Aquaculture 574 (2023) 739643

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Analysis of spatial conflicts of large scale salmonid aquaculture with coastal fisheries and other interests in a Norwegian fjord environment, using the novel GIS-tool SEAGRID and stakeholder surveys

Øivind Bergh [a,*], Alexander Christian Beck [a], Anna Nora Tassetti [b,c], Erik Olsen [a], Trude H. Thangstad [a], Genoveva Gonzalez-Mirelis [a], Fabio Grati [b,c], Luca Bolognini [b,c], Guldborg Søvik [a]

[a] Institute of Marine Research, PO Box 1870, Nordnes, 5817 Bergen, Norway
[b] National Research Council,Institute for Marine Biological Resources and Biotechnology (CNR-IRBIM), L. go Fiera della Pesca, 2, 60125 Ancona, Italy
[c] NFBC, National Biodiversity Future Center, Palermo, Italy

ARTICLE INFO

Keywords:
Salmon aquaculture
Fjords
Spatial interactions
Structured interviews
Marine spatial planning
Geographic information systems (GIS)

ABSTRACT

The expansion of the Norwegian aquaculture industry has generated a need for balancing aquaculture with other societal interests in the coastal zone.

The interactions, conflicts and synergies of different uses of a Norwegian coastal region heavily influenced by large-scale salmonid aquaculture was analyzed and mapped by means of systematic stakeholder participatory approach and a GIS-based spatial interaction analysis tool, SEAGRID. Our study focused on spatial conflicts/synergies, whereas non-spatial interactions were taken into account in order to elucidate the spatial effects.

The questionnaire analysis showed that there was a large agreement across the respondents that aquaculture and fisheries compete for access to sea areas, which is also in agreement with the SEAGRID analysis. All but one of the interviewees thought that conservation issues will become more important in the future. We found that societal interests and infrastructure obstruct or displace private enterprises and economic interests, whereas environmental protection measures do so to a lesser extent; an exception are coral reefs which seem to be well protected against both fishing operations as well as new aquaculture facilities. Nature protection was not found to affect fisheries nor aquaculture to a large extent, with the exception of the single salmon fjord, which is protected from salmonid aquaculture, but otherwise open to other activities, such as fisheries, tourist fisheries and tourism in general. The restricted military areas had a limited extent, and were not viewed as a cause of conflicts.

Stakeholder consultations, like our participatory GIS approach, combined with GIS-based tools for analysis of spatial conflicts/synergies may be useful in identifying areas where aquaculture production can increase with little increase in degree of conflict with fisheries, although some interactions are not strictly spatial. Our results indicated a certain degree of mistrust of management authorities since neither fishermen nor aquaculturists perceived that their own sector was given priority by management authorities, but thought the other sector was prioritized.

1. Introduction

Worldwide, coastal zones are home to some of the most biologically productive and diverse marine ecosystems (Gray, 1997). Marine biodiversity is higher in coastal areas compared with the open oceans largely because of the greater range of habitats close to the coast (Gray, 1997). For instance, the number of coastal fish species is estimated to be around 13,000 compared with only 1200 oceanic fish species (Angel, 1993). Coastal areas are important as spawning grounds for a range of fish species (Hutchings et al., 2002; Olsen et al., 2010), and the structured, three-dimensional habitats of the coastal zone constitute important nursery grounds for fish and invertebrates (Lefcheck et al., 2019). For

* Corresponding author.
E-mail address: oivindb@hi.no (Ø. Bergh).

https://doi.org/10.1016/j.aquaculture.2023.739643
Received 26 August 2022; Received in revised form 3 April 2023; Accepted 2 May 2023
Available online 4 May 2023

human beings, coastal areas provide a range of ecosystem services vital for the well-being of human societies (Barbier et al., 2011). However, as the world's coasts are home to a large and increasing portion of the world's human population there is a strong and increasing anthropogenic pressure on coastal ecosystems, resulting from urbanization, expanding industry and tourism, intensification in the use and/or overexploitation of natural resources, pollution of land and water, eutrophication, and species introductions (Gray, 1997; Gowing et al., 2006), where habitat loss and degradation are considered the most important threats to marine biodiversity (Suchanek, 1994; Gray, 1997). The multitude of interests and human uses of coastal environments inevitably lead to conflicts over resources and access to areas (Ahmed, 2010; Hersoug et al., 2021; Stelzenmüller et al., 2013a).

The long Norwegian coast-line, dominated by fjords, encompasses many biologically valuable habitats and is home to a range of commercially important fish and shellfish species (Eriksen et al., 2021). The fjords and sheltered coastal waters also provide ideal sites for fish farming, and farming of salmonids has grown rapidly in Norway since its onset around 1970. In 2020, the total Norwegian production of salmonids was 1,473,818 t, of which 93.5% was Atlantic salmon (*Salmo salar*) and 6.5% rainbow trout (*Oncorhynchus mykiss*) (Fiskeridirektoratet (Directorate of Fisheries), 2021a). Today, fish farming constitutes the major part of the Norwegian fisheries and aquaculture sector, which together make up the second largest industry in Norway, as measured in terms of export value. In 2014, Norway produced 42% of aquaculture biomass production, and 48% by value of the total aquaculture production in Europe (Clarke and Bostock, 2017). This growth has, however, had an impact on the marine coastal environment and has therefore not come without conflicts with other uses of the coastal zone, in particular the fisheries on wild salmonids due to proliferation of sea lice (mainly salmon lice, *Lepeophtheirus salmonis*) and genetic influence of escapees (Taranger et al., 2015). Balancing aquaculture with other coastal interests, however difficult, has long been viewed as crucial for successful Integrated Coastal Zone Management (ICZM) in Norway (Hovik and Stokke, 2007; Tiller et al., 2012).

Aquaculture also affects wild populations of commercially important fish and shellfish species in the vicinity of fish farms. Large numbers of commercially important fish stocks, in particular saithe (*Pallachius virens*), have been demonstrated to aggregate in close vicinity of the fish cages where they feed on food spills (Bagdonas et al., 2012; Dempster et al., 2009; Otterå and Skilbrei, 2014). This is in conflict with the interests of fishermen as wild fish cannot be harvested close to fish farms, mainly due to a fishery exclusion zone which is intended to prevent fishing gear from damaging the cages and their moorings. Salmon farming, through food spills, has also been shown to affect the fatty acid composition and taste of wild saithe (Skog et al., 2003). Another consequence of the aquaculture facilities' attractiveness to wild fish is possible interconnectedness between farms (Johansen et al., 2011; Otterå and Skilbrei, 2014), with respect to potential transmission of pathogens due to migration of wild fish among farms.

Antiparasitic drugs are utilized to reduce infestation by the salmon lice, including both bath treatments and food-administered agents. Flubenzurons which belong to the latter group, act by interfering with the synthesis of chitin during the moulting cycle of the salmon lice. Since the bioavailability of flubenzurons in Atlantic salmon is generally moderate or low and the metabolism is minimal, most of the drug will be released from the fish as parent compound via faeces (Samuelsen, 2016). The accumulation of emamectin benzoate in sediments is well documented (Bloodworth et al., 2019). Solubility of flubenzurons in water is low, the substances associate readily with particles rich in organic content, and degradation is slow (Samuelsen, 2016). This has caused concerns about effects on, in particular, commercial crustaceans like lobsters, crabs and shrimps, but the compounds are toxic to any species that undergo moulting in their life cycle. Bath treatments are administered in well-boats or in the cages themselves. After treatment, the water containing the anti-parasitic chemicals are discharged into the sea. Hydrogen peroxide (H_2O_2) was long viewed as the most environmentally friendly agent as it degrades to water and oxygen, but recent laboratory experiments have shown detrimental effects on non-target organisms (Bechmann et al., 2019; Escobar-Lux et al., 2019; Escobar-Lux and Samulsen, 2020). Similarly, bath treatments like azametiphos and in particular deltametrin have been shown to adversely affect non-target crustaceans (Bechmann et al., 2020; Parsons et al., 2020).

Thus, the massive growth of the Norwegian salmon farming industry has emphasized and increased spatial conflicts with other uses of the coastal zone, in particular coastal fisheries and nature protection. In the present work, we evaluated interactions, both synergies and conflicts, between these and other human activities, utilizing a fjord system in southwestern Norway with a high concentration of industrialized aquaculture as our case study area. The interaction study was carried out through interviews with representatives from the aquaculture industry and other relevant stakeholders using an online and map-based questionnaire, and through an interaction analysis tool, SEAGRID, based on Geographic Information Systems (GIS). We address the following questions: to which extent do fisheries and aquaculture compete for access to sea areas in our study area? Are there any synergies with other activities? Which are the areas of highest conflict, presently and possibly in the future? In addition, we also discuss: Can the existing legal framework support sustainable fisheries and aquaculture? Are the existing planning tools adequate to comply with existing rules and regulations?

2. Materials and methods

2.1. Case study area

The case study area (CSA) is identical to Production Area (PA) 3 in Norway's present aquaculture management regime (Anonymous, 2017; Grefsrud et al., 2022; Myksvoll et al., 2018), geographically located in southwestern Norway between the cities of Bergen and Stavanger. Most of the CSA is located within the former Hordaland county, but the southernmost part is within Rogaland county (Fig. 1). In 2020, the number of Norwegian counties was reduced, and Hordaland was merged with its neighbour in the north (Sogn og Fjordane) into a new county, Vestland. The CSA is dominated by the Hardangerfjord, which is Norway's second largest fjord (179 km long), a deep, steep sloped valley both over and below the sea level, with a maximum depth of 893 m and a sea surface area of approximately 800 km^2 (Husa et al., 2014). The fjord has an approximately 200 m deep sill close to the entrance, and the sea bed outside the fjord entrance is shallow with many small islands and reefs. Two major glaciers (Folgefonni and Hardangerjøkulen) drain into the fjord. Freshwater supplies from the surrounding mountains create a hydrography typical of fjords, with a freshwater or brackish layer on top of the water column (Aksnes et al., 2019).

The area surrounding the fjord is an old cultural landscape dating back to the first colonization of the country during the Paleolithic era, at the end of the Ice Age. Agriculture takes place along the mostly narrow shorelines of the fjord. Apart from water reservoirs for hydroelectric power plants, the surrounding mountains are to a large extent protected. High precipitation combined with suitable height differences create excellent conditions for hydroelectric power production. A total of 3357 MW is installed in the 298 power stations within the CSA. Annual production in Hordaland county in 2019 made up around 15.8 TWh/year, equivalent to 12.4% of Norway's national hydroelectricity production and 11.7% of the total electricity production in the country (Statistisk Sentralbyrå (Statistics Norway), 2019). Cheap electricity has been fundamental for metallurgical industries (zinc, ferrosilica, titanium dioxide, aluminium) at several sites along the fjord.

2.2. Fisheries and aquaculture production data

Fisheries landings data (for all species) from the CSA were provided by the Norwegian Directorate of Fisheries, by statistical rectangle (30′

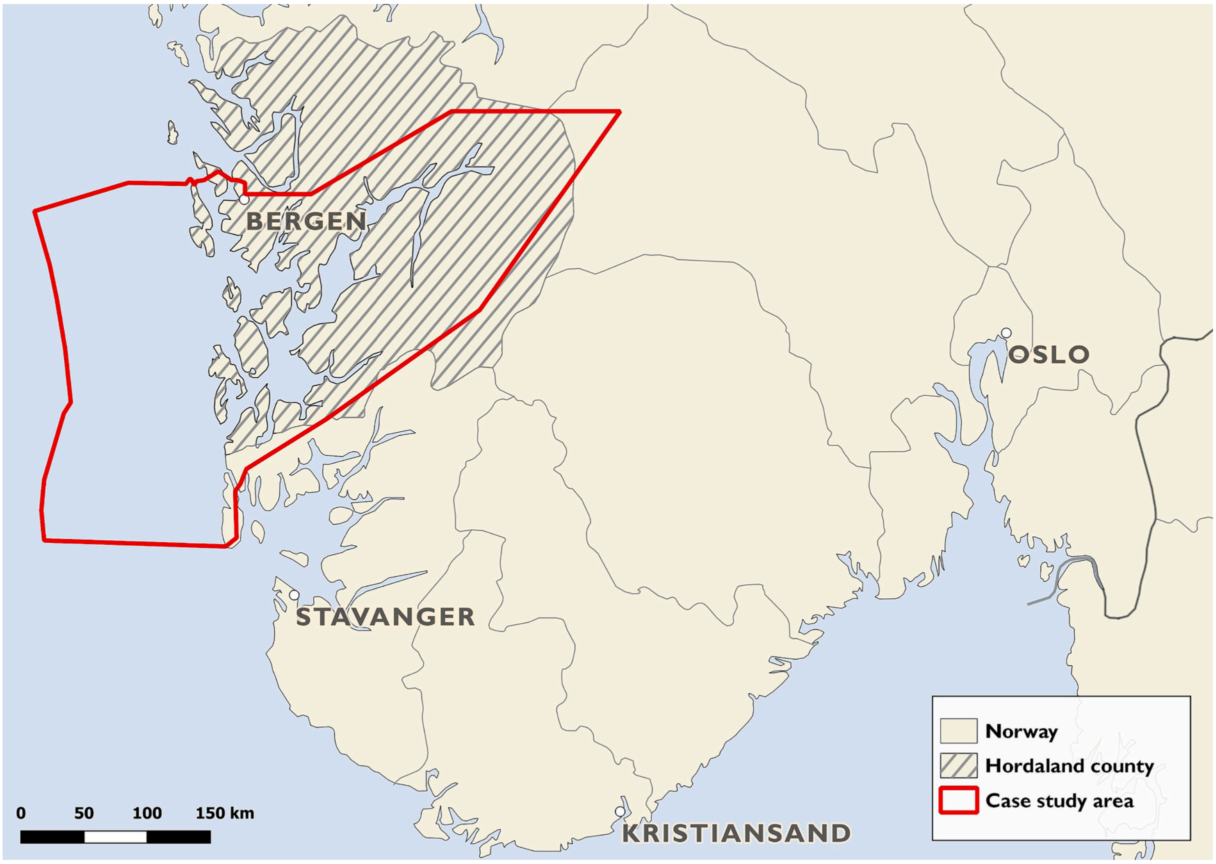

Fig. 1. Overview of the case study area (equivalent to Salmon Production Area 3 in Norway's present aquaculture management regime), with county borders (until December 31, 2019). From January 1, 2020, some counties were merged. Hordaland was merged with the county north of it, into Vestland, while Rogaland south of Hordaland remained unchanged.

latitude by 1° longitude, corresponding to ICES statistical rectangles). As the statistical rectangles do not correspond exactly with the borders of the PAs (Fig. 2), exact landings numbers from the CSA could not be obtained. In particular, approximately just one-fourth of the rectangle 08–16 lies within the CSA. Statistical rectangle in the landings statistics may in some cases erroneously reflect location of the landing facility rather than fishing location, which adds to the uncertainty in the landings data. Landings statistics were extracted for 2017 when our study took place, as well as for 2020, for a temporal comparison.

Aquaculture biomass data and other statistics from the aquaculture sector were also provided by the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b). Biomass data for Hordaland county (which is larger than the CSA) were available from 1994 to 2019. Statistics from PA 3 which is identical to our CSA, are available since 2017.

2.3. GIS tool (SEAGRID)

SEAGRID (SEA GeoReference Interactions Database) is a webGIS application that provides stakeholders involved in Marine Spatial Planning with a transparent decision support tool to evaluate interactions between uses which take place in marine coastal areas and to quantify environmental and socio-economic impacts. It was originally developed and named GRID within the projects COEXIST (Stelzenmüller et al., 2013a) and ECOAST (Grati et al., 2019) and has been further developed into SEAGRID through additional international projects (ArtReef, 2015; AquaAccept, 2015) that included environmental as well as socio-economic considerations and aimed to enable stakeholders to assess the suitability of specific scenarios. SEAGRID is online (http://seagrid.irbim.cnr.it/) and accessible with login and password that can be required for free.

In this study, SEAGRID was only used to locate and analyze the level of coexistence among different marine uses existing in the CSA, by calculating spatial interaction scores, and providing an interaction matrix and maps. Interactions between marine uses were determined to be negative (conflicts) or positive (synergies) based on expert judgment or existing management rules and legislation, while a set of criteria was used to define and quantify these interactions and to represent them in a matrix. Each activity was classified according to five traits (see below). According to these traits, predefined rules in SEAGRID were used to calculate the level of spatial conflicts/synergies (interaction scores) (see below).

The interaction scores were calculated for pairs of activities (e.g. pipelines and bottom trawling) depending on the traits of each of the single activities (Table 1). Following COEXIST methodology (Stelzenmüller et al., 2013a), the five traits of an activity were defined as vertical scale (VS), spatial scale (SS), time scale (TS), mobility (M) and location. According to the rules, a SEAGRID module calculates a matrix of spatial interactions of all pairs of marine uses. Spatial conflict scores ranged from −1 to −6, and spatial synergies from 1 to 6 (−6: activities are mutually exclusive; 0: no conflicts; 6: activities are mutually synergistic). Finally, in case of more than two human uses existing in a cell of analysis, the resulting score is the sum of the scores for each combination of pair of uses. Based on the scores for all cells, resultant CSA maps were built and categorized, where the whole CSA area was divided into a grid of square cells of 1 km^2. The spatial database of the map service of the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b) was used as input for the maps produced by SEAGRID.

