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Multiple stakeholders' perspectives of marine social ecological systems, a case study on the Barents Sea

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ABSTRACT

The Barents Sea ecosystem components and services are under pressure from climate change and other anthropogenic impacts. Following an Ecosystem-based management approach, multiple simultaneous pressures are addressed by using integrative strategies, but regular prioritization of key issues is needed. Identification of such priorities is typically done in a 'scoping' phase, where the characterization of the social-ecological system is defined and discussed. We performed a scoping exercise using an open and flexible multi-stakeholder approach to build conceptual models of the Barents Sea social-ecological system. After standardizing vocabulary, a complex hierarchical model structure containing 155 elements was condensed to a simpler model structure containing a maximum of 36 elements. To capture a common understanding across stakeholder groups, inputs from the individual group models were compiled into a collective model. Stakeholders' representation of the Barents Sea social-ecological system is complex and often group specific, emphasizing the need to include social scientific methods to ensure the identification and inclusion of key stakeholders in the process. Any summary or simplification of the stakeholders' representation neglects important information. Some commonalities are highlighted in the collective model, and additional information from the hierarchical model is provided by multicriteria analysis. The collective conceptual stakeholder model provides input to an integrated overview and strengthens prioritization in Ecosystem-based management by supporting the development of qualitative network models. Such models allow for exploration of perturbations and can inform cross-sectoral management trade-offs and priorities.

1. Introduction

With a growing global population, exploitation of marine resources is increasing worldwide (Jouffray et al., 2020; Nystrom et al., 2019). Simultaneously, many marine ecosystems are under added pressure due to impacts of climate change (Bindoff et al., 2019; Cooley et al., 2022; Hoegh-Guldberg et al., 2014; Pörtner et al., 2019) and a range of other anthropogenic activities. In the Barents Sea (BS),[2] ecosystem sea ice cover is declining due to climate warming (Meredith et al., 2019; O'Hara et al., 2021) and new areas become available for economic activities (Parviainen et al., 2019). Concurrently, ice biota and ice dependent species are disappearing, and sub-arctic species, including commercially important fish species, are expanding their distribution area northwards (Fossheim et al., 2015; Ingvaldsen et al., 2021). As a consequence, industrial fisheries, including trawlers, are expanding their activities into previously unfished waters (Fauchald et al., 2021). Also, the northern limit of petroleum activity linked to sea ice distribution (Bay-Larsen et al., 2020), are subjected to new discussions (Bjørndal, 2020) and new

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[2] List of abbreviations: BS = Barents Sea, BSMP = Barents Sea Management Plan, EBM = Ecosystem Based Management, ERA = Ecosystem Risk Assessment, IEA = Integrated Ecosystem Assessment, MCE = Ministry of Climate and Environment, ME = Ministry of the Environment, MEA = Millennium Ecosystem Assessment, MPE = Ministry of Petroleum and Energy, SES = Social Ecological System.

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spatial management measures are introduced to protect the sensitive Arctic benthic communities (Jørgensen et al., 2019). Impacts from climate change and diverse anthropogenic activities often interact in non-linear ways, that attenuate or amplify individual pressures (Cooley et al., 2022). It is therefore an accepted necessity to study and understand the cumulative effects of the different pressures, including potential non-additive impact (Millenium Ecosystem Assessment (MEA), 2005; Reum et al., 2020a).

Ecosystem complexity and the many human activities call for an Ecosystem-based management (EBM) approach, which is holistic in design and promotes integrated strategies to support an overall sustainable use of marine ecosystems (Leslie and McLeod, 2007; O'Boyle and Jamieson, 2006; Tallis et al., 2010). While the importance of an EBM approach is increasingly demonstrated (Fulton et al., 2019; Holsman et al., 2017; Levin et al., 2014; Winther et al., 2020), the implementation of EBM remains challenging, in part because it demands too much information, is methodologically excessively complex (Link et al., 2019) and lacks policy alignment (Rudd et al., 2018). Although EBM is by design more comprehensive than traditional sector-based management, the broad scope, and the dynamic nature of interactions within marine social-ecological systems (SESs) can still be covered through prioritization processes to identify key issues in order to best allocate limited resources for monitoring and assessment (Holsman et al., 2017). In the management of marine SESs, the tradeoffs and benefits across society and ecosystems are examined (Alexander and Haward, 2019; Alexander et al., 2019; Holsman et al., 2020). A main challenge for EBM is characterizing and addressing the multiple simultaneous pressures (natural and anthropogenic) acting on marine SESs. The characterization of SESs by scientists and stakeholders, will depend on available data, the methods used, and not least on different perspectives. Following, stakeholder involvement is considered a key principle in EBM (Curtin and Prellezo, 2010; Long et al., 2015; O'Boyle and Jamieson, 2006).

Integrated Ecosystem Assessment (IEA) is a framework for supporting EBM implementation (Levin et al., 2009). IEAs take a comprehensive multi-sectoral, multi-pressure, ecosystem view of the entire SES. The IEA framework outlines five stages of the assessment: scoping, indicator development, risk analysis, management strategy evaluation, and ecosystem assessment (Harvey et al., 2017; Holsman et al., 2017; Levin et al., 2009, 2014). The scoping process typically aims to identify the spatial scale of the IEA, its focal ecosystem components and associated key concerns. Finally, a common understanding of the context of the IEA is the ultimate step in this first part of the IEA (Levin et al., 2014). Stakeholder dialogue is critical in the scoping process to ensure that assessment outcomes are relevant and inclusive of diverse stakeholder perspectives (Levin et al., 2014). Such scoping processes should be as comprehensive and transparent as possible, provide opportunities for participation in a way that stakeholders find meaningful (Crandall et al., 2019) and ensure that diverse knowledge sources are respected and valued (Schroeder and Fulton, 2017).

Stakeholder dialogues can be facilitated by applying different approaches, including surveys and interviews (Friedrich et al., 2020; Ruiz-Frau et al., 2019; Vasslides and Jensen, 2016; Özesmi and Özesmi, 2004), and participatory workshops (Planque et al., 2019; Rosellon-Druker et al., 2019). Consensus among stakeholders is typically sought to achieve efficient prioritization in the assessment process (Stephenson et al., 2019), although a range of stakeholder perspectives is needed to ensure that environmental policies are robustly informed (Gray et al., 2012). Open and flexible approaches may provide stakeholders freedom to discuss what they consider important (Eelderink et al., 2020) and scope for novel and innovative solutions (Reum et al., 2020a), while more constrained approaches may be more efficient when the aim of engagement is clearly focused on specific issues or when it is important to reach consensus on priorities among stakeholders (Robinson et al., 2014). The commonly used Delphi technique, where survey respondents can re-evaluate their responses after seeing the overall results from the initial survey, is an example of a flexible participatory method which can be used to produce consensus among stakeholders in an iterative process (Mukherjee et al., 2015). Differences in viewpoints and priorities among stakeholders may be marginalized or overlooked when aiming for consensus and can mask more fundamental disagreements and reduce sustainability of long-term policy partnerships (Lawton and Rudd, 2013). Reductive approaches aimed exclusively at consensus can paralyze decision making when assessing impacts and risk across multiple interacting sectors (Adger et al., 2018). Consensus driven approaches also limits range of options for decision-makers, allowing them less room to maneuver (Olsen et al., 2014). In contrast, although adding complexity, inclusive and participatory approaches can support robust decision making in the EBM context through quantitative modelling informed by stakeholder input (Bhave et al., 2016).

Conceptual network models, or diagrams, have proven to be efficient tools for integration of both expert knowledge across disciplines and diverse stakeholder perspectives based on their professional experience (DePiper et al., 2017; Harvey et al., 2016; Lamere et al., 2020) and can be used for qualitative and semi-quantitative modelling to support IEA (Harvey et al., 2017; Kasperski et al., 2021; Reum et al., 2020b; Vasslides and Jensen, 2016). Such network models join different elements (e.g., human activities, ecosystem components, services) via links (positive or negative effects that can be weak or strong) (Kluger et al., 2020). Various approaches exist for participatory conceptual modelling, from open and flexible bottom-up approaches where the system and linkages are synthesized (*sensu* Reum et al., 2020b) to more constrained approaches where stakeholders are introduced to a model structure developed by scientists (e.g., Rosellon-Druker et al., 2019). For example, Pedreschi et al. (2019) used the Options for Delivering Ecosystem-based Marine Management (ODEMM) framework to build a conceptual model of linkages among sectors, pressures, and ecosystem components, before stakeholders identified the strengths of these linkages. Combined, this information provided the basis for identifying the most important linkages to be prioritized in more quantitative assessments from a cumulative impact perspective (Pedreschi et al., 2019; Robinson et al., 2014). Another approach is to ask stakeholders to identify key elements and interactions, such as which ecosystem services are most important, or ecosystem services associated with trade-offs among users (Herbst et al., 2020a, 2020b; Rosellon-Druker et al., 2019). Fletcher et al. (2013) have extended stakeholder involvement, inviting them into the process of building full conceptual models (Fletcher et al., 2013; Nuttle and Fletcher, 2013), hence using a more flexible alternative than the e.g. ODEMM approach.

