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Mapping stakeholder networks for the co-production of multiple ecosystem services: A novel mixed-methods approach

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ABSTRACT

Governance of ecosystem services (ES) requires an understanding of the complex dynamics of collaboration (and contestation) of multiple stakeholders and multiple ES. However, many studies consider only a few ES or stakeholder groups. In our work, we map the co-production of multiple ES by multiple stakeholders connected through ES governance networks. Through a unique combination of Public Participatory Geographic Information Systems (PPGIS), stakeholder focus groups, surveys, and social network analysis, we reveal insights on social-ecological fit of ES co-production across an area unified by a UNESCO Biosphere Reserve designation.

By overlaying relationships between stakeholders, multiple ES, and ES co-production networks, our results reveal gaps and mismatches in the ES governance system. We identified mismatches between those ES most valued by the region's inhabitants and those managed, governed and studied by relevant institutions and stakeholders. Cultural ES were the most highly appreciated by stakeholders, but social networks of cultural ES governance were the least densely connected, with highly influential stakeholders involved in cultural ES management (e.g., farmers), not well connected to the governance network. Thus, our findings point to a weakness in cultural ES governance and the need of incorporating cultural ES more clearly into natural resource management agendas.

Our results show the importance of mapping *what* is being discussed by *whom*, and that mapping environmental governance networks alone does not necessarily provide sufficient resolution to understand co-production of different ES. We confirm the difficulties of governing ES when the ES providers and/or beneficiaries operate at different or distant scales, the scale of ecological processes does not match management (e.g., in some regulating and maintenance ES), or stakeholders which are important in affecting ES provision are not involved in governance, resulting in social-ecological misfit. Lastly, our work confirms the broad array of research methods needed to capture the complexity of governing multiple ES.

1. Introduction

Human actions in the Anthropocene compromise the flow of essential benefits from nature to people (Díaz et al. 2019). Managing landscapes to ensure the sustained and resilient provision of Ecosystem Services (ES) has become a key focus area of national, regional and local initiatives, which have begun to mainstream ES throughout environmental policy and management (European Commission, 2019, Longato et al. 2021). Although ES-centred management has been proposed to ensure continuity of nature's contributions to people (Rozas-Vásquez et al., 2019), there has been limited theoretical and empirical work done on operationalizing ES-centred governance (Sattler et al. 2018). Navigating trade-offs between ES and disparate societal interests and values is no trivial task, and requires the development of frameworks and processes to resolve collective action dilemmas (Biggs et al. 2015, Lescourret et al. 2015, Loft et al. 2015, Barnaud et al. 2018).

Ecosystem services are coproduced by the interactions between ecosystems and people, and stakeholders in a landscape can be both beneficiaries and/or co-producers of ES (Spangenberg et al. 2014, Biggs et al. 2015, IPBES 2019). Governance and management-level decisions modify ES supply at various points of the ES cascade, for example through legislative changes in access, or through direct modification of

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supply through harvesting and/or management (Primmer et al. 2015). Past research has shown that ecosystem governance simultaneously addresses different types of ES, which results in a mixture of interacting institutions that should be adapted to different ES properties, resulting in good institutional or social-ecological fit (Falk et al. 2018). The subtractability and excludability of different ES, will determine the type of institution required to ensure their provision (Falk et al. 2018). For example, in the enjoyment of iconic landscapes it is hard to exclude others (low excludability) and the enjoyment does not get exhausted by others (low subtractability), whilst fodder production has high excludability and high subtractability. Although evaluations of use and direct modification relationships of provisioning ES are more abundant in the literature (Costanza et al. 2017), there is a less clear understanding of other ES, such as cultural ES (Blicharska et al. 2017). There may be competing interests for different ES resulting in management and/or use mismatches when one, or a particular set, of ES are prioritised leading to trade-offs among ES. Thus, ES governance must be understood as a complex network of overlapping institutions, which must work to harmonize diverse sets of ES. As such, networked or polycentric governance, a governance system with multiple, nested governing authorities at different scales, has been proposed to increase social-ecological fit and foster resilience of ES (Biggs et al. 2012). These forms of governance can enable participation and collaboration, building mutually reinforcing connections for ES governance between partners and stakeholders, rightsholders, the scientific community and the population at large (Connolly et al. 2014, Kotschy et al. 2015, Bodin et al. 2020).

Landscape multifunctionality has emerged as an idea that captures the capacity of landscapes to provide multiple ES simultaneously (Manning et al. 2018). Biophysical mapping of ES supply, ES flow, and ES demand have become increasingly common (e.g., Schirpke et al., 2019; Schröter, Barton, Remme, & Hein, 2014) and biophysical studies showing provision and demand of multiple ES have helped capture ecosystem multifunctionality, synergies and trade-offs between different ES (e.g., Raudsepp-Hearne et al. 2010, Parrott & Meyer 2012, Queiroz et al. 2015). However, reviews of ES governance literature (Sattler et al. 2018, Winkler et al. 2021) highlight that the extensive mapping of ES has not been matched with systematic mapping of governance (Primmer et al. 2021). In fact, social processes in general are considered underrepresented in the ES cascade framework, and we have limited understanding of how management and governance of landscapes affect ES at different points of the ES cascade (Spangenberg et al. 2014, Primmer et al. 2015). Although an increasing number of studies address this question (Connolly et al. 2014, Lienhoop and Schröter-Schlaack 2018, Vialatte et al. 2019), we are still far from matching the broad-scale understanding gained in many biophysical ES studies, approaching the complexity of multiple ES and multiple stakeholder groups at the same time (Howe et al. 2014). Mapping ES stakeholders, and their respective values, motives, and interests can help understand conflict and contestation over ES trade-offs and ES management decisions (Howe et al. 2014, Biggs et al. 2015).

Studies of ES as social-ecological phenomena must capture the complexity of relationships between multiple ES and multiple stakeholders. Network approaches have become a popular way to capture social-ecological systems properties, as complex adaptive systems which are constituted relationally through networks of actors and social-ecological relationships (Preiser et al. 2018). Social network analyses have revealed important insights on questions of collaboration and conflict in natural resource management, for example, by tying social network structure to environmental management outcomes (Bodin et al. 2020). Social network analyses have also contributed to the knowledge of social-ecological and institutional fit and mismatch, where institutional structures and networks should match the scales and processes of the ecological systems they govern (Bodin and Tengö 2012, Bodin et al. 2014, Guerrero et al. 2015, Dee et al. 2017). The use of social network analysis in the ES literature is however relatively underdeveloped (Connolly et al. 2014, Dee et al. 2017, Gaines et al. 2017, Schröter et al. 2018, Mason et al. 2020), and has often focused on a single ES (Meyer et al. 2019). Collaboration for ES governance and management can be facilitated by key bridging organizations in collaborative ES governance (Odom Green et al., 2015). UNESCO Biosphere Reserves (BR) have been proposed as examples of "round table" institutions which cross spatial and administrative boundaries and bring diverse stakeholders together (Odom Green et al., 2015, Schultz et al. 2018, Barraclough et al. 2021b). In this work, we study a BR in western Norway, Nordhordland UNESCO Biosphere Reserve, as an example of an institution that can cross jurisdictions and spatial boundaries to enhance social-ecological fit for networked ES governance. Developing simple tools to understand social-ecological fit, and mismatches between stakeholder interests and current governance priorities for multiple ES across collaborative platforms seems to be a vital step in integrating ES into decision making.

In this study, our key objective is to comprehensively map the social dimensions of the ES cascade and understand how multiple stakeholder groups participate in the co-production of multiple ES. Our study uses a simple mixed-methods approach to outline the relationships between stakeholder groups and ES ("stakeholder-ES relationship bundles") and stakeholder social networks to understand how natural resource management overlaps with ES governance. By systematically mapping stakeholders' relationships to ES and to each other, we aim to show the networks on which ES supply depends across multiple municipalities unified by a UNESCO BR designation. Our key questions are (1) How are different co-production relationships (management, governance, knowledge production and valuation) connected to bundles of ES? (2) What stakeholders are involved in the management and governance of multiple ES? (3) What is the structure of the ES co-production network and how does it differ for different ES classes (provisioning, cultural and, regulating and maintenance)?