The rules were applied in the exact order in which they are listed

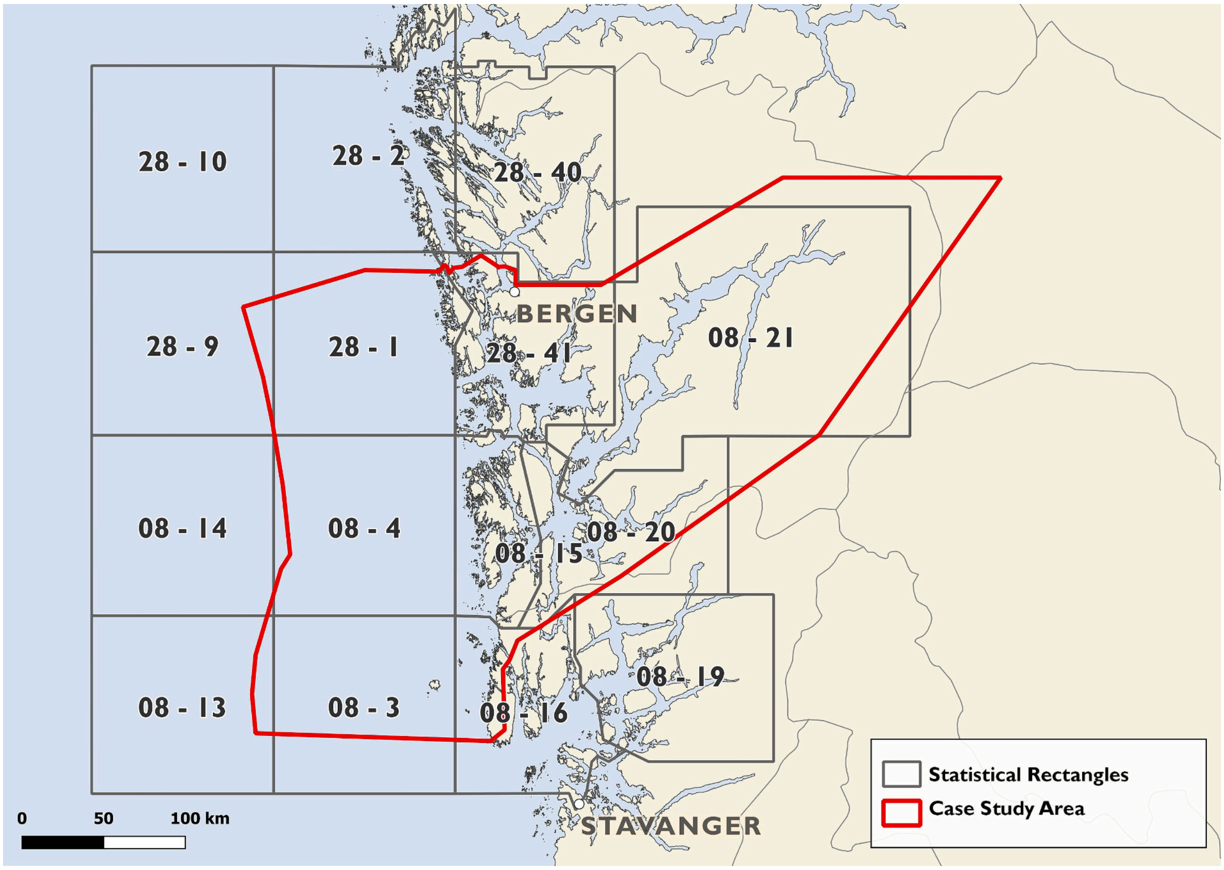

Fig. 2. Overview of the case study area (Salmon Production Area 3 in Norway's present aquaculture management regime) and statistical rectangles from the Norwegian Directorate of Fisheries (30′ latitude by 1° longitude, corresponding to ICES statistical rectangles). The first two digits denote the main statistical areas (in this case 08 and 28), and the last digits denote the smaller statistical rectangles. County borders (until December 31, 2019) are shown in the map.

below and mathematically they represent the level of potential spatial and temporal conflict/synergy between marine uses:

- Rule1: If VS of activity 1 was different from VS of activity 2 and none of them affected the whole water column then interaction score was equal to 0.
- Rule 2: If both activities were "mobile" then interaction score was equal to the minimum of TS plus the minimum of SS.
- Rule 3: If Rule 1 and Rule 2 could not be applied then the interaction score was equal to the maximum value of TS plus the maximum value of SS.

To analyze interactions, values were entered based on expert judgment (Table 1). Expert judgment was also used to overwrite the value calculated by the rules for specific pair of uses if some particular cases made this necessary (e.g. particular management measures in force for some activities).

When considering interactions and conflicts between a range of human uses of the CSA, as well as between human uses and areas protected in various ways, we limited ourselves to strict spatial interactions, i.e. we only considered which human uses exclude other uses from a specified area. We did not consider the impact of human use on the *quality* of a habitat or the *quality* of other human uses. For instance, we did not consider qualitative effects of salmon farms on fishing grounds. The interaction between a pair of human uses can be one-way or two-ways, but the SEAGRID matrix of conflicts did not allow considerations of uni-directional effects, only combined. Thus, if the effect of one human use on another use is neutral (e.g. a fishing ground does not exclude the laying of a cable), while the opposite is negative (a cable may prevent bottom trawling), the interaction was set to be negative.

Most of the interactions in the SEAGRID matrix followed directly from legal restrictions on the use of areas with specially designated purposes. However, we did not find legislation covering all possible conflicting uses, and most likely it does not exist. Thus, we had to use common sense when considering some interactions, e.g. we did not think a sea cable would be laid across a coral reef, even if we were not able to find a paragraph prohibiting this. Furthermore, we assumed that the existence of coral beds and important spawning grounds increased the likelihood of the establishment of natural protection areas.

2.4. GIS layers

GIS layers of areas used for active and passive fishing gears, fishing grounds for the commercially important northern shrimp (*Pandalus borealis*), spawning areas for fish, coral reefs, aquaculture sites, national salmon fjords and protected areas (Figs. 3-6) were based on the GIS database of the map service of the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b). Sites for hydropower plants (Fig. 4) were provided by the Norwegian Mapping Authority. GIS layers with military areas (Fig. 6) were provided by the Norwegian Defence Estates Agency.

2.4.1. Aquaculture sites

It is illegal to go closer than 20 m of aquaculture sites (Nærings- og fiskeridepartementet, 2008) (SEAGRID layer: Aquaculture sites, Fig. 3). In addition, there is a 100 m zone around fish farms where fishing is forbidden. This pertains to the whole water column. The distance is measured from a straight line drawn through the external points of the farm at the surface. These restrictions apply to farms in production as well as farms that lie fallow. The moorings of fish farms occupy a much

Table 1
Spatial interaction scores for all pairs of human marine use in the case study area. For each pair, the two one-sided influences are given as either positive (+), negative (−) or neutral (0), listing first the influence of Use 1 on Use 2, thereafter the influence of Use 2 on Use 1. Methods for determining the scores were either SEAGRID Rules or expert opinion. The final column details the rationale behind the interaction scores and influences.

Use 1	Use 2	Score	Influence	Method	Rationale
500 m zone	Passive gear	−5	−/0	Rules	100 m zone. Fishers avoid area within anchors
500 m zone	Active gear	−5	−/0	Rules	100 m zone. Trawling impossible within anchors
500 m zone	Milit. restrict.	−6	0/−	Rules	Legislation, see text
500 m zone	Milit. training	−6	0/−	Rules	Legislation, see text
500 m zone	Nat. protection	−3	0/−	Expert opinion	Existing fish farms allowed, with some restrictions
500 m zone	Pipelines	−1	0/0	Expert opinion	Pipelines considered unproblematic
500 m zone	Salmon fjords	−6	0/−	Rules	Legislation, see text
500 m zone	Corals	−5	0/−	Rules	Increased restrictions on fish farms close to coral beds
500 m zone	Sea cables	−5	−/−	Rules	Anchors close to sea cables considered problematic
500 m zone	Shipping routes	−1	0/0	Expert opinion	Vessels may pass by fish farms
500 m zone	Spawning area	−2	0/−	Expert opinion	Establishment of fish farms close to spawning areas is advised against
500 m zone	SVO	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
500 m zone	Aquaculture	5	+/+	Rules	500 m zone is integral part of fish farms
Aquaculture	Passive gear	−5	−/0	Rules	Legislation, see text
Aquaculture	Active gear	−5	−/0	Rules	Legislation, see text
Aquaculture	Milit. restrict.	−6	0/−	Rules	Legislation, see text
Aquaculture	Milit. training	−6	0/−	Rules	Legislation, see text
Aquaculture	Nat. protection	−3	0/−	Expert opinion	Existing aquaculture allowed in natural protection areas
Aquaculture	Pipelines	−1	0/0	Expert opinion	Pipelines under fish farms considered unproblematic
Aquaculture	Salmon fjords	−6	0/−	Rules	Legislation, see text
Aquaculture	Corals	−5	0/−	Rules	Increased restrictions on fish farms close to coral beds
Aquaculture	Sea cables	−1	0/0	Expert opinion	Sea cables under fish farms considered unproblematic
Aquaculture	Shipping routes	−5	−/−	Rules	Mutually exclusive
Aquaculture	Spawning area	−6	−/0	Rules	Fish farms expected to destroy spawning areas in close vicinity
Aquaculture	SVO	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Passive gear	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Active gear	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Milit. restrict.	−6	0/−	Rules	Legislation, see text
SVO	Milit. training	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Nat. protection	6	+/0	Rules	An SVO-area is expected to increase chances of an MPA
SVO	Pipelines	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Salmon fjords	6	+/+	Rules	Considered mutually beneficial
SVO	Corals	6	+/+	Rules	Considered mutually beneficial
SVO	Sea cables	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Shipping routes	−1	0/0	Expert opinion	No formal restrictions on human use in SVO-areas
SVO	Spawning area	6	+/+	Rules	Considered mutually beneficial
Spawning area	Passive gear	−1	0/0	Expert opinion	No legislation against fishing
Spawning area	Active gear	−1	0/0	Expert opinion	No legislation against fishing
Spawning area	Milit. restrict.	−1	0/0	Expert opinion	Spawning areas do not hinder military areas. Human activity/constructions may influence spawning areas
Spawning area	Milit. training	−6	0/−	Rules	Shooting will scare away spawners
Spawning area	Nat. protection	6	+/+	Rules	Considered mutually beneficial
Spawning area	Pipelines	−1	0/0	Expert opinion	No negative effects from established pipelines
Spawning area	Salmon fjords	6	0/+	Rules	A salmon fjord is considered beneficial for a spawning area
Spawning area	Corals	0	0/0	Rules	No spatial overlap/interaction
Spawning area	Sea cables	0	0/0	Expert opinion	No spatial overlap/interaction
Spawning area	Shipping routes	0	0/0	Rules	No spatial overlap/interaction
Shipping routes	Passive gear	−2	−/0	Rules	Fishing needs to adjust
Shipping routes	Active gear	−2	−/0	Rules	Fishing needs to adjust

(continued on next page)

Table 1 (*continued*)

Use 1	Use 2	Score	Influence	Method	Rationale
Shipping routes	Milit. restrict.	−6	0/−	Rules	Legislation, see text
Shipping routes	Milit. training	−1	0/0	Expert opinion	Outside training periods shipping is allowed
Shipping routes	Nat. protection	0	0/0	Rules	No spatial overlap/interaction
Shipping routes	Pipelines	0	0/0	Rules	No spatial overlap/interaction
Shipping routes	Salmon fjords	0	0/0	Rules	No spatial overlap/interaction
Shipping routes	Corals	0	0/0	Rules	No spatial overlap/interaction
Shipping routes	Sea cables	0	0/0	Rules	No spatial overlap/interaction
Sea cables	Passive gear	−5	−/0	Rules	Legislation, see text
Sea cables	Active gear	−5	−/0	Rules	Legislation, see text
Sea cables	Milit. restrict.	−6	0/−	Expert opinion	Legislation, see text
Sea cables	Milit. training	−1	0/0	Expert opinion	Cables exist in military training areas
Sea cables	Nat. protection	−5	0/−	Expert opinion	Cables may be permitted in certain areas
Sea cables	Pipelines	−1	0/0	Expert opinion	Expected that cables and pipelines may cross
Sea cables	Salmon fjords	0	0/0	Expert opinion	No spatial overlap/interaction
Sea cables	Corals	−5	0/−	Rules	No cables expected to be laid over coral beds
Corals	Passive gear	−5	−/0	Rules	Prohibited to destroy coral reefs
Corals	Active gear	−5	−/0	Rules	Prohibited to destroy coral reefs
Corals	Milit. restrict.	−1	0/0	Expert opinion	Corals do not hinder military restricted areas
Corals	Milit. training	−1	0/0	Expert opinion	Impact from military training considered negligible
Corals	Nat. protection	6	+/+	Rules	Considered mutually beneficial
Corals	Pipelines	−6	−/0	Expert opinion	No pipeline would be laid across a coral reef
Corals	Salmon fjords	6	0/+	Rules	Salmon fjords are considered beneficial for coral reefs
Salmon fjords	Passive gear	−1	0/0	Expert opinion	Salmon fjords do not hinder fishing
Salmon fjords	Active gear	−1	0/0	Expert opinion	Salmon fjords do not hinder fishing
Salmon fjords	Milit. restrict.	−1	0/0	Expert opinion	Salmon fjords do not hinder military restricted areas
Salmon fjords	Milit. training	−1	0/0	Expert opinion	Military training takes place in salmon fjords
Salmon fjords	Nat. protection	6	+/0	Rules	A salmon fjord is expected to increase chances of an MPA
Salmon fjords	Pipelines	−1	0/0	Expert opinion	No negative effects from established pipelines
Pipelines	Passive gear	−1	0/0	Expert opinion	Fishing is possible
Pipelines	Active gear	−1	0/0	Expert opinion	Fishing should be possible over covered pipelines
Pipelines	Milit. restrict.	−6	0/−	Expert opinion	Legislation, see text
Pipelines	Milit. training	−1	0/0	Expert opinion	Pipelines exist in military training areas
Pipelines	Nat. protection	−5	0/−	Expert opinion	Restrictions on pipelines
Nat. protection	Passive gear	−1	0/0	Expert opinion	Passive gears are allowed
Nat. protection	Active gear	−3	−/0	Expert opinion	Pelagic fishing allowed, demersal fishing not allowed
Nat. protection	Milit. restrict.	−6	0/−	Rules	No MPA expected established in military restricted area
Nat. protection	Milit. training	−3	0/−	Expert opinion	Some military training within existing MPA
Milit. training	Passive gear	−1	0/0	Expert opinion	Outside training periods fishing is allowed
Milit. training	Active gear	−1	0/0	Expert opinion	Outside training periods fishing is allowed
Milit. training	Milit. restrict.	0	0/0	Rules	No spatial overlap/interaction
Milit. restrict.	Passive gear	−6	−/0	Rules	Legislation, see text
Milit. restrict.	Active gear	−6	−/0	Rules	Legislation, see text
Active gear	Passive gear	−2	−/−	Rules	Gear conflicts

Abbreviations are as follows: "Milit. Restrict." = restricted military area; "Milit. Training" = military training areas; "Nat. protection" = Natural Protection Areas / Marine Protected Areas (MPA); SVO = Especially Sensitive Areas.

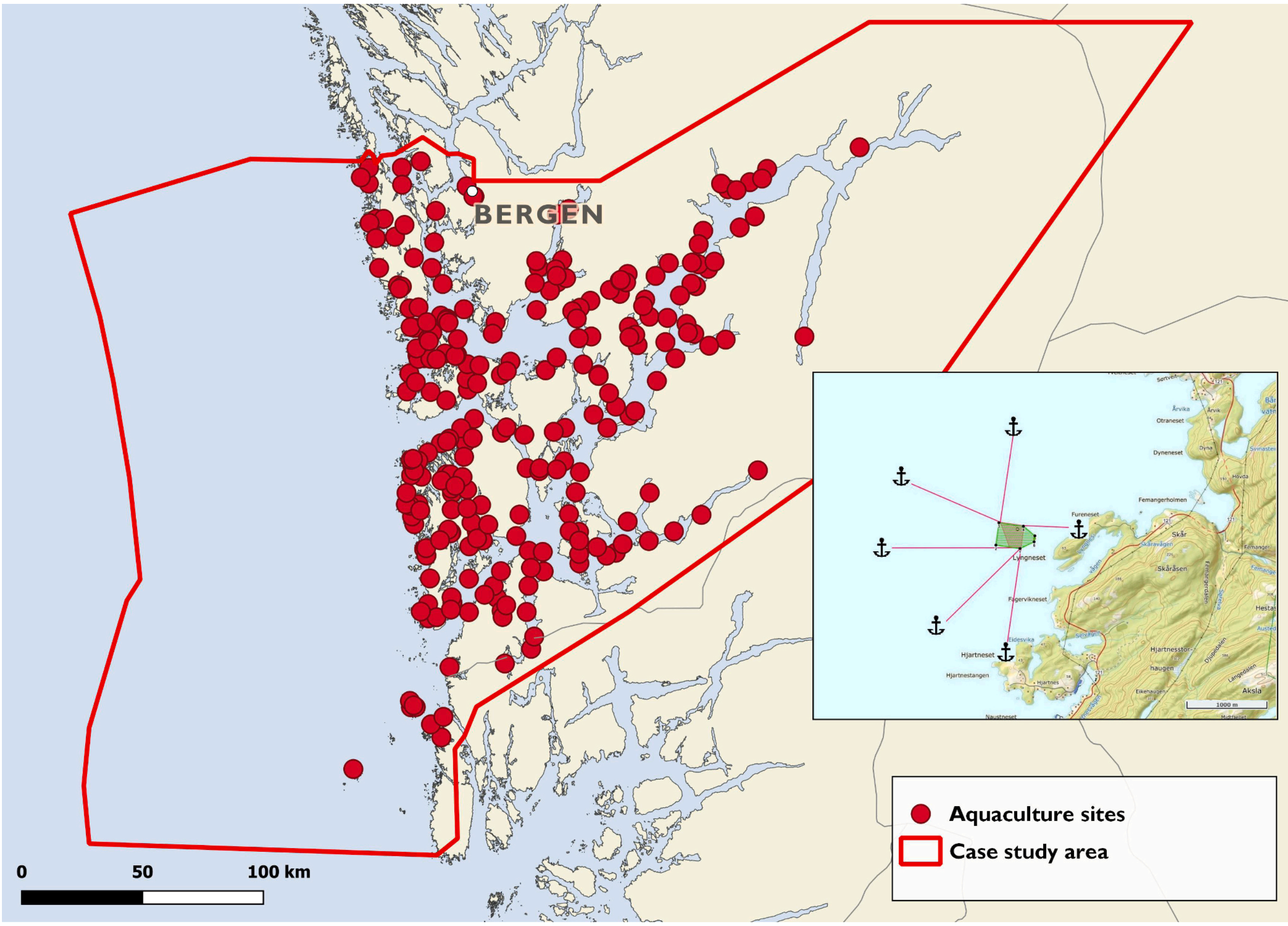

Fig. 3. Location of all aquaculture permits (fish, mussels, algae) within the case study area (Salmon Production Area 3 in Norway's present aquaculture management regime) in 2018. The inserted figure shows a fish farm with anchors extending out from the cages, illustrating the extent of the bottom area made inaccessible for bottom trawling around a fish farm. Data and inserted figure from the Norwegian Directorate of Fisheries.

larger area than the cages at the surface (Fig. 3) (Hersoug et al., 2021) and prevent trawling within or in the proximity of these installations on the sea floor. Based on positions of moorings around several fish farms within the CSA (illustrated on maps in the map service of the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b)), we used an average distance of 500 m from a farm to its moorings to define the extent of this area around farms (SEAGRID layer: 500 m zone). Passive gears (traps, gill nets etc.) are allowed within anchoring points as long as they are set >100 m from the farm. However, based on accounts from local fishers, it seems that they are concious about the moorings and do not go into the area within them. Thus, we set the area within 500 m of the fish cages as an area of spatial conflict also for passive gears.

2.4.2. *Fishing grounds and spawning areas*

Fishing grounds for active gears in the CSA were registered by the Norwegian Directorate of Fisheries in 1988 and 2000, with the exception of the inner parts of the Hardangerfjord where fishing grounds were registered between 2001 and 2008 (Fiskeridirektoratet (Directorate of Fisheries), 2021b). Shrimp fishing grounds and fishing grounds for passive gears were registrered in 1988 and 2002, respectively. Since we only considered *spatial* interactions between human uses, shrimp fishing grounds were merged with fishing grounds for active gears (SEAGRID layer: Fishing grounds–Active gear, Figs. 4, 5). The use of chitin synthesis inhibitors is prohibited within 1000 m of shrimp fishing grounds, as defined on maps (Fiskeridirektoratet (Directorate of Fisheries), 2021b) by the Norwegian Directorate of Fisheries (Nærings- og fiskeridepartementet, 2008b). This pertains to the whole water column. The law applies only to the use of chitin synthesis inhibitors, as such it does not exclude fish farms themselves. Emptying water with delousing chemicals (bath treatment) from well-boats must happen at least 500 m from shrimp fishing grounds or spawning areas (SEAGRID layer: Spawning area, Fig. 4) (Nærings- og fiskeridepartementet, 2008b). Establishment of catch based aquaculture (wild species stored and fed in the sea >12 weeks before slaughtering) is not allowed in spawning areas of the same species (Nærings- og fiskeridepartementet, 2014). We are not aware of any specific regulations regulating other human activities in or near the fishing grounds for active or passive gears (SEAGRID layers: Fishing grounds-Active gear, Fishing grounds-Passive gear, Fig. 5), but fisheries management advice that new aquaculture facilities (including salmon) should not be established close to cod spawning areas. Certain restrictions may be implemented following site plans. According to Hersoug et al. (2021) salmon farms cannot be placed in fishing grounds or spawning areas. This may pertain to new facilities as maps of the CSA (Fiskeridirektoratet (Directorate of Fisheries), 2021b) show several farms within such areas.

