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Lobster reserves as a management tool in coastal waters: Two decades of experience in Norway

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ABSTRACT

The positive effects of reduced fishing pressure in marine protected areas (MPAs) are now well documented globally. Yet, evidence of MPA benefits from long-term replicated before-after control-impact (BACI) studies and their usefulness in protecting target species are still rare, especially in northern temperate areas. Scientific rigor in the monitoring of MPAs is considered important for obtaining trust and compliance and can increase interest and enthusiasm for the benefits of marine conservation. Off the coast of southern Norway, a MPA implementation process started up in 2002. Based on comprehensive consultations with local fishers and managers, four experimental lobster reserves were appointed in 2004. Two years later (2006), the reserves came into effect as the Norwegian Directorate of Fisheries implemented regulations as a by-law of the Saltwater Fisheries Act that effectively banned all fixed gear. Long-term monitoring of the MPAs and adjacent control areas has enabled a rigorous scientific evaluation of the effects of these MPAs on lobster populations, including effects on density, growth, demography, behavior, and phenotypic diversity. As protection effects started to manifest, the lobster reserves attracted high public attention and were soon considered a credible supplement to traditional fisheries management. In the period from 2002 to 2021, more than 50 lobster reserves have been implemented in Norway. Here, we review the experiences since the lobster reserves were designated, implemented, and embraced by local communities in Norway, and over two decades have become an important tool for fishery management. Thoughts on the future of MPAs along the coast of Norway are discussed.

1. Introduction

Marine protected areas (MPAs) have received considerable attention over the last decades and are increasingly implemented around the world to enhance coastal fisheries, conserve biodiversity and to maintain ecosystems services [1–3]. During the last 20 years, studies have repeatedly documented that the absence or reduction of fishing in MPAs lead to an increase in biomass, size, density, and diversity of protected species within the MPA borders [4,5]. There is also extensive evidence that MPAs strengthen ecosystem resilience by protecting critical habitats [6], ecological processes [3,7], and benefit coastal fisheries through increased egg and larval production [8], or spillover of mobile juveniles and adults [9]. Today, MPAs have gained increased importance and act as a “primary tool” [10] and become a “cornerstone” [11] in marine conservation science.

Coastal marine ecosystems are impacted by a range of factors, such as habitat modifications, harvesting, temporal variability in current strength, salinity and temperature, and longer-term processes, like

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climate change [11]. The coastal environment contains a tremendous diversity of wildlife, habitats, spawning areas and larval supply, as well as mobile species using different habitats at different stages of a species' life cycle [12–15]. Also, in near-shore coastal systems the pelagic ecosystems converge with benthic ecosystems, creating dynamic and complex food webs and modes of energy transfer [16]. With such an array of variables, evaluation of effects of MPAs on target populations across time and space represents an intricate scientific challenge. Jones et al. [17] stressed early on the need for improved assessment methods in marine conservation science if the effects of various types of MPAs were to be rigorously tested. "Before-after control-impact" (BACI) approaches is a means to overcome this challenge and are, therefore, the recommended method when evaluating MPA effects on target populations [17–21].

Globally, MPAs are often implemented through top-down approaches by governments, managing authorities and conservation bodies [22], that often results in "paper parks" with low legitimacy among stakeholders [23]. Early engagement from local communities is strongly recommended as the establishment of MPAs not only involve conservation and management aspects, but also include cultural and socio-economic impacts important to many stakeholders [24,25].

The European lobster (*Homarus gammarus L.)* was for centuries the most high-valued shellfish along the coast of Norway. Apparently, footprints of harvesting were evident already by the early 1800s, when abundance of large lobsters was said to be in decline [26]. Over the past few decades, the population has collapsed due to overfishing and has remained at historically low levels since 1970 (Fig. 1) [27]. In the early 2000s, stock estimates of lobster indicated an extreme all-time low, resulting in a shared interest by fishers, scientists and managers to reverse the trend and rebuild lobster populations.

Here, we review the experiences from when lobster reserves were designated, implemented, and embraced in local communities in southern Norway over a period of nearly two decades. We describe how the "bottom-up" processes, consultations, and involvement with fishers, local communities, and stakeholders, influenced the implementation of MPAs. In addition, we briefly summarize the scientific studies conducted in the lobster MPAs for the purpose of evaluating their function and effectiveness and advice. Finally, we discuss how to achieve motivation and legitimacy when planning for a scaling up of MPAs in coastal waters in Norway and elsewhere.

2. Materials and methods

2.1. The southern coast of Norway

Glacial scouring has shaped the topography of the coastline of the southern coast of Norway, resulting in a multitude of small fjord systems with several sills and basins (Fig. 2) [28]. A string of larger islands and smaller skerries stretch parallel to the mainland and form more sheltered lagoon areas with a few deeper basins. The sea floor is dominated by hard bottom habitats in steep terrains and along fjord edges [29]. Flat bottom and mid-fjord areas consist of sand and soft sediments. Deep waters in fjord basins are vulnerable to oxygen depletion [30]. Along the outer coast, glaciers deposited an enormous moraine of boulders, cobble, coarse sand and pebbles down to 30 m, thus creating a porous hard bottom matrix and rocky reef habitat favorable to kelp forest and lobsters.