To support EBM implementation in the BS, the Norwegian Barents Sea Management Plan (BSMP), covering the Norwegian part of the BS was implemented in 2006 (Norwegian Ministry of Environment (ME), 2006; Olsen et al., 2007). The BSMP has typically been revised and expanded every 5–6 years (Norwegian Ministry of Environment (ME), 2011; Norwegian Ministry of Climate and Environment (MCE), 2014, 2020).

The main objective of this study is to support the development of EBM for the Barents Sea by applying an open and flexible multi-stakeholder approach to inform EBM priorities and address contemporary challenges associated with cross-sector management. An important aspect of our approach is not to enforce a demand for consensus, this demand has now also been lifted from the advisory processes supporting the BS EBM. Further, the conceptual models described in this paper displays that there in reality is a lot of agreement between the different interest groups, opening for a more collaborative attitude. However, as there are relatively few cases in the literature reporting on this type of approach (but see Herbst et al., 2020a; Herbst et al., 2020b; Rosellon-Druker et al., 2019, and Fletcher et al., 2013), we believe our work, using the Barents Sea as a case study, also will be of interest for the methodological development of stakeholder approaches for SES/EBM contexts in general.

Stakeholders from key sectors were invited to develop conceptual network models of the BS with the aim to answer the following two main research questions: (1) How do perspectives about the BS SES differ among stakeholder groups with different sectorial/environmental interests, and (2) Can the cross-sector conceptual models provide an integrated overview of key elements and links, to potentially identify ecosystem threats and thereby support the focus of the IEA and further EBM implementation?

2. Material and methods

2.1. Case study: the Barents Sea social-ecological system

The BS is situated off the Northeast Atlantic, north of Norway and north-western Russia between 70 and 80°N (Fig. 1). An important feature of the BS is the polar front, a biologically highly productive and dynamic transitional zone between open water in the south and drift ice to the north. The BS climate has high seasonal variability, with extensive variations in ice cover which affect biological dynamics and human activities. Important ecosystem components in the BS SES are fish (e.g., Atlantic cod, haddock and capelin), seabirds, benthos and marine mammals. The dominating commercial sectors are fisheries, marine transportation, petroleum, and tourism (Supplementary 1). Fisheries are an essential part of the economy, livelihoods, and culture in the communities along the coast of Northern Norway and the Russian Kola peninsula, and the rich fish resources are probably the main reason that this area is one of the more densely populated areas in the Arctic (Larsen and Fondahl, 2015). The recent increase in maritime transportation and tourism is expected to continue as sea ice retreats (Borch et al., 2016; Hauser et al., 2018; Stocker et al., 2020). Exploration for oil and gas resources on the Norwegian Continental Shelf in the BS dates back to 1980. The first and currently only operating petroleum fields within the BSMP came on stream in 2007 (Snøhvit) and 2016 (Goliat) (NPD, Fact Pages).

Assessments of sector impacts on the ecosystem are key elements of the knowledge base supporting the revisions, including identifying measures needed to reach management objectives (Sander, 2018a). The BSMP aims to ensure sustainability and facilitate coexistence among sectors. Stakeholder interactions are considered crucial for engagement, relevance, and legitimacy of the management process (Olsen et al., 2016). An important aspect is that as an integrated part of the process the representatives from the different interest groups meet physically in cross-sectoral groups on a semi-regular basis, enhancing dialogue (Olsen et al., 2016). Yet, balancing environmental and sectorial interests, including e.g., fisheries, petroleum and marine transportation is an ongoing challenge.

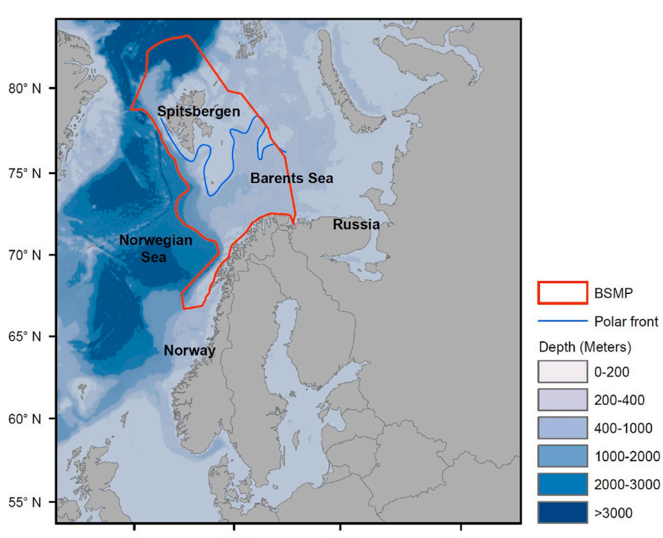

Fig. 1. Barents Sea with the Norwegian Barents Sea Management Plan area (BSMP) and the productive thermohaline Polar front.

Two advisory groups, consisting of the main marine scientific institutions and governmental management institutions, are involved in the advisory work for the development of the BSMP, "The Advisory Group on monitoring" which provides the scientific basis responsible for the running activity of assessing ecosystem development and state, and the "Management forum", responsible for additional knowledge support; including identifying biological and ecological significant areas, assessments of sector activities, cumulative impacts and associated ecosystem services. The practical responsibility for the advisory work lies with the Management forum, which is led by the Norwegian Environment Agency (NEA) with representation from the other main governmental agencies and research institutions. In addition to the environment, the key governmental areas represented are petroleum, fisheries and marine transportation. Until recently, the conclusions on risks and priorities by the Management forum required consensus between all scientific and governmental management institutions involved. The consensus driven approach may conceal conflicting perspectives between environmental and other interests (Andersen et al., 2019), which may hamper the transparency of the management process and thereby undermine confidence in resulting management decisions, as well as blurring priorities communicated to monitoring and research. However, the most recent version of the BSMP acknowledges value-based conflicts between different users and between use and conservation (Norwegian Ministry of Climate and Environment (MCE), 2020), and the consensus requirement in the advisory work is removed, allowing for expressions of disagreements. The consequences of removing the consensus requirement on the further development of the advisory work for the BSMP will first be visible in 2023 and 2024, when the Management forum will report on key concerns and associated management challenges and knowledge gaps as key input to the next revision of the plan. The revision is led by the Ministry of Climate and environment (MCE) but requires support from the parliament.

2.2. Participatory approach

To identify stakeholder perspectives on the Barents Sea SES, we used a participatory scoping approach. This included a two-days' workshop followed by individual stakeholder group meetings and further email correspondence. The following steps were used to develop sector-specific and common conceptual models of the BS SES where stakeholders represent the social agents in the system:

(1) identify, invite, and set up stakeholder groups
(2) present guidelines for drawing conceptual models, using five main categories (*Sectors*, *Activities*, *Drivers*, *Ecosystem Component*, *Ecosystem Service*) and provide examples of elements associated with each category
(3) conduct a workshop with a mixture of plenary and group sessions where the stakeholder groups a) draw conceptual models, b) share their first draft in plenary, and c) revise their models independently
(4) standardize the vocabularies used by the different stakeholder groups
(5) organize the elements into a common hierarchical model structure
(6) simplify individual conceptual models by *condensation* and compile the condensed models into one collective model

The preparation steps 1 and 2 and the simplification step 6 were conducted by scientists only, while stakeholders contributed directly to steps 3, 4 and 5 (Fig. S1).

2.2.1. Sectorial based stakeholder groups

Approximately 20 stakeholders were invited to take part in a two-day workshop. We considered expertise on the Barents Sea SES and experience from the work supporting BSMP to be more important than having a larger number of participants. All the invitees accepted and participated, with one exception due to illness. Most stakeholders were directly involved and participated in both workshop and follow up meetings, but due to time limitations, some stakeholders were not available for all activities. A few stakeholders were indirectly involved through internal meetings in the organization/industry of governmental institution they belong to. One group, which was unable to attend the workshop, was introduced to the assignment following the same procedure and material as the workshop participants. This group (F) was assisted more closely by project facilitators and was provided examples from other groups to imitate the plenary session held at the end of the first workshop day. Most stakeholders were either from governmental management institutions (environmental, fisheries, maritime transport, petroleum), industry (fisheries, petroleum, cruise tourism) or research institutes with the addition of one stakeholder from an environmental NGO and one from the maritime law enforcement.

