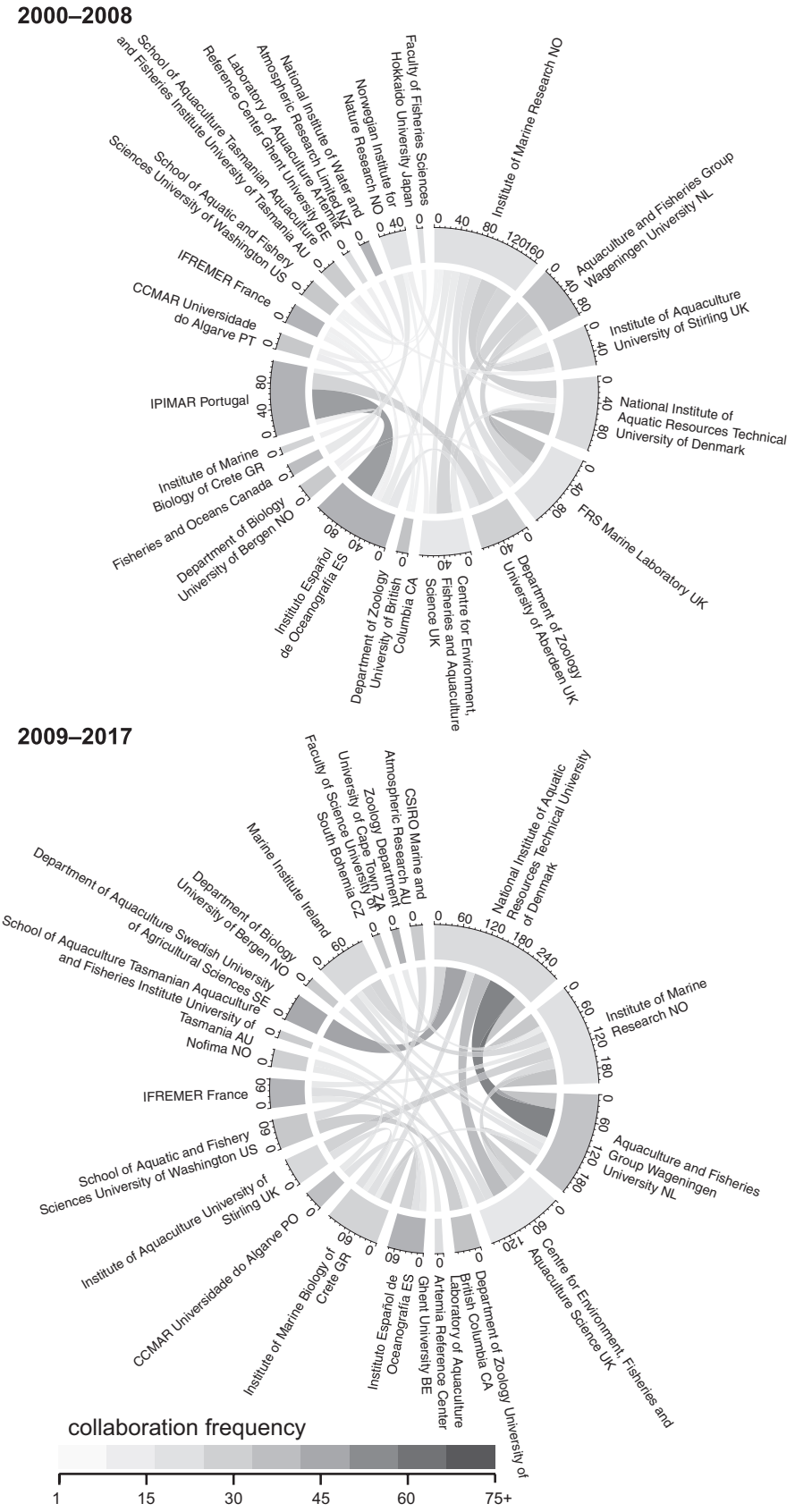

FIGURE 5 The collaboration frequency counts of only the international collaborations (excluding domestic collaboration) amongst affiliations (i.e., institutions) for the time frame 2000–2008 and 2009–2017. Only the top-10% strongest links of the top-25 largest collaborating affiliations are shown

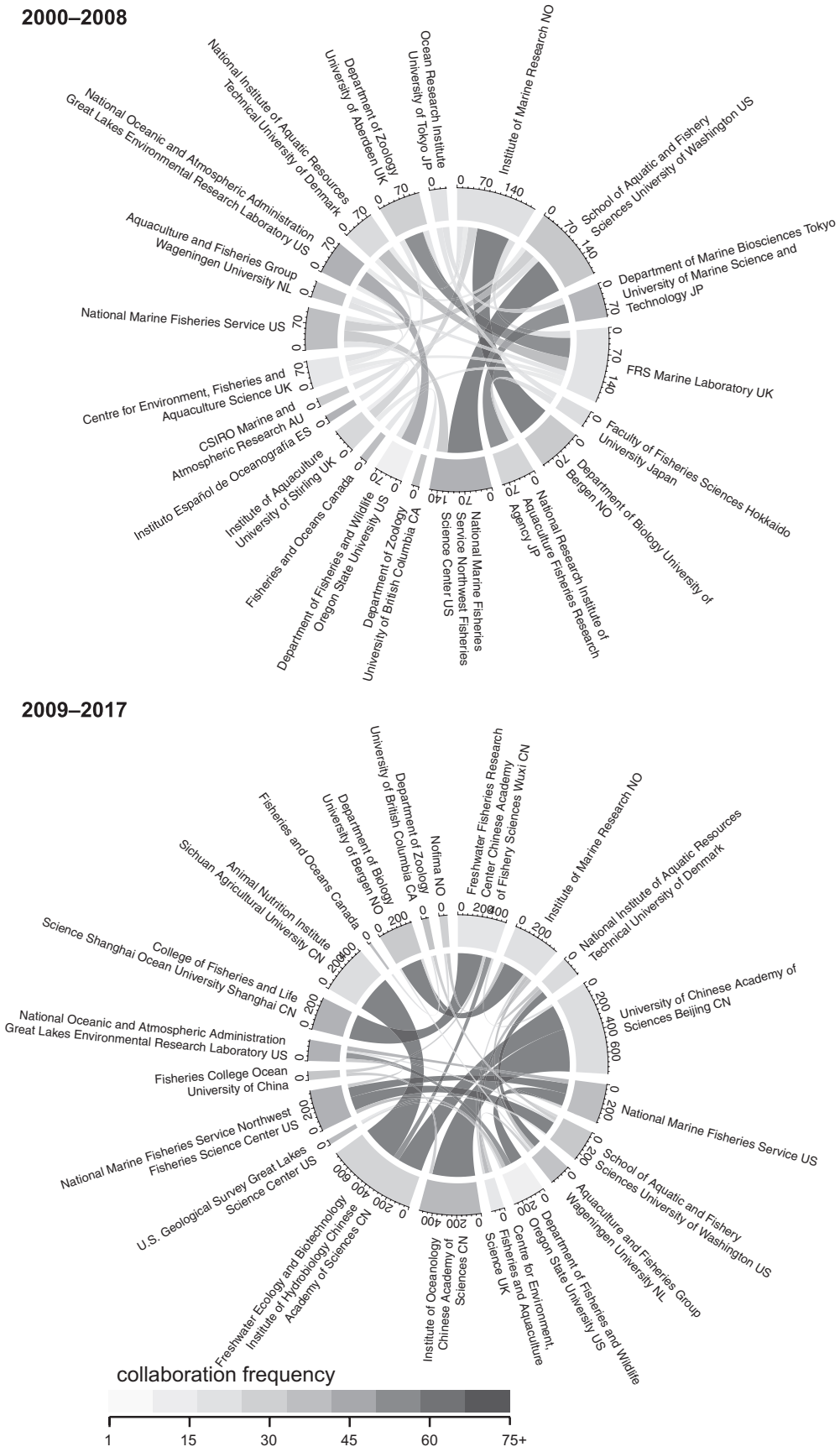

FIGURE 6 The collaboration frequency counts of the international and domestic collaborations amongst affiliations (i.e., institutions) for the time frame 2000–2008 and 2009–2017. Only the top-10% strongest links of the top-25 largest collaborating affiliations are shown