2.2. The European lobster and its fishery

The European lobster is distributed from Morocco to northern Norway [31]. Lobsters normally prefer rocky habitats and boulders at depths down to about 60 m [32]. The European lobster is also a species with high site-fidelity and limited mobility [33,34]. Agnalt et al. [35] found that 84% of hatchery-reared and released European lobsters off the southwestern coast of Norway were recaptured within 500 m off the release site. However, a few individuals disperse and undertake excursions up to tens of km [33,34]. During the winter, lobsters seek deeper water (50–60 m) within the constraints of their home range location [36].

Lobster fishing with traps has a unique history along the Norwegian southern coast, originally introduced by Dutch sailors in 1660–1670 [37]. The Dutch were in Norway to buy valuable oak for harbors and buildings, as well as coal for fuel, and noticed the abundance of lobster stocks. The Dutch soon established a highly profitable industry based on the shipping of live lobsters from Norway to the capitals of Europe (Fig. 1a). Ever since, the lobster has been of great importance as currency and tradable commodity for Norwegian coastal communities. Encompassing a lengthy historical period, the official catches of lobster have ranged between 500 and 700 tons, with a peak of 1300 tons in 1932 [38–40].

In the year 2000, the official catches (50 tons) were estimated to be less than 10% of the historical average. At that time, commercial and recreational fishers, along with managers, recognized the need for new comprehensive measures. The historically low stock population was also confirmed by Norway's Institute of Marine Research who had collected an extensive time series index on lobster catch-per-unit-effort (CPUE) dating back to 1928, based on standardized logbook reports from commercial fishers (number of lobsters/trap/24 h, CPUE) (Fig. 1b). For example, before 1950, CPUE was 0.15–0.20 n lobsters per trap day^{-1}, compared to a CPUE of less than 0.1 over the last decades [35]. Although the lobster fishery has been an important source of income for coastal

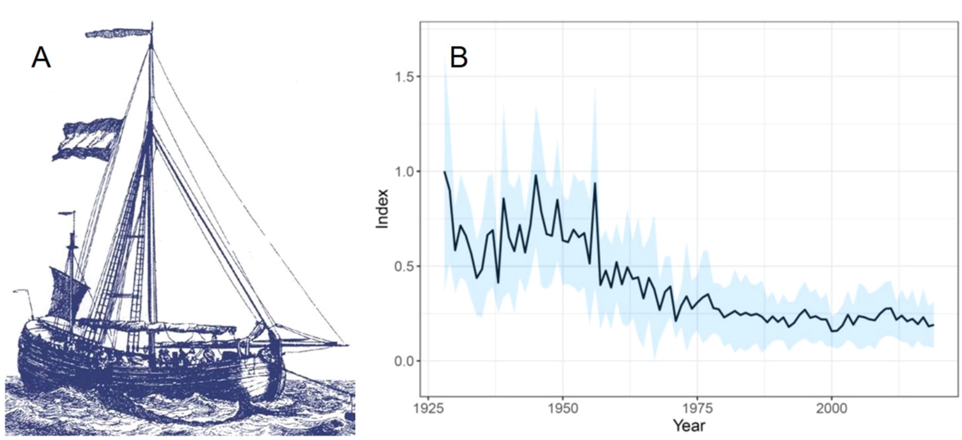

Fig. 1. (A) Dutch sailing vessel carrying live lobster from Norway's Southern coast to the capitals of Europe starting from ca. 1700. (B) Catch-per-unit-effort (CPUE): mean lobsters trap^{-1} day^{-1} (error band: ± 1 SE) as reported by a selection of professional lobster fishers to the Institute of Marine Research from 1928 to 2020. (a) Source: Knutsen et al. [27]. (b) Source: Kleiven et al. [39].