2.4.3. *National salmon fjords*

National salmon fjords, established in 2007, (SEAGRID layer: Salmon fjords, Fig. 6) have a special protection for wild salmon stocks (Miljøverndepartementet, 2007). Within these fjords, no new salmon farms are allowed. Farms which were established before this special

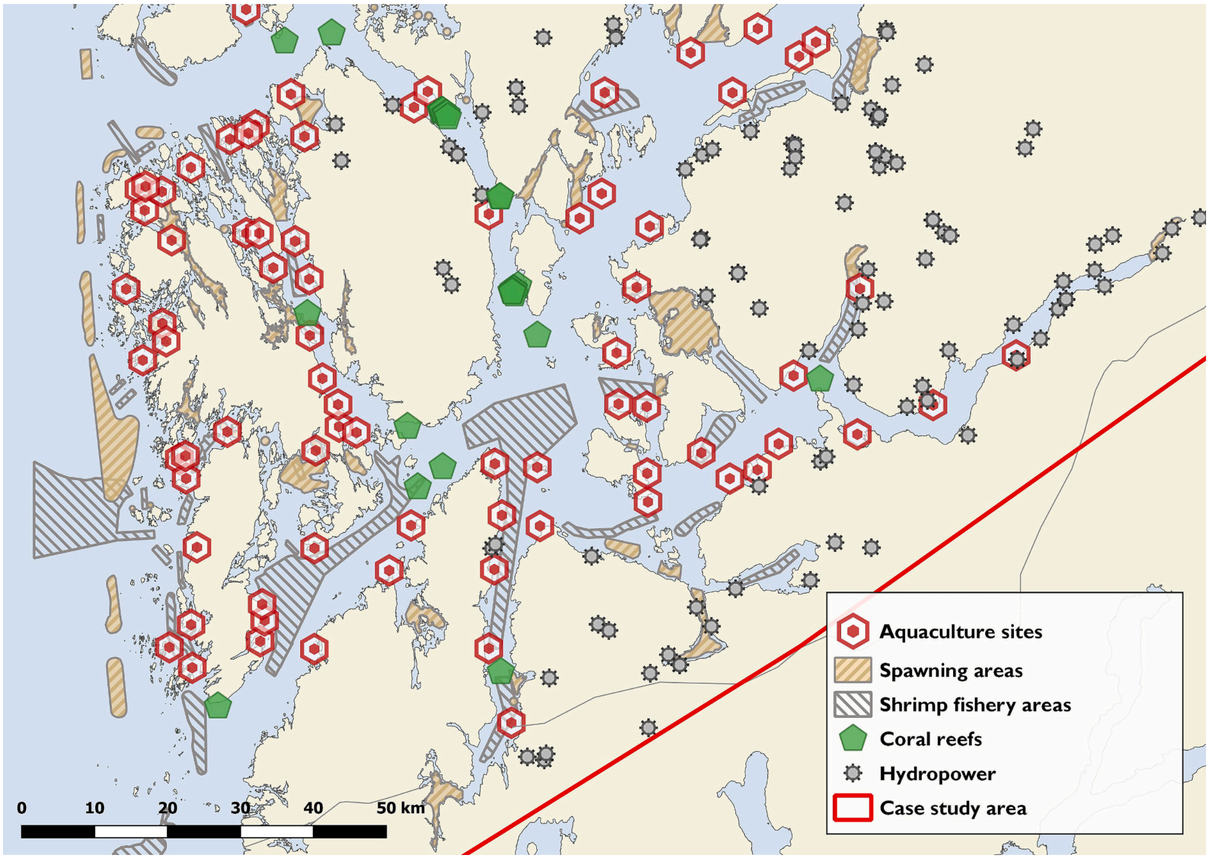

Fig. 4. Location of shrimp fishing grounds, spawning areas for fish, aquaculture sites (active in 2018), coral reefs (mapped by 2018) and hydropower plants in outer Hardangerfjord. Data from the Norwegian Directorate of Fisheries and the Norwegian Mapping Authority.

protection was implemented are in general allowed, but are subject to stronger regulations concerning escapees and salmon lice (Hersoug et al., 2021). There is only one such fjord system within the CSA, the Ølenfjord and Etnefjord.

2.4.4. Sea cables and oil pipelines

No generic restrictions apply for cables or pipelines (SEAGRID layers: Sea cables, Pipelines (b300)). In some areas, there will be a "cable area" in maps where anchoring, fishing and use of sea-bed gear are prohibited. Some local shrimp fishers informed us that they trawl across covered cables. In our analysis, however, we determined that sea cables exclude demersal trawlers. Establishment of fish farms in the proximity of cables is decided on a case-by-case basis. Normally, there are no buffer zones around oil pipelines, and by default, it should be possible to trawl over all installations on the sea bed. However, local shrimp fishers informed us that they do not trawl across pipelines.

2.4.5. Particularly valuable areas

Particularly valuable and vulnerable areas (SEAGRID layer: Especially Sensitive Areas (SVO)) have been described in management plans for the Norwegian oceans (Klima- og miljødepartementet, 2019–2020). Management plans are intended to clarify the overall framework, co-ordination and priorities in the management of the Norwegian marine areas, as well as creating a common understanding between industry, authorities and NGOs regarding management of the seas. Especially Sensitive Areas are important for the biological diversity and production, within but also often outside the areas themselves. They do not in themselves provide any restrictions on human use, but signal the importance of special consideration within these areas (Eriksen et al., 2021). The Especially Sensitive Areas pertaining to the CSA encompass the Korsfjord and Karmøyfeltet and are described in the management plan for the North Sea (Miljøverndepartementet, 2013) and by Eriksen et al. (2021) (Fig. 6). The Korsfjord is also suggested as a natural protection area (see below). Karmøyfeltet has high biological production and is a retention area for spawning products. It also constitutes an important shrimp fishing ground. Karmøyfeltet is suggested to be included in the SVO-area Boknafjorden and Jærstrendene (the Boknafjord and beaches at Jæren) (Eriksen et al., 2021).

2.4.6. Marine protected areas

There are three Natural Protection Areas / Marine Protected Areas (MPA) within the CSA (SEAGRID layer: Natural Protection areas, Fig. 6): Vinnesleiro (already protected), and Outer Hardangerfjord and the Korsfjord (suggested protected). The Vinnesleiro natural reserve was protected in 1995 (Fylkesmannen i Hordaland, 2016) and consists of 241 daa, of which 60 daa are on land. As this reserve is very small and only consists of a bay with shallow water, we chose not to include it in our analysis. In addition to these three areas, there are several small protected areas in the CSA, all of which are land based, but with the protected area stretching (normally 50 m) into coastal waters (e.g. breeding sites for birds). These areas have not been included in our analysis.

The suggested Outer Hardangerfjord and Korsfjord MPAs are, in practice, already valid as any requested activity within the areas will have to take into account the MPA rules, although the areas do not yet have the formal status of MPAs (Miljødirektoratet, 2021). The suggested areas include the sea and the seabed from a depth of 2 m and deeper. The Korsfjord (Fylkesmannen i Hordaland, 2017a) constitutes a reference area due to its proximity to a research station of the University of Bergen, making it among the best described and most studied marine areas in Norway. The area has a large variety of habitats, like kelp forests and shell sand. Within the Korsfjord there are two small clusters of islands

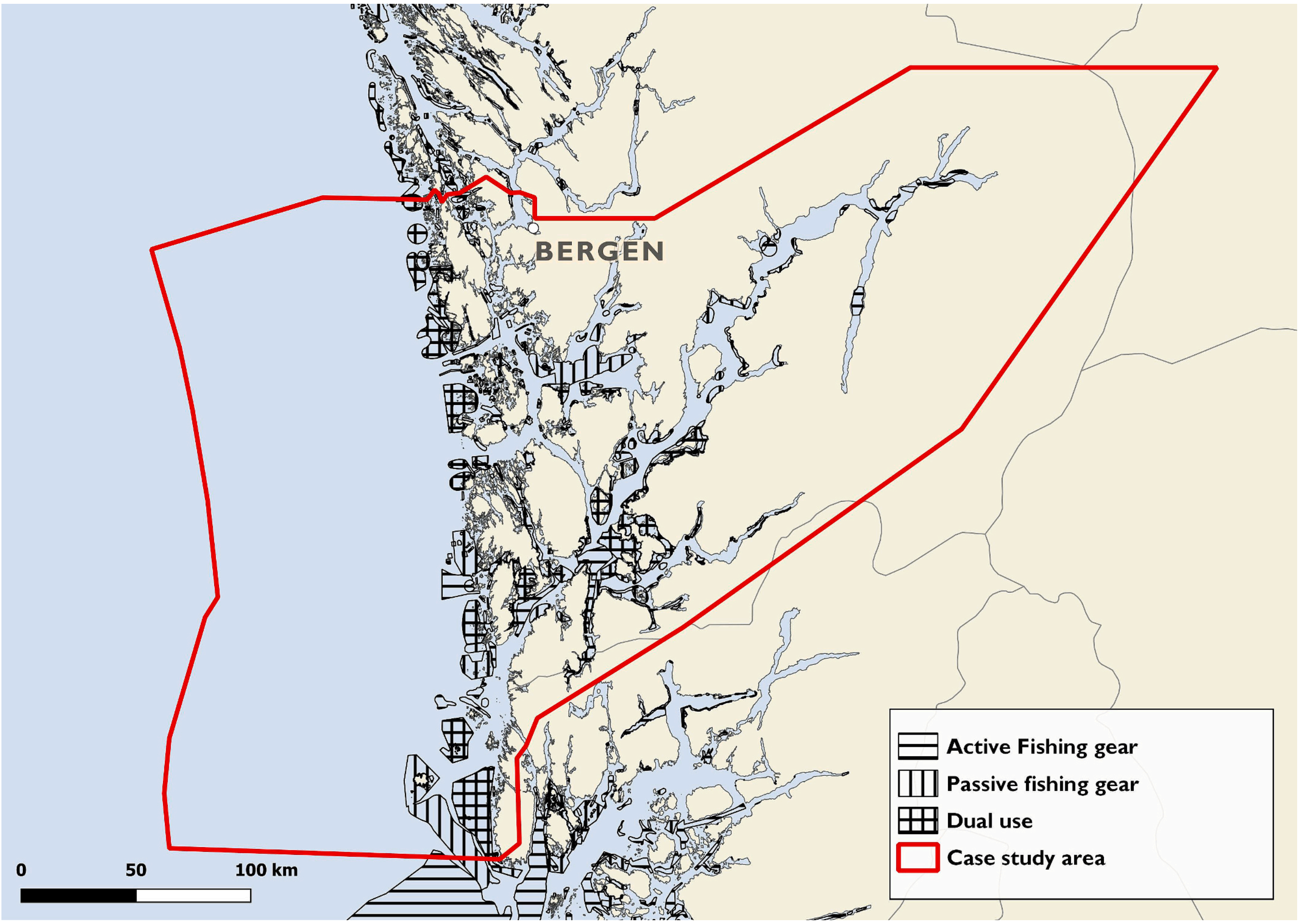

Fig. 5. Areas used for passive and active fishing gears within the case study area (Salmon Production Area 3 in Norway's present aquaculture management regime). County borders (until December 31, 2019) are shown in the map. Data from the Norwegian Directorate of Fisheries.

that are already protected due to breeding sites for birds. Within the suggested MPA of outer Hardangerfjord (Fylkesmannen i Hordaland, 2017b), there are four bird reservations on a total of 67 small islands, with a total area of 6.35 km^2, all consisting of a land area extending into the sea. Visiting these islands is prohibited in the period April 31–July 15.

Both areas are of major importance for recreation and tourism, and both fjords are important shipping routes. Both areas are used for fisheries, both commercial and recreational. Outer Hardangerfjord presently has three approved licenses for salmon farming, with a combined production capacity of 10,100 t. In the Korsfjord, the present aquaculture activity includes four approved licenses for salmonid ongrowth with a total capacity of 10,140 t. Realization of the two MPAs will imply that fishing and aquaculture activities may be continued as long as they do not interfere with the reasons for establishing the MPAs. Shrimp trawling has been going on in the Korsfjord until recently. Activities involving permanent change of the seabed must be avoided, although there might be permissions for cables etc. in certain areas. Plans exist for new roads which may affect the MPAs. Also, the Royal Norwegian Navy utilizes parts of the Korsfjord for limited military activity (see below).

2.4.7. *Coral beds*

There are many registered coral reefs within the CSA (Fig. 4, SEAGRID layer: Coral beds). The fishing fleet is obliged to show considerable caution when fishing close to coral reefs, and it is forbidden by law to destroy reefs on purpose. Some coral reefs are protected against all interference (Anonymous, 2009), and two of these are situated in the CSA: Straumsneset in Langenuen and Nakken by Huglo. In these two areas, the use of all demersal fishing gear is forbidden (towed gears, gill nets, longlines, creels and gears with fishing hooks (Nærings- og fiskeridepartementet, 2016)). Given the complex structure of the coral framework, cold water coral ecosystems have been identified to function as nurseries, breeding and spawning areas for fish. They harbor a large diversity of associated fauna (Fosså and Skjoldal, 2010). The dominating species is *Desmophyllum pertusum*, formerly known as *Lophelia pertusa* (Anonymous, 2023), which can grow as shallow as 30 m given the right conditions, although they do not reach high densities at such depths. There is a broad consensus within management, industry and science that new aquaculture facilities should not be placed above coral reefs.

2.4.8. *Marine traffic*

In general, shipping lanes for marine traffic have a width of 1000 m (Kystverket, 2014, chapter 4, SEAGRID layer: Shipping route_b300). This excludes fish farms from shipping lanes, but apparently not trawling, as local shrimp fishers told us that it is no problem trawling in shipping lanes. In this study, an arbitrary buffer of 300 m was used.

2.4.9. *Military areas*

Several areas with different military use are located within the CSA (Fig. 6). These areas can be divided into two main categories based on their location, main use, and the legal framework which applies. The first category (SEAGRID layers: Restricted military areas) are mainly land based domains with a given outreach to the sea and may consist of fortifications, signal stations, buildings or other constructions. Within

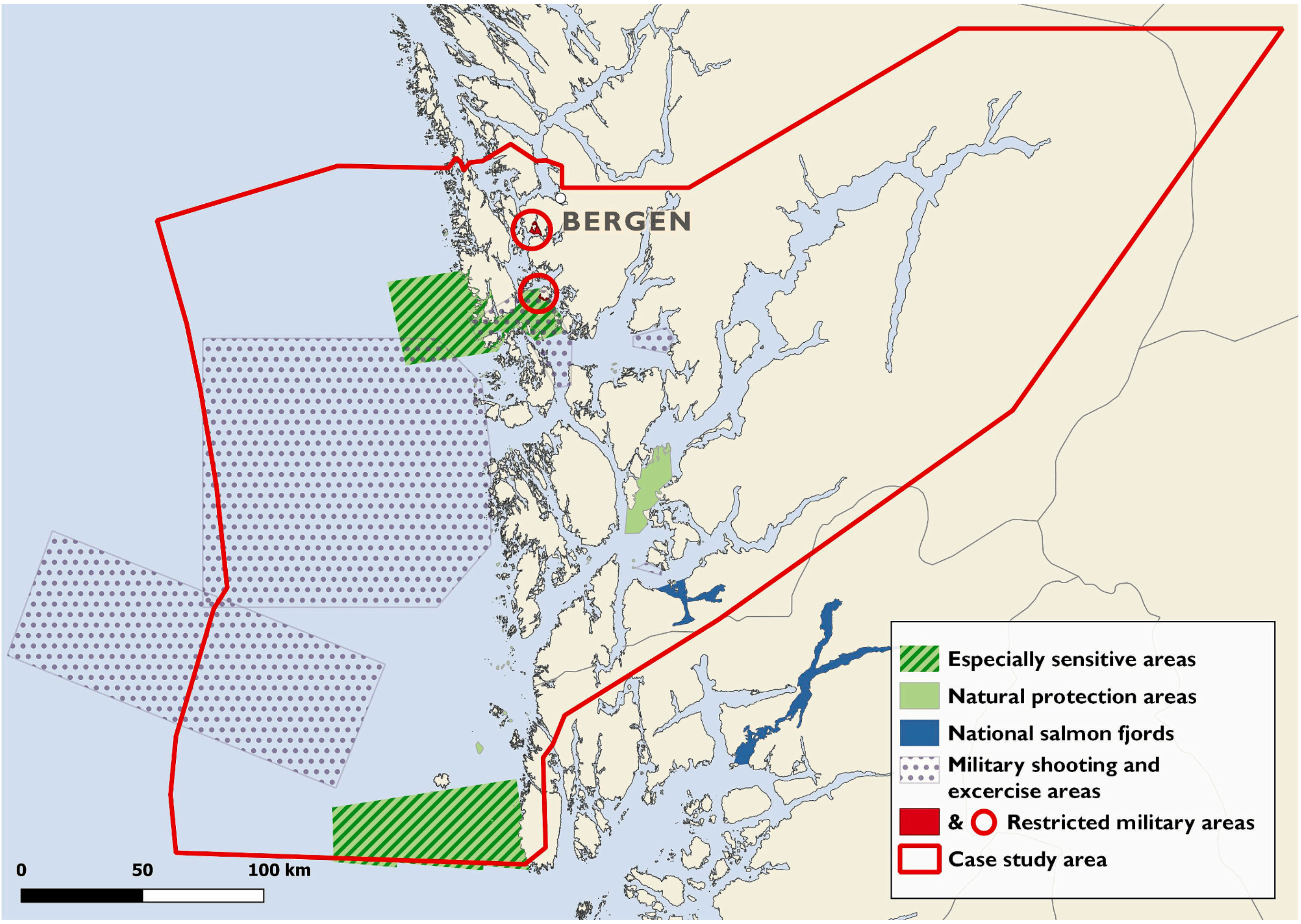

Fig. 6. Location of military areas, Especially Sensitive Areas, Natural Protection Areas / Marine Protected Areas, and national salmon fjords within the case study area (Salmon Production Area 3 in Norway's present aquaculture management regime). Circles indicate the location of areas too small to be noticeable on the map. County borders (until December 31, 2019) are shown in the map. Data from the Norwegian Directorate of Fisheries and the Norwegian Defence Estates Agency.

the CSA, three such domains can be identified, and the Norwegian Defence Estates Agency is the responsible legal body. In the domain Korsnes, the restrictions encompass prohibited entry within a distance of 50 m from the shore, and no diving, anchoring, fishing or trawling in the whole area. Haakonsvern is the main base of the Royal Norwegian Navy and is located within the Bergen municipality. Here, diving, anchoring, trawling and use of sea-bed gear are prohibited, and leisure boats have to use the shortest route through the area but are in principle allowed to pass. The military area around the submarine bunker in Laksevåg, Bergen municipality, has similar restrictions. However, as this small domain is situated within the harbor area of Bergen, it is not considered relevant in the present study.