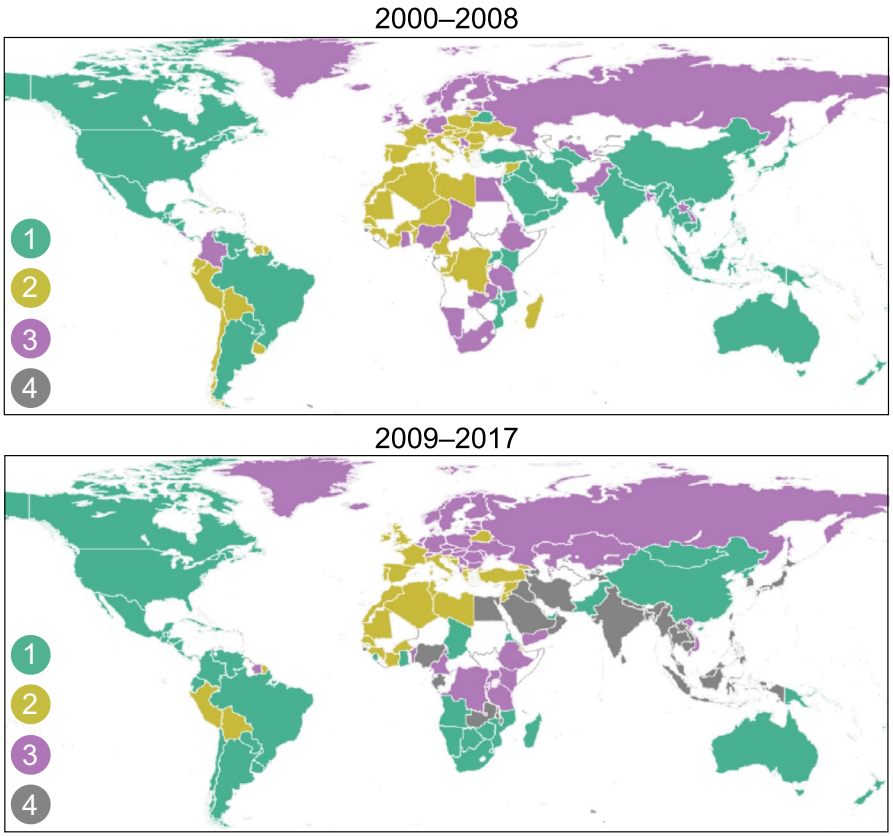

FIGURE 7 Country clusters ranked 1–4 based on the total number of countries within them for the periods 2000–2008 and 2009–2017. Cluster 4 in the period 2000–2008 contains the countries Jamaica and Grenada only

the best-connected country within that cluster. A further Europe-centred cluster is also evident, with France and Spain the prominent collaborators in this grouping. The fourth cluster which comprises partners from Africa, Asia and the Middle East—amongst them some of the largest aquaculture producers in those regions (FAO, 2018)—is centred on Malaysia and Japan. That said, a number of smaller countries (e.g., Bulgaria, Tunisia and Cambodia) are positioned favourably on the shortest path between other authors and thus may be playing important roles as knowledge brokers within their clusters (Newman, 2004).

3.5 | Communities of authors

Moving to a more fine-grained level of analysis again, in excess of 3,000 communities of authors were identified in the fisheries science network, which we ranked according to the number of authors within them. The distribution of the community size across the network is highly skewed, with the largest fifty communities comprising in excess of 80% of the authors in the network, whilst the remaining 20% is composed largely of sole authors or groups of two to three authors (Figure S6). Figure 8 presents the largest fifteen (ranked 1–15) communities within the network, which together comprise almost 60% of the network (communities 16–30 can be viewed in Figure S7). Though the communities are globally dispersed, all display dense points of regional centralisation. Across many, rather than having diminished, this spatial clustering has intensified over time.

To varying degrees, each of the fisheries science communities has grown in size over time, with the weighted degree (i.e., the average number of connections attached to each node, accounting for the weight of each connection) increasing (Figure S8). The density across each of these fifteen communities is low, however, indicating that although collaboration has increased, only a small number of the potential connections in each of the communities have been realised. This suggests that, when viewed at the individual level, the communities of authors in the fisheries science network are quite loosely knit. With respect to the interlinkages between these communities, the most frequent collaborative links are amongst the European, American and Oceania communities (Figure 9).

3.6 | Topical foci

In total, sixteen latent topics were identified within our corpus (Appendix 2; from most prevalent to least prevalent): Management; Aquaculture (growth effects); Habitats; Diet; Immunogenetics; Gear technology & bycatch; Models (estimation & stock); Salmonids; Diseases; Climate effects; Aquaculture (health effects); Physiology; Genetics; Age & growth; Reproduction; and Shellfish. Figure 10 provides an additional representation of the 16 uncovered fisheries science topics, alongside their proportions across the entire network. Here, the distance between the nodes represents the topic similarity with respect to the distribution of words, whilst the size of the nodes indicates the topic prevalence within the corpus, with larger nodes representing topics being more prominent within the corpus.