2. Material and methods:

2.1. Methodological framework and considerations

Our methodology is situated in the importance of considering synergetic bundles of ES rather than single selected ones (Malmborg et al. 2021). We follow a sustainability science approach, by which we combine different methods to produce actionable knowledge which contributes to sustainability transformation – thus taking a normative stance in our work (Miller et al., 2014; Mach et al., 2020).

We use a mixed-methods approach to understand how natural resource management overlaps with the governance and co-production of multiple ES, by seeing ES co-production as a network where actors interact with ES via different kinds of relationships: benefit and societal demand, management, governance, and knowledge production (Fig. 1). We approach each of these with specific analytical tools (Fig. 1, blue squares): (1) A PPGIS survey to understand stakeholder valuation of ES benefits; we used PPGIS because it captures social-cultural values for ES (Brown and Weber 2011, Scholte et al., 2018) (as opposed to biophysical values), (2) a survey of governance, management and knowledge production relationships of key stakeholders involved in networked governance to map stakeholder involvement in the co-production of different ES and, (3) a social network analysis, to understand the structure of the ES networked governance and the relationships between different stakeholder groups involved. We integrate our analysis the existing frameworks on ES governance and institutional mapping of Primmer et al. (2021).

2.2. Case study

The study took place in the Nordhordland Biosphere Reserve (NBR), Norway's first and only UNESCO Biosphere Reserve declared in 2019 (Fig. 2). Nordhordland itself was a historic province that no longer holds administrative status and now encompasses 9 municipalities. NBR is managed by a municipally funded company supported by those 9

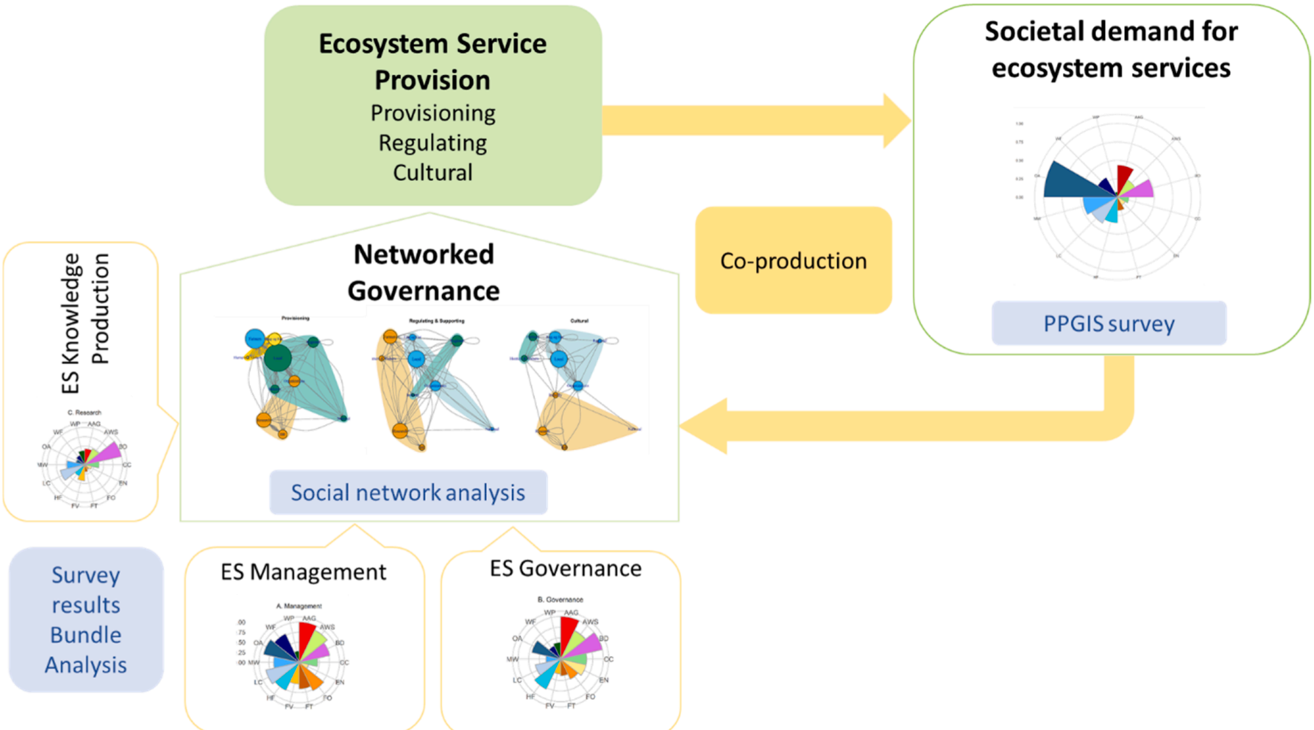

Fig. 1. Diagram depicting our methodological and conceptual approach to the institutional and stakeholder dimensions of Ecosystem Services (ES), modified from the framework by Primmer et al. (2021). The analysis tools employed to approach each are shown in blue squares: ES-stakeholder relationships of governance, management, and knowledge production (flower diagrams), social valuation of ES (through PPGIS), and the structure of ES networked governance (social network analysis).

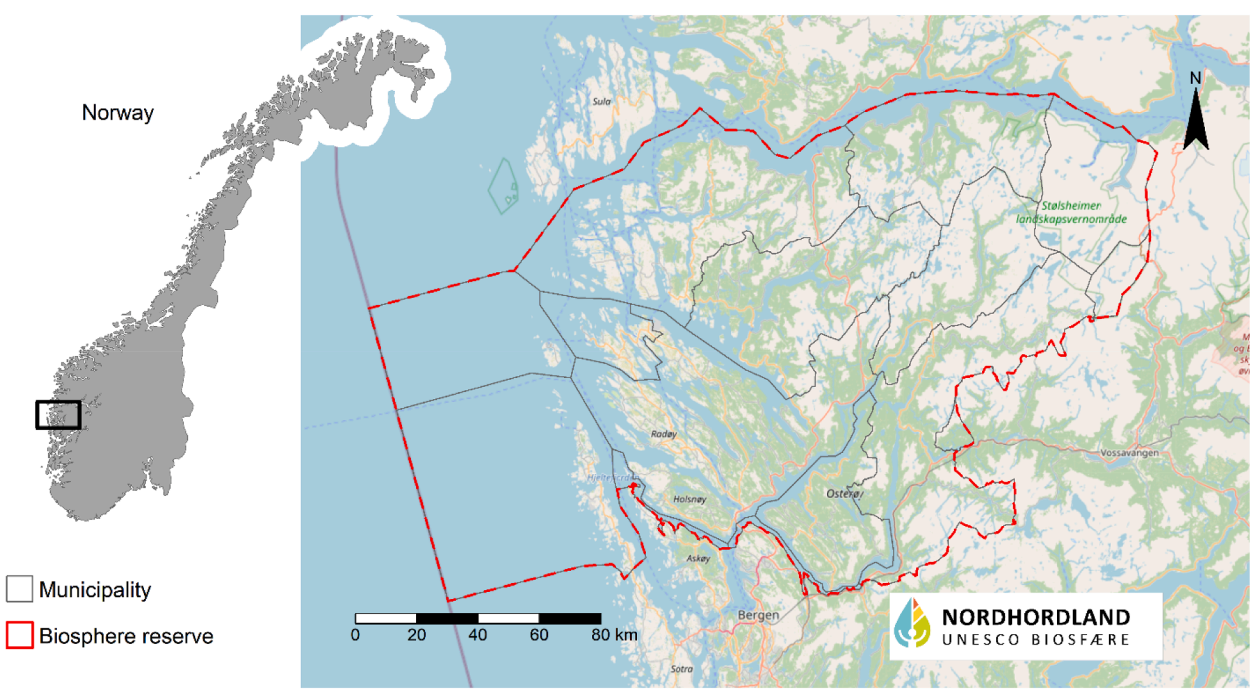

Fig. 2. The location of Nordhordland Biosphere Reserve on the West coast of Norway. Basemap provided by Open Street Map.

municipalities, and is still in its initial phases of establishment, with its organizational structure still under development. This case study was chosen because it constitutes a comparatively large region (6,698 km^2) where municipalities are unified by a UNESCO designation which is intended to foster collaborative environmental governance (see Introduction).