Communication between many of the stakeholders was already established through collaboration on the BSMP framework, enhancing direct and informal exchange of views. The participants were split into six groups (two to three participants at workshop), according to affiliation and interest. The group affiliation is anonymized, named by the letters A–F. The participants were granted anonymity because Norway is a small country and individuals' opinions could be easily detected by insiders, possibly hinder them to speak freely and share their true perspectives. Clustering stakeholders that share a common understanding of the issues of relevance to a sector facilitates conversation and deep engagement. Responsible chairing and small group size may aid communication within groups as shy or cautious persons may be more inclined to speak in smaller groups (Cuppen, 2012). The small group setting and clustering may enhance a more open provision of diverse and detailed expertise representing the multiple perspectives (Planque et al., 2019; Rosellon-Druker et al., 2019).

In the meeting invitation, stakeholders were asked to consider the following: (a) identify key activities related to their sector/interest considered to have an impact on the ecosystem and which ecosystem components are affected, (b) connect these activities to ecosystem services, (c) identify the key activities related to other sectors/interest relevant to their sector/interest both directly (spatial overlap) or indirectly (through e.g. impacts on ecosystem components or ecosystem services).

2.2.2. Guidelines for developing conceptual models

Guidelines were developed to assist stakeholders in constructing directed graphs, by drawing elements (nodes) and the relationships between them (edges). The elements were colored according to the main category they were classified into; *Sectors*, *Activities*, *Drivers*, *Ecosystem Components*, and *Ecosystem Services*. While some methods provide a closed list of available vocabularies (e.g., ODEMM) the approach proposed here is open in the sense that stakeholders are free to choose the vocabulary that best describe the elements of the system that they consider relevant. To guide stakeholders' work, examples of possible constituting elements (i.e., which *sector*, or which *ecosystem component*) were provided in the guidelines (Supplementary 2).

In SES, societal nodes can be represented by societal entities such as organizations, human stressors, ecosystem beneficiaries and industries (Sayles et al., 2019; Zhao et al., 2018), while ecological nodes may represent plants, animals, specific habitat patches, marine areas (Sayles et al., 2019) and ecosystem services (Kelble et al., 2013). Yet, ecosystem services can also be considered as bridging nodes between social and ecological nodes in SESs (Dee et al., 2017). In this study, the five main categories of elements were not predominantly classified as either societal or ecological nodes as the main purpose of the scoping exercise was to identify stakeholders' perspectives without constraining them to a predefined model structure. We consider *Sectors* and *Activities* as "true" societal nodes, *Ecosystem Components* as "true" ecological nodes, and *Ecosystem Services* as bridging nodes. In addition to pressures related to human activities, climate change and drivers within the natural system, the category of *Drivers* includes other elements important to stakeholders (e.g., *Governance*), including those considered positive for society (e.g., *Social Welfare*). Therefore, *Drivers* can be classified as either societal (e.g., *Shipping Regulations*), natural (e.g. *Species Displacement*), or bridging nodes (drivers from the human system on the natural system or vice versa, e.g. non-indigenous species).

2.2.3. Drafting stakeholder group models

A two-day workshop was organized (Fig. S2), starting with a brief plenary introduction on how to construct conceptual models with examples from other systems. During this session, the questions from the meeting invitation were repeated also adding the task to identify the drivers related to their sector/interest. Thereafter, stakeholder groups drew directed graphs following the guidelines (Section 2.2.1). Some groups found this step difficult and needed assistance from a project scientist as facilitator. Stakeholders were encouraged to focus on the elements that were most relevant from their sector/interest perspectives rather than drawing the most comprehensive diagram. Interactions between elements (e.g., fishing affecting fish populations) were represented by directed arrows. Bidirectional arrows were used to inform about feedback. Stakeholders were encouraged to provide additional information about connections in tables associated with the drawings: sign (positive or negative effects), strength, knowledge base and uncertainty.

The diagrams drawn during this first group session were presented in a plenary session to share results across groups. During the second group session, participants revised their original conceptual diagrams and the corresponding supporting tables, resembling a Partial Delphi approach, chosen to potentially strengthen the identification of common priorities (Mukherjee et al., 2015). The open choice of vocabulary combined with focus on sectorial interests and iterative discussions and presentations provided a flexible framework in which it was possible for the different stakeholder groups to represent their perspective on the Barents Sea without being too constrained by pre-established methodological choices.

2.2.4. Standardizing model vocabulary

After the workshop, we reviewed the elements identified by all groups and harmonized the naming and category classification. When necessary, groups were consulted to clarify the meaning of elements names, their assignment into categories and revised terminology. For example, one group may have used the term 'temperature' while others have used 'ocean temperature' or 'warming.' In such cases, a single term was selected (here, 'ocean temperature'). As not all stakeholders were Norwegian, the diagrams contained both English and Norwegian names, which were all re-written in English. A series of individual stakeholder group (A–F) meetings were conducted to ensure that interpretation of the diagrams (standardizing vocabulary) was correct.

2.2.5. Organizing the elements into a common hierarchical model structure

We structured the different elements of the diagram into a common hierarchy. While some groups referred to certain components with a low level of detail (e.g., *Fish*), others specified more detailed sub-categories (e.g., *Demersal Fish* or *Atlantic Cod*). We therefore constructed a hierarchical structure that could accommodate all the elements named by all groups. The broader elements are referred to as "parents" and more detailed elements are referred to as "children".

We represented the hierarchy of elements listed by the stakeholders using a dendrogram which shows each individual element and how it is related to elements above (parents) or below (children). When an element was identified by a stakeholder group, we automatically assumed that the group also identified the parental element(s). The hierarchical model structure was presented to stakeholders at the individual stakeholder group meetings (A–F) (Fig. S1) using the interactive software Kumu (www.kumu.io) to ease visualization, discussion, and revisions. Thereafter, the hierarchical model structure was revised based on stakeholders' feedback. Further exchanges by correspondence were conducted to address specific questions.

The group specific inputs were compiled into two data tables. The first contains the list of all individual elements as well as their hierarchical position and category type. The second table describes the connections and their additional attributes when identified (Section 2.2.3).

2.2.6. Condensing stakeholder models and compiling them into one collective model

To ease visual interpretations and comparison of the complete diagrams, individual conceptual diagrams can be simplified by a process termed *condensation* (Kontogianni et al., 2012a; Özesmi and Özesmi, 2004). To do this, one option is to only represent the interactions between elements that are at a high level of aggregation (Level-1). In this process, all elements below hierarchical Level-1 are removed and the corresponding connections are re-assigned to their parental element at Level-1. For example, connections that involved 'oil spill' were re-assigned to the higher category 'pollution.' In this way, it is possible to draw simplified representations of the conceptual diagrams, with a reduced set of elements and connections. The condensed group models were then combined into a collective model that summarizes elements and connections at Level-1 across stakeholder groups (Kontogianni et al., 2012a; Tan and Özesmi, 2006; Vasslides and Jensen, 2016).

2.3. Analysis of conceptual models

As a first step, we summarized the conceptual models that were originally drawn by each stakeholder group (A–F). We identified and counted elements and connections and compared these across stakeholder groups. In addition, we identified group specific elements i.e., elements that were identified by one stakeholder group only, and elements that were common across groups.

2.3.1. Comparison of cross-sectoral condensed models

We analyzed the properties of the conceptual models using graph theory (Özesmi and Özesmi, 2004). The degree of centrality measures the total number of links pointing towards an element (in-degree) or departing from an element (out-degree) (Falardeau and Bennett, 2020). The stakeholders' framing of the SES was expected to reflect the number of elements and links they provided within different parts of the system and can be compared by category centrality (Vasslides and Jensen, 2016). The frequency of total centrality within a category is expected to reflect how the stakeholder group emphasizes interactions for this part of the system. Accordingly, we summed the 1) total degree (D) (number of connections), 2) in-degree (IN) and 3) out-degree (OUT) centrality within each category for each stakeholder group in the condensed models. We tested if the number of identified elements and their connections by categories (*Sectors, Activities, Drivers, Ecosystem Components and Ecosystem Services*) were independent of the stakeholder group using Chi-Square test of independence.

2.3.2. Analysis of the collective model

Differences and commonalities between stakeholder groups were explored by visualizing the frequency of elements and connections in the collective model. For this purpose, we counted the number of stakeholder groups that identified each element in the simplified models. Similarly, we counted the number of stakeholder groups that identified each single connection. Centrality measures were used to assess the role of the elements in the collective model as senders, receivers, or hubs. Hubs are elements that are both receivers and senders. We classified an element with a high in-degree (IN > 20) as a "receiver", an element with a high out-degree (OUT > 20) as a "sender" and an element with high in- and out-degree (IN > 20 and OUT > 20) as a "hub". Senders can be defined as transmitters in other studies (Gray et al., 2012; Özesmi and Özesmi, 2004).