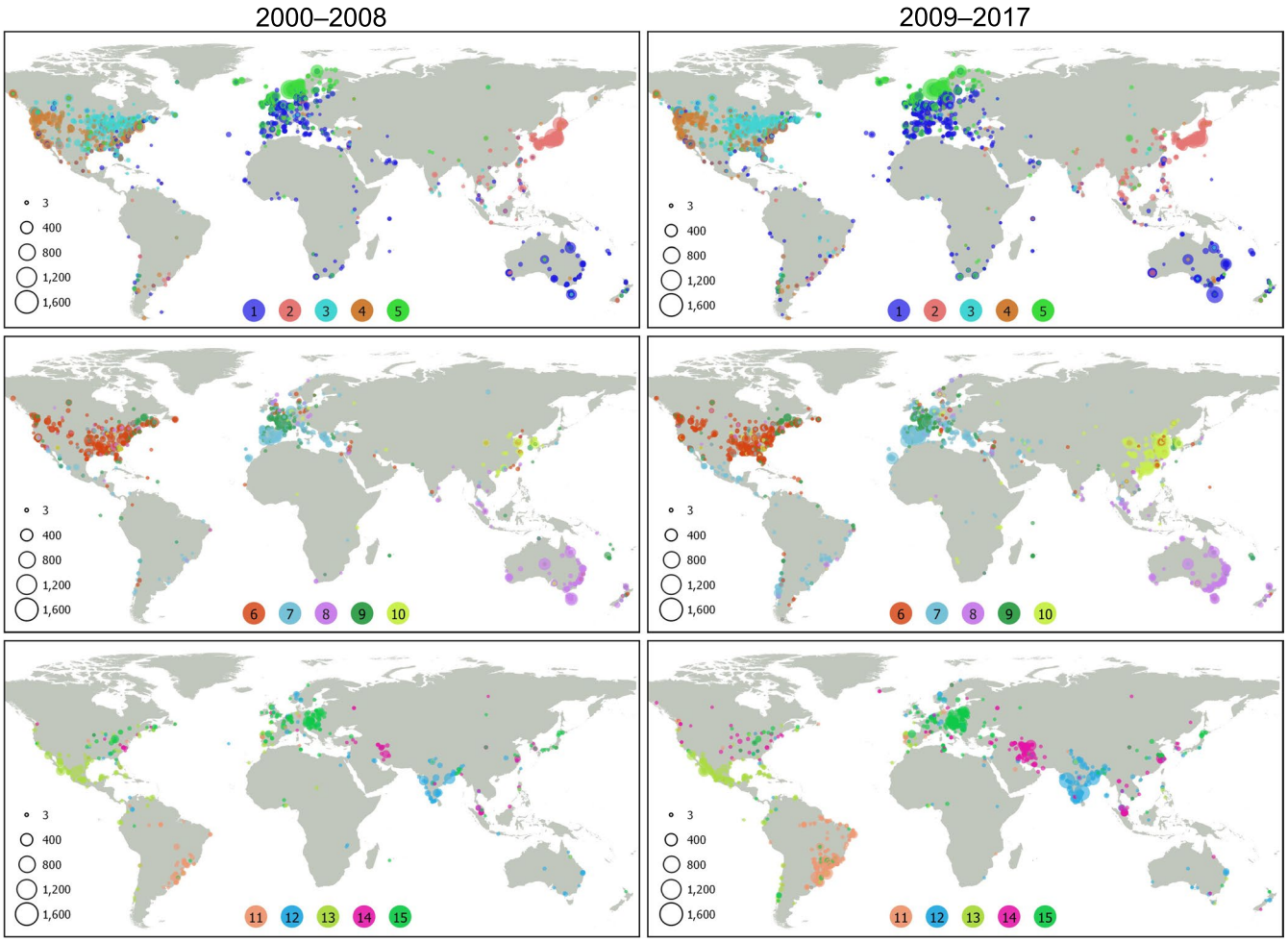

FIGURE 8 Spatial distribution of authors within communities for the period 2000–2008 and 2009–2017. Communities are ranked (1–15) based on the number of authors within the community and differentiated by different colours. The size of the nodes represents the number of authors within the same location. Spatial distribution of communities 16–30 can be found in Figure S7

Thus, we can see, for instance, that the topic Management is the most prominent of the 16 topics identified across the entire corpus and so on.

Figure 11 details the topical foci of the top 15 communities, alongside the variations therein, ordered based on the largest to smallest topics within both their periods. In terms of community-level and temporal variations in topics, whilst there are commonalities, and each of the communities includes authors that are engaged in the sixteen topics we have identified, variations in this respect are evident. For example, whilst our analysis indicates an almost across-the-board increase in publication output focused on Management, the most intense focus on this topic is seen across the European, North American and Oceania communities. In contrast, a much weaker focus on this topic is seen within the China-, Japan- and Iran-centred communities. Indeed, on calculating the similarities in cumulative topic distributions across the communities (Figure S9), our analysis reveals greater topical similarities amongst the North American, European and Oceania communities. A comparable pattern of similarity is discernible across the topical output of a number of communities centred on newer entrants to the network (e.g., European-south, Brazilian, East European- and Iran-centred communities).

Overall, a distinct geography of topics is detectable across the network. A clear division of focus across the communities is seen whereby the topics Management, Models (estimation & stock), Gear technology & bycatch, and Habitats are areas of central, and in some instances intensifying focus for a number of the largest (Western-centred) communities in the network. On the other hand, a stronger topical leaning towards aquaculture-related topics (e.g., Aquaculture [effects on growth], Diet, Diseases and Immunogenetics) is seen across the communities centred on the large emerging economies, many of whom are large aquaculture (and fish feed) producers (FAO, 2018). That said, a focus on aquaculture is also seen amongst European and North American communities that are concentrated in regions with large-scale interests in aquaculture production (e.g., Norway, USA, Spain, Eastern Europe [FAO, 2018; Österblom et al., 2015]). For instance, we see a strong topical focus on salmonids amongst a number of North America and North European

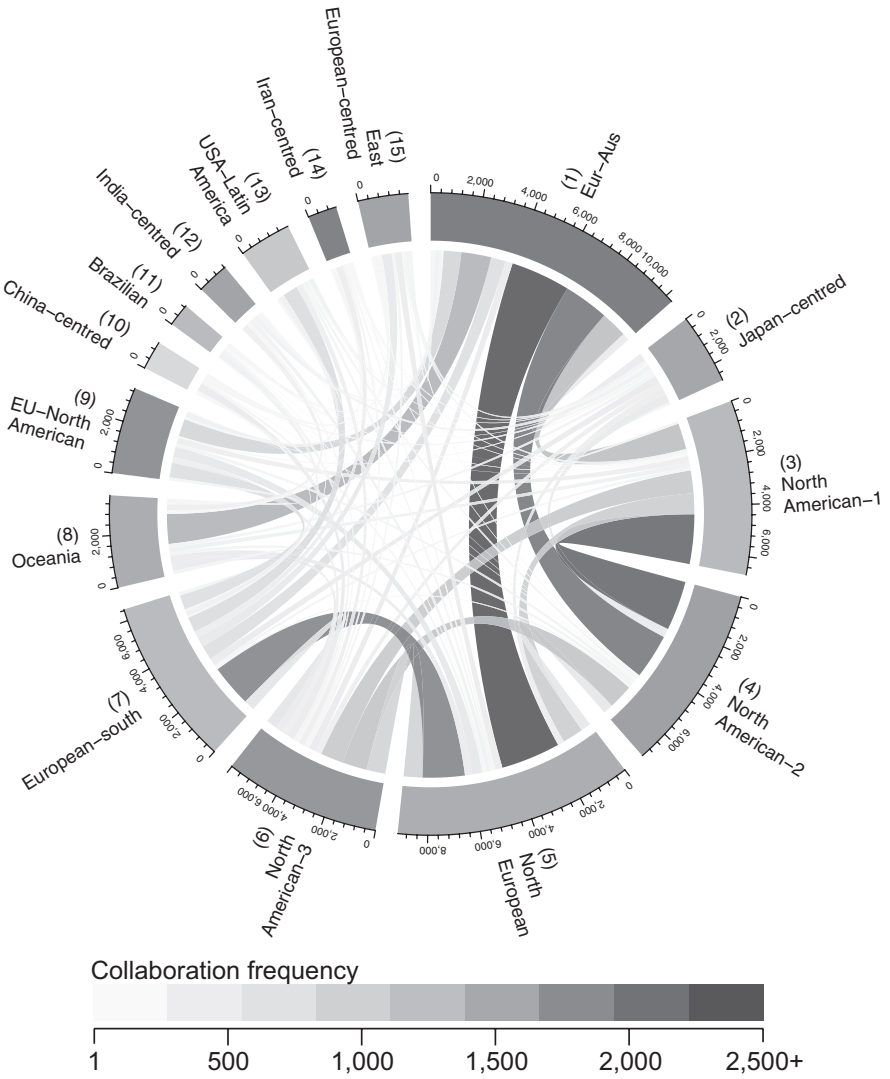

FIGURE 9 Inter-community collaboration for the top-15 largest communities (ranked 1–15). The geographical label for each of the 15 communities indicates where the majority of authors within the community are spatially located

communities, which may well be aquaculture-related. In this regard, previous analysis has detected an increased focus on aquaculture species such as Atlantic salmon and rainbow trout (Aksnes & Browman, 2016; both of which are salmonids) in fisheries science.

3.7 | Publication outlets

Figure 12 maps the publication outlets of the top 15 fisheries science communities. In many respects, the above uncovered geography of topics is, rather unsurprisingly, reflected in the journals within which each of the communities publishes most frequently. For instance, as we might expect, many of the communities that are centred on large emerging economies and are focused on aquaculture-related topics are publishing in journals that are topic-oriented in that direction. For example, the China-centred community publishes most frequently (65%) in *Aquaculture*, *Fish and Shellfish Immunology*, *Aquaculture Research and Aquaculture Nutrition*. Conversely, none of the top communities centred on emerging economies, for example, have published in *Fish and Fisheries* over our time frame, whilst most of the Western-centred communities have. Again, this is likely reflective of this journal's focus, which is oriented towards capture fisheries and their management (Syed et al., 2018).