NBR represents a typical coastal and fjord landscape of Western Norway, extending from the most western archipelagos through deep fjords into high mountain areas inland. There is one Protected Landscape Area (Stølsheimen, 37.5 ha) and one marine protected area

(Lurefjorden and Lidåsosane, 6.9 ha) in NBR, in addition to several smaller Nature Reserves in the region. The main economic activities and sources of employment are in public services and industry (mainly connected to petroleum). Hydroelectricity production is also a significant source of income for local municipalities with a high proportion of rivers having energy production infrastructure (Kaland et al., 2018). Agriculture is of cultural and historical importance, although of minor economic importance, where the size of holdings is on average small (14.5 ha) and with farmers often relying on government subsidies. Main farming activities are cattle holding, mainly cows for milk and meat, sheep for wool and meat, and goats for milk and meat (Måren et al. 2022). Outfield grazing is historically important in the region and in maintaining the cultural landscape (Vandvik et al. 2014). Vegetable production is of low importance although it is currently being encouraged by several market-garden production projects. Forestry is of growing importance, with many of the plantations established in the 1950s, predominantly on private land, now reaching harvest maturity. Although there are no state-owned forests in NBR, there is a large association of private forest owners contributing to management and forestry road development.

2.3. Survey design and data collection

The online survey was a conditional branched survey, with two distinct sections: 1) a PPGIS survey aimed at the public where respondents were provided a list of 12 different ES (see Supplementary Material) to choose from at will and then place on a map of the BR where they received this ES (Cusens et al. 2022), and 2) a set of questions aimed only at key stakeholders which were selected through conditional questions asking if they were involved in natural resource management in the region. We defined key stakeholders as those working in agriculture, forestry, hunting or fishing, and any form of cultural, biocultural or natural resource-related management, governance, industry or research. This section of the survey contained questions on stakeholder roles and asked participants to identify their relationship to a list of 14 ES as either “direct management or modification” (hereon referred to as “management” relationship), “enforcement, regulation or legislation” (hereon referred to as “governance” relationship), or” knowledge gathering or research” (hereon referred to as “research”) (modified from Alonso Roldán et al. 2015). This section also contained questions relevant to the social network of stakeholders working in natural resource management in NBR, following an Organizational Network Analysis (ONA) method (Eisenberg and Swanson 1996), where the unit of analysis is stakeholder interest groups. Participants were asked to identify general stakeholder classes with whom they communicated with on a regular basis to achieve their natural resource management goals. Respondents could choose from a list of 10 stakeholder classes (see Table 1) and place an icon of them on a map in the municipality or area this stakeholder was based (Barraclough et al. unpubl.). For each selected stakeholder, participants were asked to complete an open question on what their communication was about in relation to the landscape of NBR and rate how effective the communication was to achieve their work related to nature.

The survey went through different stages of participatory design with local stakeholders. Firstly, the list of ES was chosen in consultation with the BR organization’s documents, primarily the UNESCO Biosphere Reserve candidacy application (Kaland et al., 2018), while the list of relevant stakeholder classes was elaborated from the BR’s stakeholder analysis documents part of their start-up strategy process (Table 1). A focus group session with representatives of the local municipalities (planning, agriculture, and environment), agriculture advisories and the BR organization allowed us to refine and complete the list of ES and relevant stakeholder classes. The list of ES provided to the general public in the PPGIS exercise (12 ES), and to core stakeholders in the management-oriented exercise (14 ES), differed slightly as after focus group discussions we chose to adapt the ES to each context (see also Supplementary Material & Cusens et al. 2022). During this process, we decided to have 12 ES categories for the general public, but two additional ES categories for the key stakeholder evaluation (“fodder” and “fruit and vegetables”, Appendix Table 1) since they were considered of particular importance by focus group participants.

Table 1
Survey participants (n = 313) who responded to the survey by stakeholder class in the Nordhordland Biosphere Reserve, those marked with an * asterisk were key respondent classes.

Stakeholder Class	Participants (n)	Description
General public	111	General public who only participated in the PPGIS section of the survey
Farmers*	72	Farming union representatives, individual part- and full-time farmers
Hunters and Fishers*	21	Hunting and fishing organization representatives and individual hunters and fishermen
Industry*	11	Representatives of the aquaculture industry, oil industry, energy industry and forestry
Business*	21	Consultants engaged in environmental monitoring and mapping, tourism businesses, gastronomy related businesses, small-scale timber and wood businesses
“Lag og foreiningar” (clubs and community groups)*	17	Small (neighbourhood or local) community clubs, groups, and associations for local culture, environment, nature, or outdoor pursuits.
Organizations*	14	Larger regional scale organizations and non-profits for the preservation of cultural landscapes, nature conservation, and cultural heritage
Local Government*	22	Local municipality heads of agriculture, forestry, landscape planning, culture and general coordination (in the case of very small municipalities)
National Government*	2	Coastal management, environment office
Regional Government*	7	Regional government representatives for nature management, agriculture, culture, education and general coordination
Scientist/Researcher*	11	Researchers from higher education institutions and research centres working on environmental science, ecology, eco-economics and marine research
Other*	4	Community members, landowners, and foragers
Total	*313*	*All participants*

We launched the online survey in February 2020 which was open for six months. The survey was sent out in an email campaign to a list of 224 key stakeholders, with an initial invitation, a midway reminder, and a final invitation. The email list was compiled via grey literature review, website searches, and consultation with the BR organization. The stakeholder list contained key organizations, local community groups, farming unions (and their mailing lists), relevant businesses, and higher education institutions and research institutions connected to natural resource management, in addition to representatives of relevant office sections at each of the 9 local municipalities, and regional and national government offices. The emails contained an invitation for forwarding the survey, thus in addition to directed sampling, we also engaged in snowball sampling (Biggs et al. 2021). After the last email reminder, we consulted the list of participants to identify missing key respondents, who were invited to participate via phone calls. The survey was also shared with the general public via several articles and advertisements in three local newspapers, a workshop campaign in which we visited local libraries in all 9 municipalities and helped locals fill in the PPGIS component of the survey, and a social media promoted add campaign through the NBR social media pages (more in Cusens et al. 2022).

A total of 313 participants completed at least one of the two survey components. The general public, who only completed the PPGIS portion of the survey, totalled 111 respondents. Key respondents, who completed the questions related to natural resource management, totalled 202 respondents (111 male, 89 female, 2 other/prefer not to say). Key respondents represented 75 unique organizations, clubs, unions, government offices and other collective entities (Table 1), as well as individual farmers and hunters.

2.4. Ecosystem service and stakeholder-Ecosystem service relationships data analysis

To ascertain links between stakeholders and the different ESs, we tabulated the responses to the questions on relationships between stakeholders and ES. On the one hand, all positive responses to an ES were summed for the different relationship categories of modification and management, governance, and research, and total sums were scaled between 0 and 1 within each relationship category, from which ES-relationship flower diagrams were constructed. On the other hand, to show connections to ES within each stakeholder class, we summed all positive ES responses counting maximum one link as a positive response to any relationship category, and then divided the sum by total participants of each stakeholder class to create a weighed proportion, from which ES-stakeholder flower diagrams were constructed. We used flower diagrams to represent the relationships where different connections to ES were shown for either stakeholder or relationship type (Foley et al. 2005). Stakeholder-ES bundles were then analysed via *k-means* clustering to test for similarities between bundles (Raudsepp-Hearne et al. 2010), with the *kmeans* function in R (R Core Team, 2020). To calculate the benefit relationship as shown by ES public valuation, we summed all points resulting from the PPGIS mapping exercise and ranked the ES by total number of points chosen (Brown and Weber 2011), and then scaling between 1 and 0.

