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Original Article

Tracking integrated ecosystem assessments in the ICES network: a social network analysis of the ICES expert groups

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The advice the International Council for the Exploration of the Sea (ICES) provides to its member countries is crucial for the sustainable management of shared marine resources, and the conservation of relevant marine ecosystems. In 2014, ICES made a strategic decision to integrate marine and social sciences in a new type of assessment framework called "integrated ecosystem assessments" (IEA) to deliver advice on societal trade-offs between different policy options. The IEA-focused expert groups formed before and after this period now cover all major ecoregions. To track the progression of IEAs in the ICES network over time, we conducted a social network analysis (SNA) on expert group attendance for the years 2015–2019. The IEA-focused expert groups generally ranked lower in the overall ICES network. Our study shows that some IEA-groups become more connected over time, while others decline. We also evaluated the role of workshops in the ICES network, particularly their role in the development of IEA knowledge. Our study shows that workshops play an important role in ICES network connectivity. The study demonstrates how social network analysis can be used to study an organization such as ICES and determine the effectiveness, or impact, of that organizational function.

Keywords: expert groups, ICES, information-sharing, integrated ecosystem assessments, social network analysis.

Introduction

Since its founding in 1902, the International Council for the Exploration of the Sea (ICES) has focused on meeting societal needs for impartial science and research on our oceans and the sustainable use of the marine resources within. Central to its work is the aim to "advance and share scientific understanding of marine ecosystems and the services they provide" (ICES, 2022b). This work is coordinated by the ICES Secretariat and supported by a network of over 6 000 marine scientists from over 700 institutions in 60 countries. Much of the ICES network is comprised of 150 Expert Groups that meet annually to conduct the scientific work that is used to generate high quality advice for conservation, management, and sustainability goals.

Over 100 years after its naissance, ICES leadership made a strategic choice in 2014 to integrate marine and social sciences in a new type of assessment framework called "integrated ecosystem assessments" (IEA), a framework with success in other large national marine science and advice organizations in North America (e.g. the National Oceanic and Atmospheric Administration; NOAA) and Australia (e.g. the Commonwealth Scientific and Industrial Research Organisation; CSIRO). The broad aim of ICES IEAs was to provide scientific knowledge and advice to ICES member countries for specific objectives on sustainability, adopting a holistic and comprehensive perspective to include information on physical, chemical, ecological, human, and environmental processes affecting regional seas and their ecosystems. To do so, ICES structured the IEA geographical areas using a regional seas approach and capitalized on existing interdisciplinary (social science and marine science) research groups within its network in Northern Europe.

IEAs are "a formal synthesis and quantitative analysis of information on relevant natural and socioeconomic factors, in relation to specified ecosystem management objectives" (Levin *et al.*, 2009), and have become a core component to the work of ICES. ICES itself defined IEAs at the 2012 Workshop on Benchmarking Integrated Ecosystem Assessments (WKBEMIA) as an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the interactions of a problem can be evaluated to provide useful information to decision-makers (ICES, 2013; Dickey-collas, 2014). What sets IEAs apart from other ecosystem assessments is the integrated nature of the information analyzed, which aims to "underpin guidance on meeting **ecological**, **social**, and **economic** objectives" (ICES, 2022a) (*emphasis Author's own*). Given the growing interest in IEAs within the scientific and management communities, it becomes necessary to understand not just how IEAs are, or can be, conducted, but also how emerging knowledge on them is, or can be, shared between groups for enhanced critical analysis on the assessments

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Table 1. Acronyms and full titles of ICES Expert Groups for integrated ecosystem assessments.

ICES Acronym	Full title	Year of est.[1]
WGIAB	Joint ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea	2007
WGNARS	Working Group on the Northwest Atlantic Regional Sea	2010
WGEAWESS	Working Group on Ecosystem Assessment of Western European Shelf Seas	2011
WGINOSE	Working Group on Integrated Assessments of the North Sea	2011
WGINOR	Working Group on the Integrated Assessments of the Norwegian Sea	2013
WGCOMEDA	Working Group on Comparative Ecosystem-based Analyses of Atlantic and Mediterranean marine systems	2014
WGIBAR	Working Group on the Integrated Assessments of the Barents Sea	2014
WGICA*	ICES/PICES/PAME Working Group on Integrated Ecosystem Assessments for the Central Arctic Ocean	2016
WGIAZOR	Working Group on Integrated Assessment of the Azores	2020
WGIEAGS	Working Group on Integrated Ecosystem Assessment of the Greenland Sea	2020
WGIEANBS-CS	Working Group on Integrated Ecosystem Assessment of the Northern Bering Sea-Chukchi Sea	2021

*In 2015 WGICA was known as the ICES/AMAP Workshop on Integrated Ecosystem Assessment for the Central Arctic Ocean (WKICA).
[1]Determined by the year of the first published meeting report.

and the application of the assessments to management and policy.

As a science network, ICES responds to the latest ecological challenges by providing scientific advice to its members, thus adopting the de facto role of a "science leader" for collaborative learning and solving complex environmental problems. This includes much of the scientific knowledge used for IEAs. In such a leadership role, the ICES network provides the core support for IEA science, and thus impacts that science at the regional and international scales. Maintaining and optimizing the ICES network to further support IEA science is an increasingly important aspect of organizational management and responsible leadership for a more sustainable world, especially considering that IEAs and interdisciplinary sciences are crucial to understanding how to bring about social and systems change.

Under the framework of the ICES Integrated Ecosystem Assessment Steering Group (IEASG), Expert Groups develop quantitative and interdisciplinary evaluations and syntheses of biophysical and human social information to provide the scientific understanding to deliver advice on societal trade-offs between different policy options (ICES, 2022a). Twenty-two expert groups exist under the IEASG, with 11 of those Groups specific for IEAs (Table 1). These IEA expert groups were established as early as 2007 (the Joint ICES/HELCOM Working Group on Integrated Assessment of the Baltic Sea—WGIAB), with the most recent inauguration in 2021 (the Working Group on Integrated Ecosystem Assessment of the Northern Bering Sea-Chukchi Sea—WGIEANBS-CS).

With these IEA expert groups ICES now covers all its ecoregions (Figure 1), which presents new opportunities and challenges for regional scientific collaboration.

ICES expert groups are comprised of scientists from various background to generate scientific knowledge and conduct the analyses that underpin ICES advice. In total, ICES hosts 150 expert groups (as of the time of writing). ICES expert groups are considered to include two types of groups: working groups (statutory groups with terms of reference updated triennially), and workshops (more ad-hoc meetings to discuss issues as needs arise). Some workshops meet regularly, some meet only once. In this paper, "expert groups" refers to working groups and workshops, unless otherwise specified. The study specifically looks at the impact of workshops on the overall connectedness of the ICES network because of the relatively ad-hoc

Figure 1. Regional sea areas covered by ICES integrated ecosystem assessments. Map reproduced with permission from the ICES Secretariat (ICES, 2020).

nature of workshops but with much evidence that workshop outputs are key inputs to ICES scientific advice. Measuring the impact of workshops on the ICES network structure can help to target resources to support the timely organization of workshops and ensure their outputs are integrated in an efficient way to ICES.