Further divergences may also be discerned in terms of a visible tendency amongst the large Western-centred communities to publish within international (albeit somewhat regional) journals. This is seen, for example, with two of the North American-centred communities publishing more than 30% of their output in *Transactions of the American Fisheries Society*. Similarly, 18% of the output from the largest European/Australian community is published in *ICES Journal of Marine Science*. In contrast, communities centred on emerging economies display a propensity towards publishing within national-level journals. For example, much of the work being produced by the Iran-centred community is published in *The Iranian Journal of Fisheries Sciences*, the Indian-centred community tends to publish in

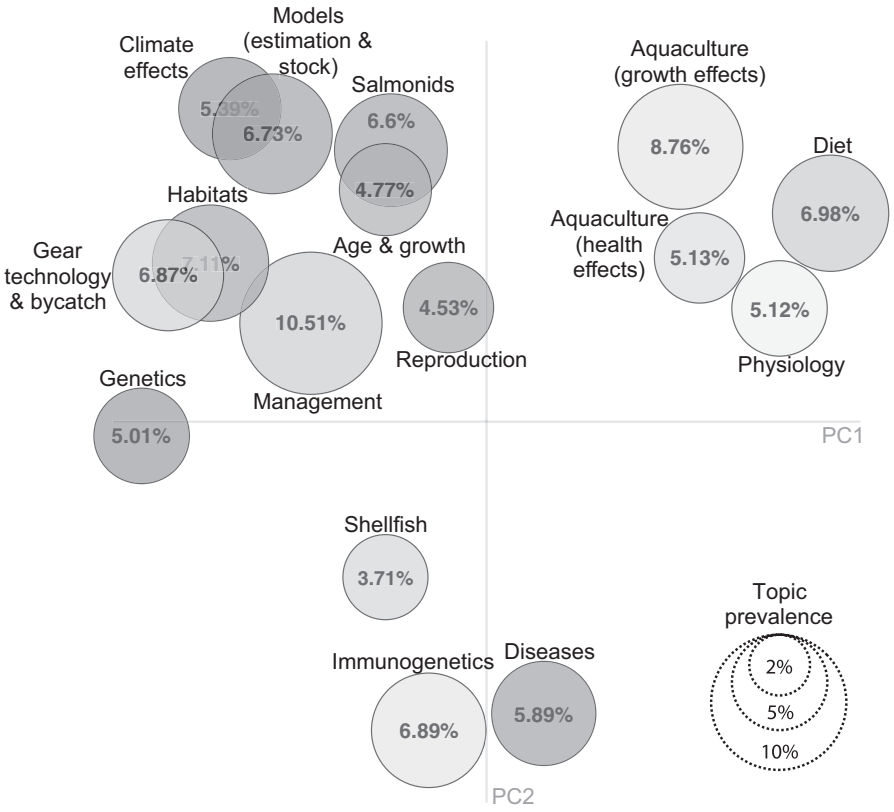

FIGURE 10 Inter-topic distance map that shows a two-dimensional representation (via multidimensional scaling) of the 16 uncovered fisheries science topics with labels. The distance between the nodes represents the topic similarity with respect to the distributions of words. The surface of the nodes indicates the topic prevalence within the corpus, with bigger nodes representing topics being more prominent within the document collection (all nodes add up to 100%)

The Indian Journal of Fisheries, whilst a high proportion of the work from the Japanese community is published in *Fisheries Science*, which is the official journal of the Japanese Society of Fisheries Science.

3.8 | Impact

In terms of impact factor, only one of the 50 journals covered by the fisheries category as defined by the SCIE 2016–2017 has an impact factor >8 (i.e., *Fish and Fisheries*) (Appendix 1). None of the communities centred on emerging economies publish in this journal, whilst most of the largest European, North American and Oceania-centred communities do (Figure 12). That said, as indicated, this is likely reflective of the distinct geography of topics across the communities. Considering impact further, however, Table 2 depicts the citation to publication ratios across the top 15 communities and indicates North European- and North American-centred communities have the highest citation to publication ratios, whilst those centred in emerging economies score the lowest.

Figure 13 reveals a similar pattern in terms of the distribution of citations across each of the top 15 communities, whereby Western-centred communities have a higher distribution of highly cited papers (i.e., >250) vis-à-vis the emerging economy communities. Indeed, most of the European-, North American- and Oceania-centred communities have articles which have >350 citations. In contrast, amongst the communities that are centred on emerging economies, none but the India-centred community have articles with >250 citations. The China-centred community, for example, does not have any articles with >175 citations, placing it at the bottom of the top 15 fisheries science communities with respect to highly cited fisheries papers.

4 | DISCUSSION

As science has become increasingly internationalised, scholars investigating the shifting spatial structure underlying scientific practice (Hoekman, Frenken, & Tijssen, 2010) have posed questions as to whether networks of research collaboration are expanding in every region of the globe (Adams, 2012). Others have suggested that a globalised science may open up research fields in a generative manner to new perspectives that challenge underlying assumptions, develop new methods and point to previously unrecognised biases (Hess, 2015). In this sense, scientific networks may be understood as reflecting not only authors, but people, actors, organisations and things that uphold scientific patterns and beliefs, with different networks having different epistemological and ontological implications (Forsyth, 2003). The picture we have uncovered here of fisheries science is in many respects similar to the broader trend in scientific output, which has led some scholars to suggest that the historically dominant "Atlantic axis" (an axis that has also been dominant in the production of fisheries science) is unlikely to be the main focus of research in the coming decades (Adams, 2012, p. 335). In a sense, given China's rapid growth over our time frame, and its outpacing of the USA in terms of total volume of scientific papers published in 2016 (Tollefson, 2018), this does seem likely. That said, it remains to

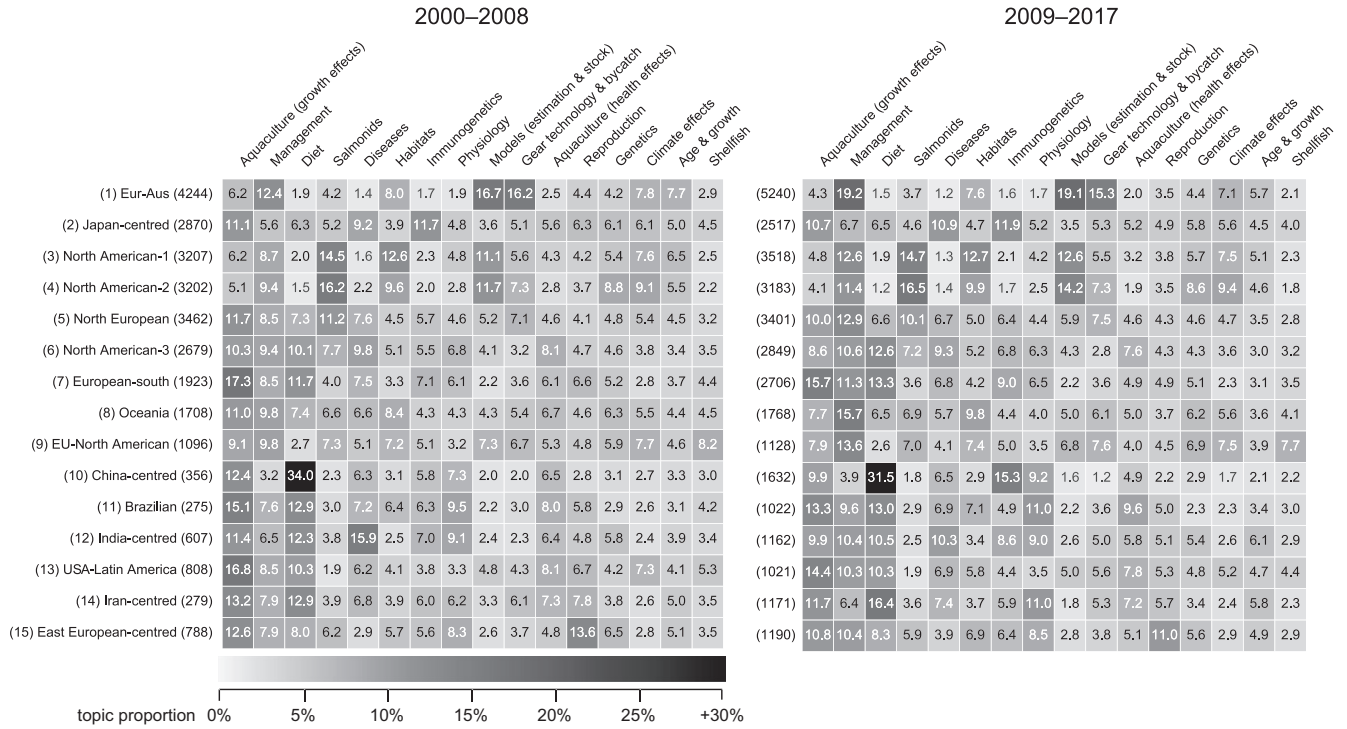

FIGURE 11 The proportion of topics published within each of the 15 largest communities for the periods 2000–2008 and 2009–2017. The number of publications published by each of the 15 communities, and for each time period, is shown in parentheses. For example, (1) Eur-Aus (4,244) is the largest community (rank 1), with most of the authors spatially located in Europe and Australia, and 4,244 publications published between 2000 and 2008. The 4,244 publications cover aspects of Age & Growth for 7.7%, Aquaculture (growth effects) for 6.2% and so on

be seen what this shift means for the production, shape or order of knowledge (Escobar, 2004) relating to fisheries.