The second category encompasses military training areas (SEAGRID layer: Military training areas). A total of nine zones within the CSA are used as military firing ranges. The Royal Norwegian Navy is responsible for these zones. Shooting, and the use of torpedoes, bombs and rockets temporarily take place. Within these training areas, fixed structures, e.g. aquaculture sites, are in general not allowed, although some cables and pipelines do exist within them. Outside training periods, which are broadcasted and published in advance, civil use like fishing or shipping is possible. However, some of the shooting ranges closest to the coast and in the fjords now have a significant amount of aquaculture sites within their boundaries, thus it seems likely that they are no longer operative. Hence, they were excluded from the dataset.

In addition to these well-defined military areas, there are many smaller ones along the Norwegian coast, also within the CSA, including dumping areas for ammunition (following the end of World War II), minefields (from World War II) and near-coast shooting ranges with ammunition on the seabed in connection with now closed fortresses. Information on these areas is not easily accessible and as such they have not been included in our analysis, but all of them hamper bottom trawling.

2.5. Online questionnaire

To further explore the extent of conflicts and possible synergies mainly between aquaculture and fisheries in the fjords and coastal zone of the CSA, we interviewed 18 stakeholders from different sectors about their views using an on-line, map-based questionnaire (Table 2). The respondents filled out the questionnaire under guidance by the ECOAST project personnel through structured interviews. The online questionnaire consisted of two parts: (1) a set of statements the respondents made ranked responses to, and (2) geospatial identification (including free digitizing) of areas of importance for fisheries and aquaculture, i.e. potential areas of conflicts. Several potential conflicts between these two sectors can be identified; in our questionnaire we focused on competition for space. If an area is regulated for aquaculture, fishing is excluded, and vice versa, if an area is set aside for fishing or spatial restrictions are implemented (e.g. regarding emission of delousing chemicals), this will exclude or hamper the aquaculture sector.

The professional expertise of respondents was noted, as was the number of years of their professional experience in the sector. After the

Table 2
All questions asked stakeholders, with answer options, in the on-line, map-based questionnaire. The column "Maps" indicates which questions were linked with geospatial identification of areas of importance. With planning tools (question 6), we mean all tools involved in planning processes for marine installations (e.g. new aquaculture sites.

	Question	Answer options	Maps
1	Professional expertise	1) Academic research 2) Governmental research 3) Fisheries management 4) Fisheries 5) Aquaculture 6) Consulting 7) NGO work 8) Trade 9) Other	
2	How many years of professional experience in this sector do you have?	numerical	
3	How long have you been professionally active within this region?	numerical	
4	Today, fisheries and aquaculture compete for access to sea areas.	1) Completely agree 2) Partially agree	If agreeing, respondent indicated areas with spatial competition.
5	The existing legal framework supports sustainable fisheries and aquaculture.	3) Partially disagree 4) Fully disagree 5) Don't know	
6	The existing planning tools are sufficient to comply with the laws and regulation.		
7	Fisheries is given a high priority by management within the region.		
8	Aquaculture is given a high priority by management within the region.		
9	Until the year 2040 and in light of environmental change, fisheries will…	1) Increase 2) Not change 3) Decrease	
10	Until the year 2040 and in light of environmental change, aquaculture will…	4) Don't know.	If agreeing, respondent indicated areas with perceived future increased aquaculture activities.
11	Until the year 2040 and in light of environmental change, competition over space between fisheries and aquaculture will…		If agreeing, respondent indicated areas with perceived future spatial competition.
12	Until the year 2040 and in light of environmental change, conservation of vulnerable species and habitats will become….	1) More important 2) Neutral 3) Less important 4) Don't know	
13	Are there any new potential areas for aquaculture?	1) Yes 2) No	If positive answer, respondent indicated new potential areas for aquaculture.
14	Do you have additional comments?	Free text	

18 interviews were carried out, stakeholders were grouped into five broader categories to have more respondents per category. Respondents from 'Academic Research', 'Governmental Research', 'Consulting', 'Trade', and 'Other' were regrouped into 'Other'. Respectively 3, 7, 1, 3 and 4 respondents within the sectors of fishery, aquaculture, fishery management, NGOs, and 'Other' were interviewed. The three fishers were all fishing for saithe (among other species). As part of the project ECOAST, we also talked to several shrimp fishers, and they have been cited several places in this article.

3. Results

3.1. Fisheries and aquaculture production

Total landings of fish and shellfish from the CSA were around 9500 t in 2017, and 10,700 t in 2020 (Table 3). In both years, the statistical rectangle with highest landings was 28–41. The rectangles with the second and third highest landings were 08–15 and 08–16 in both 2017 and 2020, but it should be noted that only an unknown fraction of the landings from rectangle 08–16 was fished within the CSA. Landings from the two purely offshore rectanges 08–3 and 08–4, as well as the middle and inner parts of the Hardangerfjord were negligible.

The main bulk of the landings in both 2017 and 2020 consisted of the pelagic species mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*), as well as saithe. Other fish species caught in some quantities were sprat (*Sprattus sprattus*), herring (*Clupea harengus*), pollack (*Pollachius pollachius*), anglerfish (*Lophius piscatorius*), cod (*Gadus morhua*), cusk (*Brosme brosme*), haddock (*Melanogrammus aeglefinus*), hake (*Merluccis merluccius*), ling (*Molva molva*) and spurdog (*Squalus acanthias*). Wrasse species (caught alive to be used as cleaner fish for salmon) were also caught in considerable amounts. The most important commercial crustacean species were edible crab (*Cancer pagurus*) and northern shrimp. Most northern shrimp was landed from statistical rectangle 08–16, but likely not from the CSA as the largest shrimp fishing grounds are found south of PA 3.

Since around 1970, a large salmonid-farming industry has developed in the Hardangerfjord, with 169 licensed sites in 2018 (Fig. 3), typically with a maximum licensed biomass of around 2500 t per farm. In addition, there are several hatcheries for salmon as well as trout (*Salmo trutta*) in the CSA. Trout hatcheries are also used for restocking of rivers. Biomass production of Atlantic salmon increased from 1994 to 2017, after which the production decreased some (Fig. 7). A similar trend is seen for rainbow trout, where the production increased until 2015. The temporal trend in production in Atlantic salmon and trout in PA 3 was approximately the same as the trend in production in Hordaland for overlapping years. In PA 3, there was an overall increase in the production of Atlantic salmon over the years 2017–2021, while the producton of trout in the same time period slightly decreased (Fig. 7).

3.2. SEAGRID output

Several spatial co-existing human activities were detected in the CSA, and SEAGRID quantified interactions for pairs of sea use located in the same cell (Fig. 8), and visualized them in a single thematic CSA map by computing the resulting interaction score for each cell of analysis (1 km^2) in the whole CSA (Fig. 9). According to the interaction matrix (Fig. 8) and Table 1, the dominating spatial conflicts are related to military use (particularly the restricted military areas) and aquaculture. Military use, aquaculture, and active and passive gears are in conflict with all the other layers, with military restricted areas reaching the highest levels of conflicts (one −5, seven −6). Active and passive gears each have four −5 and two −6, but these scorings result from one-sided conflicts where fishing is spatially excluded by aquaculture, sea cables and military use, as well as the presence of coral reefs (Table 1). Active and passive gears are also in mutual conflict (−2). Shipping routes coexist with most other marine uses (interaction scores equal to 0), except aquaculture and military restricted areas (respectively scores of −5 and − 6), and to some extent fishing (−2). As might be expected, synergies occur between resources and protection measures (e.g. between coral beds and SVO-areas and between spawning and natural protected areas).

Summing up mutual scores for each combination of pair of uses existing in the same 1 km^2 grid cell, the SEAGRID map of interactions demonstrated that analyzed cells (i.e. with at least two uses overlapping)

Table 3
Landings (tonnes) per species (with landings >1 t) in 2017 and 2020, per statistical rectangle (Fig. 2), listed from highest to lowest total weight, in the case study area (Salmon Production Area (PA) 3 in Norway's present aquaculture management regime). The statistical rectangle 08–16 is split between PA 3 and PA 2 south of it.

English name	Latin name	08–03	08–04	08–15	08–16	08–20	08–21	28–01	28–41	Total
2017										
Mackerel	*Scomber scombrus*		35	1776	403	289		527	2303	5334
Horse mackerel	*Trachurus trachurus*			212	389	295	1	2	398	1297
Saithe	*Pollachius virens*	64	48	183	46	82	68		154	646
Edible crab	*Cancer pagurus*			41	314		1		22	378
Corkwing wrasse	*Symphodus melops*			34	73	45	19	32	111	315
Northern shrimp	*Pandalus borealis*			16	289				1	306
Atlantic cod	*Gadus morhua*			24	196	4	3	1	19	247
North Sea herring	*Clupea harengus*			8		21			156	185
Anglerfish (monk)	*Lophius piscatorius*			33	56	1			40	129
Ballan wrasse	*Labrus bergylta*			9	29	15	1	16	44	114
Goldsinny wrasse	*Ctenolabrus rupestris*			13	23	7	2	20	32	97
Pollack	*Pollachius pollachius*			31	36	9	9		10	95
European hake	*Merluccis merluccius*			26	42	2	2		3	74
Haddock	*Melanogrammus aeglefinus*			20	25	8	6		12	71
Coastal sprat	*Sprattus sprattus*					39	21			60
Norway lobster	*Nephrops norvegicus*	1	9	7	19		1	2	15	54
Ling	*Molva molva*			19	16	2	2		10	49
Spurdog	*Squalus acanthias*			10	7	2	3		3	25
Atlantic bluefin tuna	*Thunnus thynnus*							25		25
Norway pout	*Trisopterus esmarkii*				23					23
Cusk	*Brosme brosme*			6	2	2			11	20
Smallmouthed wrasse	*Centrolabrus exoletus*			2		3		1	6	12
European lobster	*Homarus gammarus*	2		1	5				3	10
Skates and rays				1	7				3	11
Halibut	*Hippoglossus hippoglossus*			1	2				1	4
Blue ling	*Molva dypterygia*			1	1				1	3
Spring spawning herring	*Clupea harengus*				3					3
European plaice	*Pleuronectes platessa*				2					2
Dab	*Limanda limanda*				2					2
European eel	*Anguilla anguilla*					1	1			1
Total										9590
2020										
Mackerel	*Scomber scombrus*	295		1412	970	372		771	2050	5869
Horse mackerel	*Trachurus trachurus*			375	294	196			543	1408
Saithe	*Pollachius virens*	522	23	153	200	23	96	3	123	1142
Edible crab	*Cancer pagurus*			93	278			3	70	444
Northern shrimp	*Pandalus borealis*			7	280					288
Coastal sprat	*Sprattus sprattus*			64		56	153			273
Corkwing wrasse	*Symphodus melops*			59	71	14	40	12	35	231
Pollack	*Pollachius pollachius*	8		59	49	4	12	1	8	141
Anglerfish (monk)	*Lophius piscatorius*	7		40	30		1	1	56	133
Cusk	*Brosme brosme*			11	14	39	1	29	24	117
Haddock	*Melanogrammus aeglefinus*			11	70	1	4	1	13	101
Atlantic cod	*Gadus morhua*	4		19	51	2	4	3	12	95
Spring spawning herring	*Clupea harengus*				88					88
North Sea herring	*Clupea harengus*		51	1				1	31	83
Ballan wrasse	*Labrus bergylta*			22	27	3	5	7	10	75
European hake	*Merluccis merluccius*	32		14	6		1		2	56
Ling	*Molva molva*	8		9	6	7	1	11	14	56
Goldsinny wrasse	*Ctenolabrus rupestris*			13	11	2	1	6	10	43
Spurdog	*Squalus acanthias*			15	9	1	2	2	9	39
Norway lobster	*Nephrops norvegicus*	1		9	11		1	1	12	33
Blue ling	*Molva dypterygia*			2	1	7	1	1	4	16
Skates and rays				3	3	2			3	11
European lobster	*Homarus gammarus*			1	4				2	6
European plaice	*Pleuronectes platessa*				5					5
Halibut	*Hippoglossus hippoglossus*			2	1				2	5
Smallmouthed wrasse	*Centrolabrus exoletus*			2		1	1		1	4
Greater forkbeard	*Phycis blennoides*	2				1				3
Witch	*Glyptocephalus cynoglossus*	2								2
Whiting	*Merlangius merlangus*				1					1
Total										10,767

covered 23% of the total CSA (3221 out of 13,839 1-km^2 grid cells), 20% of which resulted in a total negative score (Fig. 9). Interaction scores exceeded −15 (red and dark cells, Fig. 9) in cells located in the outermost coastal areas and the outer Hardangerfjord, where up to 4–5 conflicts co-exist, while the most common number of co-existing conflicts is two or three with scores ranging between −18 and 6. By contrast, positive interactions exist only in 7% of the analyzed cells (213 out of 3221), with scores increasing to 5 or 6 in cells where probably two single overlapping uses are in synergy. The largest areas of positive interactions were found in the SVO-area Karmøyfeltet in the southern part of the CSA (Fig. 10b). Except for the offshore areas, the largest parts of the CSA with no human use were found in the innermost half of the Hardangerfjord (Fig. 10a). In the offshore areas, stretches of orange cells mark areas where shipping lanes overlap with military training areas

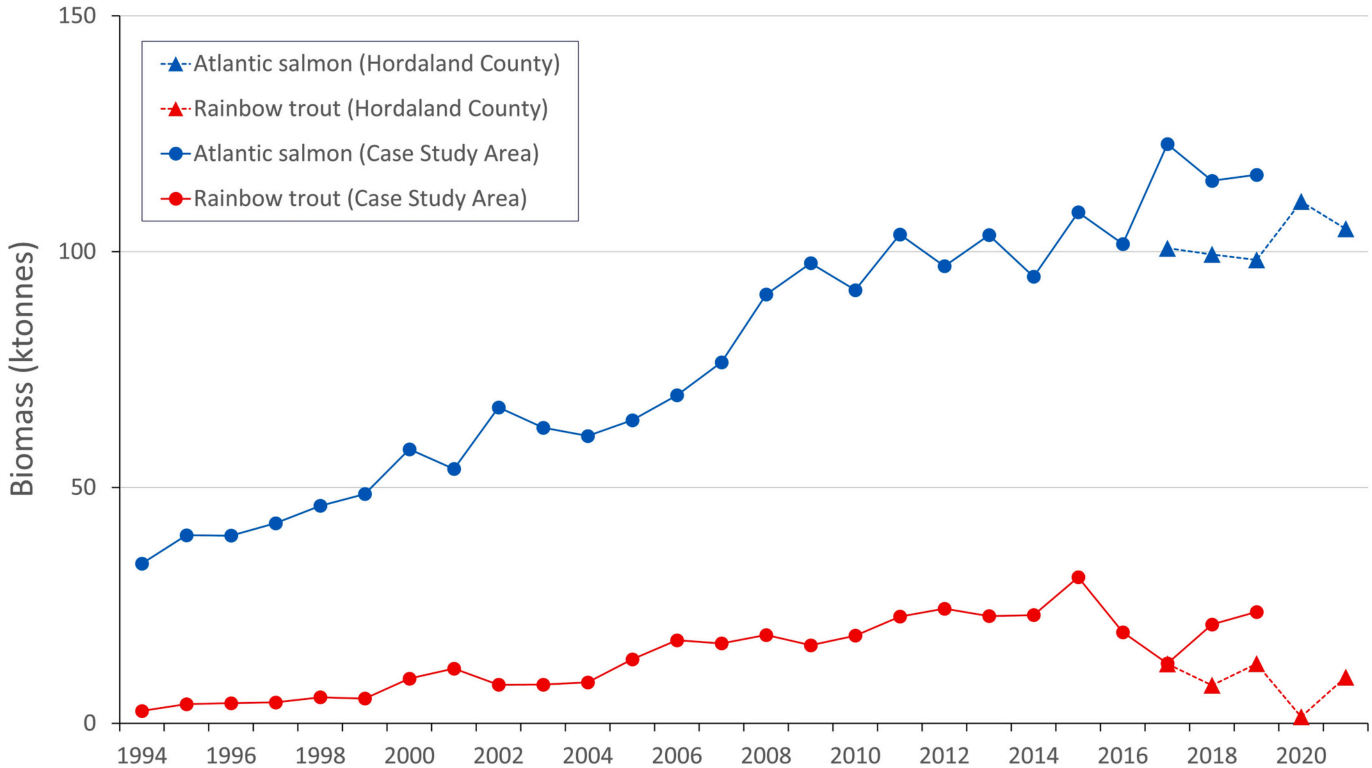

Fig. 7. Production (biomass in tonnes) of farmed Atlantic salmon (*Salmo salar*) and rainbow trout (*Oncorhynchus mykiss*) in the Hordaland county, 1994–2019, and in Salmon Production Area 3 in Norway's present aquaculture management regime, 2017–2021. Data from the Norwegian Directorate of Fisheries.

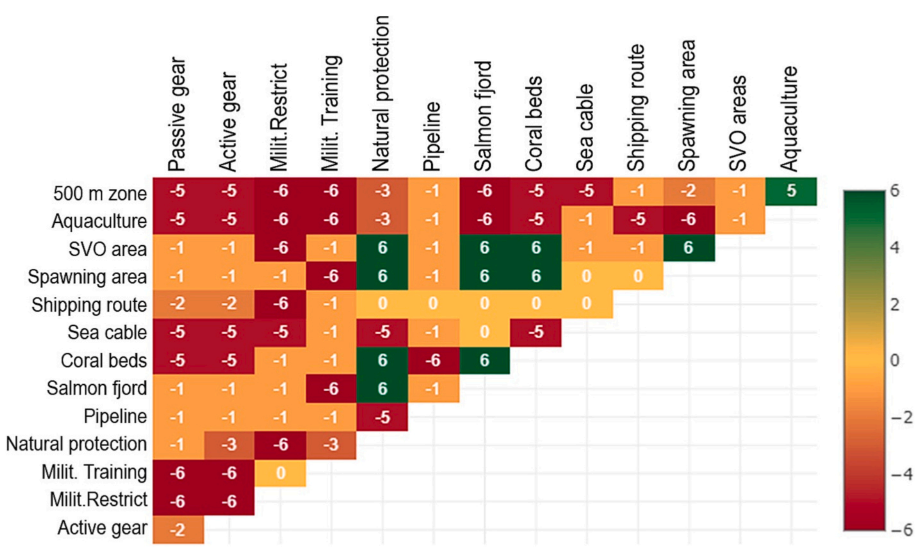

Fig. 8. Matrix from SEAGRID of spatial interactions between all pairs of all specified human activities (uses) as well as natural areas like coral reefs and spawning grounds. Yellow cells signify no interaction, green cells signify synergies, while red cells signify conflicts between two activities. Numbers indicate the strength of the conflicts/synergies, ranging from 6 to −6, while 0 indicates no spatial overlap or spatial co-existence without any conflict/synergy. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Fig. 9).

3.3. Stakeholder questionnaire

The questions in the interview survey were mainly about fisheries and aquaculture, but with one question about conservation of species and habitats. All respondents except one fisherman believed that this will become more important in the coming 20 years (Fig. 11). The respondents were divided over the questions of legal framework and planning tools (all tools involved in planning processes of marine installations). Eleven out of 18 were of the opinion that the existing legal framework ensured sustainable fisheries and aquaculture, while eight out of 18 thought the present planning tools were sufficient for complying with laws and regulations.