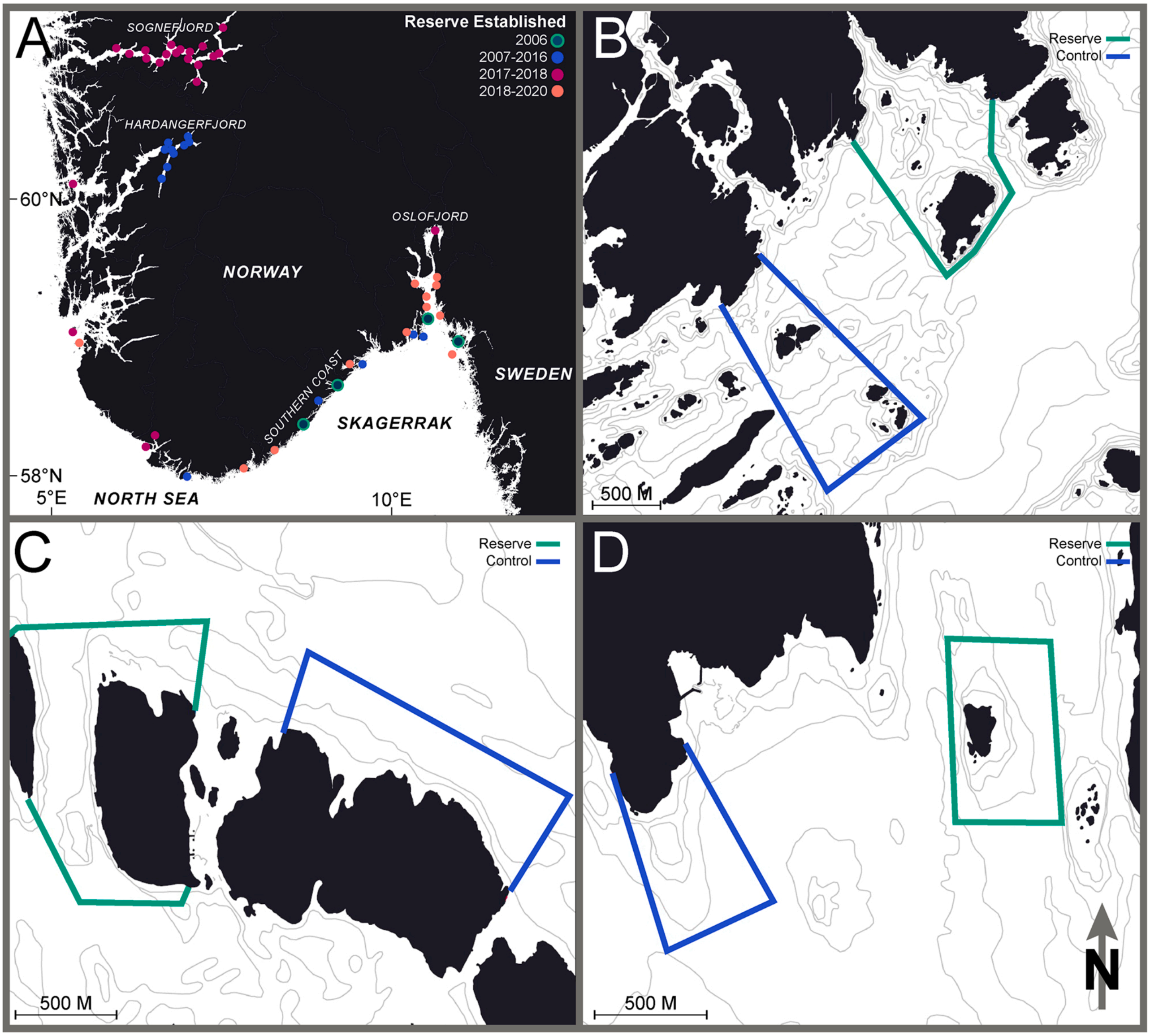

Fig. 2. (A) The geographical locations and timeline of lobster reserves implemented along the Norwegian Coast from 2006 to 2020. The first lobster reserves were established by the Department of Fisheries on 19 Sept 2006 (green points).) (B-D) Map of the first experimental MPAs lobster reserves and control areas in (B) Flødevigen, (C) Bolærne, and (D) Kvernskjær -in Agder, Vestfold and Telemark, and Viken counties, respectively. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

fishers for generations, recreational fishing now dominates the effort and catches in the fishery [38,39].

In southern Norway, lobsters can only be fished from 1st October until 30th November, whereas on the west coast the fishing season is extended to 31th of December. Commercial fishers may use up to 100 traps per day, whereas recreational fishers may use 10 traps per day. The lobster fishery has a suite of technical regulations, such as minimum (25 cm) and maximum (32 cm) total length (South Norway only), protection of egg-bearing females, escape vents for undersized individuals and the rigging of traps with biodegradable cotton thread weak links or panels to prevent ghost fishing if lost. Even though many new regulations have recently been implemented, the overall lobster population remains at historically low levels [38].

3. Planning lobster reserves in southern Norway

3.1. Step zero

In Norway, lobster management was founded on the assumption that fishing has limited effect on population viability. This, in turn, is based on the observation that historically there have been few restrictions on the allowable number of traps (until 1993), that the lobster minimum size of retention did not correspond to the sexually mature age until 2008, and that there also was no ban on fishing of reproductive females until 2008. Summer closures, at the time when most females spawn – and when brooding females' eggs hatch, were introduced early on (1848) after a heavy debate. However, this was mainly related to the quality of the lobster meat [40]. As noted by Dannevig [40], there was always a substantial amount of lobsters outside the traditional fishing areas, suggesting that these areas functioned as refugia that were protected from fishing and likely played an important role in maintaining the stock. Historically, a lack of equipment and technology hindered fishermen from catching lobsters in exposed and deep areas, and the narrow entrance to the traps was adapted to catching market-size lobsters of 21–23 cm total length.