2.3.3. Ranking elements by multiple criteria

Elements that are identified by many stakeholder groups or that are highly connected to the rest of the system can be considered as most relevant. To prioritize key elements according to these criteria, we used a triple ranking procedure. We first ranked elements based on the number of stakeholder groups that named them. We then ranked elements according to graph theory indices (Kontogianni et al., 2012a), using the number of inbound connections (in-degree) and the number of outbound connections (out-degree). For parent elements, the connections assigned to children were also counted. Each element was ranked for each of the above three criteria and the final ranking was obtained by summing up the three individual ranks.

3. Results

3.1. Elements unique or common to the stakeholder groups

The stakeholder groups identified between 38 and 57 elements as central to their perspective of the Barents Sea SES. After harmonization of vocabularies, this resulted in a total of 151 unique elements identified within the main categories: *Sector* (4), *Activity* (30), *Driver* (64), *Ecosystem component* (31) and *Ecosystem service* (22). Elements pertaining to the category *Drivers* were most frequently identified by all groups (range 13–26) (Table 1). Approximately 47% of the elements were specific to one stakeholder group only (Fig. S3, left panel). Group A, B and D identified approximately 7 unique elements each, 8 unique elements were identified by group C, while group E and F identified 23 and 22 unique elements respectively (Table 1). No *Sectors* were identified by group A, but the same group identified 3 *Activities* which are related to three different *sectors*.

3.2. Hierarchical model structure of the Barents Sea SES

The final hierarchy of elements was relatively complex and consisted of 155 elements organized in six hierarchical levels (Fig. 2) and 588 unique connections. By grouping elements identified at a fine scale into broader categories (parents), six hierarchical levels were constructed (see Section 2.2.4). For example, the list of *Drivers* (Level-0) includes *Pollution* (Level-1) containing "*Oil and Chemicals*" (Level-2) containing "*Operational Pollution* (Level-3) containing "*Discharge Sea*" (Level-4) which finally contains "*Waste Water*" (Level-5). Four "parent" elements, which were not originally identified by the stakeholder groups, were

Table 1
Original elements identified by stakeholder groups and categories. Unique group specific elements are listed in brackets. Overall unique elements are summarized for the main categories (Sector, Activities, Drivers, Ecosystem components, Ecosystem Services).

	Stakeholder groups						
Category	A	B	C	D	E	F	Unique
Sector		3	2	3	2	1	4
Activity	3	6 (1)	8 (2)	5 (1)	12 (8)	13 (11)	30
Driver	24 (3)	13 (1)	24 (5)	22 (5)	17 (4)	26 (6)	64
Ecosystem component	11	10 (3)	5	5	18 (11)	10 (4)	31
Ecosystem service	13 (4)	7 (2)	5 (1)	3 (1)	4	7 (1)	22
Total	51 (7)	39 (7)	44 (8)	38 (7)	53 (23)	57 (22)	151

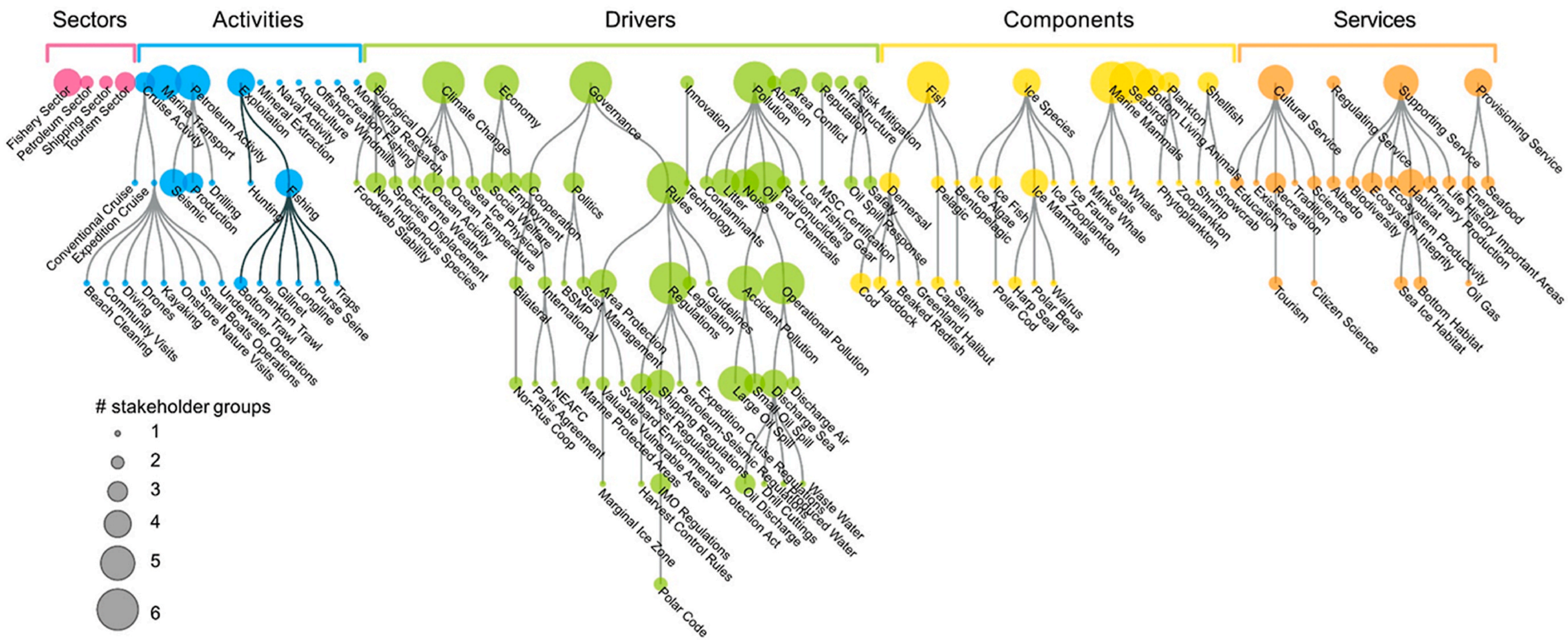

Fig. 2. Complete set of elements (circles) identified by all stakeholder groups, and their hierarchical structure (lines). The elements are classified into five major categories characterized by unique colors: sectors (pink), activities (blue), drivers (green), ecosystem components (yellow) and ecosystem services (orange). Level-1 indicates the major sub-categories. Elements that are described at greater level of detail (children elements) are found at levels- 2 to 6. The size of the circles is proportional to the number of stakeholder groups which identified the corresponding element or one of its children.

included to complete the hierarchy: *Biological Drivers* (parent to *Non-Indigenous Species*, *Foodweb Stability* and *Species Displacement*), *Exploitation* (parent to *Fishing* and *Hunting*), *Ice Fish* (parent to *Polar Cod*) and *Regulating Service* (parent to *Albedo*).

The number of stakeholder groups that identified each element in this structure is illustrated by the size of the circles in Fig. 2. Group specific elements (i.e. identified by only one or two groups) were frequent in the hierarchical structure, (Fig. S3, left), especially at low hierarchical levels (Fig. S4), but 13 out of 26 elements at Level-1 were also group specific (Fig. S1, right). For example, all groups identified *Governance* as an important *Driver*, but which types of *Governance* they prioritized varies considerably between groups. Although time was dedicated at the beginning of the workshop to present the different types of ecosystem services, important regulating services (e.g., *Albedo* (surface ability to reflect sunlight)) and provisional services (e.g., *Energy* and *Seafood*) were identified by only two stakeholder groups.

In their original diagrams, each group connected elements with directed arrows. Plotting all connections onto the complete hierarchical representation resulted in cognitive maps of the Barents Sea SES that were too complex to be easily read and interpreted, even when plotting one stakeholder group's representation at a time. Simpler graphical representations were therefore produced by focusing on the upper level of the hierarchy, i.e., *condensed models*.

3.3. Condensed conceptual models

Aggregating stakeholder input at hierarchical Level-1 reduced the number for elements to 36. The elements are allocated to the categories: 4 *Sectors*, 10 *Activities*, 11 *Drivers*, 7 *Ecosystem Components* and 4 *Ecosystem Services* (Fig. 3). Group specific condensed models contained from 16 to 23 elements (Fig. 4). Prioritized outbound links differ across stakeholder groups, categories and number of original connections (i.e. connections at any original hierarchical level) (Fig. 4).