A growing field of research in the last three decades has interested itself with how organizations function and how their structures influence this function, such as the study of organizational knowledge (Blackler, 1995), organizational culture (Hatch & Schultz, 1997) (Schneider, Ehrhart, & Macey, 2013), organizational learning (Lam, 2000), and organizational innovation (Alves & Galina, 2018). The theoretical framing for this research is social network analysis, which can be used to study how organizations and institutions interact, and how the quantity and quality of those interactions then determines the effectiveness, or impact, of that organizational function. How connected are the ICES expert groups to each other, and does the type of connection determine the level of influence those groups have?

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The application of social network analysis (SNA) to the study of institutional structures and networks broadly agrees that better organization at the institutional level means better aligned policies and action (Böhmelt & Spilker, 2016; Schlattmann, 2017; Karali *et al.*, 2020), and therefore exposing the network structure of institutions allows us to evaluate where collaborations and connections could be improved. This has particular significance for an organization like ICES, which relies on networks of groups and sub-groups to perform its work. These "networks" do not exist in isolation from one another, and by acting as both a "source" and a "target" for information, these institutional network structures are conditionally shaped and informed (Böhmelt & Spilker, 2016). SNA can also be used to increase awareness among ICES managers and leaders about the scientific and collaborative power of its network, to further optimize relationships and connections among expert groups, and strengthen the capacity of the ICES network to act collectively (Hoppe & Reinelt, 2010).

Furthermore, understanding the network structure of an institution with multiple sub-groups, or expert groups such as in ICES, and the information sharing of scientific knowledge or institutional goals can help reduce variability, uncertainty, and duplication of efforts among the sub-groups with regards to what the other expert groups are working on. Expert groups have their own terms of reference and individual mandates, in particular the expert groups focused on IEAs, but without a consistent or clearly harmonized structure of how the different initiatives fit (or should fit) together, expert group members might spend a considerable amount of time networking with other groups in an attempt to coordinate their work, which might lead to a high number of connections but not necessarily improved outputs (Bodin, 2017).

Given the multi-institutional and intergovernmental nature of the organization, ICES offers a unique perspective on the functionality of international cooperation and collaboration in the pursuit of common goals. This unique perspective drives the key research framework for this study, which aims to understand where the IEA network is nested within the broader structure of ICES, and how the IEA network supports the development of IEA knowledge for ICES member countries. In pursuing this research, the scope of the evaluation also included how knowledge is fostered in the ICES network in general.

Our research objectives were to track the development of regional IEAs over time and to assess the role of workshops in the ICES network. To achieve these objectives, the degree of connections between ICES expert groups in the ICES network were compared over time and the overall network cohesion affected by the presence or absence of workshops determined. We hypothesized that (1) IEA-focused expert groups become more connected with the overall ICES network over time and their network position relative to other meetings becomes more influential, and (2) the presence of workshops serves to play an important role in ICES network connectivity, which would be indicated by a higher density of the ICES network compared to one excluding workshops.

Methods

This paper builds up on previous work of the ICES Working Group on Maritime Systems (WGMARS) applying SNA to ICES (see supplementary material). The authors used the ICES database of attendees at expert group meetings to quantify the connectivity (the number of shared experts between different groups) of an expert group in relation to other expert groups for each year from 2015–2019. ICES classifies "expert groups" as an umbrella term that includes both working groups and workshops.

Social network analysis (SNA) is a common method to study patterns of interactions among actors that make up complex networks. The graphical output of these networks, called sociograms, provide a visualization of that network. SNA also allows for quantitative metrics to be computed based on the ties connecting the actors (the links between them), to understand the different roles of the actors within that network. For example, seeing which actor is most connected to others in the network could be used as a proxy indicator for influence or impact. A network is defined by a finite set of nodes (i.e. individuals or groups) and by the links (i.e. "edges," relationships, or connections) that tie two or more individuals or groups to each other (Wasserman & Faust, 1994; Borgatti *et al.*, 2009; Hafner-Burton *et al.*, 2009; Ward *et al.*, 2011; Maoz, 2012). Our study focuses on working groups and workshops as the "nodes," with mutual participation by attendees as the direct links, or connections (also called "edges"), between groups. In this SNA study, we considered individual attendance at one or more meetings to be an "interaction" to represent communication and collaboration among the ICES groups. It follows that more mutual members indicate stronger ties to transfer knowledge and information between the groups (Böhmelt & Spilker, 2016).

ICES data

We used an extraction of the ICES database for the years 2015–2019, which was provided to the authors by the ICES Secretariat. The information included lists of all attendees to all expert groups that took place within those five years, as well as metadata on each meeting (e.g. whether it was a working group or workshop). Personal or identifying information about each attendee was not included in the data provided to the authors. The original database of over 20 000 entries was intensively cleaned and filtered to exclude "non-attendees" (i.e. individuals who registered for meetings but did not physically attend) and irrelevant meeting types (see supplementary material for a full list of ICES meetings not included in the analysis). The year 2020 was not included in the analysis due to complications with COVID-19 travel restrictions, and uncertainty about meetings taking place during that time. The expert groups included in the final analysis were, in general, working groups and workshops that had physical meetings, and which were not considered supplementary (e.g. breakout group meetings) or preparatory (e.g. data preparation meetings) in their objectives.

The ICES database provided an array of information that included: a unique identifier, or code, for individuals who registered for the meeting; a unique identifier for each meeting; an acronym of the meeting; a Boolean value to indicate if the person attended the meeting (1) or not (0); and the type of meeting (e.g. ACOM, ADG, benchmark, expert group, etc.). Individual meeting records that provided details on dates and locations of the meetings were consulted from the ICES meeting repository, meeting reports (if available and published online), expert judgement of the authors with knowledge of the specific meeting, and, if necessary, direct contact with the meeting

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Table 2. Definitions for the SNA analytical measures calculated in this study (table adapted from Oliveira & Gama, 2012).

SNA measures	Definition
Density	The number of connections observed in a network divided by the maximum number of possible connections, denoted as a value between 0.0–1.0 (De Laat *et al*., 2007).
Degree centrality	A measure of connectedness; the number of connections (i.e. shared attendees) each expert group has with other expert groups (Golbeck, 2013). Measures the importance and influence of a node in a social network (high degree = high importance).
Betweenness centrality	A measure of how important an expert group is to the shortest paths through the network (Golbeck, 2013).
Isolates	A node that is not connected to others within a network (Wasserman & Faust, 1994).

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Chairs to verify details such as number of attendees, type of meeting, etc.

In line with our objectives, the data were refined by unique attendees and type of expert group (i.e. working groups or workshops). The analysis focused on the eight IEA-focused expert groups established before 2020 (see Table 1 for full titles): WGIAB, WGNARS, WGEAWESS, WGINOSE, WGINOR, WGCOMEDA, WGIBAR, and WGICA. The analysis also included the top three ranked expert group meetings by degree centrality, for comparison purposes. Data collection took place in January 2020 in collaboration with the ICES Secretariat.