In Norway, the deeply rooted historical perception that management measures have limited effect on lobster stocks was still evident in the early 2000s, when the use of MPAs as a management tool started to gain international attention. For that reason, the idea of using MPAs for rebuilding lobster populations was met with a great deal of skepticism in the first phase of consultation by fishers and managers. However, some of the older fishermen still remembered the rich lobster catches just after World War II (late 1940's), after five years of low fishing pressure. These elder fishers became advocates for investigating the potential of MPAs as refugia to protect lobster populations beyond prevailing management measures. Based on the all-time low stock situation of lobsters in the early 2000s, the testing-out of a few small experimental MPAs for lobster was soon approved and rapidly embraced by both managers and commercial fishers.

Thus, when initiating the work of designating lobster MPAs in coastal areas in Southern Norway in 2002, a bottom-up approach was sought. However, there were fundamental challenges. First, there was the bouquet of administrative institutions at local, regional, and national levels, all having significant shares in governance and management of lobster and the coastal zone. Second, relevant social, economic, and political aspects in the coastal community had to be considered to nominate credible and practical MPA proposals. Third, there were few studies on the effects of MPAs on aquatic resources in the peer-reviewed scientific literature that focused on northern temperate waters [41], thus limiting scientific support for the idea of setting aside valuable coastal areas as lobster reserves.

3.2. Formal designation and implementation process

During 2002–2003, the Directorate of Fisheries and the Institute of Marine Research (IMR) developed a set of criteria for identifying potential locations of experimental lobster reserves [42]. Candidate areas should a) have an acceptable lobster population while the most important existing lobster fishing areas should be avoided, b) possess a variety of habitats suitable to house a substantial lobster population, c) be located so they could be effectively policed and scientifically monitored, and d) be supported by local commercial fishers.

Local commercial fishers and local and regional fishing organizations were asked to nominate potential locations for experimental lobster reserves in early 2004. In summer 2004, the IMR evaluated the nominated areas by conducting a scientific survey in four of the areas suggested. IMR concluded that three areas were suitable based on the before mentioned criteria [42]. The fourth locality, "Risør harbor", did not fulfill the criteria due to the low catch rate of lobster during experimental fishing and limited suitable habitat. However, the Directorate of Fisheries concluded that all four proposed areas should be sent out for public hearing in 2005. At the public hearings, 21 responses were submitted, all very positive. Respondents included commercial fishing organizations, research institutions, environmental non-governmental organizations (NGOs), the fishery sector at the national government level (Department of Fisheries), regional authorities, and local municipalities. The four lobster reserves in Skagerrak were formally announced by the Ministry of Fisheries on 19 September 2006 (Fig. 2). By excluding all but hook-and-line type fishing gear, these MPAs effectively banned the trap-based fishery of European lobster and reduced the risk of lobster by-catch in other fixed gear (such as gillnets) within the reserve boundaries.

3.3. Evaluation and dissemination phase

Research fishing including capture-recapture methodology, was conducted inside the nominated lobster reserves prior to their establishment, in 2004, 2005, and 2006. Only three of the four reserves were included in the IMR monitoring program after 2006. A strategic monitoring program was developed based on the BACI approach (see Russ [19]) securing before data in both control and reserve areas. In 2006, just before the Department's formal approval of the lobster reserves, three comparable control areas were surveyed in addition to the three nominated reserves (Fig. 2).

The standardized research fishing procedure was conducted by soaking 25 traps in both control and reserve areas for 24 h for four consecutive days and securing 100 trap hauls in all three MPA-control areas (in total 600 trap hauls per survey season across the six sites). Lobsters captured in reserves and control areas were tagged upon first capture with a plastic T-bar tag, sexed, sized, and then released. A tissue sample was collected for genetic analyses. Since implementation in 2006, monitoring based on the same standardized research design has been conducted during the same time period (late August/ early September), and simultaneously in each reserve – control area pair every year.

Populations in the three experimental lobster reserves responded rapidly by a substantial increase in CPUE after implementation. After four years of protection, the reserves showed more than two-fold average increase in CPUE, while average change in CPUE in the three control areas was modest (Fig. 3). The monitoring study provided a strong empirical basis in support of the prospect that marine reserves could be a useful management and conservation tool in rebuilding portions of the depleted European lobster population in Norwegian waters [43].