The most common elements in the collective model were *Climate Change*, *Pollution*, *Governance*, *Fish*, *Marine Mammals* and *Seabirds* (Fig. 3). Links that were commonly identified (by at least three groups)

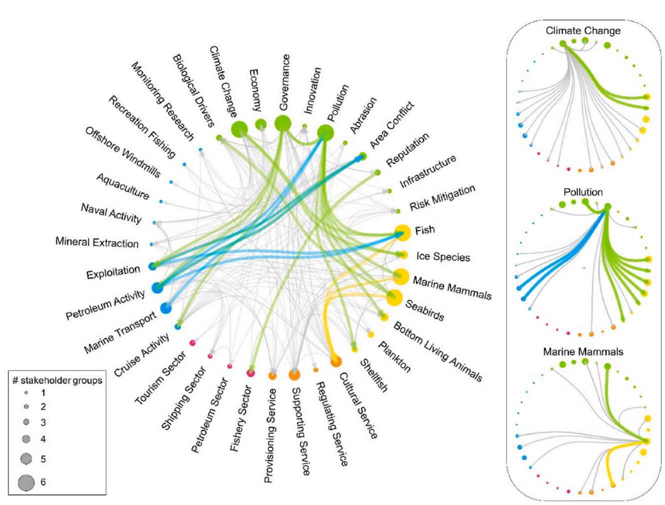

Fig. 3. Collective stakeholder model of the Barents Sea Social ecological system. The 36 circles represent the major elements (Level-1) colorized according to the main categories: sectors (pink), activities (blue), drivers (green), ecosystem components (yellow) and ecosystem services (orange). The size of each circle is proportional to the number of groups who named the correspond element (or one of its 'child' element). Colored lines show the connections that were identified by at least three of the six stakeholder groups and the color of each line correspond to the category of the 'sender' element. Thin grey lines show the connections that were identified by one or two groups only. The inlet on the right emphasizes the connections associated with climate change, pollution and marine mammals.

connect four *Activities* (*Exploitation*, *Petroleum Activity*, *Marine Transport*, and *Cruise Activity*), six *Drivers* (*Biological Drivers*, *Climate Change*, *Governance*, *Pollution*, *Area Conflict* and *Reputation*), all *Ecosystem Components* except *Plankton*, and *Cultural Ecosystem Service* (Fig. 3). Nevertheless, the way these elements were linked varied substantially between groups (Fig. 3-right panel). For example, while *Climate Change* is connected to 20 other elements, most of these connections have only been identified by one or two groups (Fig. 3, grey lines), except for the effects of *Climate Change* on *Fish* and *Ice Species* (Fig. 3, right-top panel). In contrast, the different stakeholder groups reported many identical connections between *Pollution* and the rest of the system (Fig. 3, right-middle panel). A third illustrative example concerns *Marine Mammals*. These were named by all stakeholder groups, but most connections are group specific. Only the connections between marine mammals and pollution and between *Marine Mammals* and cultural services were identified by more than 2 groups (Fig. 3, right-bottom panel).

3.4. Representation by main categories in condensed group models

Elements in the condensed group models belonging to the category of *Drivers* were most frequently identified by all groups, except group E that identified more *Ecosystem Components* (Fig. 5A). Group D and E identified fewer *Ecosystem Services* than the other groups, while group A stood out with *Ecosystem Services* as the second most important category. Overall, the proportional representation of elements classified into the five categories differ between the stakeholder groups (Fig. 5A, $\chi^2 = 27.58$, df = 15, $p < 0.05$).

The level of connectivity (degree) also varied with stakeholder group (Fig. 5B, $\chi^2 = 202$, df = 15, $p < 0.05$). Between-group differences were also significant for outbound links (Fig. 5C, $\chi^2 = 88$, df = 10, $p < 0.05$) and inbound links (Fig. 5D, $\chi^2 = 144$, df = 15, $p < 0.05$). *Activities* and *Drivers* were identified as the most important impacting categories with high out-degree (Fig. 5C) while *Ecosystem Components* are largely identified as receivers (Fig. 5D).

3.5. Senders, receivers, and hubs

Network analysis identified 13 of 36 elements as highly connected in the collective model, where *Activities* and *Drivers* were mostly senders (Fig. 6). *Ecosystem Components* were mainly connected by inbound links and most groups identified inbound links assigned to *Ecosystem Services* which predominantly came from *Ecosystem Components*. The driver elements *Governance* and *Pollution* were assigned roles as hubs (i.e. both sender and receivers).

The highly connected elements:

- five *Drivers* (*Governance* D = 63, *Pollution* D = 63, *Climate Change* D = 30, *Area Conflict* D = 25, *Biological Drivers* D = 24),
- three *Activities* (*Exploitation* D = 42, *Petroleum Activity* D = 36, *Cruise Activity* D = 27),
- three *Ecosystem Components* (*Fish* D = 35, *Seabirds* D = 30, *Marine Mammals* D = 28),
- two *Ecosystem Services* (*Cultural Service* D = 34, *Supporting Service* D = 35).

The dominating senders:

- three *Drivers* (*Pollution* OUT = 42, *Governance* OUT = 41, *Climate Change* OUT = 28),
- two *Activities* (*Exploitation* OUT = 26, *Petroleum Activity* OUT = 24),

The dominating receivers:

- *Cultural Ecosystem Service* (IN = 34),
- two *Ecosystem Components* (*Fish* IN = 25, *Seabirds* IN = 22)
- two *Drivers* (*Governance* IN = 22, *Pollution* IN = 21).

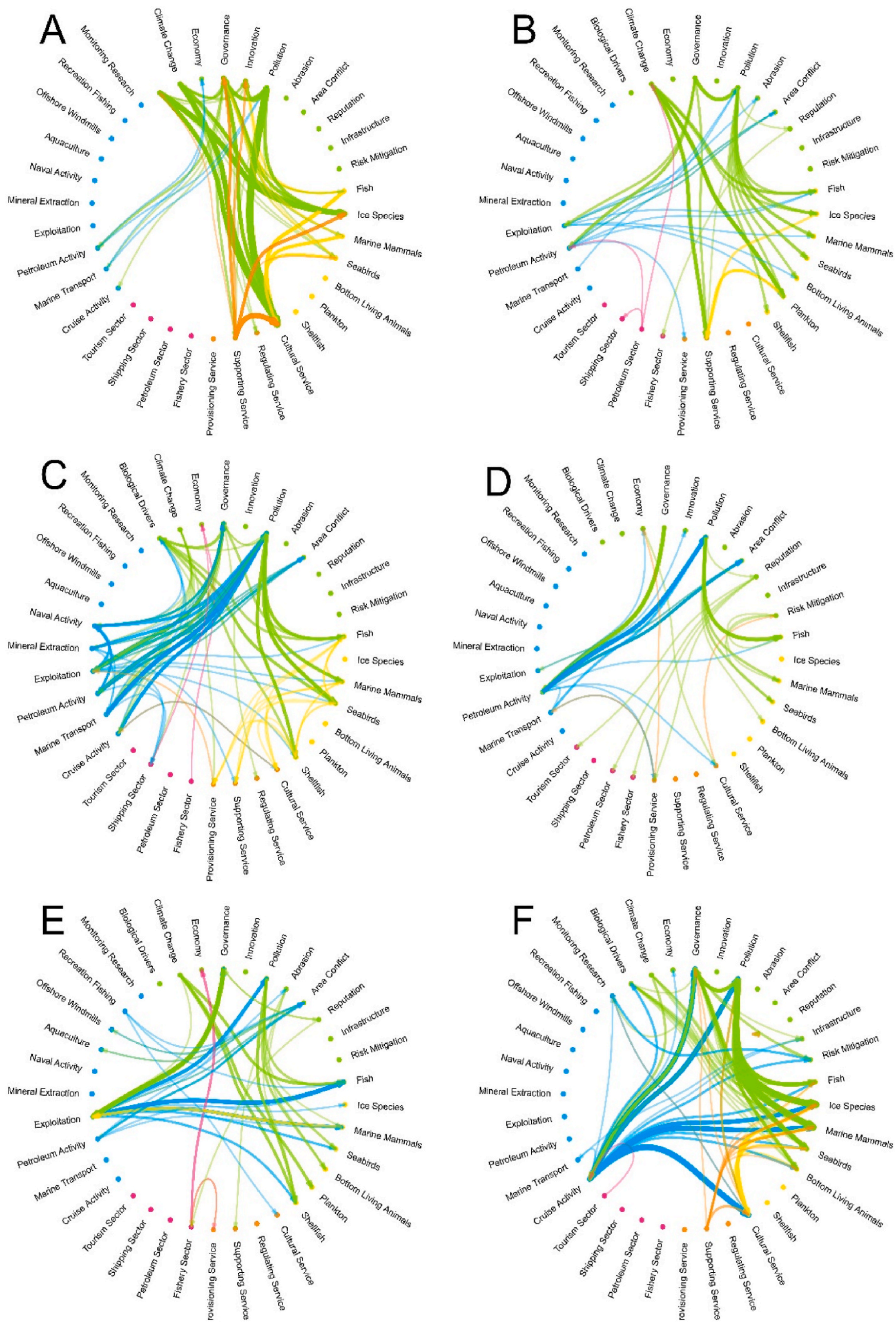

Fig. 4. Condensed stakeholder group models (A–F) of the Barents Sea Social ecological system. The 36 circles represent the major elements (Level-1) colorized according to the main categories: sectors (pink), activities (blue), drivers (green), ecosystem components (yellow) and ecosystem services (orange). Colored lines show the connections that were identified by each stakeholder group and the color of each line correspond to the category of the 'sender' element. Line thickness is proportional to the number of original connections (i.e. connections between elements at any level) behind each 'trimmed' connection (connection between elements at Level-1 only).