In this respect, though there seems to be broad acceptance that collaboration is a good thing (Adams, 2013; Katz & Martin, 1997), scholars have cautioned against viewing increased collaboration as an unquestionable good (Adams, 2012; Katz & Martin, 1997; Leahey, 2016; Xie, 2014). For instance, as research team size and internationalism have become additional metrics against which science is judged (Xie, 2014), trends towards stratification in scientific collaboration patterns at both the institutional and individual levels have been detected (Dahdouh-Guebas, Ahimbisibwe, Moll, & Koedam, 2003; Jones, Wuchty, & Uzzi, 2008; Xie, 2014). Regarding collaboration at the international level, scholars have argued that the manner in which the emerging geography of science is developing reflects historical patterns of Western control and bias (Dahdouh-Guebas et al., 2003; Peters, 2006). Despite this, recent analysis has indicated that empirical work on collaboration tends to be heavily skewed towards the benefits of collaboration (Leahey, 2016; Xie, 2014). This may, we suggest, reflect a tendency of scholars to view scientific fields (and hence networks) as largely consensual spaces. Failing to take seriously the role that power plays in shaping these spaces, however, makes it difficult to differentiate between cooperation based on equality and that which might not be (Albert & Kleinman, 2011), which could consequently work to limit our understanding of these spaces.

4.1 | A Bourdieusian perspective

Drawing on theoretical insights from the sociology of science provides one route through which a more nuanced reading of scientific collaboration might be garnered. To this end, sociologists of science have convincingly shown that the structure of scientific knowledge in any field reflects a combination of macro- and micro-sociological factors (Bourdieu, 1975; Cetina, 1999; Forsyth, 2003; Law, 1987; Mol et al., 2002). Adopting an explicitly Bourdieusian perspective helps us understand the role of power (understood as the capacity to define what legitimate science is) in these processes (Albert & Kleinman, 2011; Bourdieu, 1975, 1991; Lave, 2012), for example in directing the topics pursued, methodologies adopted, journals in which research is published or those with whom we might collaborate with (Bourdieu, 1975). Conceiving of the field in this manner also helps us take seriously the role of consumers (e.g., policy makers, funding agencies, industry and so on) in determining the structure of the scientific field (Albert & Kleinman, 2011; Bourdieu, 1991). In this respect, for instance, whilst scholars have characterised the field of fisheries science as fragmented and lacking in connectivity (Jarić et al., 2012; Symes & Hoefnagel, 2010), drawing on perspectives that are attuned to the role of power, historians of fisheries science have been astute in highlighting that much of fisheries science has been based on Western ideas about fish (Finley, 2011), people who fish and how fisheries might be managed (Bavington,

FIGURE 12 Overview of the proportional publication output in the 50 analysed fisheries science journals for each of the 15 largest communities. Values are in percentages, and row totals sum up to 100%. For example, the second largest community, ranked 2, and labelled "Japan-centred," published 34% of the publications within the analysed time period (2000–2017) in the journal "Fisheries Science"

TABLE 2 Overview of the number of citations and publications, and calculated ratio thereof for the top-15 communities (sorted by ratio)

Rank	Description	Citations	Publications	Ratio
5	North European	147,150	6,862	21.44
7	European-south	93,112	4,628	20.12
1	European/Australia (Eur-Aus)	186,375	9,483	19.65
9	EU-North American	42,942	2,223	19.32
4	North American-2	120,920	6,382	18.95
8	Oceania	65,370	3,475	18.81
3	North American-1	119,416	6,724	17.76
6	North American-3	92,556	5,527	16.75
13	USA–Latin America	26,826	1,828	14.68
15	East European-centred	28,242	1,978	14.28
12	India-centred	24,641	1,769	13.93
2	Japan-centred	72,304	5,383	13.43
10	China-centred	24,703	1,988	12.43
11	Brazilian	13,938	1,297	10.75
14	Iran-centred	13,314	1,450	9.18

Note: Higher ratio indicates, on average, more citations per publication.

2010). Historians have also argued that the direction and structure of fisheries research have long been shaped by transient political–economic forces (Bavington, 2010; Finley, 2011; Smith, 1994). This, it has been suggested, has provided the opportunity and encouragement for the development of research programmes in certain areas over others, working to sideline longer-term economic, social and scientific goals, and limit the development of the field in the process (Smith, 1994).

4.2 | Collaborative silos?

Considering these issues in terms of the fisheries science network we have uncovered here, the topological characteristics displayed by the fisheries network do indicate that the network is becoming more extensive. As we have seen, the number of authors participating in the network has increased, as has the average number of connections possessed by each scientist, whilst the extent to which

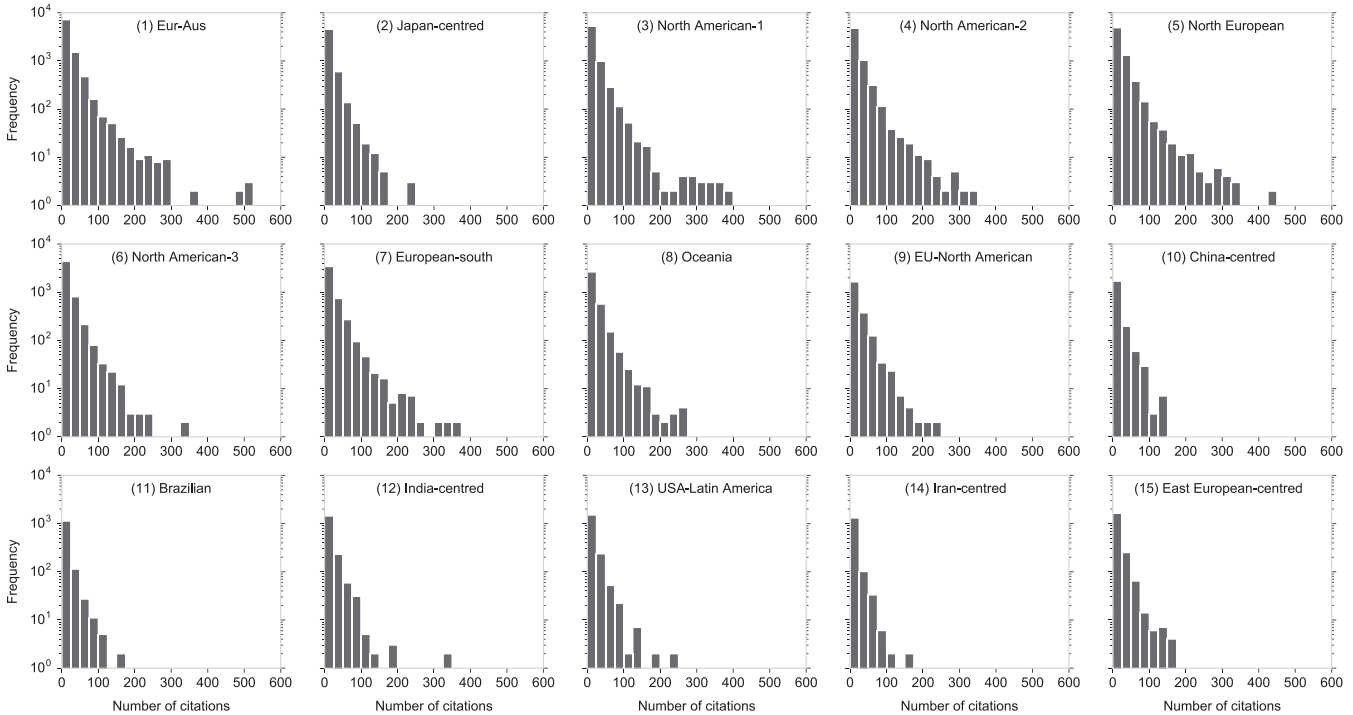

FIGURE 13 Histogram of number of citations across each of the top 15 communities. Note that the *y*-axis is log-scaled