The respondents were also divided over the statement that fisheries within the region are given high priority by managers, while the majority (12 respondents) agreed that aquaculture was given high priority by managers. All three fishermen completely agreed, while four out of seven aquaculture respondents disagreed. Conflicts between fisheries and aquaculture were perceived by stakeholders from all sectors in that all (except two) agreed that presently fisheries and aquaculture compete for space in the CSA. When asked about the location of the spatial conflicts, most respondents pointed to the outer fjord areas (Fig. 12a). Less than half of the respondents thought that competition for space, i.e.

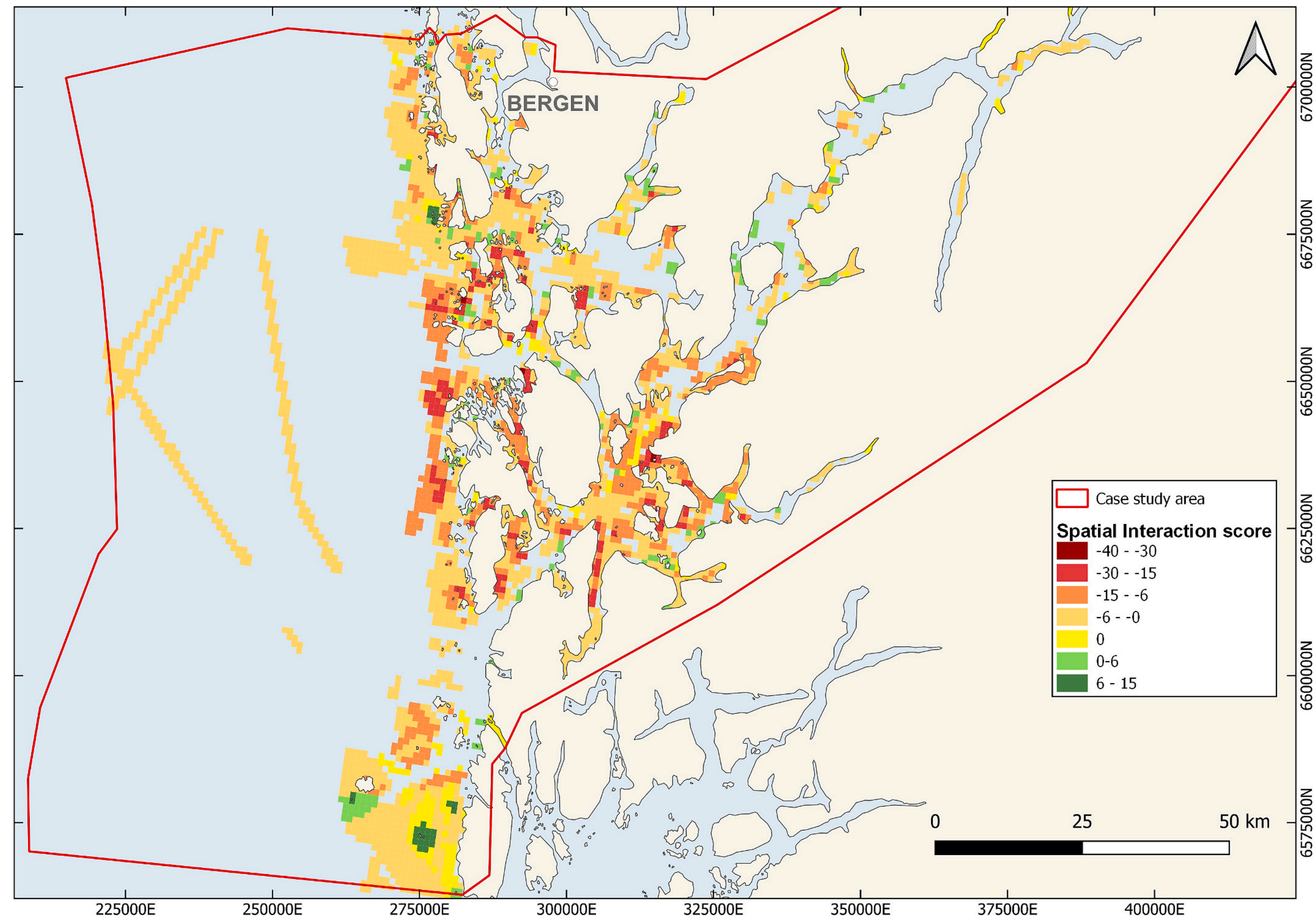

Fig. 9. SEAGRID map for the case study area (equivalent to Salmon Production Area 3 in Norway's present aquaculture management regime) visualizing the location of conflicts and synergies, given as spatial interaction scores for all cells of analysis within a grid of square cells of 1 km^2. Yellow cells signify no interaction, green cells signify synergies, while red cells signify conflicts. The spatial interaction score for a cell is the sum of the scores for each combination of pair of uses. The spatial database of the map service of the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b) was used as input for the maps produced by SEAGRID. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

conflict between the two sectors, will increase in the years to come, while eight thought that there would be no change. When asked about the location of areas of increased competition/conflict, some respondents pointed to inner areas of the Hardangerfjord with presently few fish farms, while others suggested offshore and outer coastal areas (Fig. 12b).

Regarding potential future growth of respectively fisheries and the aquaculture sector, sixteen respondents believed that fisheries will either see no change or decrease, while fifteen believed that aquaculture will increase. New areas for aquaculture were, by most of the respondents, identified in the inner part of the Hardangerfjord with presently few fish farms (Fig. 3), as well as along the outer coastline and in offshore areas (Fig. 13a). This question is linked with the question of where aquaculture activities potentially *will* increase in the coming years; again, both areas in inner parts of the Hardangerfjord and offshore areas were pointed to (Fig. 13b), but the respondents also believed that aquaculture will increase in areas with already high densities of fish farms. Respondents' views on potential new areas of aquaculture were linked with their perceptions on the future technological development of the sector. Those who believed in the development of closed fish cages, envisioned growth in inner, protected locations, while those who thought that large offshore facilities will be the way forward, predicted growth along the coast as well as in the open sea.

4. Discussion

Our results show that a wide variety of human interests are present in the CSA. These can be divided into private enterprises, societal interests and infrastructure, and environmental conservation measures. The former involves aquaculture and fisheries (and tourism which we have not considered in this paper), where the aquaculture of salmonids is of particular importance, due to the large production and high number of active farming sites, and the high economic impact of the industry. In comparison, the coastal fisheries in the area are relatively small, but have a great diversity with respect to the species caught. Societal use includes cables and pipelines, shipping lanes and military use.

The SEAGRID analyses showed that presently there are spatial interactions between human activities in large parts of the coastal and fjord areas of the CSA, and that in 86% of the cells where different uses co-exist there are at least some degree of conflict. The perception of conflicts, defined as competition for space, between various human uses as described from the interviews, was divided by stakeholder position, not only between fishermen and aquaculture, but within each of the groups. Our results indicated a certain degree of mistrust of management authorities since neither fishermen nor aquaculturalists perceived that their own sector was given priority by management authorities, but thought the other sector was prioritized.

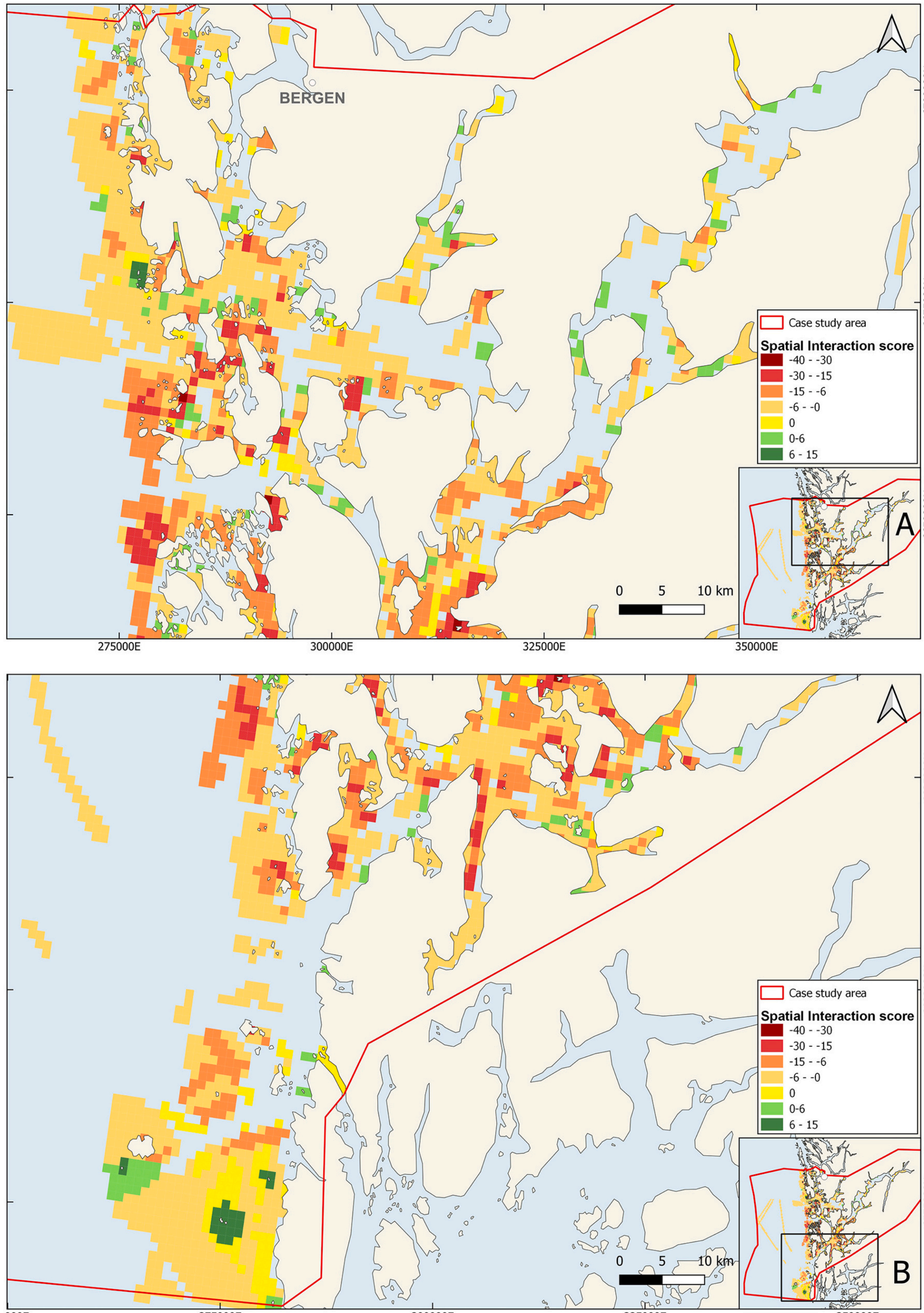

Fig. 10. SEAGRID maps for the northern (A) and southern (B) parts of the case study area (equivalent to Salmon Production Area 3 in Norway's present aquaculture management regime) visualizing the location of conflicts and synergies, given as spatial interaction scores for all cells of analysis within a grid of square cells of 1 km^2. Yellow cells signify no interaction, green cells signify synergies, while red cells signify conflicts. The spatial interaction score for a cell is the sum of the scores for each combination of pair of uses. The spatial database of the map service of the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b) was used as input for the maps produced by SEAGRID. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

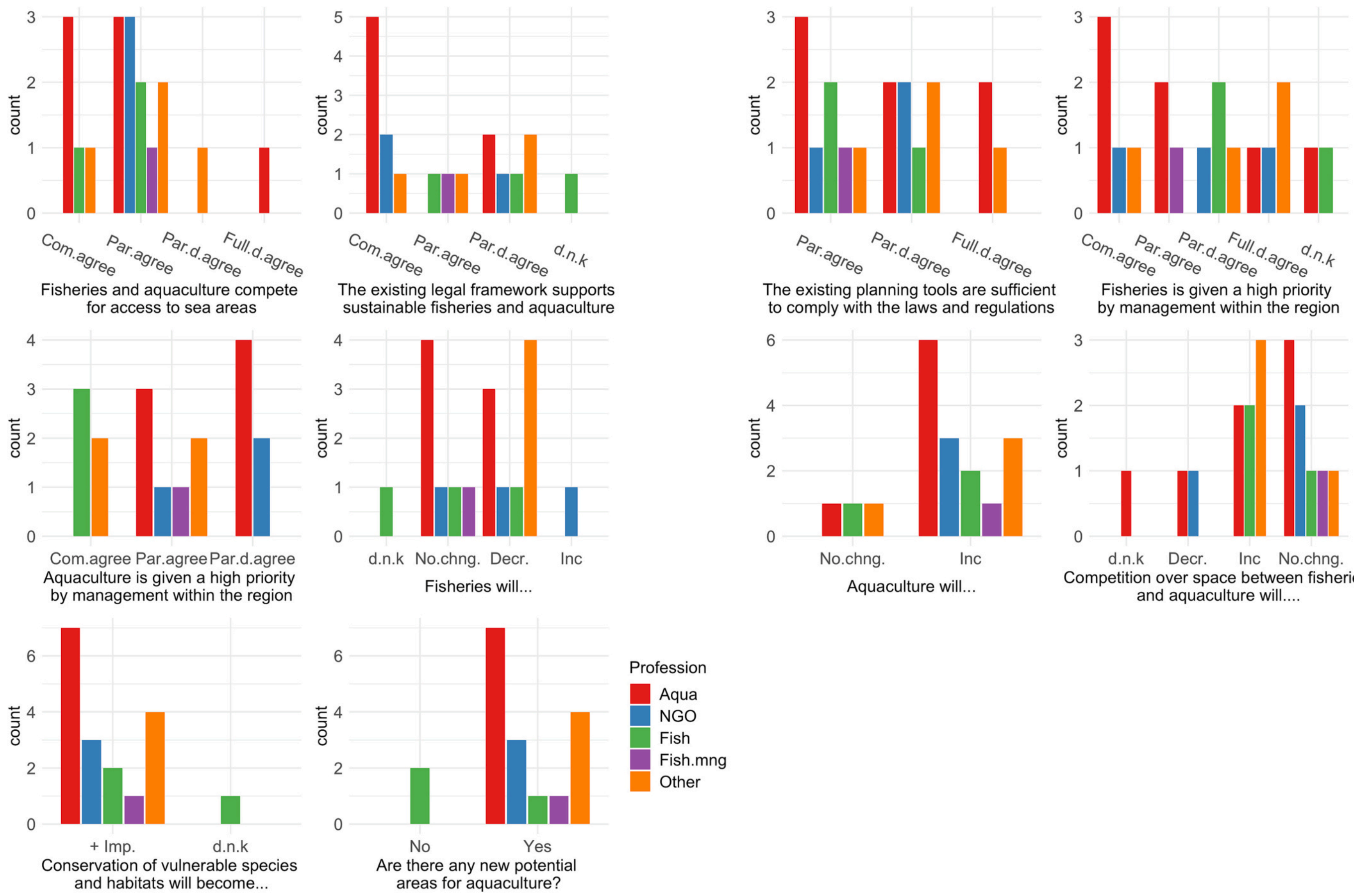

Fig. 11. Responses in the questionnaire survey from stakeholders from the sectors of fishery (green), aquaculture (red), fishery management (purple), NGOs (blue), and 'Other' (orange). The questions asked are written below the bar plots (see also Table 2). Abbreviations are as follows: "Com.agree" = completely agree, "Par. agree" = partially agree, "Par.d.agree" = Partially disagree, "Full.d.agree" = fully disagree, "d.n.k" = do not know, "No.chng" = no change, "Decr" = decrease, "Inc." = increase, and "+ Imp" = more important. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.1. Spatial conflicts

Risk assessments and surveillance of the Norwegian aquaculture industry have so far concluded that proliferation and release of salmon lice and escapees are the two major threats against wild Norwegian salmonids (Taranger et al., 2015). In addition, infectious diseases and release of in particular viruses, but also pathogenic bacteria are considered important (Johansen et al., 2011; Jones et al., 2015), posing a threat towards wild salmon and sea trout, but less towards other fish species. Our results suggest that spatial conflicts, although not of biological nature, are a part of the overall picture. Salmon farming still mainly occurs close to land (McIntosh et al., 2022), necessarily leading to competition over space in the coastal zone (Hersoug et al., 2021). The permanent nature of the salmon farms entails exclusion of other human uses, and while the number of cages have remained on the same level since 2005, the diameter of the pens has increased, resulting in Norwegian salmon farm sizes having increased by 221% from 2005 to 2020 (McIntosh et al., 2022).

Military areas were similarly viewed as a major cause of spatial conflicts due to restrictions on other human uses like fishing, aquaculture, shipping and cables/pipelines. The restricted military areas have, however, a limited extent, as both the Haakonsvern naval base and the submarine bunker at Laksevåg are located within harbor areas not suitable for fisheries nor aquaculture. The military training areas are larger, but the degree of conflicts between these and other human interests has been reduced in recent years. A main reason is probably the closure of the Norwegian Coastal Artillery, which led to the termination of the coastal fortress with adjacent shooting ranges for fixed torpedo and artillery batteries at Korsneset in 2001–2002. The sea area is still used for military exercises, but the activity is temporary. Thus, although military use and aquaculture score equally high in the interaction matrix regarding number of pairwise conflicts with other human uses, the training areas are less prevalent, mostly offshore and restrictions on other uses are temporary.

Fishing grounds for passive and active gears (including shrimp fishing grounds) were also involved in many spatial conflicts. However, contrary to aquaculture and military use, when fishing grounds overlap in space with other human uses, fishing is displaced. There is little information available on the present use of fishing grounds in Norwegian coastal waters as vessels <15 m length until recently have not been obliged to use a position reporting Vessel Monitoring System (VMS) (new requirements for vessels <15 m from July 2022 (Fiskeridirektoratet (Directorate of Fisheries), 2021c). This limits the provision of spatially explicit knowledge for the management processes (Said and Trouillet, 2020) and opens up to alternative approaches that could fill major quantitative and spatial data gaps through fishers' participation (Grati et al., 2022) or low-cost tracking systems (Mujal-Colilles et al., 2022; Tassetti et al., 2022).