2.5. Social network construction and analysis

We constructed a social network based on the responses of 126 participants whose social network responses were deemed valid via a manual data check. To be deemed valid, respondents needed to have answered at least one open question per chosen social connection and chosen at least two different social connections. Participants placed a total of 506 stakeholder points, an average of 4 connections per person. For the purposes of this work, it was sufficient to generate a single mode directed network aggregated by stakeholder role. To do this, first we generated a directed matrix whose first dimension was “link givers”, which were the participants who had placed stakeholder dots on the map, and the second dimension were “link receivers”, who were the stakeholders who participants said they were talking to. We then aggregated each dimension by stakeholder class, summing all links and generating link weights which were divided by the number of total participants (“link givers”) of each class. Stakeholder classes were aggregated across municipalities (see Supplementary Material Table 1). Average connection efficiency between stakeholder classes was averaged across the same link type and incorporated as a second-dimension link weight.

Three additional social networks were constructed for three main ES categories of provisioning, regulating and maintenance, and cultural ES. Supporting and regulating and maintenance ES were pooled into one class, and we included biodiversity as we considered it analogous to the ES “maintenance of habitats” as per the CICES classification 5.1 (Haines-Young and Potschin 2018). Node links for each of these networks were obtained by qualitatively coding the responses to the open questions that asked participants which topics they discussed with each of the actors they had selected in the social network questions of the survey (for more details of coding criteria please see Supplementary Material). Whenever an ES was mentioned, the response was coded to the appropriate 14 ES categories as a 1 (mentioned, a link), or a 0 (not mentioned, no link). The links for the 14 ES were summed to yield total link weights for each of the three ES categories. This initial multiplex network of three different link types and identical nodes (Baggio et al. 2016) was then subset to yield three individual networks for analysis. R package “igraph” was used for network manipulation, visualization, and analysis (Csardi and Nepusz, 2006). For all networks we calculated measures of network density, centrality, maximum path length and betweenness. We calculated community clusters via the optimal modularity clustering method (Brandes, 2007), using the *cluster_optimal* function in *R*, which calculates the optimal community structure for a graph, in terms of maximal modularity score. All data construction, manipulation and analyses were done in R (R Core Team, 2020).

3. Results

3.1. Ecosystem service relationships: Management, governance, research, and benefit

Respondents who identified themselves as “governing” ES (Fig. 3) predominantly chose biodiversity, clean air, water, and soil, energy, climate change mitigation, outdoor activities, and hunting, whilst the least chosen ES were extreme weather event protection and wild food provision. The ES most chosen as “directly managed” were the provisioning ES of livestock agriculture, fodder and forestry, the regulating and maintenance ES of clean air, water, and soil, and biodiversity, and the cultural ES of outdoor activities, local culture, hunting and fishing, and wild food (Fig. 3). The least directly managed were extreme weather event protection and energy. The most researched ES was biodiversity, followed by local culture (Fig. 3). Local municipality representatives and other stakeholders (e.g., farmers) did not identify as researching or gathering knowledge on almost any of the ES that they identified as managing or governing.

Benefit relationships were assessed through the PPGIS public valuation component of the survey, which had 313 participants who mapped 3,215 ES points. The most mapped ESs were outdoor recreation and biodiversity appreciation, and the lowest were protection from weather events and energy production. When comparing mismatches between ES governance and management relationships and public ES benefit relationships by comparing the total number of times each ES was selected per relationship type (see Supplementary Material Fig. 1), the highest ranked ES in governance and management was clean air, water and soil, which was only the seventh most mapped ES in the PPGIS mapping. In addition, mental wellbeing was the third most mapped by the public but came ninth in the governance ranking. Both the benefit and the governance-related rankings had outdoor activities, biodiversity, and hunting and fishing in their top five ESs. In addition, protection from extreme weather events, climate change mitigation and energy production coincided in being the least mapped by the public and the least covered by co-production links (Supplementary material).

Cluster analysis of the public ES valuation resulted in four distinct actor groups based on the number of each ES that they mapped in the PPGIS and their self-reported role (total within SS = 2.4, total SS = 8.4, between SS / total SS = 70,9 %). *Group 1* was constituted by farmers and foresters, characterized by high valuation of agricultural and forest products, local culture, biodiversity, and outdoor recreation. *Group 2* was constituted by actors who identified as entrepreneurs and valued agricultural products, and forestry and timber production, with relatively low valuation of commonly mapped cultural ES like outdoor recreation or local culture. *Group 3* was made up of students, scientists and researchers, and tourists, characterized by high values for biodiversity and outdoor recreation. Finally, *Group 4* was made up of all remaining stakeholder classes (business, cabin owners, hunters and

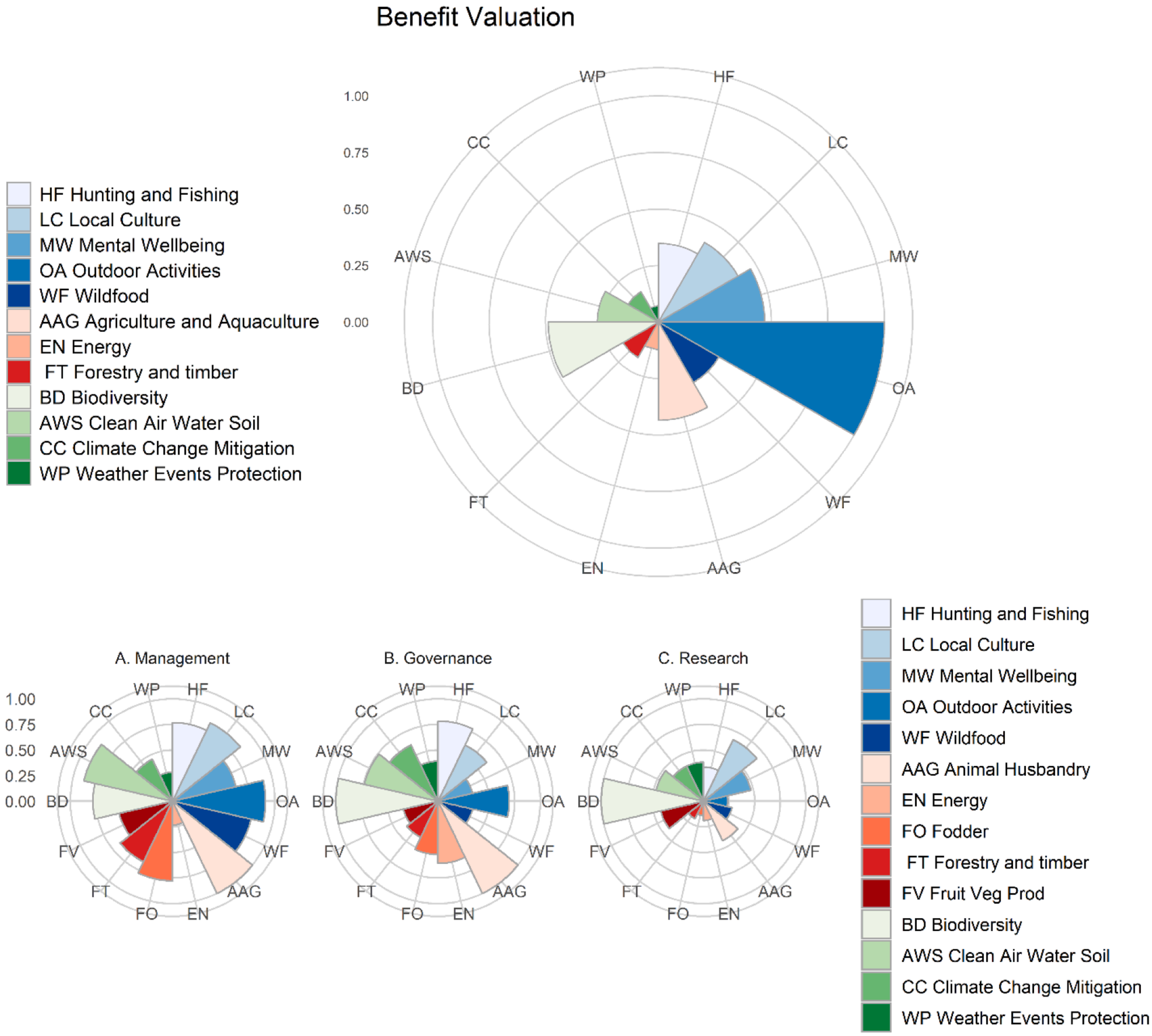

Fig. 3. Relationships to the ecosystem services categories across Nordhordland Biosphere Reserve key stakeholders. Top panel: General public valuation of ecosystem services as obtained by a participatory geographic information system (PPGIS). Bottom panel: Ecosystem services connected to key stakeholders through management (A), governance (B) and research or knowledge gathering (C). Ecosystem services categories of PPGIS valuation and governance categories were adapted to each context.