Data analysis

All SNA centrality measures were calculated using the Software UCINET (Borgatti *et al*., 2002). Final network visualization was conducted using UCINET and *Gephi* (Bastian *et al*., 2009). Centrality measures direct attention to the potential importance of individual nodes based on how they are situated in the network. There are many ways to assess centrality (Wasserman & Faust, 1994; De Laat *et al*., 2007; Everett & Borgatti, 2010; Oliveira and Gama, 2012; Scott, 2017), but the most basic measure is degree centrality. In this study, the degree centrality measure calculates the number of connections (shared attendance) one expert group has with another. However, the number of shared connections is not equivalent to the number of participants in each group. A single individual could be responsible for more than one shared connection if they are also attending several other expert groups in the same year.

Another important aspect of centrality rests in a node's potential importance in connecting other nodes, i.e. being an intermediate (the betweenness measure). This aspect could be of particular importance in relatively sparse networks (low or medium density) since not that many nodes are directly connected with each other. Thus, the prominence of betweenness centrality builds on a different assumption of importance relative degree centrality—i.e. a node might be important not because it is connected to many others, but it connects many others (Freeman, 1979). Nodes with high betweenness scores are considered to be "gatekeepers" because they tend to control the flow of information between tightly-knit groups. We also looked at the number of isolates in each network as an indicator of general connectedness.

Although the are many ways to assess to what degree a network brings together its nodes, the perhaps most basic measure is density. It is widely used in network-centric studies across disciplines since the interpretation is intuitive but informative (Freeman, 1979; De Laat *et al*., 2007; Oliveira and Gama, 2012; Fischer, 2015; Scott, 2017; Bodin *et al*., 2020). In other words, are the nodes realizing their networking potential in the sense that they have formed links with the other nodes in the network? The more links a node have (and/or how strong these links), the more prominent it could be in relation to the other nodes based on its sheer number (and/or strength) of links.

The workshop analysis aimed to compare the two overall ICES networks: one including workshops and one excluding workshops. This was primarily to understand the relative importance of workshops, due to their *ad hoc* nature, and if their presence increased the number of connections in the network. The density measure is a general performance indicator for networks and provided a calculation of the number of connections observed within a network compared to the maximum number of possible connections. It reflects the general level of connectedness in a network via a value from 0.0 (a network with zero connections) to 1.0 (a perfectly and completely connected network). In other words, the more expert groups connected to one another through shared participation, the higher the density value for that network and the denser the network will be.

Analyzing these four values for each network (density, degree, betweenness, and the number of isolates) allows for a broad interpretation of the relative importance of expert groups in the overall network, and thus the relative influence those groups have on the dissemination of information to the overall body of knowledge in ICES. The measures included in this study are summarized in Table 2.

The analysis of the importance of workshops looked at the network as a whole and not into the role of individual groups (nodes) and on the role of workshops to connect the IEA groups. The latter analysis used links between the eight IEA-groups differentiated by shared connections *via* workshops and shared connections *via* working groups (Figure 2). Removing the workshop links from that sub-network revealed a composition of the IEA-groups without the influence of workshops.

To compare the network with and without workshops, we used weighted density values of the whole ICES network with and without workshops. We used the dataset from 2019 with all groups included and with all workshops removed and estimated the density of both networks. The two analyses could not be compared quantitatively because the smaller network, which excluded the workshops and included the working groups only, would have had a higher density value (due to fewer nodes in total). However, it still gave an indication of whether the workshops did play a large role, as we assumed they did.

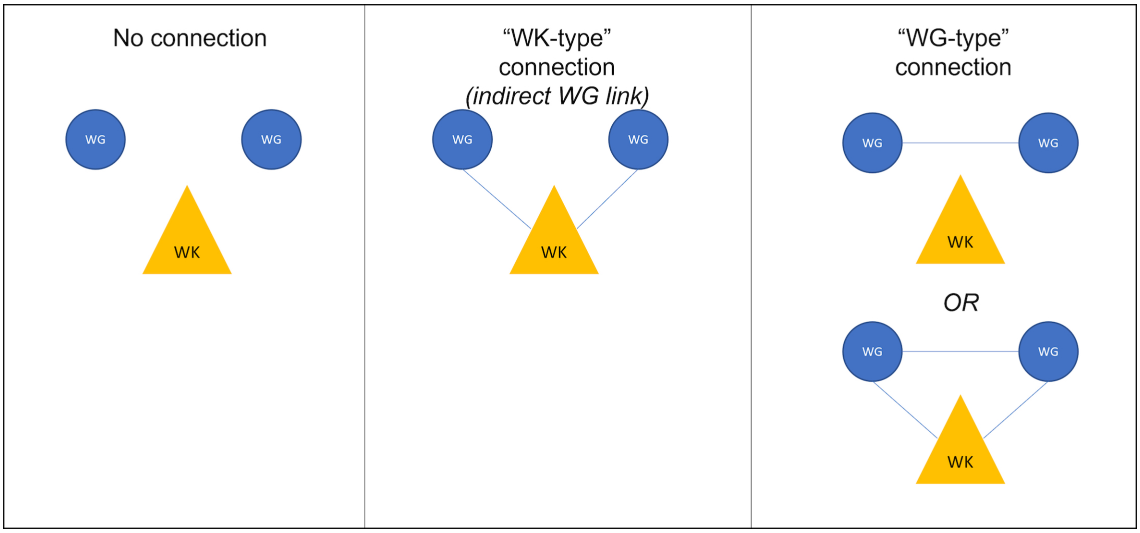

Figure 2. A visual explanation of connections (shared attendance; blue lines) determined for the workshop analysis. Blue circles denote working group nodes present in the network. Yellow triangles denote workshops present in the network. The connection type in the center column is considered a "workshop-type" connection because the two working groups are only linked via a workshop (i.e., shared attendance/link through a workshop). In the right-hand column, the connections are "working group-types" because the working groups are linked regardless of the presence of a workshop.

Table 3. Meta-summary statistics calculated for ICES expert groups from 2015 to 2019, using meeting attendance data provided by the ICES Secretariat.

	Total number EGs (WGs + WKs)	Number of WGs	Number of WKs	Unique attendees for the year (EGs)∗	Cumulative attendances for the year (EGs)
2015	126	89	37	1 603	2 455
2016	135	86	49	1 821	2 681
2017	132	90	42	1 648	2 575
2018	145	99	46	2 148	3 236
2019	154	99	55	2 341	3 645

EGs = expert groups
WGs = working groups
WKs = workshops
∗All attendees for the year filtered to remove "repeat attendances" (e.g. one person attending more than one meeting per year). This value indicates the core number of individuals who attended expert groups in one year. Obviously, an individual can attend more than one expert group meeting in a year, and this cumulative value is reflected in the last column on the right.

Results and discussion

Social network analysis of ICES IEA expert groups

ICES has been steadily growing over the last five years as indicated by the increasing number of working groups and workshops, and the increasing number of participants per year (Table 3).