4. Building a MPA knowledge base for northern temperate coastal waters

Over time, the contrasting management regimes in the experimental lobster reserves and adjacent control areas enabled a variety of studies. Huserbråten et al. [44] combined acoustic telemetry, population genetics and tag recovery data to infer spillover and putative recruitment effects from the lobster reserves. Using additional tag recovery data, Thorbjørnsen et al. [45] showed a likely effect of spillover (i.e. the net export of adult lobsters from reserves to adjacent fished areas) by means of increased biomass near lobster reserve borders. Recently, Fernandez-Chacón et al. [46] showed that beyond preserving an ageing population, demographic complexity has also increased in the lobster reserves compared to the harvested controls. The capture-recapture monitoring work has enabled estimation of increased abundance and survival, complementary to the CPUE-based indices used previously [47]. Using genetic assignment techniques on a large collection of males and egg-bearing females, Sørdalen et al. [48] performed truly novel work providing evidence of disparate mating patterns in the Flødevigen lobster reserve compared to the adjacent control area. The study showed that if females are presented with the opportunity, they prefer to mate with larger males with large relative crusher claw size (relative to body size), a trait under both sexual- and harvest selection [48,49]. By using morphometric data (body and claw measures) from all three pairs of lobster reserve and control sites, Sørdalen et al. [50] demonstrated that this important "large claw" trait is preserved in the lobster reserves.

Other species have also benefitted from the gear restrictions in the lobster reserves. Coastal Atlantic cod (*Gadus morhua*), having been afforded partial protection responded with increased density, body size and survival in the Flødevigen lobster reserve compared to multiple control areas [46,47,51]. The lobster reserve also offered protection to several species of wrasses (Labridae) that unexpectedly became commercially important from 2009 and onwards, when the salmonid aquaculture industry in Norway increased the use of wrasses as cleaner fish to reduce parasite loads in net pens. For this purpose, wrasses are only harvested by traps or other standing gear and are, therefore, fully protected from the commercial fishery inside the lobster reserves. This resulted in positive effects on density and demography for the corkwing wrasse (*Symphodus melops*), and on density in goldsinny wrasse (*Ctenolabrus rupestris*), the two most commercially important wrasse species [52]. For a recent review of all scientific studies conducted in conjunction with the network of MPAs in coastal Skagerrak, see Moland et al. [53].

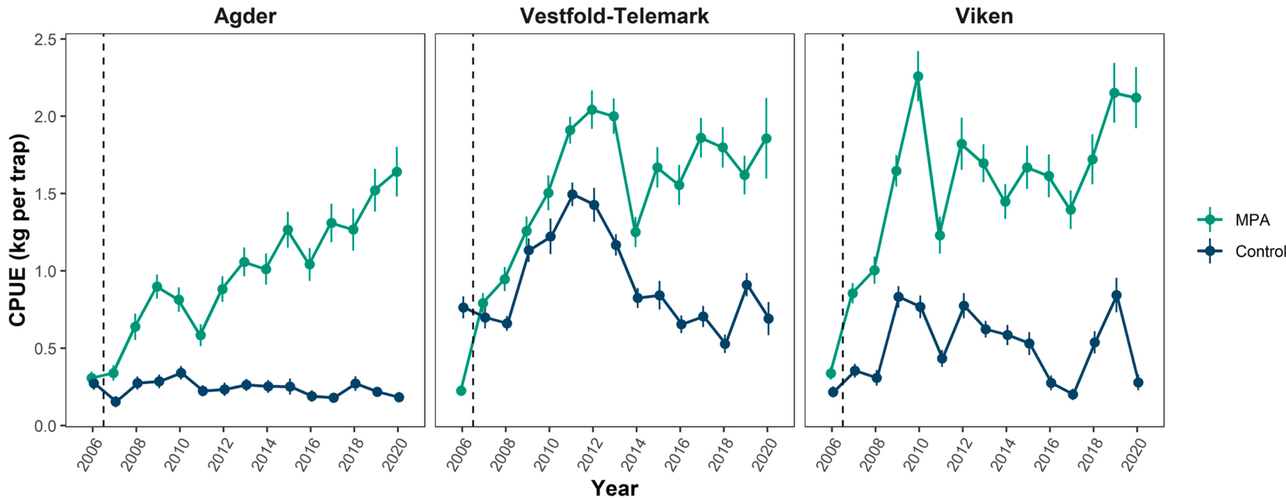

Fig. 3. Catch-per-unit-effort (CPUE; lobster in kg per trap day^{-1}) in the lobster MPAs (blue) and control areas (green) from 2006 to 2020 in Agder (Flødevigen), Vestfold and Telemark (Bolærne), and Viken (Kvernskjær) counties. In total, 19,512 lobsters were captured, marked and released in the study areas throughout the period, with a sex ratio of 33:67 (female:male). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

4.1. Communication and public engagement aided the process

For the coastal community, hopeful about positive signs from the first trials, the results from the lobster MPAs were received with enthusiasm. Lobster reserves were often mentioned in Norwegian media between 2004 and late 2020. There was substantial coverage on television (> 20 reports), radio (> 10) and in newspapers (> 200), including opinion pieces [this study]. Public communication of the results from the lobster reserves research provided opportunities for public debate and a presentation of all stakeholders' perspectives. Interestingly, people who rely on local newspapers for news tend to be more informed about marine parks, more positive towards them, and more likely to attend meetings concerning marine parks [54].