From interviews of local fishers in the CSA, we learned that saithe fishers still use the fishing grounds registered 10–20 years ago, while the shrimp fishing grounds in the fjords are no longer in use and the shrimp fishers today only trawl along the outer coast in the southern part of the CSA. Thus, the conflict map may be somewhat misleading when it comes to shrimp fishing grounds, depicting spatial conflicts where such

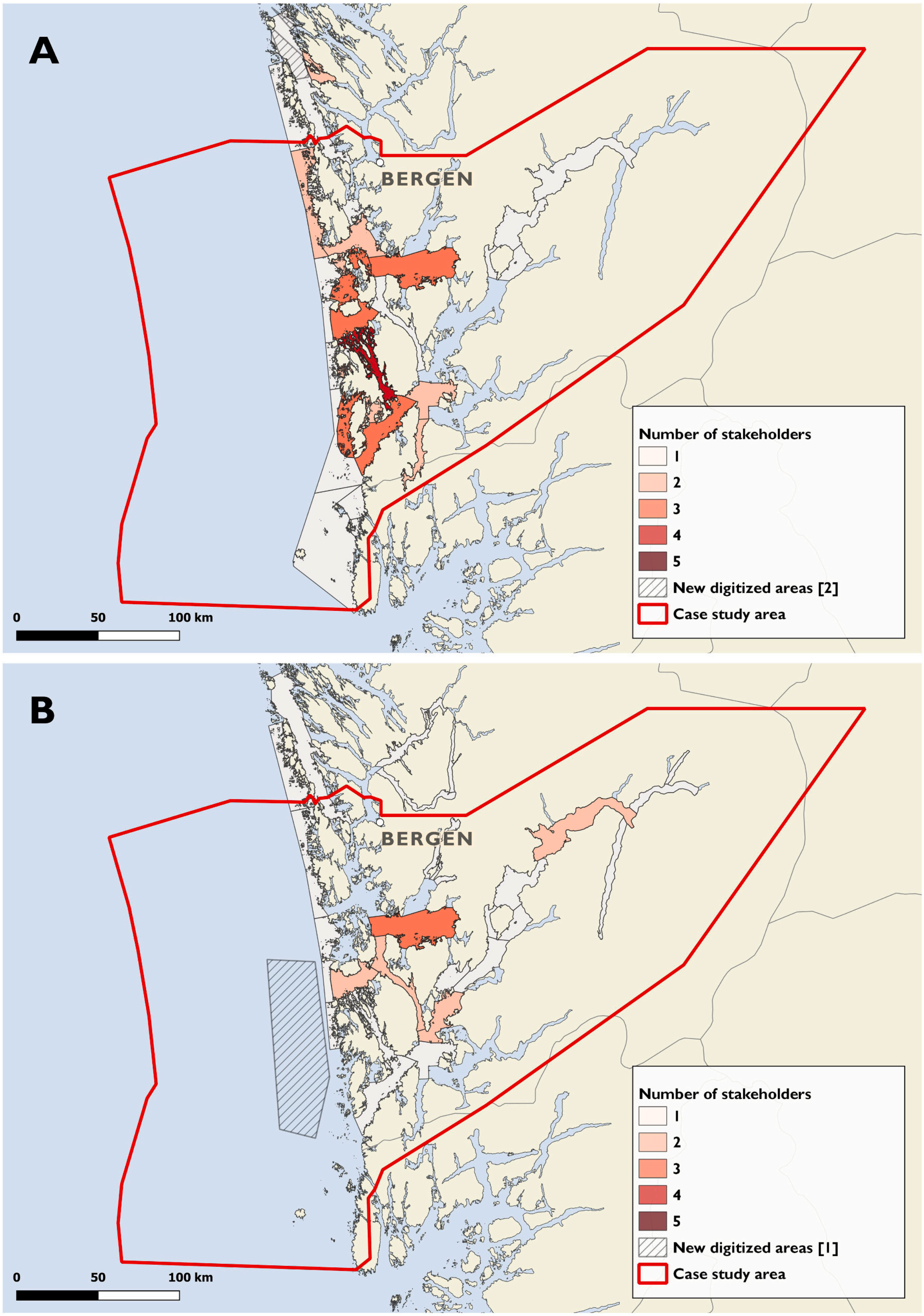

Fig. 12. Map showing present (A) and future (until 2040) (B) areas of conflict between fisheries and aquaculture in the case study area (Salmon Production Area 3 in Norway's present aquaculture management regime), as perceived by interviewed stakeholders. The colour scale and numbering show how many stakeholders considered each polygon a conflict area. Digitized areas (hatched) were drawn on the map by stakeholders, where the number in brackets shows the number of digitized areas. County borders (until December 31, 2019) are shown in the map.

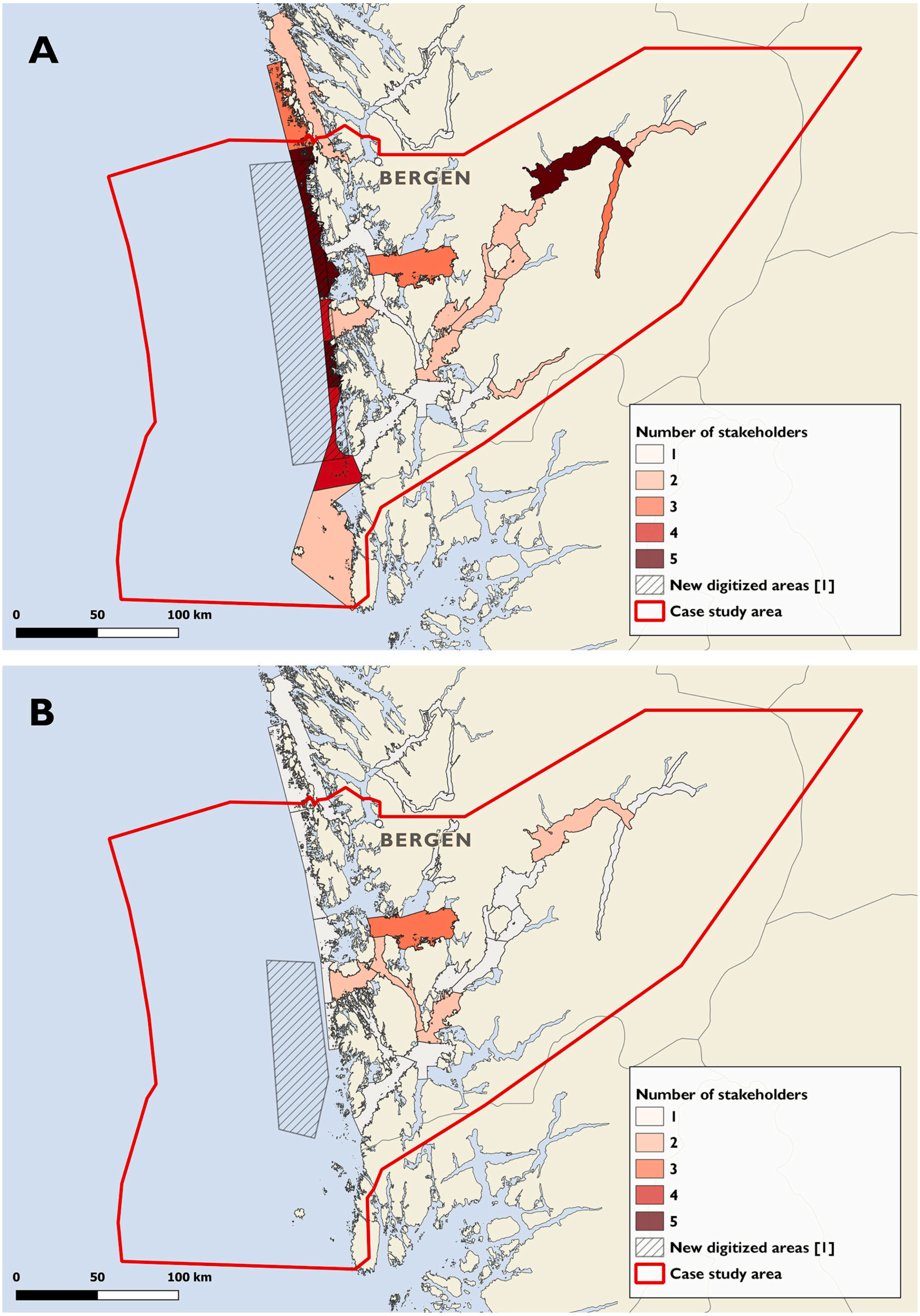

Fig. 13. Map showing new, potential areas for aquaculture (A) and increase in aquaculture until 2040 (B) in the case study area (Salmon Production Area 3 in Norway's present aquaculture management regime), as perceived by interviewed stakeholders. The colour scale and numbering show how many stakeholders considered each polygon a new, potential area for aquaculture. Digitized areas (hatched) were drawn on the map by stakeholders, where the number in brackets shows the number of digitized areas. County borders (until December 31, 2019) are shown in the map.

conflicts no longer exist.

Nature protection were not found to affect fisheries nor aquaculture to a large extent, with the exception of the single salmon fjord, which is protected from salmonid aquaculture, but otherwise open to other activities, such as fisheries, tourist fisheries and tourism in general. The large natural protection areas in the Korsfjord and outer Hardangerfjord do not affect existing activities in aquaculture and fisheries, but are limiting the potential for increased utilization by these sectors, which is the intention of the protection. The SVO-areas on the other hand, do not have any formal restrictions on human use (Eriksen et al., 2021).

We found that societal interests and infrastructure obstruct or displace private enterprises and economic interests, whereas environmental protection measures do so to a lesser extent; an exception are coral reefs which seem to be well protected against both fishing operations as well as new aquaculture facilities. According to Hersoug et al. (2021), salmon farms cannot be placed in fishing grounds or spawning areas; aquaculture and fisheries could therefore be considered mutually exclusive. Nevertheless, fishing grounds seem to be the losing party, as farms once established expel fishing operations. Due to the omnipresence of both salmon farms and fishing grounds in the CSA, these sectors probably display the highest level of spatial conflicts in the Hardangerfjord region. As the conflict map only shows areas (cells) with overlapping uses or interests, e.g. fish farms within fishing grounds, and not areas where an activity is ruled out, e.g. a fish farm did not obtain a locality permit within a fishing ground, it may undercommunicate the extent of competition for space in the region.

With altogether 950 commercial licenses (by March 2020) (Hersoug et al., 2021), the salmon farming industry is an important sector along most parts of the Norwegian coast. Likewise, coastal fisheries constitute an important sector with a fleet of nearly 5200 commercial vessels (in 2019) (Zimmermann et al., 2022) and large recreational and tourist fisheries (Vølstad et al., 2011; Vølstad et al., 2020). The map service from the Norwegian Directorate of Fisheries (Fiskeridirektoratet (Directorate of Fisheries), 2021b) shows the omnipresence of fishing and spawning grounds (Olsen et al., 2010), and aquaculture facilities along the whole Norwegian coast. Similarly, coral reefs are found along large stretches of the coast as well as in near-coastal offshore areas (Fosså and Skjoldal, 2010); the same pertains to SVO-areas (Eriksen et al., 2021), national salmon fjords and marine protected areas. Regional differences exist, both in the type of use as well as the degree of use. In Troms county, military use seizes large areas (Hersoug et al., 2021), while intense conflicts over new marine deposits of mine tailings presently take place in the Repparfjord and Førdefjord. The Porsangerfjord and Tanafjord in the northernmost county of Finnmark are closed for all bottom trawling (Søvik et al., 2020). Spawning grounds for the large and economically important stocks of cod, saithe, haddock, capelin and herring are found along the coast of the Troms and Finnmark counties, overlapping in space with important fishing grounds, shipping lanes, aquaculture and petroleum fields (Olsen et al., 2010). This suggest that despite regional differences, spatial conflicts on the scale of what we have described for our CSA will be found along large parts of the Norwegian coast.

The high degree of spatial conflicts found in the present study is not unique in a global context. Worldwide, marine aquaculture is still mainly found in coastal waters, competing for space with other human activities (Sanchez-Jerez et al., 2016). In a comparison of 16 study sites in a wide range of countries, with 614 stakeholders in total, representing research, aquaculture, government, conservation groups, education and fisheries, Galparsoro et al. (2020) found a high level of commonality in the main issues hindering aquaculture growth. Most was attributed to interactions with other maritime activities, including conflicts with other users, and administrative procedures, including licensing. Farella et al. (2021) used a web-based decision support tool to quantitatively build their multi-pressure scenario, to communicate with fishers and stakeholders and identify a portfolio of possible management measures, highlighting how the different sectors of human activities strongly interact with each other and exert multiple consistent biological, physical and energy related pressures to the environment.

4.2. Emerging spatial conflicts

All but one of the interviewees thought that conservation issues will become more important in the future. Norway has been supporting a global goal (Jørgensen et al., 2021), formulated by the UN Convention on Biological Diversity (CBD), of conserving 10% of its coastal and ocean areas within 2020 as MPAs or other effective area-based conservation measures (CBD, 2018). This goal was not reached as Norway currently has protected <5% of its territorial waters (within 12 nautical miles of the baseline). The Norwegian "National Salmon Fjords" are limited to a ban on salmon farming, as a means to protect wild salmon (Serra-Llinares et al., 2014). Furthermore, the existing Norwegian MPAs and the four marine national parks allow continued activity of fisheries and aquaculture. The MPAs have been enrolled to CBD as International Union for Conservation of Nature (IUCN) category Ia (Jørgensen et al., 2021) which is the strongest protection possible where human visitation, use and impacts are strictly controlled and limited (Day et al., 2019). Currently, parties to the CBD are discussing an ambitious increase to 30% by 2030. If Norway is going to fulfill its international obligations and implement stricter protection of larger parts of its waters, this will surely increase conflicts over space in coastal areas. Within the two planned MPAs in the CSA, there are currently 17 small and large fishing grounds for active gears, 20 fishing grounds for passive gears, two shrimp fishing grounds and eleven fish farms, which would have to be abandoned (fishing grounds) or moved (aquaculture facilities) if the strictest protection is implemented. Furthermore, if goals for rebuilding ecosystems should be adopted and implemented larger areas may have to be protected, e.g. the Oslofjord (see below).

Another emerging area-demanding human use of near-coastal areas are offshore wind farms. As part of the shift from fossil to renewable energy sources presently taking place in Europe (Gusatu et al., 2020), the Norwegian government is planning largescale marine wind farms (Nærings- og fiskeridepartementet, 2022). Wind farms entail spatial conflicts with fisheries and conservation measures (Perrow, 2019; Gusatu et al., 2020; Letschert et al., 2021), as well as future offshore aquaculture facilities. Letschert et al. (2021) described how designated Natura 2000 conservation sites and new, potential offshore wind farms in the southern part of the North Sea will overlap with present trawling grounds for the Norway lobster (*Nephrops norvegicus*) fishery in the area.

4.3. Non-spatial conflicts

A limitation of our study was the restriction to spatial conflicts, which ignores important effects from different activities of a non-spatial character, such as pollution, visual impacts and sociological or sociocultural effects. Salmon farming constitutes one of the largest sectors in our CSA and environmental effects are many (Grefsrud et al., 2022), with potentially negative effects on other human uses, particularly fishing and conservation values, inevitably leading to conflicts with these interests. In other fjords and regions in Norway, other human activities dominate coastal use entailing different conflicts, illustrated by e.g. the presently very poor environmental status of the Oslofjord with no aquaculture, but high fishing pressure, environmental toxicants and runoff from land (Moland et al., 2021). Of particular importance is the impact of the hydroelectric power plants surrounding the area, in particular in the fjords. Myksvoll et al. (2014a, 2014b) found significant impact on the dispersal of cod eggs, which can also be extrapolated to any planktonic organisms, for instance salmon lice. The hydroelectric plants withhold the freshwater from the snow melting in spring and summer, and distributes this more evenly throughout autumn and winter, affecting the brackish layer on top of the water column in the fjord systems.

The Hardangerfjord has been extensively studied, with special emphasis on conflicts arising from the impacts of the aquaculture industry on trout and salmon (Skaala et al., 2014a, 2014b). Investigating benthic and pelagic communities of the fjord, Husa et al. (2014) concluded that overall, the communities beyond the immediate proximity of the fish farms seemed to be little affected by the effluents and deposition of organic matter from the salmon farming. However, the macroalgal site and deep bottom fauna in the inner basin of the fjord were only characterized as "good", in contrast to the high ecological status of the parameters in the outer part. As the innermost part is little affected by aquaculture (Fig. 3) they concluded that the fjord showed little evidence of regional impact from the fish farming industry, and that other stressors affected the innermost part. A possible additional effect of aquaculture is organic waste adding to the decline of dissolved oxygen in bottom water of sill-fjords, which is primarily linked to multidecadal warming of Atlantic water (Aksnes et al., 2019). However, oxygen depletion in bottom water was only one of the many predicted effects of fish farm emissions on the seafloor biogeochemistry up to 1 km from farms from a benthic-pelagic model of the Hardangerfjord (Yakushev et al., 2020).

Several studies have emphasized salmon lice and escapees as the major environmental impacts of the Norwegian aquaculture industry (Asplin et al., 2014, Myksvoll et al., 2018, Skaala et al., 2014a, Skaala et al., 2014b, Taranger et al., 2015,). Distribution and spreading of salmon lice has been studied in the Hardangerfjord area (Asplin et al., 2014). Exchange of the upper water masses in the fjord, lasting for several days and extending to the whole length of the fjord, caused regular transport of the lice over large areas. The antibiotic consumption in Norwegian aquaculture, which was high prior to 1992, has been low in later years (223 kg in the entire country in 2020, Norm-Vet 2020), which cannot be regarded as a high biological impact.

Over many years, coastal shrimp fishermen have experienced reduced catches (Melaa et al., 2022) and shrimp fishers have also reported lower quality of the shrimp (Søvik et al., 2021). A recent model study suggested the decline may be caused by chemical de-lousing agents used in salmon aquaculture (Moe et al., 2019). The concentration range of food-administered de-lousing agents (teflubenzurons and diflubenzurons) that induce mortality of shrimps and other crustaceans following moulting is still not known for many species. Increased mortality and non-fatal damages have been shown to occur in species as diverse as copepods (*Acartia tonsa*), European lobster (*Homarus gammarus*) and northern shrimp (Bechmann et al., 2018; Samuelsen et al., 2014; Tester and Costlow, 1981). Deformities may ultimately entail increased mortality. Recently, effects of chemical delousing agents used in bath treatments have come into attention (Bechmann et al., 2019; Bechmann et al., 2020; Escobar-Lux, 2016; Escobar-Lux et al., 2019; Escobar-Lux and Samulsen, 2020; Fagereng, 2016; Fang et al., 2018; Frantzen et al., 2019; Frantzen et al., 2020; Parsons et al., 2020; Refseth et al., 2019). Of particular interest for coastal fisheries is the delayed mortality, occurring 2–4 days after the first pulse of exposure to hydrogen peroxide observed in northern shrimp (Bechmann et al., 2019). Major differences in sensitivity between species are seen (Fang et al., 2018 and references therein, Refseth et al., 2019), where northern krill (*Meganyctiphanes norvegica*) (Escobar-Lux and Samulsen, 2020) and *Calanus* spp. (Escobar-Lux et al., 2019) are shown to be highly sensitive. Of other bath treatments, deltamethrin in particular, has been shown to be toxic to crustaceans like the European lobster (Parsons et al., 2020) and northern shrimp (Bechmann et al., 2020).

4.4. *Planning tools and stakeholder consultations*

Albeit having a limited sample size, our questionnaire analysis showed that there was a large agreement across the respondents that aquaculture and fisheries compete for access to sea areas, which is in agreement with the SEAGRID analysis. Present area-conflicts between fisheries and aquaculture were thought to be highest in the westernmost parts of the CSA, which overlap well with the SEAGRID results, although few respondents pointed to the conflicts along the outer coast shown in the conflict map (Figs. 9, 12a). When asked about the future, the majority of the stakeholders held the view that aquaculture will increase as there are still new, potential areas available: the entire outer CSA coast and mid-fjord areas of the Hardangerfjord (Fig. 13a). This is in line with political goals of continued growth in Norwegian aquaculture production (Hersoug et al., 2021). Perceived new spatial conflicts with fisheries were, however, only placed in inshore fjord areas ignoring the many fishing grounds along the outer coast (Figs. 5, 12b).

Stakeholder consultations, like our participatory GIS approach, may be useful in identifying areas where aquaculture production can increase with little increase in degree of conflict with fisheries (Galparsoro et al., 2020; Grati et al., 2019; Salas-Leiton et al., 2021). However, the sample size in our study was too small to ensure that all stakeholder opinions and views were adequately represented, and should therefore only be interpreted as indicative of the potential a participatory GIS and questionnaire analysis has. If to be useful in designing actual management plans for the region a much wider stakeholder panel ensuring broad representation should be established.