3.6. Elements ranks

Ranking all elements from the hierarchical model (Fig. 2, n = 155) by equally weighted multicriteria (Section 2.2.3), revealed that the top-30 elements belong to the *Activities* (n = 6), *Drivers* (n = 16), *Ecosystem Components* (n = 5) and *Ecosystem Services* (n = 3) (Table 2). Half of these elements belong to hierarchical Level-1 (n = 15), while the rest is identified at Level-2 (n = 10), Level-3 (n = 3) and Level-4 (n = 2). The top 10 elements include the *Drivers Pollution* (incl. *Operational Pollution, Oil and Chemicals*), *Governance* (incl. *Rules*), the *Ecosystem Components Marine Mammals* and *Fish*, and the *Activities Petroleum Activity* and *Exploitation* (incl. *Fishing*). The *Ecosystem Services* ranked among the top-30 elements include *Supporting Service* (incl. *Habitat*) and *Cultural Ecosystem Service.* Although *Politics* has 10 more out-degrees than *Area Conflict,* the latter is ranked higher because it has one more group identification and in-degrees than *Politics* (Table 2). *Ice Species* (incl. *Ice Mammals)* are ranked as number 2 by in-degrees, but when ranked by multicriteria, the overall rank is 22 because two stakeholder groups did not identify this element. Even though all groups identified *Seabirds* and *Climate Change* at Level-1, the elements were not as highly connected as the top-10 ranked elements.

4. Discussion

This study provides a first multi-sector conceptualization of the Barents Sea SES based on inputs from stakeholder groups. As compared to the Management forum, where several of our stakeholders also are members, our format is less restricted and there is no demand for consensus. This opened for a more collaborative setting, where no one felt obliged to defend their own turf, but could launch ideas and

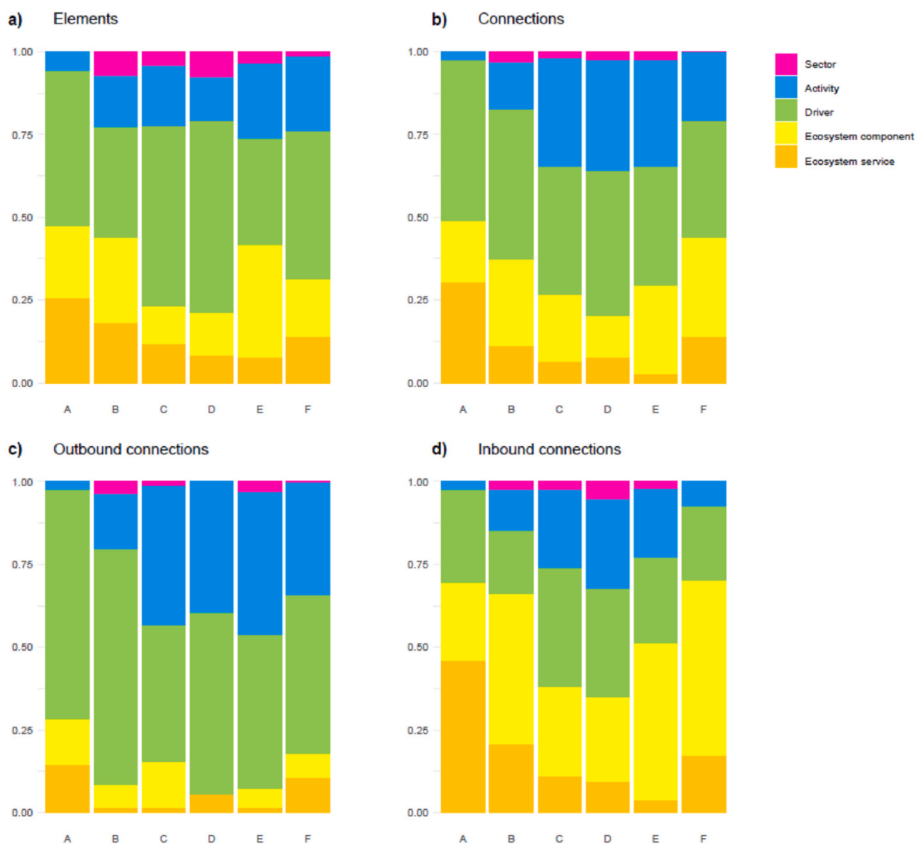

Fig. 5. Stakeholders characterization of the Barents Sea Social ecological system by proportional priority of main categories. The categories represent sectors (pink), activities (blue), drivers (green), ecosystem components (yellow) and ecosystem services (orange) identified by six stakeholder groups (A–F). Proportional number of elements (Panel A), connections (Panel B), sender elements (outbound connections) (Panel C) and receiving (inbound connections) elements (Panel D) as identified in each category by stakeholder group (A–F).

concepts quite freely.

The approach used here reveals a diversity of perspectives represented by elements and the relationships between them. The translation of stakeholder knowledge into hierarchical networks followed by condensation of the models reduces complexity and favors synthesis and between-group comparisons. Ranking of model elements and connections results in common priorities that are relevant to IEAs and more generally EBM for the BS. The identification of these priorities through a transparent and participatory process contributes to enhanced cross-sectoral dialogue, as well as a constructive dialogue between stakeholders, managers, and scientists. While common priorities are an important output of the exercise, it is equally important to recognize that any simplification leads to loss of group-specific detailed information. The network analysis reveals that, beyond common priorities, the perspectives of the different stakeholder groups contain many distinct and specific issues. While not always emerging as a common priority, some of these issues can be central to a stakeholder group as illustrated in Fig. 4 where some elements have a high connectivity.

4.1. Stakeholders cross-sector characterization of a social-ecological system

When characterizing the social-ecological system by *Sectors*, *Activities*, *Drivers*, *Ecosystem Components* and *Ecosystem Services*, we found that groups emphasized similar parts of the system. *Activities* and *Drivers* were central and highly connected to other parts of the system. Dominating focus on outbound links from driving components has been identified in previous studies (Gray et al., 2012). In this study, the *Drivers* were assigned roles as both impacting and impacted elements. Allowing bidirectional arrows in the directed graphs may have contributed to this dual role assignments.

The groups identified cultural ecosystem services more frequently than in other studies (Custodio et al., 2022). This could be an effect of the Delphi approach and examples of cultural ecosystem services provided in the guidelines. Yet, our results suggest that some of our stakeholders had limited familiarity with the concept of ecosystem services, as also observed in other studies (McKinley et al., 2019). Hence, the stakeholder output likely provides limited information on ecosystem services when characterizing SES and the following EBM prioritization.

4.1.1. Divergent stakeholder perspectives

All stakeholder groups identified many elements and relationships that were unique to their group (e.g., *Naval Activity,* group C, Fig. S4c) and identified elements at different hierarchical levels (e.g. *Cod* (Level-3) vs *Demersal Fish* (Level-2) vs *Fish* (Level-1)) (Fig. S4). This high number of group specific elements cannot be attributed to variations in labelling or terminology between groups, since terminology was standardized. The groups also assigned different roles (i.e., different connections) in the system for some elements (e.g., *Governance*) and provided different levels of detail (“children” elements). For example, while some groups identified *Pollution* as a driver, others considered explicitly *Noise*, *Litter*, *Lost Fishing Gear* and various types of chemicals as distinct elements (all related to *Pollution*). Hence, the chosen open and flexible approach uncovered different perspectives across stakeholder groups emphasized by the number of unique elements, variations in elements naming, role-assignment, and detail levels.