5. From scientific documentation to management implementation

After publication of results from the early monitoring work by Moland et al. [43] in 2013, confirming their effectiveness, lobster reserves were adopted in Norway as a documented management tool for lobster conservation. The Directorate of Fisheries invited all coastal municipalities along the coast of Norway to voluntarily designate lobster reserves.

Stakeholders, NGOs, and municipalities worked together to nominate potential lobster reserves and document the process. When local agreement was achieved on area designation, the municipality forwarded the nomination to the Directorate of Fisheries. The standard procedure has included a national public hearing for each nominated reserve before the final implementation. To date, 54 lobster reserves have been implemented along the southern and western Norwegian coast (Fig. 2a, Fig. 4).

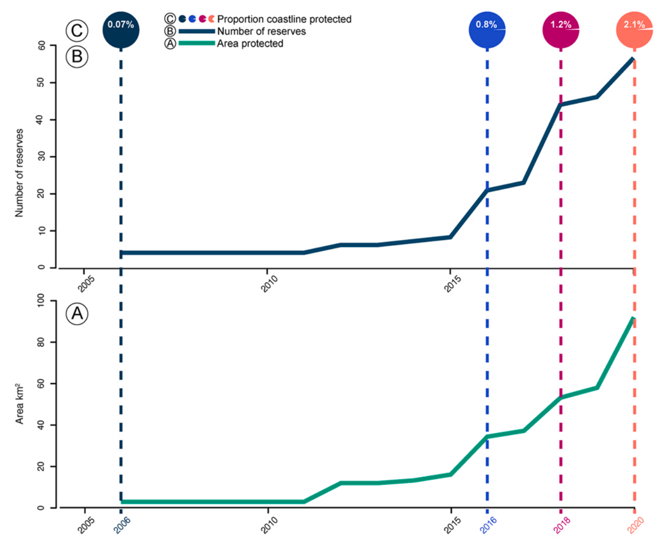

Fig. 4. Lobster reserves established along the Southern coast of Norway during 2006–2020. (A) increase in the cumulative area protected by the lobster reserves (km^2), (B) increase in the number of lobster reserves established and (C) percent of coastline protected by the lobster reserves (0–60 m) from the border of Sweden to Stad (62°N). By 2020, 54 lobster reserves were established, covering 92 km^2 across the Norwegian Coast. In 2006, the lobster reserves constituted 0.07% of the coastal areas, in 2016 (0.8%), in 2018 (1.2%) and in 2020 (2.1%).

6. Discussion

6.1. Dialogue, scientific documentation, and dissemination guided the MPA process

When MPAs were introduced as a potential tool for rebuilding lobster populations in Norway in the early 2000s, the initial response from commercial fishers and managers was skepticism. Their main worry was the lack of documentation of the effect of MPAs in northern temperate coastal waters, providing low motivation for setting aside lobster fishing grounds to preserve lobster populations. However, after a series of meetings and dialogue with scientists, managers and local fishers, commercial fishers and managers developed curiosity about the idea of testing small-scale MPAs in the form of lobster reserves.

The meetings revealed a broad consensus among fishers, managers, and scientists regarding the poor state of lobster populations. Scientists also shared important knowledge and experiences with MPAs gleaned from scientists working in foreign areas, such as Philippines, New Zealand and the Great Barrier Reef (Australia). Importantly, some of the elder fishermen repeatedly conveyed a number of sensational stories from the fishery just after World War II ended, relating their impressions that the local lobster populations had undergone a spectacular rebound after five years with limited fishing effort, also evident in the standardized CPUE time series (Fig. 1B). These stories probably had a major positive influence on the process leading up to implementation of the first lobster reserves. Also, during the initial phase, commercial fishers were responsible for nominating potential locations to be set aside as lobster reserves. Specifically, it was the fishers themselves who drew the initial lines on the map and thus had major influence on the establishment of the first MPAs [54–56], but also created a high level of ownership of the MPA process [25]. In retrospect, therefore, the lobster reserve project is an interesting example of knowledge co-production and stakeholder participation where research is conducted in collaboration and includes multiple perspectives and knowledge sources [56].

In 2013, the first major results from IMR's lobster MPA monitoring program were published. It demonstrated a substantial and significant increase of CPUE of lobster in the protected areas compared to control areas where fishing was still allowed [43] (see Fig. 3). Based on these encouraging results, the Directorate of Fisheries formally reached out to all municipalities harboring a lobster fishery, advocating for a broader scale implementation of lobster MPAs. As documented herein, this was the start of a steady increase in locally initiated- and government mediated processes to designate, debate (through hearings) and implement MPAs in Norway.

We believe that some useful lessons can be learned from our nearly twenty-year-long journey with lobster reserves in coastal Skagerrak. First, it was only when solid documentation was available from relevant studies in domestic waters that lobster MPAs were seriously considered by managers. Second, interaction from day one with the local fishers that approved the project gave legitimacy to the lobster reserve project. The fishers took pride in keeping an eye on their local lobster MPAs. Third, the fishers and the local community (schools) were regularly informed about the MPA results during monitoring cruises and at local lectures and meetings.