a scientist's co-authors also collaborate with each other has decreased. In the light of the aforementioned fragmentation and lack of connectivity which has previously been cited as problematic in fisheries science (Jarić et al., 2012; Symes & Hoefnagel, 2010), and the existing "narrow lenses" that have been detailed as persisting in the field (Syed et al., 2018), we might tentatively infer that the structural trends exhibited by the network are a good thing. Very dense ties can have a homogenising effect on a network (Bodin & Crona, 2009), whilst high levels of clustering are indicative of fragmentation and division (Lambiotte & Panzarasa, 2009). For example, the more an individual's collaborators are also connected to one another, the less likely those connections will lead to new collaborations with "dissimilar others," thereby making exposure to new ideas similarly unlikely (Granovetter, 1973; Lambiotte & Panzarasa, 2009). That the global fisheries science network exhibits trends in the opposite direction may well suggest that the network is becoming less fragmented (Borrett, Moody, & Edelmann, 2014).

As it has expanded, however, the number of potential connections across the network that have been realised has decreased, and the network has become less structurally cohesive. This pattern could work to limit the spread of ideas across the network (Moody, 2004), with ties in this sense working to enhance knowledge production (Bodin & Crona, 2009). Seen from this angle, this trend may be indicative of a field that is becoming increasingly divided into silos, albeit silos within which there is considerable collaboration. This could have implications in terms of inhibiting knowledge exchange (Borrett et al., 2014), reinforcing lines of division that already exist or generating new ones. That said, an element of agonistic pluralism is desirable in all fields, certainly in terms of creating space for historically underrepresented ideas (Matulis & Moyer, 2017). Therefore, cast in a more favourable light, this pattern might suggest that the field is becoming more heterogeneous, in a manner that could provide welcome space for addressing particular problems and the nurturing of new ideas (Borrett et al., 2014) or place-based epistemologies (Escobar, 2004).

4.3 | Democratising fisheries science?

Exploring these issues further in relation to the trends exhibited by the aggregated network, it is worth noting that although a spirit of internationalism has always animated the field (Hamblin, 2000; Rozwadowski, 2004), the bulk of fisheries science has long been produced by states with significant fishing interests around the globe (Finley, 2011; Smith, 1994). In this regard, whilst the geography of fisheries science (Adams, 2012) may have expanded, this pattern has not. The largest fisheries research nations (Aksnes & Browman, 2016), including the new entrants, are countries with highly industrialised fishing fleets or significant aquaculture interests (FAO, 2018; Kroodsma et al., 2018). Thus, whilst the arrival of new entrants might in one sense be seen as a shift towards an increasingly democratised global network of science (Xie, 2014), in another it may well work to marginalise some actors further (Jones et al., 2008; Xie, 2014), for instance countries from the Global South with significant interests in fisheries in terms of food security and livelihoods (Oliveira Júnior et al., 2016).

A number of regions remain marginal in this system despite increasing volumes of fisheries-related knowledge produced by authors in Asia and Latin America (much of which is aquaculture-related). For example, in spite of strong relative growth rates over the past decades (Aksnes & Browman, 2016), output from the Middle East is negligible when viewed at the macro-level. Similarly, standing as a stark reflection of the inequalities in output between developed and developing countries in this field (as in others; Jarić et al., 2012), the African continent remains without any large hubs of production. Thus, although the network has become more geographically extensive, this extension appears to be mirroring the shifting patterns of fisheries production and the growing contribution of aquaculture to the global production of fisheries, much of which is produced in Asia (FAO, 2018), rather than necessarily mirroring a shift towards an increasingly democratised global network of science (Forsyth, 2003; Xie, 2014).

Considering this further, with respect to the potential implications of the collaboration patterns displayed across the network, in the light of the already existing inequality in publication output, it seems reasonable to suggest these may work to amplify these. For instance, the largest cross-border collaborators at the country level comprise of Western countries and large emerging economies. At the institutional level, Western—more specifically, European—countries dominate the landscape almost entirely. Though prominent North–North and North–South collaborations are certainly visible within the fisheries science network, South–South collaboration remains peripheral when evaluated from a global perspective (Leydesdorff et al., 2013). This matters in the sense that whilst North–South collaboration might be an indicator of increased research capacity, South–South partnerships provide a much stronger indication of such (Boshoff, 2009). Further, given existing structural inequalities and historical patterns of dominance, North–South collaborations run the risk of perpetuating these via, for instance, the imposition of a foreign-led research model (Boshoff, 2009), which may not necessarily meet the particular research needs of the developing country (Shrum & Shenhave, 1995).

Alongside this, as is the case in other fields, whilst much of the publication output being produced by developed countries displays an increasingly international character, large swathes of the research being published in emerging economies remain entirely domestic (Adams, 2013; IOC-UNESCO, 2017; Figure S5). This may explain the divergences amongst the largest Western communities and those centred on emerging economies in terms of the journals within which they publish, with the former publishing predominantly in more internationalised journals, whilst the latter display a tendency to publish in national-level journals, with implications in terms of reach (Jarić et al., 2012). Given that internationally collaborated scientific papers are more likely to be published and cited and are therefore more visible (Adams, 2012; Katz & Martin, 1997), these patterns could further sideline work by authors from countries who are already marginalised within this research system. They may also

explain, at least partially, the differences in citation rates across the largest communities in the network, whereby, in line with previous findings with respect to the field (Aksnes & Browman, 2016; Branch & Linnell, 2016; Jarić et al., 2012), much of the work being produced by Western-centred communities is highly cited, and thus may reasonably be assumed to be more influential in the field (Aksnes & Browman, 2016; Branch & Linnell, 2016).

By and large, each of these patterns may work to reinforce dominant ways of thinking in the field towards perspectives from the Global North (Forsyth, 2003), which have previously been cited as problematic within this domain (Bavington, 2010; Finley, 2011; Francis, 1980). Considering this, in line with the sentiments explicitly expressed in the Sustainable Development Goals (SDGs) and the UN's 2017 Global Oceans Science Report, increased capacity building at the individual, institutional and country levels (e.g., increased investment, more and better partnerships) may go some way to closing some of the gaps detected here in terms of research output inequalities between countries in the Global North and Global South (Boshoff, 2009; Dahdouh-Guebas et al., 2003; Jarić et al., 2012; Lansang & Dennis, 2004). That said, democratisation is not simply a case of extending networks, and capacity building does not imply the unidirectional flow of ideas across space. Beyond this, they involve "revealing the tacit politics within scientific statements" and "diversifying and localising universalistic scientific explanations" (Forsyth, 2003, p. 228)—both of which demand plurality, reflexivity and transparency, alongside the acknowledgement of the social and political values underlying a field (Forsyth, 2003).