This could be an indication that the workload within ICES is increasing, which requires more participation and individual scientific support to get the work done. In addition, an increasing number of workshops means more dedicated work on specific issues, and people outside the core membership of an ICES working group can be attracted to workshops because of their timely relevance and focus.

With an increasing number of individuals, we expected to see more nodes and ties within the network, and this is evident from the sociograms for each year from 2015–2019 (Figure 3), which suggests more shared connections between the nodes (as the sociogram networks become denser over time).

The study considered all the expert groups (working groups and workshops) for each year of analysis and provided a longitudinal comparison over five years. Tables 4, 5, 6, 7, and 8 provide an overview of the top three connected groups for each year based on the calculated centrality measures for degree and betweenness. Tables 4–8 also include the centrality measures for all eight IEA-focused groups, even though none of them (with one exception that we discuss further on) ranked in the top 10 for degree centrality. Complete tables with centrality measures for all expert groups, by year, can be found in Supplementary Material.

Shared links (i.e. one or more individuals attending both meetings) between expert groups can allow for the spread of information on working procedures, regulations, or performance in general and this then influences the performance of the expert groups. Accordingly, an "important" group would have a greater number of shared linkages (Böhmelt & Spilker, 2016), or a high degree centrality measure, and therefore two well-connected IEA groups are likely to contain similar scientific and knowledge profiles. While the results indicate a general trend where expert groups with a higher degree centrality measures also had high betweenness centrality measures (Tables 4–8), the authors did not systematically verify this.

Interpreting the centrality measures in Tables 4–8 shows that, in 2015, WGCOMEDA ranked the highest out of all IEA-focused groups for degree centrality, with a total of 15 shared connections with other expert groups that year. This means that there were 15 connections between WGCOMEDA and one or more expert groups that year. However, this does not indicate that 15 unique individuals attended other expert groups (22 individuals attended the 2015 WGCOMEDA

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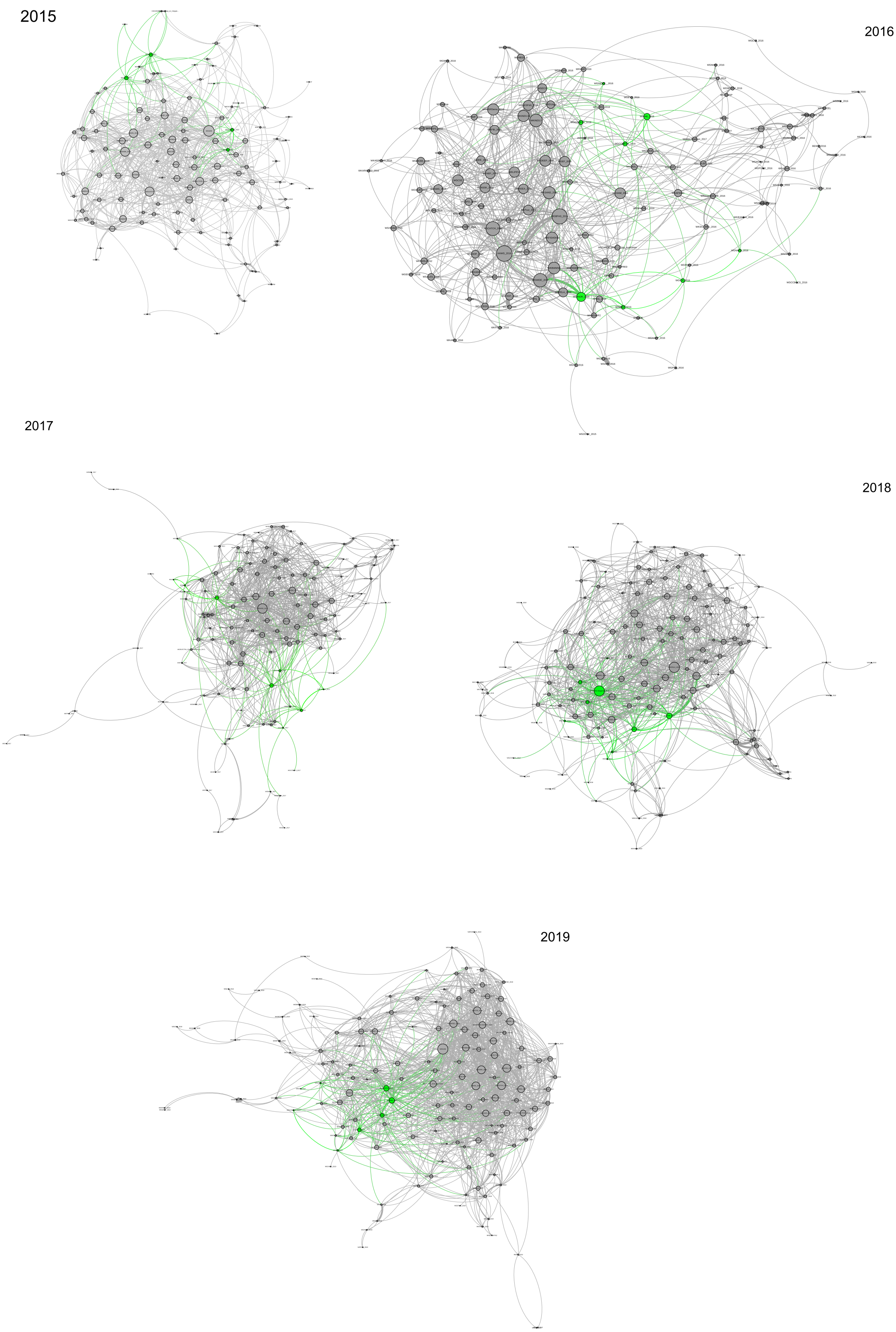

Figure 3. Sociograms created for 2015–2019 showing all ICES expert groups for each year, with IEA-focused Groups highlighted in Green (sociograms created with *Gephi*). Figures have been cropped to the network web, and full sociograms (including isolates) can be found in supplementary materials. Isolates for each year are noted in Tables 4–8 in this manuscript. The layout and node position in each of the sociograms is random, determined by *Gephi*. However, the graphs are usually laid out with "force-based" algorithms, where linked nodes attract each other, and non-linked nodes are pushed apart (*Gephi* tutorial).

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Table 4. ICES expert groups convened in 2015 with associated social network analysis metrics. The table shows the top three expert groups ranked by degree centrality, and the IEA-focused groups. The *Ranking* score indicates the relative ranked position of each group according to its degree centrality measure, in relation to the total number of expert groups for that year. The analysis revealed seven (7) isolates (WGMRE, WGMS, WGBEC, MCWG, WGDAM, WGMABS, WGPDMO).

2015			
Ranking	Id	Degree measure	Betweenness measure
1	WGSAM	43	901.609
2	WGCATCH	37	287.926
3	WGWIDE	36	457.836
38	WGCOMEDA	15	123.585
43	WGINOR	14	202.13
51	WGIBAR	13	149.925
64	WGEAWESS	11	8.768
65	WGIAB	11	8.981
94	WKICA*	4	0
114	WGINOSE	2	4.426
121	WGNARS	1	0
127	**TOTAL EXPERT GROUPS ASSESSED FOR 2015**		

* In 2015 WGICA was recorded as the ICES/AMAP Workshop on Integrated Ecosystem Assessments for the Central Arctic Ocean (WKICA).