The importance of dialogue and documentation has been highlighted by Ballantine [56]. Summarizing 50 years of experience with marine reserves in New Zealand, he concluded that "successful establishment of marine reserves in the first stage was only possible when the proponents were very persistent and had community support". Furthermore, Ballantine [55] recommended careful examination of objections to marine reserves, to counter the public mind by answers based on common sense arguments or well-established facts. This procedure was found to prove "surprisingly useful in both scientific work and in practical politics". Alcala and Russ [25] also emphasized the importance of initial consultations with local fishing communities and concluded that this local involvement approach has been a model for the extraordinary expansion of no-take reserves nationally in Philippines. No-take marine reserve areas, protected and managed by local communities, now play a key role in biodiversity conservation and fisheries management in Philippines' waters.

Thus, while the focus on biological aspects for many years dominated MPA science, a growing number of studies have elucidated that social, economic and institutional aspects of MPAs strongly affect the degree of acceptance from communities and have significant impact on their long-term success [58–62].

The positive biological effects of the lobster reserves gained considerable media attention from national TV networks, newspapers, magazines and from local interest groups. The historical position of lobster in Norway as a highly priced (both in cultural and economic terms) catch in coastal fisheries may explain the considerable interest generated. We argue that the comprehensive dissemination of results and the interest by media has been of high importance and may well have inspired neighboring municipalities to establish their own local lobster MPAs. In summary, we found that a combination of (i) a good dialogue with fishers, coastal communities and management; (ii) a common understanding related to the state of the lobster stock, (iii) use of recognized scientific methods and, in parallel (iv) emphasis on regular dissemination of results to local groups,- was a successful MPA implementation recipe in coastal Skagerrak.

6.2. Norway's optimal coastal geography for realizing biodiversity benefits of MPAs

As we have stressed, transparent and meaningful engagement with local, regional, and national constituents was fundamentally important to the success of the program to establish lobster MPAs along the southern Norwegian coast. However, it must also be noted that Norway's coastal geography is optimal for the development of such a program. Norway is inundated with fjords, fjord-like bays, and other topographical features (rocks, skerries, islands) that limit physical oceanographic mixing with deeper ocean waters. These constraints on water current flow also serve to limit the biological exchange of individual organisms. These oceanographic and biological features increase the probability that relatively small MPAs, through the establishment of harvesting and fishing regulations, will have a positive impact on the abundance of lobster in local municipalities. All else being equal, the smaller the spatial scale at which MPA benefits are realized by the public, the greater the societal support for such management measures.

The nearly 20-year long MPA program in support of lobsters in coastal Norway can also have significant, if unintended, side benefits that can strengthen the protection of coastal biodiversity. Coastal Atlantic cod along the Norwegian Skagerrak is made up of two coexisting 'ecotypes' (an ecotype is a genetically distinct group or variety within a single species). The *fjord* ecotype is found predominantly in near-shore, fjord-like waters and the *North Sea* ecotype is predominantly found outside the skerries and islands that demarcate the shallower nearshore waters from the deeper offshore waters [42,63]. There is good reason to believe that fishing restrictions inside the lobster MPAs have benefitted coastal cod. For example, the small (1 km^2) nearshore Flødevigen lobster reserve afforded partial protection to cod which resulted in an increase in median length and a reduction in the mortality of cod in the partially protected area compared with cod from nearby waters that were unprotected [64].

6.3. Future perspectives on marine protected areas in Skagerrak coastal waters

The Skagerrak is among the most productive coastal areas in Northern Europe, once supporting profitable fisheries on a wide range of species, that are now considered heavily depleted or commercially extinct [65–67]. Historically, these coastal areas were drivers for human economies in local communities encompassing the Skagerrak [68], which still hold true although today's fishery in Norwegian Skagerrak is based almost entirely on bottom trawl capture of Northern shrimp (*Pandalus borealis*) [69]. Decades of overfishing on population structures and behavioral units due to poorly known populations dynamics (see e. g., [69,70]) and non-targeted management of riverine input to coastal water (accelerated by long-term climate change) has now led to reduced water quality, loss of coastal biodiversity and collapse in coastal fisheries of Skagerrak, and outer Oslofjord [71–73]. The management goal of securing 'sustainable' harvest adjusted to present day stock productivity might fall short of the action needed to rebuild depleted populations [65].