Stakeholder consultations are likely most useful when combined with transparent and interactive spatial planning tools like SEAGRID. Tool-based analyses allowed assessing the spatial footprint of a series of anthropogenic pressures from human activities (e.g. fisheries, maritime traffic, and aquaculture), promoting strategic decisions and highlighting management priorities (Stelzenmüller et al., 2013a; Stelzenmüller et al., 2013b). The use of such tools proved very useful to identify possible criticalities and facilitate an effective exchange with stakeholders and local authorities whose involvement is an indispensable step for a community-based and adaptive management (Newton and Elliott, 2016). Such tools can indeed provide a platform for users to view and verify data associated with the case study, as well as to have a better understanding of the scenarios. Equally important is the chance offered to compare and reveal trade-offs among possible management scenarios, and to capture and share stakeholder feedback during the co-design and co-development of management plans (Pınarbaşı et al., 2017).

4.5. *Integrated coastal zone management*

The expansion of the Norwegian aquaculture industry has generated a need for balancing aquaculture with other societal interests in the coastal zone. Hovik and Stokke (2007) studied effects of different planning strategies at regional (county) level in terms of achieving integration between the interests of the aquaculture industry with those of other coastal interests. They concluded that the more active the county authorities have been as a meta-governor in the planning and implementation processes, the higher level of integration was achieved. Integrated Coastal Zone Management, a concept developed through the 1980s and 1990s (Douvere, 2008) has been advocated to ease conflicts and competing claims (Tiller et al., 2012). Many scientists have advocated reforms centered on the idea of ecosystem-based sea use management (or ecosystem-based-approach to sea use) and Marine Spatial Planning (MSP). Analyzing and allocating parts of three-dimensional marine spaces to specific uses, to achieve certain ecological, economic and social objectives, are crucial elements in such concepts (Douvere, 2008).

Our study, and in particular the use of SEAGRID, focused on the spatial aspects of conflicts and synergies, i.e. MSP, meeting the requirements listed by Douvere (2008):

- Addresses the heterogeneity of marine ecosystems in a practical manner
- Focuses on influencing the behavior of humans and their activities over time
- Provides a management framework for new and previously inaccessible scientific information
- Makes conflicts and compatibilities among human uses visible

- Guides single-sector management towards integrative decision-making

The place-based characteristics of ecosystems, natural resources and human activities affecting them emphasize the need to look at the system from a spatial and temporal perspective. Involvement of stakeholders is considered an essential part of a successful MSP approach (Fritz, 2008; Pınarbaşı et al., 2019; Pomeroy and Douvere, 2008; Soma et al., 2013; Soma et al., 2015).

A key MSP regulatory approach in Norway in later years has been the introduction and implementation of regional zoning, mainly by a top-down approach. The country's coastline has been divided into thirteen discrete production areas (PA), of which our CSA is PA 3 (Forskrift om produksjonsområder for akvakultur av matfisk i sjø av laks, ørret og regnbueørret (Produksjonsområdeforskriften) 2017), based on the modelled potential for spreading of pathogens, in particular salmon lice (Ådlandsvik, 2015; Jones et al., 2015; Guarracino et al., 2018). This regionalization applies to regions, not to local regulations within one particular Production Area as described in the present paper.

Co-use of areas, i.e. for more than one purpose, has been advocated as a means to reduce conflicts (Gimpel et al., 2015; Stelzenmüller et al., 2013a). The potential for co-use of areas was considered limited by the aquaculturists and fishermen respondents. However, co-use of areas for protection (salmon fjord and valuable areas) was not in conflict with interests of coastal fisheries, but did put limitations on the development of aquaculture.

Declaration of Competing Interest

The authors declare no conflicts of interest regarding this paper.

Contributions of authors.

All authors have contributed to the study according to the Vancouver Protocol on authorship. All authors have approved on the submitted manuscript.

Data availability

Data will be made available on request.

Acknowledgements

We are grateful for the courtesy and co-operation of all the respondents in the interview survey. The development of the SEAGRID model was initialized by the project *COEXIST Interaction in coastal waters: A roadmap to sustainable integration of aquaculture and fisheries*, financed by the Seventh Framework Programme (FP7 2007–2013) under grant agreement no. 245178. The project *ECOAST - New methodologies for an ecosystem approach to spatial and temporal management of fisheries and aquaculture in coastal areas* was funded by the COFASP "Cooperation in Fisheries, Aquaculture and Seafood Processing" – ERA-net, under grant agreement 258831 administered by the Norwegian Research Council. Part of the writing of the paper was funded by the Norwegian Ministry of Trade, Industry and Fisheries through the Norwegian Institute of Marine Research projects "Coastal Shellfish Resources" in the research program "Coastal Ecosystems", and the Norwegian Research Council project CoastRisk (project number 299554).

References

Ådlandsvik, B., 2015. Forslag til produksjonsområder. (suggested production areas, in Norwegian) report to the Ministry of Trade, industry and fisheries. Rapport fra Havforskningen 20-215, 57.

Ahmed, F., 2010. Approaches to and tools for managing environmental conflicts in coastal zones in Africa: challenges and prospects in relation to integrated coastal zone management (ICZM). Afric. J. Conflict Resol. 10 (2), 31–47.

Aksnes, D.L., Aure, J., Johansen, P.-O., Johnsen, G.H., Salvanes, A.G.V., 2019. Multi-decadal warming of Atlantic water and associated decline of dissolved oxygen in a deep fjord. Estuar. Coast. Shelf Sci. 228 https://doi.org/10.1016/j.ecss.2019.106392.

Angel, M.V., 1993. Biodiversity of the pelagic ocean. Conserv. Biol. 7, 760–772.

Anonymous, 2009. Lov om forvaltning av naturens mangfald (Naturmangfaldslova) (Act relating to the management of biological, geological and landscape diversity, in Norwegian) paragraph 44. https://lovdata.no/dokument/NL/lov/2009-06-19-100#KAPITTEL_5.

Anonymous, 2017. Forskrift om produksjonsområder for matfisk i sjø av laks, ørret og regnbueørret (produksjonsområdeforskriften) (Act on Production Areas for ongrowth in sea of salmon, trout and rainbow trout). https://lovdata.no/dokument/SF/forskrift/2017-01-16-61.

Anonymous, 2023. Korallrev (Coral reefs, in Norwegian). https://www.mareano.no/tema/kaldtvannskoraller/korallrev-1.

AquaAccept, 2015. Developing novel socio-environmental indicators and management tools for a sustainable aquaculture, HAVBRUK2-Stort program for havbruksforskning. https://prosjektbanken.forskningsradet.no/en/project/FORISS/244269?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=date&sortOrder=desc&resultCount=30&offset=120&TemaEmne.2=Marin%20forurensning%20inkl.%20milj%C3%B8gifter (accessed 29 June 2022).

ArtReef, 2015. Innovative, competitive and integrated tools for sustainable coastal tourism and inclusive blue growth in the Mediterranean and Black seas, Grant agreement No. EASME/EMFF/2015/1.2.1.7/03/SI2.735917. http://www.artreefs.eu (accessed 29 June 2022).

Asplin, L., Johnsen, I.A., Sandvik, A.D., Albretsen, J., Sundfjord, V., Aure, J., Boxaspen, K.K., 2014. Dispersion of salmon lice in the Hardangerfjord. Mar. Biol. Res. 10 (3), 216–225.

Bagdonas, K., Humborstad, O.-B., Løkkeborg, S., 2012. Capture of wild saithe (*Pollachius virens*) and cod (*Gadus morhua*) in the vicinity of salmon farms: three pot types compared. Fish. Res. 134-136, 1–5. https://doi.org/10.1016/j.fishres.2012.06.020.

Barbier, E.B., Hacker, S.D., Kennedy, Ch., Koch, E.W., Stier, A., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81 (2), 169–193.

Bechmann, R.K., Lyng, E., Westerlund, S., Bamber, S., Berry, M., Arnberg, M., Kringstad, A., Calosi, P., Seear, P.J., 2018. Early life stages of northern shrimp (*Pandalus borealis*) are sensitive to fish feed containing the anti-parasitic drug diflubenzuron. Aquat. Toxicol. 198, 82–91.

Bechmann, R.K., Arnberg, M., Gomiero, A., Westerlund, S., Lyng, E., Berry, M., Agustsson, T., Jager, T., Burridge, L.E., 2019. Gill damage and delayed mortality of northern shrimp (*Pandalus borealis*) after short time exposure to anti-parasitic veterinary medicine containing hydrogen peroxide. Ecotoxicol. Environ. Saf. 180, 473–482.

Bechmann, R.K., Arnberg, M., Bamber, S., Lyng, E., Westerlund, S., Rundberget, J.T., Kringstad, A., Seear, P.J., Burridge, L., 2020. Effects of exposing shrimp larvae (*Pandalus borealis*) to aquaculture pesticides at field relevant concentrations, with and without food limitation. Aquat. Toxicol. 222 https://doi.org/10.1016/j.aquatox.2020.105453.

Bloodworth, J.W., Baptie, M.C., Preedy, K.F., Best, J., 2019. Negative effects of the sea lice therapeutant emamectin benzoate at low concentrations on benthic communities around Scottish fish farms. Sci. Total Environ. 669, 91–102.

CBD, 2018. Protected areas and other effective area-based conservation measures. In: Convention on Biological Diversity. CBD/COP/DEC/14/8.

Clarke, R., Bostock, J., 2017. FAO Fisheries and Aquatic Circular No 1135/1. FAO (Food and Agririculture Organization of the United Nations), p. 41. http://www.fao.org/documents/card/en/c/a4026be7-9d25-49d5-ad1f-5291d64ca152/.

Day, J.C., Dudley, N., Hockings, M., Holmes, G., Laffoley, D., Stolton, S., Wells, S., Wnzel, L., 2019. Guidelines for Applying the IUCN Protected Area Management Categories to Marine Protected Areas, Second edition. IUCN, Gland, Switzerland.

Dempster, T., Uglem, I., Sanchez-Jerez, P., Fernandez-Jover, D., Bayle-Sempere, J., Nilsen, R., Bjørn, P.A., 2009. Coastal salmon farms attract large and persistent aggregations of wild fish: an ecosystem effect. Mar. Ecol. Prog. Ser. 385, 1–14.

Douvere, F., 2008. The importance of marine spatial planning in advancing ecosystem-based sea use management. Mar. Policy 32, 762–771.

Eriksen, E., van der Meeren, G., Nilsen, B.M., von Quillfeldt, C.H., Johnsen, H., 2021. Særlig sårbare områder (SVO) i norske havområder – Miljøverdi. (Particularly vulnerable areas in Norwegian marine waters – Environmental value. In Norwegian). Rapport fra havforskningen 2021-26. ISSN: 1893-4536. 221/32. https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2021-26.

Escobar-Lux, R., 2016. The Effect of an Anti Sea-Lice Therapeutant, Hydrogen Peroxide, on Mortality, Escape Response and Oxygen Consumption on *Calanus* Spp. MSc dissertation. Pierre and Marie Curie University, Paris, France.

Escobar-Lux, R.H., Samulsen, O., 2020. The acute and delayed mortality of the northern krill (*Meganyctiphanes norvegica*) when exposed to hydrogen peroxide. Bull. Environ. Contam. Toxicol. 2020 (105), 705–710. https://doi.org/10.1007/s00128-020-02996-6.

Escobar-Lux, et al., 2019. The effects of hydrogen peroxide on mortality, escape response and oxygen consumption of Calanus spp. Facets 4 (1). https://doi.org/10.1139/facets-2019-0011.

Fagereng, M.B., 2016. Use of Hydrogen Peroxide in Aquaculture Dilution Studies and Effects on Flower Prawns. (*Pandalus montagui*). MSc dissertation. University of Bergen, Norway.

Fang, J., Samuelsen, O.B., Strand, Ø., Jansen, H., 2018. Acute toxic effects of hydrogen peroxide, used for salmon lice treatment, on the survival of polychaetes *Capitella* sp. and *Ophrytorcha* spp. Aquac. Environ. Interact. 10, 363–368.

Farella, G., Tassetti, A.N., Menegon, S., Bocci, M., Ferrà, C., Grati, F., Fadini, A., Giovanardi, O., Fabi, G., Raicevich, S., Barbanti, A., 2021. Ecosystem-based MSP for enhanced fisheries sustainability: an example from the northern Adriatic (Chioggia—Venice and Rovigo, Italy). Sustainability 13, 1211. https://doi.org/10.3390/su13031211.

Fiskeridirektoratet (Directorate of Fisheries), 2021a. Tall og analyse (Figures and analysis). https://www.fiskeridir.no/Tall-og-analyse.

Fiskeridirektoratet (Directorate of Fisheries), 2021b. Kart i Fiskeridirektoratet. (Maps of the Directorate of Fisheries). https://open-data-fiskeridirektoratet-fiskeridir.hub.arcgis.com.

Fiskeridirektoratet (Directorate of Fisheries), 2021c. Utvidelse av rapporteringsplikten for alle fiskefartøy. (Extended reporting duties for all fishing vessels). https://www.fiskeridir.no/Yrkesfiske/Rapportering-paa-havet/utvidelse-av-rapporteringsplikten-for-alle-fiskefartoy.

Fosså, J.H., Skjoldal, H.R., 2010. Conservation of cold-water coral reefs in Norway. In: Grafton, R.Q., Hilborn, R., Squires, D., Tait, M., Williams, M. (Eds.), Handbook of Marine Fisheries Conservation and Management. Oxford University Press, pp. 215–230.

Frantzen, M., Evenset, A., Bytingsvik, J., Reinardy, H., Tassara, L., Geraudie, P., Watts, E. J., Andrade, H., Torske, L., Refseth, G.H., 2019. Effects of hydrogen peroxide, azamethiphos and deltamethrin on egg-carrying shrimp (*Pandalus borealis*). In: Akvaplan-niva report APN-8926−1, p. 33.

Frantzen, M., Bytingsvik, J., Tassara, L.M., Reinardy, H.C., Refseth, G.H., Watts, E.J., Evenset, A., 2020. Effects of the sea lice bath treatment pjharmaceuticals hydrogen peroxide, azamethiphois and deltametrin on egg-carrying shrimp (*Pandalus borealis*). Mar. Enrviron. Res. 159 (2020), 105007.

Fritz, J.-S., 2008. Towards 'a new form of governance' in science-policy relations in the European maritime policy. Mar. Policy 34, 1–6.

Fylkesmannen i Hordaland, 2016. Forvaltningsplan for Vinnesleiro naturreservat (*Management plan for Vinnesleiro natural reserve*, in Norwegian). The County Governor of Hordaland, p. 47. https://gammel.fylkesmannen.no/Documents/Dokument%20FMHO/Dokument%20miljø%20og%20klima/Høringer/Vinnesleiro/Forvaltningsplan%20for%20Vinnesleiro.pdf.

Fylkesmannen i Hordaland, 2017a. Krossfjorden (*Krossfjorden* in Norwegian). 6pp. The County Governor of Hordaland.

Fylkesmannen i Hordaland, 2017b. Ytre Hardangerfjord (*Outer Hardangerfjord*, in Norwegian). 6pp. The County Governor of Hordaland.

Galparsoro, I., Murillas, A., Pinarbasi, K., Sequeira, A., Stelzenmüller, V., O'Hagan, A.M., Boyd, H., Bricker, S., Garmendia, J., Gimpel, A., Gangery, A., Billing, S., Bergh, Ø., Strand, Ø., Hiu, L., Fragoso, B., Icely, J., Ren, J., Papageorgiou, N., Grant, J., Tett, P., 2020. Global stakeholder vision for marine aquaculture expansion under an ecosystem-based expansion from coastal to offshore areas. Rev. Aquac. 12, 2061–2079.

Gimpel, A., Stelzenmüller, V., Grote, B., Buck, B.H., Floeter, J., Nunez-Riboni, I., Pogoda, B., Teming, A., 2015. A GIS modelling framwwork to evaluate marine spatial planning scenarios: Co-location of offshorw wind farms and aquaculture in the German EESZ. Mar. Policy 55, 102–115.

Gowing, J.W., Tuong, T.P., Hoanh, C.T., 2006. Land and water management in coastal zones: Dealing with agriculture-aquaculture-fishery conflicts. In: Hoanh, C.T., Tuong, T.P., Gowing, J.W., Hardy, B. (Eds.), Environment and Livelihoods in Tropical Coastal Zones: Managing Agriculture-Fishery-Aquaculture Conflicts. CAB International, London, UK.

Grati, F., Finioa, M., Søvik, G., Agustson, T., 2019. Final report for the project funded in the ERA-net COFASP "New methodologies for an ecosystem approach to spatial and temporal management of fisheries and aquaculture in coastal areas - ECOAST", 45 https://doi.org/10.13140/RG.2.2.25411.53285.

Grati, F., Azzurro, E., Scanu, M., Tassetti, A.N., Bolognini, L., Guicciardi, S., Vitale, S., Scannella, D., Carbonara, P., Dragičević, B., Ikica, Z., Palluqi, A., Marčeta, B., Ghmati, H., Turki, A., Cherif, M., Bdioui, M., Jarboui, O., Benhadjhamida, N., Mifsud, J., Milone, N., Ceriola, L., Arneri, E., 2022. Mapping small-scale fisheries through a coordinated participatory strategy. Fish Fish. 23, 773–785. https://doi.org/10.1111/faf.12644.

Gray, J.S., 1997. Marine biodiversity: patterns, threats and conservation needs. Biodivers. Conserv. 6, 153–175.

Grefsrud, E.S., Bjørn, P.A., Grøsvik, B.E., Hansen, P.K., Husa, V., Karlsen, Ø., Kvamme, B. O., Samuelsen, O., Sandlund, N., Solberg, M.F., Stien, L.H., 2022. Risikorapport norsk fiskeoppdrett 2022 – kunnskapsstatus. Effekter på miljø og dyrevelferd i norsk fiskeoppdrett. (Risk report Norwegian Aquaculture 2022 –knowledge status. Effects on environment and animal welfare in Norwegian fish farming). Rapport fra havforskningen 2022-13. ISSN:1893–4536.

Guarracino, M., Qviller, L., Lillehaug, A., 2018. Evaluation of aquaculture management zones as a control measure for salmon lice in Norway. Dis. Aquat. Org. 130, 1–9.

Gusatu, L.F., Yamu, C., Zuidema, C., Faaij, A., 2020. A spatial analysis of the potentials for offshore wind farm locations in the North Sea region: challenges and opportunities. ISPRS Int. J. Geo Inf. 9, 96. https://doi.org/10.3390/ijgi9020096.

Hersoug, B., Mikkelsen, E., Osmundsen, T.C., 2021. What's the clue; better planning, new technology or just more money? – The area challenge in Norwegian salmon farming. Ocean Coast. Manag. 199 (2021), 105415 https://doi.org/10.1016/j.ocecoaman.2020.105415.

Hovik, S., Stokke, K.B., 2007. Balancing aquaculture with other coastal interests: a study of regional planning as a tool for ICZM in Norway. Ocean Coast. Manag. 50, 887–904.

Husa, V., Kutti, T., Ervik, A., Sjøtun, K., Hansen, P.K., Aure, J., 2014. Regional impact from fin-fish farm in an intensive production area (Hardangerfjord, Norway). Mar. Biol. Res. 10 (3), 451–452. https://doi.org/10.1080/17451000.2013.810754.

Hutchings, L., Beckley, L.E., Griffiths, M.H., Roberts, M.J., Sundby, S., van der Lingen, C., 2002. Spawning on the edge: spawning grounds and nursery areas around the southern African coastline. Mar. Freshw. Res. 53 (2), 307–318.