4.4 | Systems of regionalisation

On balance, the fisheries science landscape we have uncovered depicts a more regionalised than globalised system of knowledge production. In this regard, existing research has shown that scientific collaboration at the international level is shaped by the dynamic interplay of geographical, political, economic, historical, cultural and linguistic factors (Adams, Gurney, Hook, & Leydesdorff, 2014; Dahdouh-Guebas et al., 2003; Hoekman et al., 2010; Katz, 1994; Katz & Martin, 1997; Saetnan & Kipling, 2016). Our analysis suggests a complex mix of these are at play in the fisheries science network. In line with work in other fields (Hoekman et al., 2010; Katz, 1994; Leahey, 2016; Parreira, Machado, Logares, Diniz-Filho, & Nabout, 2017), even if collaboration has become increasingly internationalised, spatial proximity remains an important feature of the collaborative entanglements within the field, and this is seen across the cross-border institutional patterns, as well as the country clusters and communities of authors within the network.

This visibly spatialised pattern is in keeping with scholarship that has indicated that though the bias towards collaboration within territorial borders (regional, national and linguistic) has decreased over time, spatial proximity remains an important determinant of research collaboration (Hoekman et al., 2010). This is not to argue that, for instance, linguistic ties are not an important driver of collaboration, but rather to highlight that research collaboration does have a spatial character that goes beyond this, and this in itself is reflective of an array of complex overlapping factors. Amongst these are regional political groupings, for example trade blocs (Parreira et al., 2017), funding mechanisms or opportunities that remain at the national and regional levels (Hoekman et al., 2010) and colonial ties (Adams et al., 2014; Boshoff, 2009; Nagtegaal & de Bruin, 1994). With respect to our immediate interests here, no doubt overlapping fishing interests—proximate and distant—matter too in shaping collaboration.

Considering this latter point further, it has been suggested that different scientific fields might have specific "spatial requirements" due to their research topics (Hoekman et al., 2010). For example, collaborative proximity may be due to environmental similarities amongst countries. It may, therefore, make sense that researchers focused on similar geographical areas or biomes would work together (Parreira et al., 2017). As regards fisheries, this seems reasonable given that many countries share closely overlapping fishing grounds and thus proximate fisheries interests, across shared ecoregions. Indeed, historians have shown that the requirements of the marine environment—for instance, the (de)territorialising impulse of people, fish and the sea (Bear, 2013)—have historically been amongst the drivers of internationalisation in the field (Hamblin, 2000; Rozwadowski, 2004). However, our analysis suggests that distant fishing interests also breed collaboration, as do distant colonial ties. As an illustrative point, with respect to the country clusters, the fishing interests of France and Spain which extend along the Eastern Tropical Atlantic and Western Indian Ocean (Campling, 2012), or those of the USA that extend into Pacific region (Hamblin, 2000; Havice, 2018), might reasonably be highlighted. As a further example, the well-documented research links that France has with its former colonies in North-West and West Africa (Adams et al., 2014) are apparent also in our analysis.

4.5 | Reinforcing or broad-based structures of knowledge production?

Thus far, we have been discussing the macro-level drivers of the fisheries science network. As indicated, however, sociologists of science have also stressed the role of micro-level characteristics in shaping the structure of scientific fields (Bourdieu, 1975). In line with this, an additional driver of collaboration highlighted in the literature relating to scientific networks is preferential attachment at the individual level (Wagner & Leydesdorff, 2005), with studies indicating that authors have a tendency to collaborate with "like-minded others" (Leahey, 2016), which may lead to a particular style of collaboration. Indeed, in this respect, it is worth noting here also that scholars have cautioned that scientific networks may well be even more spatially situated than they appear on a map, on account that prominent scientists and researchers in developing countries may have studied overseas, and in the very same universities as other international experts (Forsyth, 2003).

In this regard, whilst we have detected an increasingly collaborative field, albeit a regionalised one, our analysis of the fisheries

science network has identified structural characteristics that suggest the style of collaboration authors are engaging in is a thin one. For example, the number of intensely collaborative subnetworks (i.e., max cliques) in the network has increased over time. Further, though the number of authors and connections within each of the largest communities has increased quite rapidly, the number of potential connections within those communities that have been realised has only risen marginally, whilst at the level of the entire network the potential connections that have been realised have actually decreased over time. This pattern may indicate that though the network has become more collaborative, scholars are engaged in repeated collaborations within their subgroups, rather than forming new links beyond these (Leahey, 2016; Leahey & Reikowsky, 2008; Saetnan & Kipling, 2016). The points of intensification uncovered across the aggregated network and the disaggregated network would seem to support this suggestion.

This pattern may be reflective of the tendency of scholars to work within their own networks, rather than forming new links beyond those (Saetnan & Kipling, 2016), and may be driven by an array of factors. For instance, it has been suggested such a strategy may offer returns in terms of trust building and help mitigate against the cost of collaboration (Leahey, 2016). Scholars may also engage in repeat collaborations with others in their speciality area, who share methodological or theoretical perspectives (Leahey, 2016; Leahey & Reikowsky, 2008). In a sense, given the increasingly specialised nature of science (Casadevall & Fang, 2014), including fisheries science (Mather, Parrish, & Dettmers, 2008), we might expect these patterns. Indeed, existing research has highlighted that specialisation and collaboration in science are not unrelated (Leahey & Reikowsky, 2008). On the one hand, it is precisely this specialisation that is driving the need for collaboration (Casadevall & Fang, 2014; Leahey & Reikowsky, 2008). On the other, specialisation has been found to inform collaboration strategies, with scientists often having a tendency to engage in within-speciality collaboration rather than complementary collaboration that spans boundaries (Leahey & Reikowsky, 2008).

As indicated, adopting a specifically Bourdieusian perspective helps us to understand the role that power may play in directing these choices, and thus the structure of the scientific field in a broad sense (Bourdieu, 1975). From this angle, it is likely that the same drivers that work to homogenise fields as they develop (leading to increased specialisation) influence collaboration strategies also. For example, depending on one's position within the field, investments in intensive, specialised research (e.g., focusing on established questions, through the application of particular methods) may offer greater returns to the individual, rather than engaging in the riskier investment of extensive research beyond the limits of one's speciality (Bourdieu, 1975). This might explain why research has found that the steps to interdisciplinary science over the past three decades have actually been very small, oftentimes drawing on neighbouring fields and only modestly increasing the connections to areas further afield (Porter & Rafols, 2009). The danger with such a strategy, however, is that it can become a reinforcing style of collaboration (Leahey, 2016), which may have potential costs in terms of the production of novel information, and hindering exposure to heterogeneous ideas (Blondel et al., 2008). Given that much advancement in fisheries science has been cited as coming from the branches of the discipline rather than the roots (Francis, 1980, p. 95), this pattern may work to limit the development of the field in a direction that may equip it to address some of the ongoing challenges in the field.

4.6 | The topical landscape of fisheries science

Following on from this discussion, the topical foci we have uncovered across the scientific network are relatively consistent with previous analysis of the content of fisheries science (Aksnes & Browman, 2016; Jarić et al., 2012; Syed et al., 2018). This content has been discussed at length elsewhere, most recently by Syed et al., 2018; Syed and Weber (2018), and is therefore not reported on in detail here. That said, uncovering these foci is instructive, as it allows us to investigate whether the fisheries science communities are clustered around particular or similar topics (Clauset et al., 2004), how these may have changed and how they might be related (Moody & Light, 2006). In this respect, whilst our analysis indicates an almost across-the-board increase in publication output focused on Management, reflecting the increasing propensity of fisheries scientists in the West to focus their attention on managing human interactions with the natural environment, rather than managing fish per se (Bavington, 2010), a distinct geography of topics has been detected across the field. Though likely reflective of a combination of the macro- and micro-sociological characteristics we have discussed, this geography is further suggestive of the political and economic influences directing the research priorities in this field and the continuing dominance of specific ideas about fish and fisheries within this space.