Table 5. ICES expert groups convened in 2016 with associated social network analysis metrics. The table shows the top three expert groups ranked by degree centrality, and the IEA-focused groups. The *Ranking* score indicates the relative ranked position of each group according to its degree centrality measure, in relation to the total number of expert groups for that year. The analysis revealed zero (0) isolates.

2016			
Ranking	Id	Degree measure	Betweenness measure
1	HAWG	34	452.914
2	WGBFAS	33	958.83
3	WGCATCH	30	282.681
23	WGINOR	19	412.963
39	WGIAB	13	176.099
75	WGCOMEDA	8	43.949
77	WGEAWESS	8	15.03
85	WGIBAR	7	34.666
86	WGICA	7	126.112
98	WGNARS	5	136.125
112	WGINOSE	4	3.646
135	**TOTAL EXPERT GROUPS ASSESSED FOR 2016**		

meeting in 2015; (ICES, 2015), but that possibly one person or several individuals comprised 15 total attendances to other meetings in the same year. However, WGCOMEDA ranks lower for betweenness measure (123.58) than for the two expert groups below it in Table 4: WGINOR (14 degree measure; 202.13 betweenness measure) and WGIBAR (13 degree measure; 149.92 betweenness measure). This indicates that although WGCOMEDA had 1–2 more shared connections than either WGINOR or WGIBAR, both of the latter groups (especially WGINOR) occupied a more critical position in the network structure with regards to acting as a "gatekeeper" or intermediary for information flow.

Except for 2018, none of the IEA groups were included in the top three ranking for degree centrality, indicating that none of these groups are very influential in ICES. The 2018 WGINOSE-Skagerrak meeting was the top-ranked for that year in terms of degree (Table 7; Figure 4), however, a closer inspection of the meeting itself revealed that it was a workshop attracting 21 attendees. The regular annual WGINOSE meeting later that year was attended by seven people. For further details on the case of the 2018 WGINOSE-Skagerrak meeting, please see supplementary materials.

Table 6. ICES expert groups convened in 2017 with associated social network analysis metrics. The table shows the top three expert groups ranked by degree centrality, and the IEA-focused groups. The *Ranking* score indicates the relative ranked position of each group according to its degree centrality measure, in relation to the total number of expert groups for that year. The analysis revealed three (3) isolates (MCWG, WGEXT, WGPDMO).

2017			
Ranking	Id	Degree measure	Betweenness measure
1	WKWIDE	57	891.591
2	WGNSSK	39	430.452
3	HAWG	36	320.899
22	WGINOSE	21	610.449
26	WGINOR	20	459.505
51	WGIAB	13	225.73
60	WGEAWESS	11	56.67
82	WGIBAR	7	60.787
96	WGNARS	5	127
101	WGCOMEDA	4	19.23
110	WGICA	3	0
132	**TOTAL EXPERT GROUPS ASSESSED FOR 2017**		

Table 7. ICES expert groups convened in 2018 with associated social network analysis metrics. The table shows the top three expert groups ranked by degree centrality, and the IEA-focused groups. The *Ranking* score indicates the relative ranked position of each group according to its degree centrality measure, in relation to the total number of expert groups for that year. The analysis revealed one (1) isolate (WGPDMO).

2018			
Ranking	Id	Degree measure	Betweenness measure
1	WGINOSE-Skagerrak	50	922.376
2	WKPELA	50	459.339
3	WGMARS	37	575.94
17	WGINOR	26	319.624
29	WGIBAR	22	183.696
50	WGINOSE	16	30.854
57	WGEAWESS	15	29.666
94	WGIAB	8	12.423
103	WGNARS	7	146.66
115	WGCOMEDA	5	2.312
125	WGICA	4	5.289
145	**TOTAL EXPERT GROUPS ASSESSED FOR 2018**		

Role and function of ICES expert groups

The results also reveal that the centrality measures of degree (number of shared attendees) and betweenness (the position of the node with regards to other nodes) are not necessarily correlated. This means that even if one group has many connections (a high degree measure), it does not necessarily follow that they have a high betweenness measure, which would indicate that the node occupies a critical role in the network structure and is therefore important for connections with other nodes. For example, in the 2015 analysis, WGSAM is ranked the highest with a degree of 43 (i.e. 43 shared connections) and has a betweenness value of 902. However, the

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Table 8. ICES expert groups convened in 2019 with associated social network analysis metrics. The table shows the top three expert groups ranked by degree centrality, and the IEA-focused groups. The *Ranking* score indicates the relative ranked position of each group according to its degree centrality measure, in relation to the total number of expert groups for that year. The analysis revealed four (4) isolates (WGEUROBUS, WGHIST, WGBEC, WGECOA).

2019			
Ranking	Id	Degree measure	Betweenness measure
1	WKIrish6	61	578.959
2	WGCATCH	47	258.878
3	WGWIDE	47	263.071
19	WGEAWESS	32	175.467
21	WGIBAR	32	416.322
51	WGINOR	22	112.258
54	WGINOSE	21	73.605
107	WGIAB	8	11.358
117	WGNARS	6	1.594
120	WGCOMEDA	5	6.528
138	WGICA	2	0
154	**TOTAL EXPERT GROUPS ASSESSED FOR 2019**		

second-highest ranked group is WGCATCH with a degree of 37 (i.e. 37 shared connections) and a betweenness value of only 288. This is interesting because it indicates that although many WGCATCH members attended other meetings that year, these attendances did not serve much to connect WGCATCH with other expert groups. To understand this better, further analysis is needed to identify the type, or "quality," of connections between groups: who are the individuals that are making up these connections, and what is it about their background and qualifications that determines if they play critical roles as intermediaries or key connections?

The analysis looked at the variation of the degree centrality measure over time to see if this was correlated in any way with the size of the meetings (i.e. the number of participants). Figure 4 illustrates this and reveals that, over time, most IEA-focused expert groups (five out of eight in the analysis: WGINOR, WGIBAR, WGEAWESS, WGINOSE, and WGNARS) in our analysis have a generally increasing number of shared connections with other meetings (i.e. an increasing degree measure over time, as indicated by the increasing trendlines). On the other hand, WGIAB, WGCOMEDA, and WGICA have a decreasing number of shared connections with other groups over time, which suggests they are becoming less connected (more isolated). However, for all eight IEA-focused working groups there is somewhat poor fit of the line to the data. Therefore, we assume that most of the participants to the 2019 WGCOMEDA meeting are relative "outsiders" to the ICES network in general because they did not attend any other expert groups that year.

Figure 5 shows a similar graph for the betweenness centrality measure, however the trendline fit is very poor for five of the working groups (WGINOR, WGIAB, WGINOSE, WGICA, and WGNARS). The trendlines for WGIBAR, WGEAWESS, and WGCOMEDA fit moderately well, and show that WGIBAR and WGEAWESS both have increasing betweenness scores over time, indicating they are occupying an increasingly important role in the network, while WGCOMEDA is not.