fishers, industry, inhabitants, government workers, NGO workers, part-time inhabitants, and voluntary workers), whose ES values were dominated by cultural ES appreciation, particularly outdoor recreation, mental wellbeing, local culture and hunting and fishing, in addition to biodiversity appreciation (Supplementary Material Fig. 2).

3.2. Key stakeholder ecosystem service co-production bundles

Farmers, fishers, and hunters all identified themselves as highly connected to provisioning ES, like animal husbandry, fodder, and timber production (in the case of farmers), and hunting and fishing in the case of hunters and fishers (Fig. 4). All three groups also identified themselves as connected to regulating and maintenance ES, such as clean air, water, and soil, biodiversity, and to cultural ES like outdoor activities, wild food, mental wellbeing, and local culture, especially farmers and fishers for the latter. Businesses were connected sparsely to all ES, but predominantly to biodiversity, and cultural ES such as outdoor activities, mental wellbeing, and hunting and fishing. Local community groups' work was connected predominantly with cultural ES such as outdoor activities, local culture, and mental wellbeing. Local organizations had similar ES connections, but a higher proportion worked in connection with biodiversity (Fig. 4).

Researchers were mainly concerned with biodiversity, clean air, water and soil, and climate change mitigation. Local government was evenly connected to all ES, but predominantly to biodiversity, clean air, water and soil, climate change mitigation, and cultural ES like outdoor activities, local culture and hunting and fishing. The regional government was similar to local government, but with a higher proportion connected to provisioning ES like animal agriculture, and fruit and vegetable production. National government was connected to regulating and maintenance ES of biodiversity, clean air, water and soil and climate change mitigation. Overall, very few key stakeholders saw themselves in connection with climate change mitigation, except industry, and the local and national government (Fig. 4). A *k-means* cluster similarity analysis showed four clusters, where the *ES Cluster 1* contained business, industry, *lag og foreiningar*, local government and organizations. *ES Cluster 2* was farmers and regional government. *ES Cluster 3* was hunters and fishers, and *ES Cluster 4* was national government, scientists and

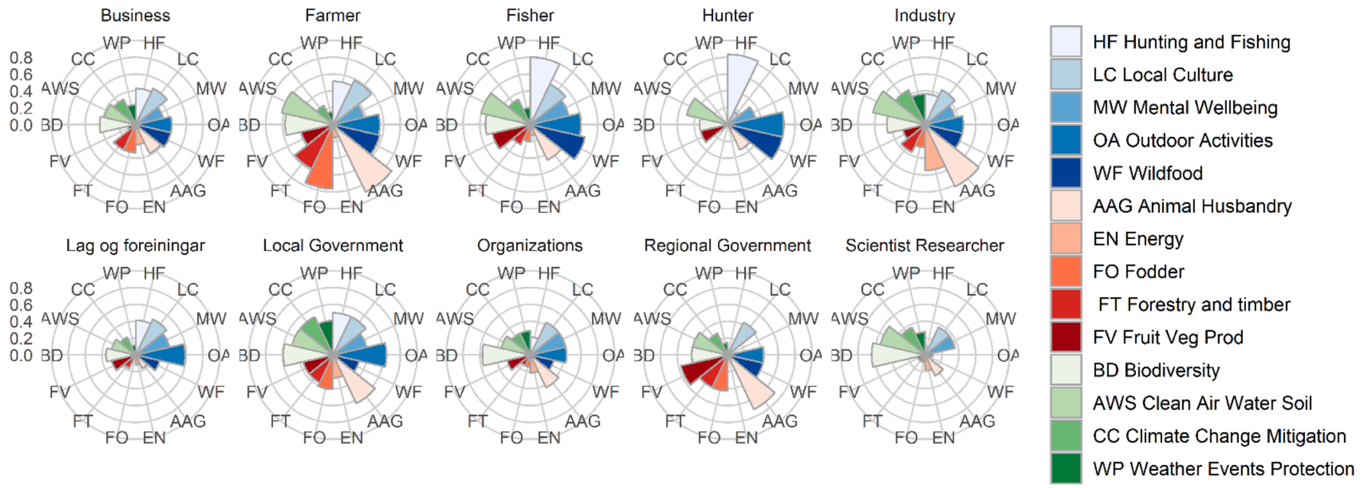

Fig. 4. Ecosystem Service flower diagrams for each key stakeholder class, showing the total proportion within each stakeholder group that identified a management, governance or knowledge gathering relationship to the different Ecosystem Services. The Biosphere Reserve organization was included in the group "Organizations", and "lag of foreiningar" encompasses local groups, clubs, and associations.