Johansen, L.-H., Jensen, I., Mikkelsen, H., Bjørn, P.-A., Jansen, P., Bergh, Ø., 2011. Disease interaction and pathogens exchange between wild and farmed fish populations with special reference to Norway. Aquaculture 315, 167–186.

Jones, S.R.M., Bruno, D.W., Madsen, L., Peeler, E.J., 2015. Disease management mitigates risk of pathogen transmission from maricultured salmonids. Aquac. Environ. Interact. 6, 119–134.

Jørgensen, L.L., Moland, E., Husa, V., Kutti, T., Kleiven, A.R., van der Meeren, G., 2021. Marint vern. Havforskningsinstituttets ekspertvurdering av utfordringer og status for arbeid med marint vern og beskyttelse i Norge (Marine Protected Areas (MPAs) and Other Effective Area-based Conservation Measures (OECMs). The Institute of Marine Research's expert evaluation of challenges and status in Norway) Rapport fra havforskningen 2021-9, p. 28 (In Norwegian).

Klima- og miljødepartementet, 2019–2020. (Ministry of Climate and Environment). Helhetlige forvaltningsplaner for de norske havområdene (Management plans for the Norwegian waters) Stortingsmelding nr. 20. Meld. St. 20 (2019–2020) - regjeringen.no.

Kystverket, 2014. (The Directorate of the Coast) Farledsnormalen - instruks for Kystverkets planlegging, prosjektering og vurdering av arealbehov for farleder. (The sailing route advisor. Instructions on sailing routes by the Directorate of the Coast). http://docplayer.me/13375522-Farledsnormalen-instruks-for-kystverkets-planlegging-prosjektering-og-vurdering-av-arealbehov-for-farleder.html.

Lefcheck, J.S., Hughes, B.B., Johnson, A.J., Pfirrmann, B.W., Rasher, D.B., Smyth, A.R., Williams, B.L., Beck, M.W., Orth, R.J., 2019. Are coastal habitats important nurseries? A meta-analysis. Conserv. Lett. 12 (4), e12645 https://doi.org/10.1111/conl.12645.

Letschert, J., Stollberg, N., Rambo, H., Kempf, A., Berkenhagen, J., Stelzenmüller, V., 2021. The uncertain future of the Norway lobster fisheries in the North Sea calls for new management strategies. ICES J. Mar. Sci. 78 (10), 3639–3649. https://doi.org/10.1093/icesjms/fsab204.

McIntosh, P., Barrett, L.T., Warren-Myers, F., Coates, A., Macaulay, G., Szetey, A., Robinson, N., White, C., Samsing, F., Oppedal, F., Folkedal, O., Klebert, P., Dempster, T., 2022. Supersizing salmon farms in the coastal zone: A global analysis of changes in farm technology and location from 2005 to 2020. Aquaculture 553. https://doi.org/10.1016/j.aquaculture.2022.738046.

Melaa, K., Zimmermann, F., Thangstad, T., Søvik, G., 2022. Historic landings of northern shrimp (*Pandalus borealis*) in Norway. Rapport fra Havforskningen nr. 2022.

Miljødirektoratet, 2021. (Directorate of Environment). Naturbase (In Norwegian) Enkelt søk i Naturbase - Miljødirektoratet (miljodirektoratet.no).

Miljøverndepartementet, 2007. (Ministry of the Environment). Om vern av villaksen og ferdigstiling av nasjonale laksevassdrag og laksefjorder. (On protection of wild salmon and on the establishment of national salmon rivers and fjords). Stortingsmelding (White paper) nr. 32 (2006/07). https://www.regjeringen.no/contentassets/0cd46706c4544870a2579212d980726e/no/pdfs/stp200620070032000dddpdfs.pdf.

Miljøverndepartementet, 2013. (The ministry of the Environment) Forvaltningsplan for Nordsjøen-Skagerak Mangagment plan for the North Sea and Skagerak. Stortingsmelding 37 (2012−13). https://www.regjeringen.no/no/dokumenter/meld-st-37-20122013/id724746/?ch=1.

Moe, S.J., Hjermann, D.Ø., Ravagnan, E., Bechmann, R.K., 2019. Effects of an aquaculture pesticide (diflubenzuron) on non-target shrimp populations: extrapolation from laboratory experiments to the risk of population decline. Ecol. Model. 413 https://doi.org/10.1016/j.ecolmodel.2019.108833.

Moland, E., Synnes, A.-E., Naustvoll, L.-J., Brandt, C.F., Norderhaug, K.M., Thormar, J., Biuw, M., Jorde, P.E., Knutsen, H., Dahle, G., Jelmert, A., Bosgraaf, S., Olsen, E.M., Deininger, A., Haga, A., 2021. Krafttak for kysttorsken. Kunnskap for stedstilpasset gjenoppbygging av bestander, naturtyper og økosystem i Færder- og Ytre Hvaler nasjonalparker. (Operation coastal cod. Knowledge for place-based ecosystem restoration in Færder- and Ytre Hvaler national parks). Rapport fra Havforskningen 2021-2, p. 50.

Mujal-Colilles, A., Mendo, T., Swift, R., James, M., Crowe, S., McCann, P., 2022. Low-cost tracking system to infer fishing activity from small scale fisheries in Scotland. In: Trends in Maritime Technology and Engineering Volume 2. CRC Press. https://doi.org/10.1201/9781003320289-14.

Myksvoll, M.S., Jung, Kyung-Mi, Albretsen, J., Sundby, S., 2014a. Modelling dispersal of eggs and quantifying connectivity among Norwegian coastal cod subpopulations. ICES J. Mar. Sci. 71 (4), 957–969.

Myksvoll, M.S., Sandvik, A.D., Asplin, L., Sundby, S., 2014b. Effects of river regulations on fjord dynamics and retention of coastal cod eggs. ICES J. Mar. Sci. 71 (4), 943–956.

Myksvoll, M.S., Sandvik, A.D., Albretsen, J., Asplin, L., Johnsen, I.A., Karlsen, Ø., Kristensen, N.M., Melsom, A., Skardhamar, J., Ådlandsvik, B., 2018. Evaluation of a national operational salmon lice monitoring system – from physics to fish. PLoS One 13 (12), e0299949. https://doi.org/10.1371/journal.pone.0201338.

Nærings- og fiskeridepartementet, 2008a. (Ministry of Trade, Industry and Fisheries) Forskrift om drift av akvakulturanlegg (Akvakulturforskriften). Act on the Management of Aquaculture Farms (In Norwegian) https://lovdata.no/dokument/SF/forskrift/2008-06-17-822/§18%29.%28.

Nærings- og fiskeridepartementet, 2008b. (Ministry of Trade, Industry and Fisheries) Forskrift om transport av akvakulturdyr (Akvakulturtransportforskriften) Act on transport of aquaculture organisms (In Norwegian). https://lovdata.no/dokument/SF/forskrift/2008-06-17-820.

Nærings- og fiskeridepartementet, 2014. (Ministry of Trade, Industry and Fisheries) Forskrift Om Fangstbasert Akvakultur. Act on Catch Based Aquaculture (In Norwegian). https://lovdata.no/dokument/SF/forskrift/2014-12-15-1831.
Nærings- og fiskeridepartementet, 2016. (Ministry of Trade, Industry and Fisheries) Forskrift om beskyttelse av korallrev mot ødeleggelser som følge av fiskeriaktivitet. Act on Protection of Coral Reefs against Destructions caused by Fisheries Activities (In Norwegian). https://lovdata.no/dokument/SF/forskrift/2016-01-08-8.
Nærings- og fiskeridepartementet, 2022. (Ministry of Trade, Industry and Fisheries) Kraftfull satsing på havvind. (Strong efforts for more offshore wind farms). https://www.regjeringen.no/no/aktuelt/kraftfull-satsing-pa-havvind/id2912297/ (In Norwegian).
Newton, A., Elliott, M., 2016. A typology of Stakeholdersand guidelines for engagement in transdisciplinary, participatory processes. Front. Mar. Sci. 3 (2016), 230.
Olsen, E., Aanes, S., Mehl, S., Holst, J.C., Aglen, A., Gjøsæter, H., 2010. Cod, haddock, saithe, herring, and capelin in the Barents Sea and adjacent waters: a review of the biological value of the area. ICES J. Mar. Sci. 67 (1), 87–101.
Otterå, H., Skilbrei, O.T., 2014. Possible influence of salmon farming on long-term resident behaviour of wild saithe (*Pollachius virens* L.). ICES J. Mar. Sci. 71 (9), 2484–2493. https://doi.org/10.1093/icesjms/fsu096.
Parsons, A.E., Escobar-Lux, R.H., Sævik, P.N., Samuelsen, O.B., Agnalt, A.-L., 2020. The impact of anti-sea lice pesticides, azamethiphos and deltamethrin, on European lobster (*Homarus gammarus*) larvae in the Norwegian marine environment. Environ. Pollut. 264 https://doi.org/10.1016/j.envpol.2020.114725.
Perrow, M., 2019. Wildlife and Wind Farms - Conflicts and Solutions, Volume 3. Offshore: Potential Effects. Pelagic Publishing, Exeter, UK, p. 300.
Pınarbaşı, K., Galparsoro, I., Borja, Á., Stelzenmüller, V., Ehler, C.N., Gimpel, A., 2017. Decision support tools in marine spatial planning: present applications, gaps and future perspectives. Mar. Policy 83, 83–91.
Pınarbaşı, K., Galparsoro, I., Borja, A., 2019. End users perspective on decision support tools in marine spatial planning. Mar. Policy 108 (2019), 103658.
Pomeroy, R., Douvere, F., 2008. The engagement of stakeholders in the marine spatial planning process. Mar. Policy 32, 816–822.
Refseth, G.H., Nøst, O.A., Evenset, A., Tassara, L., Espenes, H., Drivdal, M., Augustin, S., Samuelsen, O., Agnalt, A.-L., 2019. Risk assessment and risk reducing measures for discharges of hydrogen peroxide (H_2O_2). Ecotoxicological tests, modelling and SSD curve. Ocean Model. 113. Akvaplan-niva report: 8948–1.
Said, A., Trouillet, B., 2020. Bringing 'deep knowledge' of fisheries into marine spatial planning. Maritime Stud. 19, 347–357.
Salas-Leiton, E., Vieira, L.R., Guilhermino, L., 2021. Sustainable fishing and aquaculture activities in the Atlantic Coast of the Portuguese north region: multi-stakeholder views as a tool for maritime spatial planning. Sustainability 13, 663. https://doi.org/10.3390/su13020663.
Samuelsen, O.B., 2016. Persistence and stability of Teflubenzuron and diflubenzuron when associated to organic particles in marine sediment. Bull. Environ. Contam. Toxicol. 96 (2), 224–228.
Samuelsen, O.B., Lunestad, B.T., Farestveit, E., Grefsrud, E.S., Hannisdal, R., Holmelid, B., Tjensvoll, T., Agnalt, A.-L., 2014. Mortality and deformities in European lobster (*Homarus gammarus*) juveniles exposed to the anti-parasitic drug teflubenzuron. Aquat. Toxicol. 149, 8–15. https://doi.org/10.1016/j.aquatox.2014.01.019.
Sanchez-Jerez, P., Karakassis, I., Massa, F., Fezzardi, D., Aguilar-Manjarrez, J., Soto, D., Chapela, R., Avila, P., Macias, J.C., Tomassetti, P., Marino, G., Borg, J.A., Franičević, V., Yucel-Gier, G., Fleming, I.A., Biao, X., Nhhala, H., Hamza, H., Forcada, A., Dempster, T., 2016. Aquaculture's struggle for space: the need for coastal spatial planning and the potential benefits of allocated zones for aquaculture (AZAs) to avoid conflict and promote sustainability. Aquac. Environ. Interact. 8, 41–54.
Serra-Llinares, R.M., Bjørn, P.A., Finstad, B., Nilsen, R., Harbitz, A., Bergh, M., Asplin, L., 2014. Salmon lice infections on wild salmonids in marine protected areas: an evaluation of the Norwegian "National Salmon Fjords". Aquac. Environ. Interact. 5, 1–16.
Skaala, Ø., Johnsen, G.H., Lo, H., Borgstgrøm, R., Wennevik, V., Hansen, M.M., Merz, J. E., Glover, K.A., Barlaup, B.T., 2014a. A conservation plan for Atlantic salmon (*Salmo salar*) and anadromous brown trout (*Salmo trutta*) in a region with intensive industrial use of aquatic habitats, the Hardangerfjord, western Norway. Mar. Biol. Res. 10 (3), 308–322.
Skaala, Ø., Kålås, S., Borgstrøm, R., 2014b. Evidence of salmon-lice induced mortality of the anadromous brown trout (*Salmo trutta*) in the Hardangerfjord, Norway. Mar. Biol. Res. 10 (3), 279–288.
Skog, T.-E., Hylland, K., Torstensen, B.E., Berntssen, M.H.G., 2003. Salmon farming affects the fatty acid composition and taste of wild saithe *Pollachius virens* L. Aquac. Res. 34 (12), 999–1007. https://doi.org/10.1046/j.1365-2109.2003.00901.x.
Soma, K., Ramos, J., Bergh, Ø., Schulze, T., van Oostenbrugge, H., van Duijn, A., Kopke, K., Stelxenmüller, V., Grrati, F., Mäkinen, T., Stenberg, C., Buisman, E., 2013. The "mapping out" approach: effectiveness of marine spatial management options in European coastal waters. ICES J. Mar. Sci. 71 (9), 2630–2642.
Soma, K., van Tatenhove, J., van Leeuwen, J., 2015. Marine governance in a European context: regionalization, integration and cooperation for ecosystem-based management. Ocean Coast. Manag. 117, 4–13.
Søvik, G., Nedreaas, K., Zimmermann, F., Husson, B., Strand, H.K., Jørgensen, L.L., Strand, M., Thangstad, T.H., Hansen, A., Båtevik, T., Albretsen, J., Og Staby, A., 2020. Kartlegging av fjordøkosystemene i Tana- og Porsangerfjorden. Råd og kunnskapsbidrag fra Havforskningsinstituttet i forbindelse med vurdering av en eventuell åpning av direktefiske etter reker med bunntrål i Tana- og Porsangerfjorden. Rapport fra Havforskningen 2020–39. ISSN:1893–4536. 140 s. https://www.hi.no/hi/nettrapporter/rapport-fra-havforskningen-2020-39.
Søvik, G., Dalpadado, P., Falkenhaug, T., Sævik, P.N., Jenssen, M., Larsen, M., Hannisdal, R., Rønning, J., Olsen, S.A.A., Samuelsen, O., Agnalt, A.-L., Thangstad, T. H., Danielsen, H.E.H., Grøsvik, B.E., Hatland, S., Bruvik, A., Tjensvoll, T., Couillard, F.D., Og Korneliussen, P.-A., 2021. Døde og strandete krepsdyr - Nitti tilfeller rapportert til Havforskningsinstituttet i perioden 2014–2020. Rapport fra havforskningen 2021–3. 312 s. ISSN:1893–4536. report-pdf (hi.no). (in Norwegian).
Statistisk Sentralbyrå (Statistics Norway), 2019. Electricity Generation by Type, County and Ownership Group. https://www.ssb.no/en/energi-og-industri/statistikker/elektrisitet/aar.
Stelzenmüller, V., Schulze, T., Gimpel, A., Bartelings, H., Bello, E., Bergh, Ø., Bolman, B., Caetano, M., Davaasuren, N., Fabi, G., Ferreira, J.G., Gault, J., Gramolini, R., Grati, F., Hamon, K., Jak, R., Kopke, K., Laurans, M., Mäkinen, T., O'Donnell, V., O'Hagan, A., O'Mahony, C., Oostenbrugge, H., Ramos, J., Saurel, C., Sell, A., Silvo, K., Sinschek, K., Soma, K., Stenberg, C., Taylor, N., Vale, C., Vasquez, F., Verner-Jeffreys, D., 2013a. Guidance on a Better Integration of Aquaculture, Fisheries, and other Activities in the Coastal Zone: From tools to practical examples, Ireland: Coexist project, 2013, p. 79. Printed. ISBN: 978-0-9926602-0-8.
Stelzenmüller, V., Lee, J., South, A., Rogers, S.I., 2013b. Practical tools to support marine spatial planning: a review and some prototype tools. Mar. Policy 38, 214–227.
Suchanek, T.H., 1994. Temparate coastal marine communities: biodiversity and threats. Am. Zool. 34, 100–114.
Taranger, G.L., Karlsen, Ø., Bannister, R.J., Glover, K.A., Husa, V., Karlsbakk, E., Kvamme, B.O., Boxaspen, K.K., Bjørn, P.A., Finstad, B., Madhun, A.S., Morton, H.C., Svåsand, T., 2015. Risk assessment of the environmental impact of Norwegian Atlantic salmon farming. ICES J. Mar. Sci. 72 (3), 997–1021. https://doi.org/10.1093/icesjms/fsu132.
Tassetti, A.N., Galdelli, A., Pulcinella, J., Mancini, A., Bolognini, L., 2022. Addressing gaps in small-scale fisheries: A low-cost tracking system. Sensors 22, 839. https://doi.org/10.3390/s22030839.
Tester, P.A., Costlow, J.D., 1981. Effect of insect growth regulator Dimilin (TH 6040) on fecundity and egg viability of the marine copepod *Acartia tonsa*. Mar. Ecol. Prog. Ser. 5, 297–302.
Tiller, R., Brekken, T., Bailey, J., 2012. Norwegian aquaculture expansion and integrated coastal zone management (ICZM): simmering conflicts and competing claims. Mar. Policy 36, 1086–1095.
Vølstad, J.H., Korsbrekke, K., Nedreaas, K.H., Nilsen, M., Nilsson, G.N., Pennington, M., Subbey, S., Wienerroither, R., 2011. Probability-based surveying using self-sampling to estimate catch and effort in Norway's coastal tourist fishery. ICES J. Mar. Sci. 68 (8), 1785–1791. https://doi.org/10.1093/icesjms/fsr077.
Vølstad, J.H., Christman, M., Ferter, K., Kleiven, A.R., Otterå, H., Aas, Ø., Arlinghaus, R., Borch, T., Colman, J., Hartill, B., Haugen, T.O., Hyder, K., Lyle, J.M., Ohldieck, M.J., Skov, C., Strehlow, H.V., van Voorhees, D., Weltersbach, M.S., Weber, E.D., 2020. Field surveying of marine recreational fisheries in Norway using a novel spatial sampling frame reveals striking under-coverage of alternative sampling frames. ICES J. Mar. Sci. 77 (6), 2192–2205. https://doi.org/10.1093/icesjms/fsz108.
Yakushev, E.V., Wallhead, P., Renaud, P.E., Ilinskaya, A., Protsenko, E., Yakubov, S., Pakhomova, S., Sweetman, A.K., Dunlop, K., Berezina, A., Bellerby, R.G.J., Dale, T., 2020. Understanding the biogeochemical impacts of fish farms using a benthic-pelagic model. Water 12, 2384. https://doi.org/10.3390/w12092384.
Zimmermann, F., Kleiven, A.R., Ottesen, M.V., Søvik, G., 2022. Inclusion of recreational fishing in data-limited stocks: a case study on Norway lobster (*Nephrops norvegicus*) in Norway. Can. J. Fish. Aquat. Sci. https://doi.org/10.1139/cjfas-2021-0152.