Unsurprisingly, given that Western fisheries management has been built on, and remains based upon, calculations of maximum sustainable yield and the allocation of quotas (Campling et al., 2012; Finley, 2011; Nielsen & Holm, 2007; Winder, 2018), a number of the largest communities in the network remain heavily focused on Models (estimation & stock). In many respects, this has long been the central problem (Bourdieu, 1975) in this field and one that is not unrelated to the demands on fisheries scientists to provide numbers for policy. Similarly, reflecting the heavy spotlight on discarding in fisheries over the past two decades (Alverson, Freeberg, Murawski, & Pope, 1994; Borges, 2015; Kelleher, 2005), Gear technology & bycatch is a further area of strong topical focus for the largest community of authors within the network. Further, that a large proportion of the publication output of fisheries science is increasingly commanded by aquaculture-related topics is not unrelated to the rapid investment and consequent expansion in production this area has seen (Aksnes & Browman, 2016; Winder, 2018). As capture fisheries have continued to diminish, this area has been given increasing priority by both fisheries managers and governments (Bavington, 2010; Winder, 2018), as a growth strategy under the rubric of “blue growth” (Barbesgaard, 2018; Hadjimichael, 2018; Winder, 2018;

Winder & Le Heron, 2017), and this is reflected not only in the topical foci we have uncovered in the fisheries science network, but, as detailed, across the entire structure of the network.

5 | CONCLUSION

Broad-based collaboration, it is argued, is crucial to solving the challenges ongoing with respect to fisheries. In the light of this "collaboration imperative," we have mapped and examined the landscape of scientific collaboration across the field of fisheries science. Overall, our analysis has presented a shifting field that has become increasingly collaborative, though less cohesive, with a number of key players maintaining hegemonic positions within the network. By and large, the most productive (and collaborative) countries in terms of fisheries science are those which have large industrialised fisheries-related interests, many of them global in nature. Although China (along with a number of emerging economies) has become a formidable force in terms of volumetric output, the historical dominance of Western nations is apparent in a number of guises across the network.

Whilst the collaboration network has become more extensive, it has also become more intensive in places, with a clear spatial pattern evident in the structure of scientific collaborations across the field. In this respect, the fisheries science landscape is one whereby the centres of knowledge production and the connections between them display trends more akin to regionalisation than globalisation. Alongside this, some of the topological characteristics of the network (e.g., the decreasing levels of overall cohesion exhibited, dense points of geographical collaboration) suggest that authors across the field may be engaging in a repeat, rather than a broad style of collaboration, which may work as a reinforcing mechanism with respect to the knowledge that is produced by the field. This pattern is likely to limit the potential gains of collaboration and could have consequences in terms of pushing the boundaries of fisheries science in new and fruitful ways, in a manner which may help address some of the ongoing challenges within this area.

Though likely shaped by an array of both micro- and macro-sociological factors, the patterns of collaboration and the geography of topics uncovered across the field betray a number of political–economic influences, which merit reflection by both policymakers and scientists alike. For example, much of the expansion of the network appears to be mirroring shifting patterns of production (e.g., from capture to culture), whilst the topical output of the field remains tightly coupled to the demands of the policy landscape.

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DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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APPENDIX 1

The complete list of journals covered by the fisheries category as defined by the SCIE 2016–2017. This category spans a list of 50 journals covering all aspects of fisheries science, technology and industry. All 50 journals were included in the data set. IF = impact factor.

Rank	Journal name	IF	Publications
1	Fish and Fisheries	9.013	525
2	Reviews in Aquaculture	4.618	195
3	Reviews in Fish Biology and Fisheries	3.575	588
4	Fish & Shellfish Immunology	3.148	4,530
5	Fisheries	3	503
6	Aquaculture Environment Interactions	2.905	161
7	ICES Journal Of Marine Science	2.76	3,350
8	Aquaculture	2.57	8,551
9	Reviews in Fisheries Science & Aquaculture	2.545	321
10	Canadian Journal of Fisheries and Aquatic Sciences	2.466	3,446
11	Fisheries Research	2.185	3,683
12	Journal of Fish Diseases	2.138	1,408
13	Ecology of Freshwater Fish	2.054	938
14	Marine Resource Economics	1.911	378
15	Marine and Freshwater Research	1.757	2,202
16	Aquaculture Nutrition	1.665	1,403
17	Fish Physiology and Biochemistry	1.647	1,848
18	Fisheries Oceanography	1.578	714
19	Aquacultural Engineering	1.559	786
20	Diseases of Aquatic Organisms	1.549	2,528
21	Journal of Fish Biology	1.519	5,419
22	Transactions of the American Fisheries Society	1.502	2,266
23	Aquaculture Research	1.461	3,873
24	CCAMLR Science	1.429	156
25	Fisheries Management and Ecology	1.327	837
26	Knowledge and Management of Aquatic Ecosystems	1.217	342
27	North American Journal of Fisheries Management	1.201	2,359
28	Marine and Coastal Fisheries	1.177	291
29	Aquaculture International	1.095	1,383
30	Journal of the World Aquaculture Society	1.015	1,254
31	New Zealand Journal of Marine and Freshwater Research	0.938	1,003
32	Journal of Aquatic Animal Health	0.906	615
33	Fishery Bulletin	0.879	785
34	Journal of Applied Ichthyology	0.845	2,785
35	Fisheries Science	0.839	2,861
36	Journal of Shellfish Research	0.721	1,946
37	North American Journal of Aquaculture	0.715	1,035
38	Fish Pathology	0.673	415
39	Acta Ichthyologica et Piscatoria	0.67	538
40	Latin American Journal of Aquatic Research	0.594	583
41	California Cooperative Oceanic Fisheries Investigations Reports	0.586	177
42	Turkish Journal of Fisheries and Aquatic Sciences	0.484	825

(Continues)

APPENDIX 1 (Continued)

Rank	Journal name	IF	Publications
43	Aquatic Living Resources	0.448	710
44	Bulletin of the European Association of Fish Pathologists	0.431	630
45	Israeli Journal of Aquaculture-Bamidgeh	0.348	631
46	Boletim do Instituto de Pesca	0.295	232
47	Iranian Journal of Fisheries Sciences	0.285	516
48	Indian Journal of Fisheries	0.235	481
49	California Fish and Game	0.219	231
50	Nippon Suisan Gakkaishi	0.09	3
		Total	73,240

APPENDIX 2

Overview of the 16 uncovered latent topics, together with the top-10 high probability words, the prevalence (proportion in percentages) within the data set of 73,240 fisheries science publications, and a logical topic label that best captures the semantics of the latent topic.

Nos.	Topic label	Proportion	Top-10 high probability words
1	Management	10.51	fish, management, aquaculture, study, system, fishery, species, production, use, research
2	Aquaculture (growth effects)	8.76	day, larvae, growth, rate, survival, high, pond, group, feed, experiment
3	Habitats	7.11	fish, species, habitat, lake, site, prey, abundance, community, study, tilapia
4	Diet	6.98	diet, feed, fish, protein, acid, level, dietary, growth, lipid, weight
5	Immunogenetics	6.89	cell, gene, carp, tissue, sequence, protein, expression, analysis, show, muscle
6	Gear technology & bycatch	6.87	catch, sea, species, area, fishing, fish, net, fishery, depth, survey
7	Models (estimation & stock)	6.73	model, estimate, stock, data, population, fishery, rate, mortality, catch, size
8	Salmonids	6.6	river, trout, fish, salmon, rainbow, tag, hatchery, lake, oncorhynchus, rainbow trout
9	Diseases	5.89	infection, disease, isolate, meal, shrimp, fish, strain, parasite, virus, mortality
10	Climate effects	5.39	temperature, water, year, summer, period, change, abalone, high, winter, spring
11	Aquaculture (health effects)	5.13	water, concentration, treatment, mg, high, study, total, sample, quality, ph
12	Physiology	5.12	fish, activity, catfish, level, control, increase, effect, group, stress, response
13	Genetics	5.01	population, genetic, species, analysis, sample, region, study, locus, variation, marker
14	Age & growth	4.77	length, growth, size, mm, age, weight, fish, cm, total, estimate
15	Reproduction	4.53	female, egg, male, sturgeon, sex, stage, reproductive, spawning, spawn, sperm
16	Shellfish	3.71	oyster, shell, crab, mussel, clam, scallop, species, bivalve, injection, site