Despite the increasing number of lobster reserves established in Norway, from four in 2006 to > 50 in 2021, a key question is if the reserves have any ecological or management relevance. Particularly, a fishery management issue is whether the lobster reserves have decreased, increased or have not affected the absolute density or catches of lobster in these coastal areas of Norway. One of the mechanisms through which lobster reserves could increase density and catches of lobsters in open areas is the spillover of adults. In fact, Thorbjørnsen et al. [44] showed that lobster reserves support movement of larger, but not more European lobsters to neighboring fished areas. Both official catch data and independent time series (CPUE data collected by IMR, see Fig. 1b) along coastal Skagerrak of Norway suggest, however, that lobsters catches throughout the period (2006–2020) have remained relatively stable at a historically low levels after the implementation of MPAs [38]. One reason for this could be that the sizes of the lobster reserves are relatively small, encompassing just 2.1% (92 km^2) of coastal areas from 0 to 60 m depth from the border with Sweden up to 62^0 North (Stad).(Fig. 4). Most likely, such 'spillover lobsters' are fished out quickly as Nillos Kleiven et al. [74] found that fishing pressure impacted the abundance gradient of lobsters across the borders of a newly established marine protected area [74]. Studies at other locations showed, however, the potential of lobster reserves to increase catches in fished areas. Goñi et al. [75] found that spillover from a lobster reserve overcompensated the loss of fishing area after 17 years of protection. However, this MPA was considerable bigger (44 km^2) than the Norwegian lobster MPAs studied ($\pm$ 1 km^2)· Similarily, Alcala et al. [57] also found that no-take marine reserves may help to maintain, or even enhance, local fishery yields in the long term.

In a biodiversity and conservation context, it is important to be aware that the lobster reserves in Norway are only partially protected and thus provide only partial protection for other species (except for one no-take reserve). There are now many studies available in the scientific literature that have demonstrated key features for establishing successful marine reserves to maximize conservation outcomes and ecosystem resilience. In a meta-analysis, Sala and Giakoumi [6] documented that no-take marine reserves undoubtedly are the most effective method in the ocean for reversing global degradation of ocean life and enhancing ecosystem resilience. The biomass of fish assemblages was on average 670% greater in highly protected marine reserves than in unprotected areas, and 343% greater than in partially protected MPAs. Marine reserves were also found to cause indirect effects that restore the structure and complexity of the ecosystem once predator abundance recovered sufficiently. In a recent review, Costello and Ballantine [76] discussed whether MPAs are relevant for conserving biodiversity, as most research papers study fishery effects of MPAs rather than conservation goals. They found that 94% of MPAs allowed fishing and suggested that biodiversity conservation should focus on no-take marine reserves. Stewart et al. [77] claimed that one of the main reasons why conservation has failed to protect biodiversity is that there has been a focus on action, rather than ensuring that the action and measures taken were effective. When evaluating the social and ecological effectiveness of MPAs in southern parts of Australia, Thurnbul et al. [78] found no social or ecological benefits for partially protected areas compared to areas open to fishing. They further argue that "partially protected areas act as red herrings in marine conservation because they create an illusion of protection and consume scarce conservation resources". In a comprehensive review, Edgar et al. [79] investigated the conservation benefits of 87 MPAs worldwide and found that these increased exponentially with the accumulation of five key features: no take, well enforced, old (>10 yrs), large, and isolated by deep water or sand. Conservation targets based on the size of the protected area alone was not found to optimize protection of marine biodiversity.

In 2021, the Norwegian government published a report to the Parliament (white paper) for the way forward of MPAs and supported the global initiative to protect 30% of the ocean within 2030. Worldwide, several countries have established coherent, representative, and large networks of marine reserves to conserve biodiversity [80]. Acknowledging that Norway only has protected 4.5% of its coasts and oceans by 2021, and with hardly any MPAs that are highly or fully protected, there is an urgent need for increased focus on the establishment of no-take MPAs in Norwegian waters to rebuild and secure populations and function. Most MPAs in Norway are implemented with few or no limitations on fishing activities which strongly weakens the expected population, ecosystem, and societal benefits. The lobster reserves in Norway have increased the public understanding of fishery-regulated MPAs and shown the potential for bottom-up approaches to achieve conservation goals. Therefore, in the future, it is highly important to focus on fully protected MPAs to achieve both ecological and societal goals.

6.4. Closing remarks

The UN intergovernmental panel on biodiversity and ecosystem services (IPBES) identifies fisheries as the most important driver of change in the global oceans [81]. The rapid and lasting effects measured in the lobster MPAs described herein are likely resulting from the heavily depleted state of the lobster populations prior to implementation of MPAs [39]. This lends support to the notion that a range of target species in Skagerrak fisheries may be in similarly depleted states – and that the prevailing fishing pressure combined with unfavorable environmental and climate effects is a likely hindrance to rebuilding of local populations. We thus strongly support the call for inclusion of 30% of Skagerrak coastal waters in effectively protected areas. Furthermore, progress towards this target may be initiated by a phasing-in of pilot areas treated as adaptive management 'experiments' – wherein the successes gleaned from the lobster MPAs are scaled up accordingly to achieve similarly positive outcomes in terms of acceptance and support for this new paradigm in ocean and fisheries management.

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Author contributions

JAK, EM, ARK, EMO contributed to the conception and outline of the review. JAK, EM, ARK, JAH, AFC, EMO, MH, SHT, KTH, and TKS wrote the manuscript. DVR, PJNK, HK, SHE, TKL commented on versions of the draft. All authors contributed to manuscript revision, read and approved the submitted version.

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