While acknowledging and addressing the multiple perspectives across stakeholder groups may help inform a more equitable management approach, failing to capture a specific group’s points of view can exacerbate conflicts and hamper progress to address management challenges (Simpson et al., 2016). The disparities across sectors in this study appear in the elements connectivity, uniqueness and proportional representation by categories in condensed stakeholder models. This underlines the importance of including a broad, diverse group of stakeholders for identifying cross-sector perspectives to support EBM prioritization, and to ensure that priorities that may be specific to one or

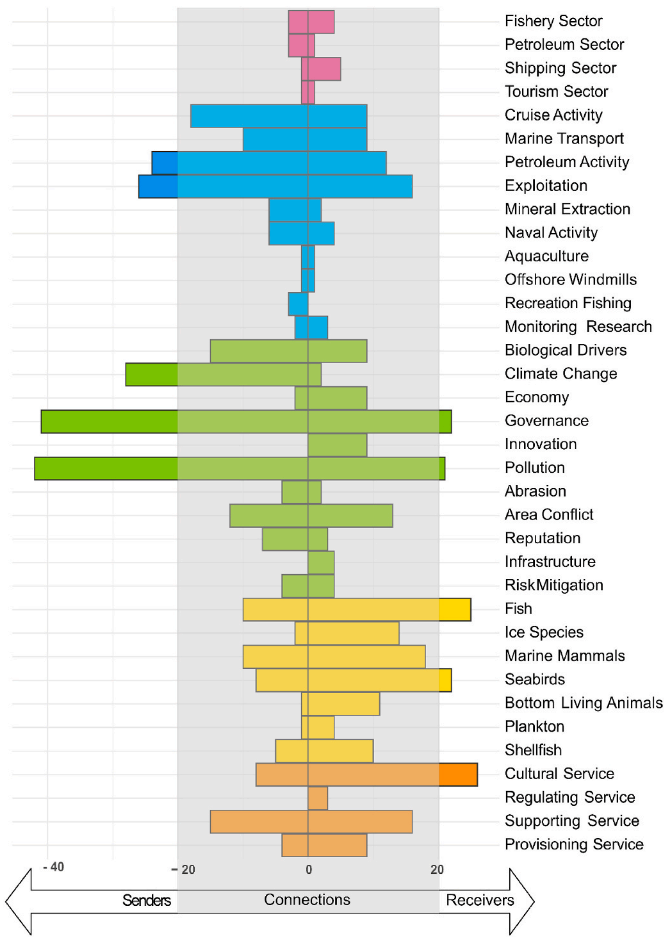

Fig. 6. Proportional connectance in summarized condensed conceptual network model (collective model) for the Barents Sea social-ecological system with elements (n = 36) classified to sectors (pink), activities (blue), drivers (green), ecosystem components (yellow) and ecosystem services (orange). Senders (Out-degree >20) and Receivers (In-degree >20) from negative (Sender) to positive scale (Receiver) and stretch outside grey area.

few groups are not overlooked. The observed pattern of stakeholder specific perspectives supports using an approach which is less focused on consensus in the scoping phase and more directed at describing and identifying group specific perspectives, as chosen in this study. However, the flexible approach also adds complexity with the diverse stakeholder perspectives which challenge the identification of key concerns across perspectives.

4.1.2. *Commonalities in stakeholders' perspectives*

The five most important elements identified by stakeholders – based on the multicriteria ranking– were *Pollution*, *Governance, Oil and Chemicals*, *Rules*, and *Marine Mammals*. Of these, *Oil and Chemicals* and *Rules* are "children" elements of *Pollution* and *Governance* respectively. Pollution was also identified as a key concern in a previous stakeholder-informed modelling of the BS (Koenigstein et al., 2016).

Summarizing stakeholder inputs in the condensed collective model highlights commonalities across stakeholder groups. *Pollution* and *Governance* are highly connected and complex elements that include many "children". Although there was a high agreement across stakeholder groups that these were key elements, the hierarchical structure reveals that different groups focus on different parts of the SES, hence these elements are important in different contexts. For example, although all groups identified *Governance*, they identified different "children" such as *Regulations* (e.g., *Petroleum-Seismic Regulations* and *Harvest Regulations*) which connect to different *Drivers*, *Ecosystem Components* and *Ecosystem Services*. Similarly, the assigned links from *Accidental* and *Operational Pollution* ("children" under *Pollution*) differed among groups, as their sector activity have different impacts on ecosystem components. The most common *Ecosystem Components* (e.g. *Marine Mammals, Seabirds and Fish*), were mainly acting as elements impacted by *Drivers* and *Activities*. Nevertheless, the stakeholder groups also identified links outbound links from *Ecosystem Components* to *Cultural Ecosystem Services*, highlighting the relationships where Ecosystem Components impacts other elements in the Barents Sea SES.

The stakeholders categorized *Area Conflict* as a highly connected *Driver* in the BS SES, most frequently performing as a receiving element from human activities. This confirms that area conflict related to cross-sectoral use of the ocean can be considered a common concern across stakeholder groups. Disagreements and conflicts among users have been identified in other systems (Bellanger et al., 2020; Sander, 2018b) and in the BS (Arbo and Thủy, 2016; Olsen et al., 2016).

4.2. *Cross-sectoral models as input for an integrated system overview*

The goal of building conceptual models based on stakeholder's inputs is to identify their perspectives on the SES, not to reveal its "true" underlying SES functioning. It is noticeable that important ecosystem components central for ecosystem functioning such as primary and secondary production and key pelagic fish species are not frequently identified. On the other hand, elements that may easily be overlooked by scientists involved in IEA groups (e.g. *Area Conflicts*, *Shipping Regulations*) were clearly identified by some stakeholders. In this way, the collected results from individual models directly contribute to scoping, which is a critical step in the IEA process (Levin et al., 2014), and can be used to structure and update the conceptual models used by IEA groups.

The International Council for the Exploration of the Sea (ICES) publishes Ecosystem Overviews (EO) for the different (mainly northeast Atlantic) ICES ecoregions, so also for the Barents Sea (ICES, 2021), where several of the authors of the present paper had central roles. The EOs use risk-based methods to identify the main human pressures and explain how these affect key ecosystem components in the ecoregion. By following a risk-oriented approach, the current Ecosystem overview for the BS is likely to miss out on important feedbacks, non-sequential and positive interactions between activities and various components of the SES. In risk-oriented approaches, impact chains typically run from sectorial activities to ecosystem components, which can be further linked to ecosystem services (Robinson et al., 2014). Thus, the impact chains are sequential (e.g., from human activities to pressures and from pressures to ecosystem components) and uni-directional (e.g., from pressures to impacts, but not the other way around). Such linear approach precludes the assessment of other significant links in the system. The results of the current study offer an opportunity for scoping that is wider than risk-oriented frameworks, for example by allowing direct links between *Activities* (e.g., *Fishing*) and *Ecosystem Services* (e.g., *Seafood*), as well as candidates for more complex feedback loops in evaluation of impacts versus benefits.

Risk-oriented assessments also have a normative bias towards negative effects of human activities, as reflected in the terms "pressure," "impact" or "risk". In this study, the stakeholders were asked to identify both positive and negative impacts of human activities in the BS SES. Following, elements considered to have cross-sectoral benefits such as *Infrastructure*, *Innovation*, *Economy (*e.g., *Social Welfare*, *Employment)* and *Risk Mitigation* were identified and connected to human activities.

4.3. *Using stakeholder models to support EBM implementation in the Barents Sea*

The open and flexible approach enhances cross-stakeholder dialogue and engages the stakeholders to identify cross-sectoral issues in the Barents Sea SES. This entails inclusion of cross-sectoral drivers with cross-sectoral benefits. Integrating links of such cross-sectoral or cross-

Table 2
The top 30 elements of the Barents Sea SES. The elements are listed by decreasing order of importance. The rank of each element is determined by 3 criteria: the number of stakeholder groups who cited it, the number of in-degrees and the number of out-degrees. Elements that are equally prioritized have the same rank number.