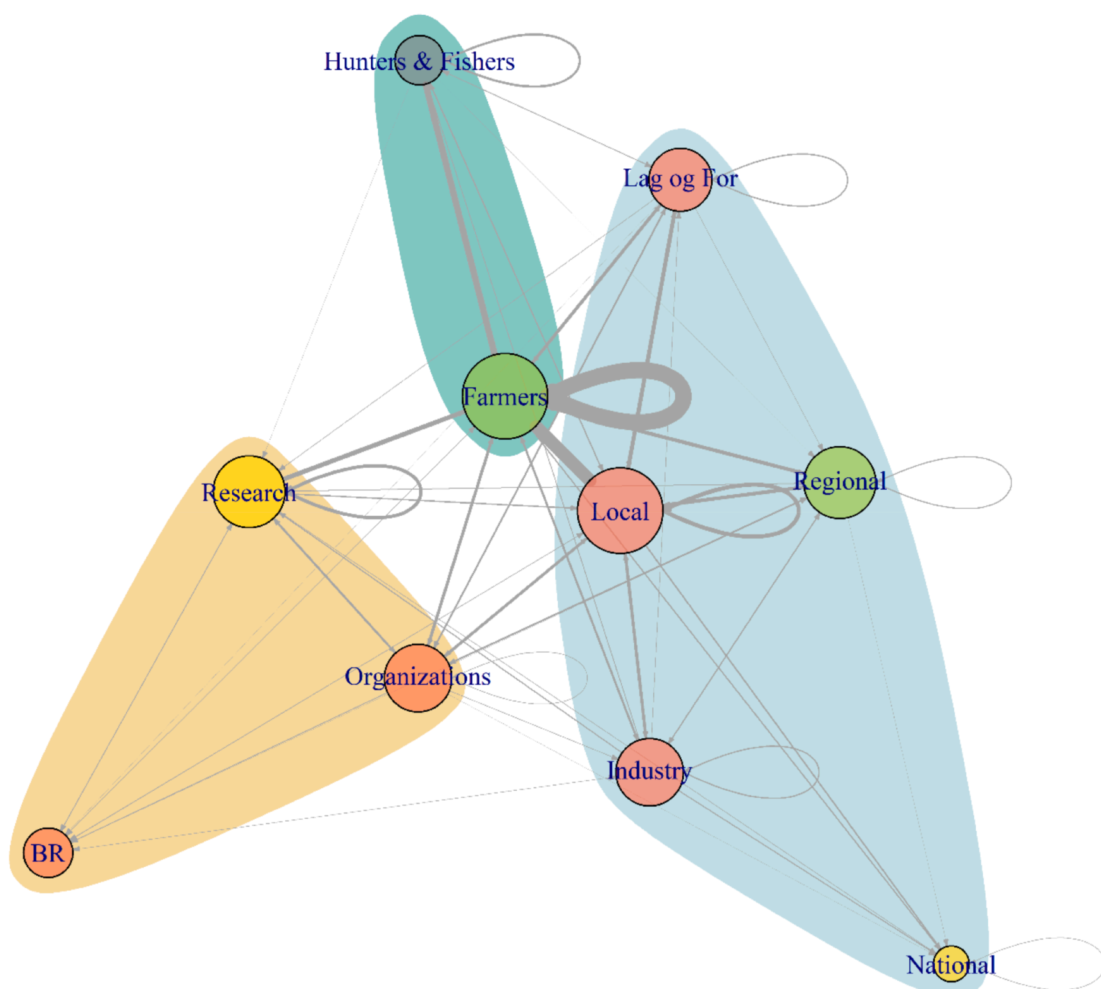

Fig. 5. Simplified natural resource management social network of the Nordhordland UNESCO Biosphere Reserve. Nodes are marked with the stakeholder classes outlined in Table 1 where BR stands for Biosphere Reserve organization. Node colours show the ecosystem service co-production cluster (Cluster 1, pink; Cluster 2, green; Cluster 3, grey; Cluster 4, Yellow; see Results ES Cluster1-4). Large colour polygons show stakeholder membership to a network community calculated with a network modularity cluster analysis.

researchers (total within SS = 2.3, total SS = 7.16, between_SS/total_SS = 66.7 %) (Fig. 5, node colours).

3.3. Social networks of ecosystem service management, and governance

Network nodes with the highest degree centrality (both out- and indegree centrality) were farmers and local governments (Farmers = 19, Local Government = 19) (Fig. 5). Betweenness centrality, which is thought to be a measure of "brokerage" was highest for the BR organization (29.18) and regional government (19.33). Highest link weight in the network was found between farmers and (1) other farmers, (2) local governments, (3) hunters, and fishers. Highest communication efficiency was between organizations and farmers (both directions, non-significant), whilst the lowest was between local organizations, and local and regional governing bodies (directed, Kruskal-Wallis p-value < 0.01). The results of the network modularity cluster analysis showed that there were three distinct communities. *Community 1* was formed by farmers, and hunters and fishers, *Community 2* was formed by *lag og foreiningar*, industry, and local, regional and national governments, and *Community 3* was formed by organizations, researchers, and the BR organization (optimum clustering modularity score = 0,38). No single social network community contained representatives of all ES-clusters, where the most diverse community was the largest (Cluster 2), which contained three different ES-clusters in it (richness = 3) (Fig. 5).

Multiplex ES social network construction (a network showing different link types) revealed three distinct social networks for provisioning, regulating and supporting, and cultural ES (Fig. 6). The provisioning ES network was the most like the overall social network, with high density (density = 1.4), and similar node-level measures with highest degree centrality of local municipalities (centrality = 57) and farmers (centrality = 41), and highest betweenness centrality of local municipalities and local associations (betweenness = 10.79 and 9.4 respectively). The provisioning ES network had the same stakeholder community membership in the clustering analysis (clustering score = 0.59), except farmers did not cluster with any other community.

The networks for regulating and supporting, and for cultural ESs,

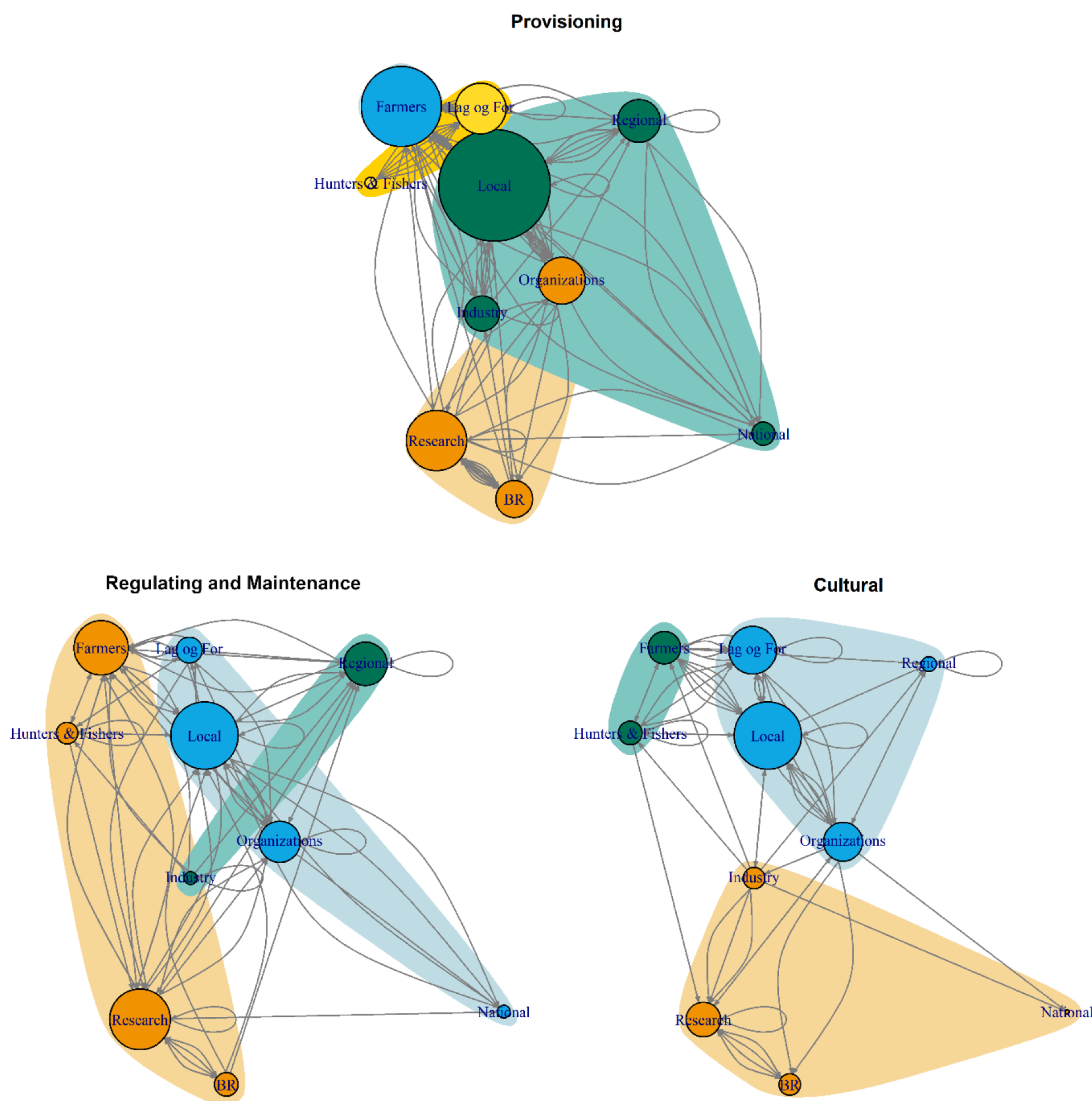

Fig. 6. Social networks for all evaluated Ecosystem Services (ES) grouped into provisioning, regulating and maintenance, and cultural ES. Size of node is a measure of centrality, both node and polygon colour show node community membership based on a network modularity cluster analysis.

showed a distinctly different network measure and community composition to the overall and provisioning networks (Fig. 6). Regulating and maintenance ES had lower network density than the provisioning network (0.93), whilst the cultural ES network had the overall lowest network density (0.79) of all the ES networks. Both the regulating and maintenance, and cultural ES networks also showed the highest degree centrality for local municipalities (centrality = 31), similar to the overall and provisioning networks, but differed in showing the second highest degree centrality for researchers (centrality = 28), in the case of regulating and maintenance ES network, and local associations and clubs (centrality = 22), in the case of the cultural ES network (Fig. 6). Betweenness centrality was highest for farmers in the case of regulating services (betweenness = 12.3), and for local organizations in the case of cultural services (betweenness = 36.4). Community network modularity cluster analysis also showed that the nodes of regulating and maintenance, and cultural ES networks clustered into very different communities. Regulating ES social network nodes clustered into communities *Regulating 1*: farmers, hunters and fishers, researchers and scientists and the BR organization, *Regulating 2*: local associations, local government, organizations and national government, and *Regulating 3*: industry and regional government. Cultural ES social network nodes clustered into *Cultural 1*: farmers, and hunters and fishers, *Cultural 2:* local associations, local government, organizations and regional government, and *Cultural 3:* industry, researchers and scientists, the BR organization and the national government.