Overall, some general indications can be made, for example, with WGINOR which has an *increasing trend for the degree measure over time* (indicating more shared connections over

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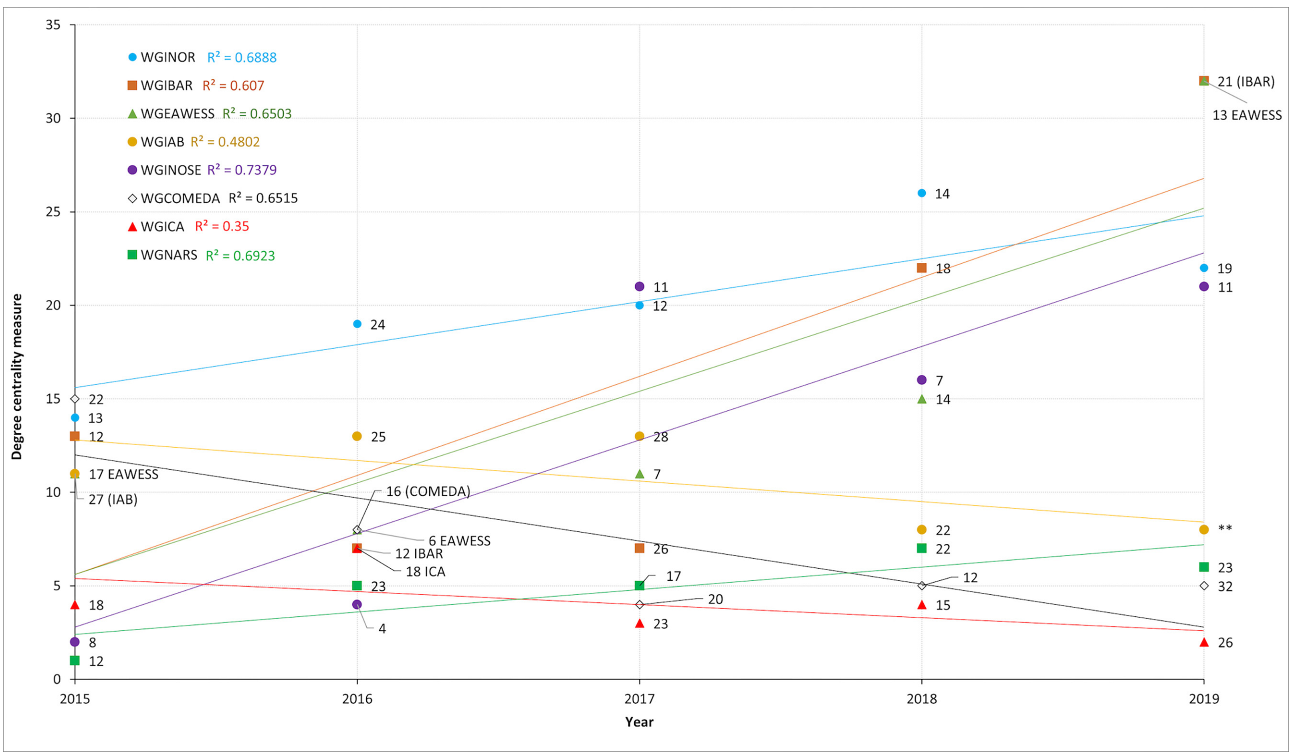

Figure 4. Graphical representation of the degree centrality measure over time (2015–2019) per IEA-focused group (data points). Lines represent the linear trendlines, with associated R^2 values in the legend. Values at each data point represent the number of participants for that meeting, taken from the meeting reports (** = no participant information available).

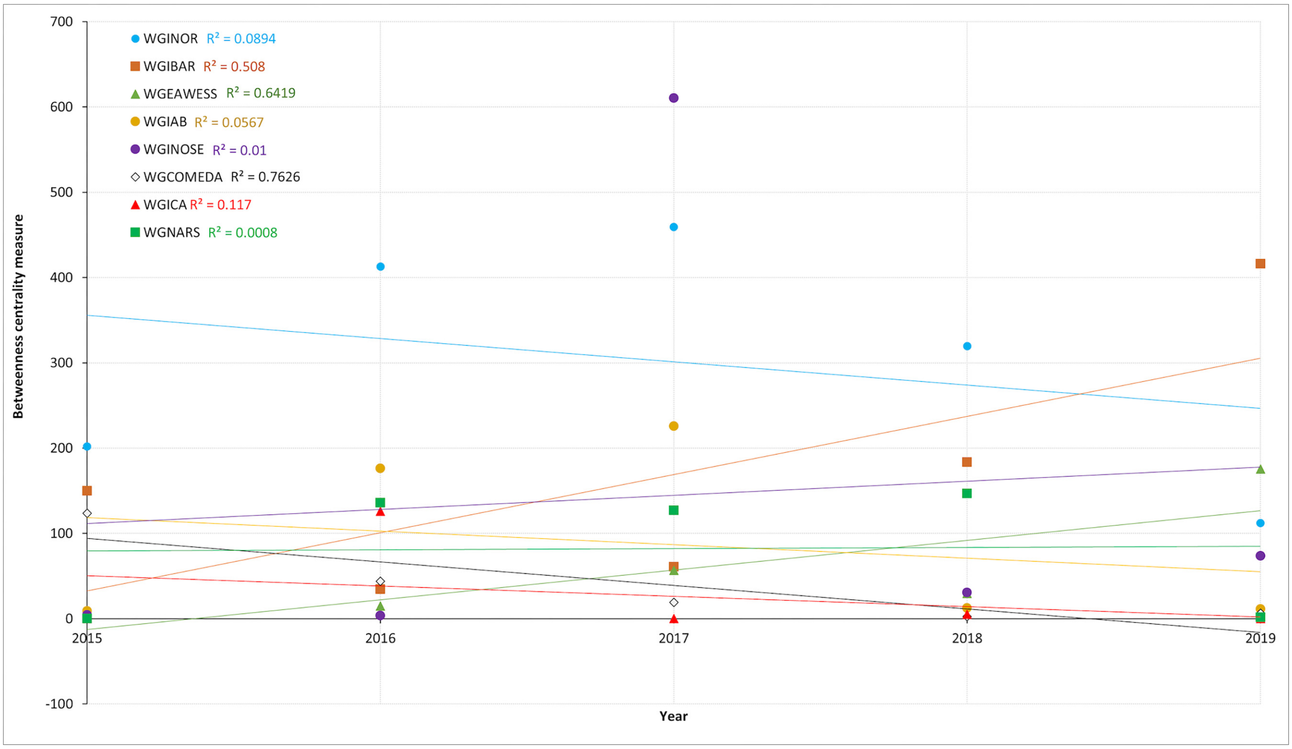

Figure 5. Graphical representation of the betweenness centrality measure over time (2015–2019) per IEA-focused group (data points). Lines represent linear trendlines, with associated R^2 values in the legend.

time), and a *decreasing trend for betweenness measure over time* (the working group is occupying a less critical role in the network over time). Thus, this indicates more connections between WGINOR and other groups, but these connections are becoming less influential.