Rank	Element	Type	Criteria					
			Groups		In-degrees		Out-degrees	
			#	Rank	#	Rank	#	Rank
1	Pollution	Driver	6	1	60	3	148	1
2	Governance	Driver	6	1	52	4	90	2
3	Oil and Chemicals	Driver	6	1	38	9	82	3
4	Rules	Driver	6	1	17	19	60	6
5	Marine Mammals	Component	6	1	52	4	18	23
6	Fish	Component	6	1	52	4	17	24
7	Operational Pollution	Driver	6	1	21	16	34	13
8	Petroleum Activity	Activity	5	11	26	14	40	11
8	Exploitation	Activity	4	18	29	11	50	7
10	Fishing	Activity	4	18	29	11	48	9
11	Accident Pollution	Driver	5	11	17	19	48	9
11	Seabirds	Component	6	1	41	7	11	31
13	Supporting Service	Service	5	11	25	15	32	15
14	Cultural Service	Service	5	11	99	1	11	31
15	Large Oil Spill	Driver	5	11	13	31	34	13
16	Regulations	Driver	6	1	8	41	27	16
17	Discharge Sea	Driver	4	18	14	27	24	17
18	Cruise Activity	Activity	3	33	14	27	64	4
18	Area Conflict	Driver	4	18	17	19	15	27
20	Marine Transport	Activity	5	11	10	35	16	26
21	Litter	Driver	4	18	10	35	20	21
22	Climate Change	Driver	6	1	3	71	63	5
22	Ice Species	Component	4	18	63	2	6	57
24	Biological Drivers	Driver	3	33	12	33	36	12
25	Non-Indigenous Species	Driver	3	33	9	38	24	17
26	Politics	Driver	3	33	7	44	24	17
27	Ice Mammals	Component	4	18	39	8	4	71
27	Noise	Driver	4	18	6	49	12	30
29	Habitat	Service	4	18	5	56	17	24
29	Seismic	Activity	4	18	6	49	11	31

pressure drivers allows for exploration of how to balance negative impacts versus benefits, a core challenge in EBM (Rudd et al., 2018). A wide range of perspectives may also expand the number of options for decision makers, providing them more room to maneuver (Olsen et al., 2014). By accounting for multiple values in the decision making processes the management can be more adaptive to changes and ensue policy to gain public acceptance (Simpson et al., 2016).

Although the diverging perspectives across stakeholder groups underlines the need to remove the consensus requirement in the Management forum (which is involved in the implementation of the BSMP), some consensus on key elements in describing the Barents Sea SES is required as part of the scoping process for priorities in further Ecosystem Risk Assessment (ERA) and IEA (Holsman et al., 2017). The high complexity of group specific stakeholder models impedes the identification of clear priorities for ERA, although ranking by multicriteria does show some commonalities across groups. A more constrained approach, e.g., using a less complex and predefined model structure, could have been more efficient and provided more consensus across stakeholder groups, but it would be at the cost of less detailed information.

The anticipated increase in marine human activities in the BSMP, which is likely with both Blue Growth and Green Shift policies (Norwegian Ministry of Foreign Affairs, 2017; Norwegian Ministry of Trade, Industry and Fisheries, 2019, 2021; Norwegian Ministry of Trade, Industry and Fisheries & Norwegian Ministry of Petroleum and Energy, 2017), can increase or generate more area conflicts and sectorial disagreements. Identifying cross-sector issues at an early stage can dampen potential conflicts through compromises and trade-offs while also identifying possible win-win options (Arbo and Thủy, 2016; Ban et al., 2013; Herbst et al., 2020b; Olsen et al., 2016). Acknowledging such disagreements and partial victories and losses supports a healthy state of affairs in a democracy (Bjørkan and Veland, 2019).

4.4. Methodological considerations

Stakeholder representativeness may be understood as a stakeholder sample reflecting a balanced inclusion of the variety of perspectives that exists within the stakeholder population (Cuppen, 2012). We recognize that different outcomes may have emerged if the composition of the stakeholder groups had been different, taking into account that stakeholder perspectives can be misrepresented due to the small size of the stakeholder groups and to the small number of groups (Kontogianni et al., 2012b). This practical limitation is difficult to overcome, given the challenge associated with obtaining participation from stakeholders who have limited time to join research projects which they perceive as being mostly academic.

Stakeholders invested valuable time in taking part in this work, especially the physical meetings, which involved lengthy travels. Their participation showed trust in the scientific process, especially since they got only sparse information about the methods up front. None of the stakeholders had been involved in such an approach earlier but were introduced to it before they started to develop conceptual models. Although there was some initial uncertainty the stakeholders were enthusiastic about sharing their ideas and opinions. They also appreciated the opportunity to revise their input, as some of it was given at the spur of the moment. Most stakeholders were happy to participate in a final on-line presentation and discussion of the outcome. There was a need for some explanation, but the stakeholders were positive and found their time well-invested. However, it is too early to evaluate to what degree the new knowledge resulting from this study can be applied in actual management.

While the groups were confident and active in identifying *Activities*, *Drivers*, and *Ecosystem Components*, they often missed out on the corresponding *Sectors* and *Ecosystem Services*. This led to limited information and representation of how *Sectors* and *Ecosystem Services* can influence or be influenced by other parts of the SES. Further exercises, or revision of the conceptual diagrams should consider these limitations and allocate additional time and resources to engage stakeholders into thinking more deeply about how *Sectors* and *Ecosystem Services* interact with each other and with other parts of the Barents Sea SES.

The conceptual models presented here are a snapshot of the stakeholders' perspective in 2019–2020 and these are expected to change over time. Stakeholders emphasized that temporal and spatial scales are critical, given that some relationships operate at a smaller or even larger scale than the BS. This may partially explain why some stakeholder groups were reluctant to provide additional attributes to their identified links in the system. There are also large variations in activities, drivers and ecosystem components and services at sub regional scales. For example, petroleum activities have restricted conditions and/or access in seven areas classified as particularly valuable and vulnerable within the BSMP (Norwegian Ministry of Climate and Environment (MCE), 2020). Following, this work focuses on the Norwegian part of the BS and the results cannot be directly extrapolated or interpolated. Estimation of hypothetical values for different scales requires additional dedicated studies, potentially applying multi-layer network approaches to address the complexity, temporal and spatial challenges (Jacob et al., 2020; Kluger et al., 2020; Pilosof et al., 2017). The spatial and temporal limitations have important implications for the interpretation of the results.

We applied a relatively simple, transparent and reproducible ranking method which ordered elements based on how frequently they were identified by stakeholders and how connected they were to other elements of the system. The method is easily understood, and the interpretation of the rankings is fairly straightforward. Alternative approaches based on network analysis (e.g., using betweenness and closeness) have been applied in similar studies (Zetina-Rejón et al., 2020). The underlying assumptions, calculations and interpretations of the results from the latter approaches are more technical, which can potentially lead to misunderstanding or conflicting discussions among stakeholders, managers and scientists. We have therefore not tested these alternative approaches in the current study.

4.5. Next steps

In the present study, we analyzed the conceptual models using graph theory to identify commonalities and divergences in the sector-based stakeholder models. The conceptual models can be further operationalized by implementing qualitative network models (QNMs) based on loop analysis or fuzzy cognitive mapping. These models can be used to explore patterns underlying stakeholder's representation (Kosko, 1988) as well as to run simple scenarios (Dambacher et al., 2003; Harvey et al., 2016; Lane, 2021; Marzloff et al., 2011). Such models constitute a powerful tool to rapidly assess the dynamics of and threats to complex systems that may not be easily modeled with fully quantitative tools (Elliott-Graves, 2020; Levins, 1974). The current collection of sector-based conceptual models and the prioritization of specific elements and links provide a solid basis for inputs to QNMs which can then be used to further support EBM and ERA.

5. Conclusions

Even though the Barents Sea SES can be considered as relatively simple with few anthropogenic pressures, the observed stakeholder perspectives on the system are complex and diverse. Sector specific elements and their role assignments contribute to this diversity and confirm the value of the diligent pursuit of relevant stakeholders. This emphasizes the need for collaboration between stakeholders and scientists in future efforts to develop qualitative network models.

The flexible and open participatory approach applied in this study enhances stakeholder engagement and cooperation and provides a high level of detailed information, including cross -sector benefits and concerns. The flexibility also adds complexity which challenge the identification of key issues across perspectives for ERA. Nevertheless, some commonalities were uncovered by following an iterative process with model revisions after plenary sessions, standardization of vocabulary and construction of the hierarchical model structure. Some complexity was also reduced by condensing detailed elements into broader categories in the hierarchical structure.

In the collective model, where input from all condensed stakeholder models is summarized, some elements and relationships are common to most stakeholder groups. Here, *Pollution* and *Governance* are highly ranked drivers and act as hubs in the system, while *Fish* and *Seabirds* are considered dominating receivers together with *Cultural Ecosystem Service*. *Exploitation* and *Petroleum Activity* accompany the identified hubs as the main impacting elements in the system. Thus, the collective stakeholder model provides valuable input into an integrated overview of the BS SES. Yet, any simplification of the model structure for further analysis and identification of priorities, leads to loss of detailed information. Our collective model can strengthen EBM and the prioritization in Ecosystem Risk Assessment, by supporting the development of a qualitative network model which allows for exploration of perturbations and can inform cross-sectoral management.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2023.106724.

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