4. Discussion

Landscape multifunctionality has become an important multidisciplinary research area investigating the provision of multiple ES in "shared landscapes" (Plieninger et al. 2013, Manning et al. 2018, Kremen and Merenlender 2018, Fagerholm et al. 2019). However, we still lack an in-depth understanding of the governance of multiple ES, and how to manage trade-offs between different ES and diverse stakeholder interests (Albert et al. 2017, Sattler et al. 2018, Quintas-Soriano et al. 2019, Primmer et al. 2021, Winkler et al. 2021). We systematically mapped different kinds of relationships (benefit, management, governance, and research) between stakeholders and ES, revealing the co-production networks on which ES provision depends, across a large region unified by a UNESCO Biosphere Reserve (BR) designation. We show that mismatches exist between stakeholder values, stakeholder-ES relationships, and resource management networks. Through our approach, we address a key gap in the literature regarding the operationalization of ES governance, by seeing ES governance as a 'relational network' of multiple different stakeholders, relationships and ES.

4.1. Broadscale assessment of ecosystem service co-production relationships: From governance to valuation

It is widely acknowledged that ES are coproduced by the interactions between ecosystems and people, and that stakeholders in a particular landscape can be both beneficiaries and/or co-producers of ES (Spangenberg et al. 2014, Biggs et al. 2015, IPBES 2019). Thus, although many studies have focused on farmers as key actors which modify ES through their direct interactions with landscapes (Förster et al. 2015, Lienhoop and Schröter-Schlaack 2018, Mason et al. 2020), we are in need of approaches which capture the fuller complexity of stakeholder-ES relationships (but see Jericó-Daminello et al. 2021). Our study fills this literature gap by mapping relationships beyond direct modification of ES provision, but also indirect modification through development of collective action, development or implementation of legislation and policy, or gathering and spreading of knowledge and information (Alonso Roldán et al. 2015, Barnaud et al. 2018). By systematically mapping the relationships between different stakeholders and ES, our results reveal the diversity of groups involved in ES governance and management, which range from farmers producing food to local associations who organize around natural and cultural heritage preservation and access. Understanding the full web of relationships between actors and ES is key for understanding entry points and levers for ES management interventions, or the effect that landscape planning and ES intervention measures have on ES benefits (Rozas-Vásquez et al. 2019). This broadscale look is important since uptake of the ES concept into management and practitioner environments is still slow (Grêt-Regamey et al. 2017, Brown et al. 2020, Chan and Satterfield 2020, Longato et al. 2021). Our study explicitly considers the research attention received by different ES as a key aspect of their co-production, since the role of knowledge and information in the management of landscape benefits is well established (Opdam et al. 2016) but has not been considered important in ES before (Longato et al. 2021). This allowed us to show that some highly valued or managed ES in NBR, such as energy production and supply, receive little research attention, which highlights a potential gap for evidence-based management and continued supply of these under-researched ES. Despite being within the primary energy producing region in Norway, we found a significant gap in research on energy production as an ES. Considering energy was also one of the ES least valued by stakeholders, our results suggest the need for further investigation into the effects of proposed and ongoing hydro- and wind-power developments on the landscape and its associated values.

Although social and policy research in ES is expanding (Chan and Satterfield 2020) there are still significant gaps in our understanding of the social components of the ES cascade (Spangenberg et al. 2014); for example, the role of different stakeholders in collective action for ES or the need to consider heterogenous stakeholder groups with diverse interests (Barnaud et al. 2018, Vialatte et al. 2019). ES bundles have become one way of evaluating ES provision diversity, ES co-occurrence and stakeholder values (Raudsepp-Hearne et al. 2010, Malmborg et al. 2021,Cusens et al. 2022), but in this work we use them for the first time to map stakeholder-ES relationships and which stakeholders are relevant to the provision of each ES (but see Jericó-Daminello et al. 2021). Our stakeholder-ES relationship bundles allowed us to examine multiple social elements of ES production, from the ES benefits received by inhabitants in our study region to how these are being directly managed, legislated, and studied and by whom. Although some of our results are unsurprising, for example confirming the important role of farmers in the supply of provisioning ES, we also show that some ES types, like cultural ES, are influenced and co-produced by a more diverse set of stakeholders. For example, community clubs and groups ("*lag og foreiningar*") who organize to improve access to cultural ES and enhance the benefits of these ES for local communities. Our work also confirms that farmers (which were highly represented in our survey) see themselves as important co-producers or stewards of cultural ES which provide benefits to wider society within the region (Kvakkestad et al. 2015). Interestingly however, farmers did not often see themselves as co-producers of other ES like climate change mitigation or protection from extreme weather events, a surprising result given the importance of agricultural practices for climate change mitigation, and the impacts that climate change may have on farmers' livelihoods. These results highlight the importance of understanding key stakeholders' mental models of social-ecological inter-dependence, and how they view the effects of their activities on the landscapes and ecosystems they modify (Mathevet et al. 2011, Barnaud et al. 2018).

4.2. Disentangling governance of cultural, provisioning, supporting and regulating services

By constructing social networks for each broad ES category across a multifunctional landscape, our results are a novel contribution showing clear differences in broad-scale organization of ES governance and management, with distinct levels of stakeholder participation, and social network centralization, connectedness, and structure. Past ES governance research has often focused on the governance networks ensuring the provision of specific services, such as carbon offsetting (Buckley

Biggs et al., 2021), particularly in the context of market-based policy tools like Payment for Ecosystem services (PES) (Cook et al. 2016, Meyer et al. 2018, Schröter et al. 2018). Our work is distinct in that it explicitly maps the complex multi-actor co-production networks involved in multiple ES governance, a useful tool for approaching the complexity of interactions and interdependencies between ES, the high amount of stakeholder collaboration required in their management, and the limitations and risks of single-ES or single-stakeholder approaches to ES interventions (Loft et al. 2015, Berbés-Blázquez et al. 2016, Lienhoop and Schröter-Schlaack 2018).

One of the key findings of our study are the structural differences between co-production networks involved in the co-production of cultural, provisioning, and regulating and maintenance ES. The cultural ES network was the most sparce of our analysed networks, with the least number of connections between different stakeholder groups. Some of the main stewards of cultural ES revealed through the stakeholder ES bundles (e.g., landowners, farmers, hunters and fishers), were not so well connected to the co-production network, whereas some, like local community groups and local government bodies were well connected. The mismatch or asymmetry between the level of involvement in on-the-ground management, and importance in the governance network, was reflected throughout the cultural ES governance and management clusters (or "cliques"), which did not cross spatial or institutional scales, but were rather reflective of level of connectedness and sector. Given that cultural ES were the most highly valued by NBR stakeholders, our findings point to a weakness in cultural ES governance and the need of incorporating cultural ES more clearly into natural resource management and collaboration agendas. In addition, our study shows a need for higher involvement of all relevant stakeholders in the planning and consultation of cultural ES development in the region, in particular farmers, given their extensive role in maintaining the cultural landscape in Norway (Kvakkestad et al. 2015). Involvement of key stakeholders in the cultural ES governance and management network would also be key for the provision of outdoor recreation, which was the most valued ES by the local community in this study. This is particularly relevant in the Norwegian context, which is well known for *allemannsretten* ('freedom to roam'), meaning local landowners could be key to the provision of outdoor recreation. Given the importance of cultural ES across European landscapes (Fagerholm et al. 2019), it is important to consider the development of cultural ES governance and management networks which include all relevant players across scales, and account for power inequalities and influence in decision making (Berbés-Blázquez et al. 2016, Barnaud et al. 2018), specifically in the context of BRs or Protected Areas (Barraclough et al. 2021b, Barraclough et al., 2021a).