Of the eight IEA-focused expert groups studied in this analysis, three diverged from our first hypothesis that over time these IEA-groups would become more connected to the rest of the ICES expert group network as they become more well-known and the IEA work more robust. Over time, WGIAB, WGCOMEDA, and WGICA had fewer connections (shown by the decreasing degree centrality measure, Figure 5) and decreasing influence (shown by the decreasing betweenness score, Figure 6). This result may be a reflection of the nature of the ecosystem areas covered by these expert groups. The sea basins of the Mediterranean (WGCOMEDA), the Baltic (WGIAB), and the central Arctic (WGICA) are more closed systems when compared with the other IEA areas (i.e. the North Sea, Norwegian Sea, Barents Sea, etc.). As such, the nature of these three ecosystems may limit the need for or relevance of outside-shared participation with other groups, hence the decreasing trends in degree and betweenness centrality. There is a risk that the IEA knowledge acquired in these ecoregions is developed in isolation and is isolated from the rest of the ICES network and therefore has no relevant influence on, for example, assessment working groups in these ecoregions. This offers an opportunity for ICES to consider enhancing support to these groups to advance IEA advice for these ecoregions.

The results support our hypothesis in general that while there is a plethora of IEA-knowledge within ICES, the sources of this knowledge are not generally well-connected to each other or to other expert groups in the network. All IEA-focused expert groups included in our analysis ranked low in terms of shared participation when compared with other expert groups in the network. This suggests that the individuals involved with the IEA-focused expert groups are specialized in their expertise and knowledge and rarely attended other expert groups. This circumstance could also be a sign for a more fundamental structural problem concerning intentional links between IEA-groups and, for example, assessment expert groups. In a situation where constituencies are developing a stronger demand for integrated ecosystem-based advice, it is essential that IEA and assessment expert groups are working together and agree on the data needed to support the scientific advice.

Role of workshops in ICES IEAs

We found strong support for our second hypothesis that workshops play an important role in ICES network connectivity. The workshop analysis revealed that the full ICES network, including both working groups and workshops, had a higher density of 0.144 (total nodes 154, edges 1345) compared to the full ICES network excluding workshops with a density of 0.101 (total nodes 99, edges 492). This result suggests that, in this case, workshops indeed play an important role in the overall connectivity of the network when they are present, compared to when they are excluded (Figure 6). This finding is even more pronounced, as a smaller network (the ICES network excluding workshops) should have a higher density, which we could not confirm. This result was supported by a more detailed analysis of the workshop's influence on a network comprising of the eight IEA-focused working groups. The density in the IEA subnetwork rose considerably when

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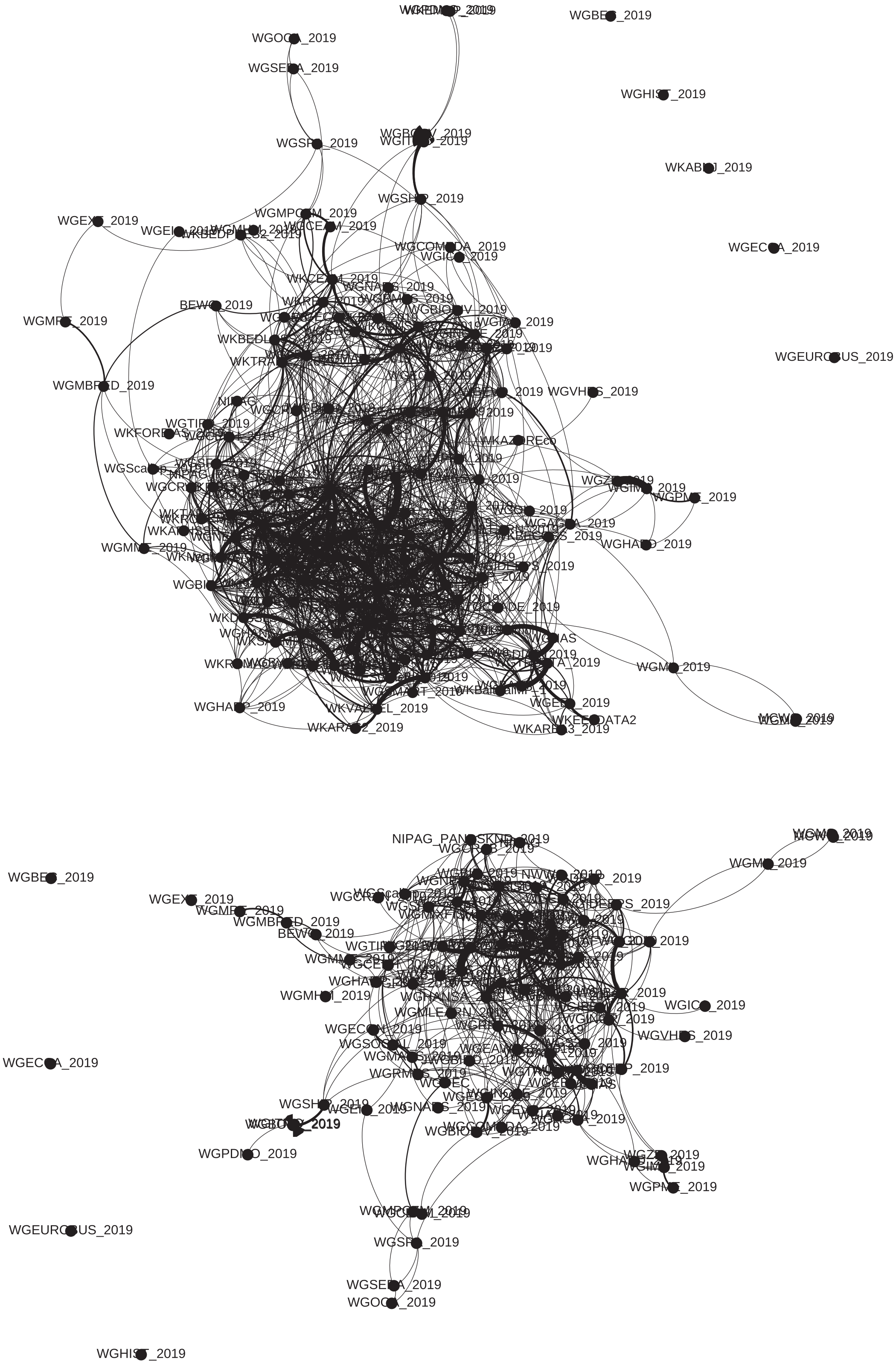

Figure 6. Network structure comparison of the ICES expert group network for 2019 including workshops (top figure) and excluding workshops (bottom figure). Graphs produced with *Gephi.*

including workshops into the analysis (Figure 7). Without workshops, WGNARS became isolated and was unconnected to the other working groups through shared participation. This result was supported by the density calculations for the sub-network with all connection types (0.786 density) and with connection types excluding Workshops (0.321 density).