We show that the regulating and maintenance ES governance and management network was one of the least concentrated. This was reflected both in the lack of centralization in the social network and in the stakeholder ES bundles, which showed regulating and maintenance ES evenly spread out across a high diversity of stakeholders (which included farmers and fishers, industry, local, regional and national government, scientists and researchers, and organizations). As opposed to cultural ES, stakeholder centrality and other social network measures of the regulating and maintenance ES matched well with the level of connection to this ES, i.e., not involved, not well connected. Social cliques also crossed different levels of involvement, in addition to different spatial and governance scales, for example, with farmers and research organizations closely connected in the same cliques. Our results thus could be indicative of a polycentric governance system which is well suited to the management of regulating and maintenance ES, a public good that is decentralized by nature (Muradian and Rival 2012, Falk et al. 2018). However, our work did identify a potential weakness when it came to climate change mitigation potential in NBR which showed different trends to other regulating ES like clean air, water, and soil. We found a distinct gap in management and governance connections to climate change mitigation and extreme weather event protection, with key stakeholders (like farmers and landowners) not considering themselves as co-producers of this ES. These results confirm the difficulties of governing ES when the ES providers and/or beneficiaries operate at distant scales and locations, and when the scale of the ecological processes is so mismatched with the scale of management, resulting in social-ecological misfit (Gómez-Baggethun et al. 2013).

The provisioning ES network was the most centralized with farmers and local governments as the most connected actors, and most like the general natural resource management network. In contrast to the other ES networks, cliques seemed to represent the three sectors of either knowledge, governance, or production. Our results demonstrate that simply mapping natural resource management networks, as has been done abundantly in the literature (Groce et al. 2019, Mason et al. 2020), might not be enough to disentangle and understand the networks governing ES, in particular for regulating and maintenance or cultural ES. By mapping each ES stakeholder network distinctly, our results provide an empirical investigation into the theories proposing that ES are a broad umbrella encompassing different kinds of goods, both public and common, which should be approached through a variety of governance strategies that cross institutional and spatial scales (Muradian and Rival 2012). Our work also confirms that, in addition to understanding the structure of natural resource management networks, it is important to gain an improved understanding of *what* is being discussed and by *whom*, and if interactions in those networks are considered positive or negative (Bodin et al. 2019, 2020).

4.3. Polycentricity, collaboration and diversity in an integrated approach to ecosystem service co-production

Providing a broadscale social-ecological systems' understanding of the social-ecological landscape of ES governance and management in NBR, our work constitutes an empirical approach to combining frameworks developed around collective action theory and the ES framework (Ostrom 2009, Haines-Young and Potschin 2010, Partelow and Winkler 2016, Barnaud et al. 2018, Primmer et al. 2021). As a method suitable to approach social-ecological system's complexity (Preiser et al. 2018), social network analysis has been applied extensively in natural resource management contexts in general (Bodin et al. 2019, Groce et al. 2019). However, the use of tools like social network analysis is still novel in the field of ES governance (Sattler et al. 2018, Schröter et al. 2018, Mason et al. 2020). We expand on existing work by showing that, due to the diversity of ES (both as common, public or private goods, or as processes which function at different scales), each ES class is embedded within structurally distinct co-production networks. One example of this is how we showed distinct levels of centralization, stakeholder participation, and cross-scale/cross-sector connections in each of the ES governance and management networks and community clusters. There were many cross-sector and cross-scale connections in the network cliques for the regulating and maintenance ES network, which were not present in either the provisioning or the cultural ES networks. The existence of cross-scale connections in ES governance networks are important, since they allow for the flow of different kinds of knowledge and information essential to ES management, and can help in processes of social-ecological learning through sharing of experience and perspectives (Olsson et al. 2004). Thus, we show our method could be a useful diagnostic tool to understand collaboration and diversity in ES management, and our work constitutes an empirical investigation into resilience theories of polycentric governance for ES, and social-ecological network diversity and connectivity, which are still notably scarce in the literature (Galaz et al., 2012).

In addition, our social network analysis shows the decentralization of environmental governance in Norway, which has recently been implemented (Kristine and Lundberg 2014, Hongslo et al. 2016), as seen by the strong degree centrality of local municipalities in our analysed networks. Decentralization is considered an example of polycentricity often considered to be positive, as it increases the fit between institutions and local environmental issues (Biggs et al. 2015, Cook et al.

2016). However, it can also be considered problematic when decisions at local scales do not account for large scale trends. Bridging institutions could help coordinate larger scale action for certain ES benefits, for example in the case of our study, cultural ES. Our results point to the potential role of the Biosphere Reserve group as a bridging organization for cultural ES, since it showed the highest score for betweenness centrality, a measure of brokerage (Guerrero et al. 2018). Due to the flexibility and diversity in BR implementation, BRs have been documented to function as bridging organizations which can encourage dialogue and collaboration for ES across multiple stakeholder groups (Förster et al. 2015, Schultz et al. 2018). Thus, BRs could be a good example of overlapping multi-layered governance arrangements for ES (Gómez-Baggethun et al. 2013, Cook et al. 2016).

5. Conclusions

Our study helps fill the lack of empirical work developing the social components of ES on a regional scale. Our systematic analysis of stakeholder networks involved in the governance, management and study of different ES helps understand the alignment between ES governance and social-cultural values for ES in the study region. Ecosystem services bundles have been shown to be an easy way to assess ES multifunctionality in a landscape (Malmborg et al. 2021), and we propose they are also a useful tool to understand diversity of ES co-production and stakeholder roles in a landscape (Jericó-Daminello et al. 2021). Combining these with social network analysis provides a large-scale view of ES governance, and potential mismatches between stakeholder interests across a large landscape. Further work should explore the potential of these methods to pinpoint conflict potential between ES users and the governance network, due to conflicting values, different priorities and ES trade-offs. Further work should also investigate why stakeholders identify themselves as holding specific roles in ES governance, a topic which we have only superficially addressed by creating *a priori* categories (Jericó-Daminello et al. 2021).

In addition to methodological advances, our results also reveal some of the key challenges underlying ES management. The different nature of ES as, for example, commons or public goods, which are connected in different ways to the established natural resource management institutional and traditional structures, means ES management networks are not always fitted to a specific ES – a form of scale mismatch. We propose that studies on ES governance and management need tailored approaches which consider the nature of each good and the level of centralization of its management. Our example points towards a potential "weakness" for cultural ES management. Firstly, cultural ES were not always explicitly considered by those connected to natural resource management. Secondly, the social network communicating about cultural ES management was the least well-connected social network, with key "ES caretakers" like farmers and hunters, not strongly connected to other actors in the network. This could be the source of conflict, considering the extensive role of farmers in the maintaining cultural landscape and recreational pathways in outfield areas in Norway (Bernués, Clemetsen, & Eik, 2016; Bernués, Rodríguez-Ortega, Alfnes, Clemetsen, & Eik, 2015; Kvakkestad, Rørstad, & Vatn, 2015).

We highlight the potential role of bridging organizations to help increase social-ecological fit of ES governance and management networks, such as the capacity of the BR organization to be a bridging organization for cultural ES management found in our work. Our study reinstates the importance of considering multi-level network approaches to ES governance and management. We propose the notion of *ES stewardship* as a concept which more accurately encompasses the multi-level and multi-actor ES co-production that occurs across multifunctional landscapes.

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

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