Both workshop analyses show the fundamental structural role of workshops to connect otherwise disconnected

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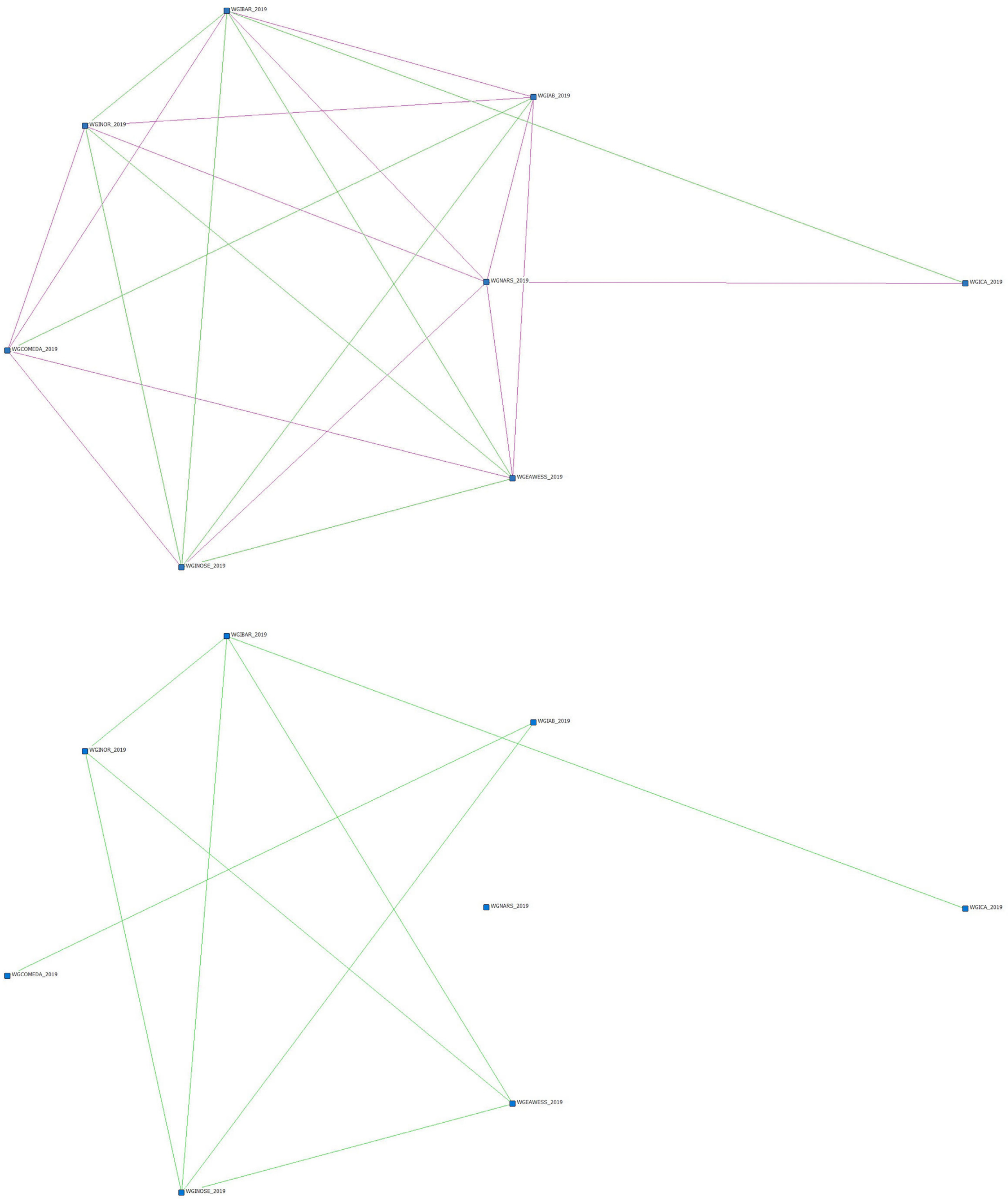

Figure 7. Sociograms for the sub-network of the eight IEA-focused working groups with green lines indicating *working group* connections and pink lines indicating *workshop* connections. Top image is the sub-network with both connection types, and the bottom image is the sub-network *excluding* workshops (i.e. only showing green links with working group connections).

working groups in the ICES network. Since workshops cover a wide range of topics, they are instrumental to facilitate and develop IEAs and more integrated approaches. Furthermore, the semi-permanent nature of working groups means the establishment of one can be a time-consuming process (to elect Chairs, identify members, and develop terms of references), thus workshops are essential to fulfill an immediate need, or to address specific and/or short-term issues.

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Study limitations

SNAs are static, only represent a snapshot in time, and do not reflect the true dynamics of a network or their responsiveness to changes. The snapshots that the sociograms give us do not perfectly reflect the complexity of intra- and intergroup collaboration, and they change interannually. SNAs also do not say anything about the quality of the social interactions, or the disciplinary composition of the groups. This requires a more in-depth look at specific expert groups, or another SNA focusing on individuals rather than groups.

Conclusion and implications

The analysis and visualization of the ICES network using SNA gives a good overview of how groups are embedded in the network and which groups do contribute but are not well connected in the wider ICES network. The analysis further showed that most expert groups were better connected than IEA-focused expert groups. Future focus should lie on the question of whether there is a mismatch between the different sources of knowledge necessary to conduct IEA advice and the existing one from IEA-focused expert group attendees, and whether structural decision-making is required to bring in intentional links. The ICES strategic plan states that *"[ICES] will seek to increase the scope, impact, and efficiency of our science through innovation, integration, and increased interdisciplinary collaboration."* (ICES, 2021). Collaboration can most efficiently be measured by joint outputs, but the organization can facilitate this collaboration by ensuring good connection between groups. SNA can help in tracking this process and identifying missing links and where topical workshops can bridge working groups. Workshops proved to be an important structural and strategic element within the ICES system to develop organizational change towards making IEAs operational. However, SNA only reflects the structure based on the used input variables, here participation in groups, and thus further content related analysis, e.g. interviews with chairs and members of groups, will help to identify in which areas collaboration is working successfully and where the structure needs to be supported by other activities. This first study of the social network of ICES could serve as a baseline for both ICES leadership and national research institutions of ICES member countries in at least three important ways: (i) for strategic structural decision-making to enhance uptake of IEA understanding; (ii) for cost-benefit decisions on who and where to fund expert group participation of the over 6 000 scientists in the ICES network; and (iii) to give insights on overall organizational integrity. Social network analysis can therefore be a new tool in the ICES toolbox to leverage the diverse capacities within its scientific network to advance ecosystem understanding for sustainable seas.

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Supplementary material

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Conflict of interest

The authors have no conflicts of interest to declare.

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Author contributions

JLF, HVS, JOS, and DJD contributed to the design and theoretical background of the study. OJB provided expert guidance on the use of the methods and study approach, and interpretation of results. JLF and JOS conducted the analyses with UCINET and Gephi and generated the figures and images. All authors contributed to writing and editing the manuscripts and approval of the final draft.

Data availability

The data underlying this article were provided by the ICES Secretariat by permission. Data will be shared on request to the corresponding author with permission of the ICES Secretariat.

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