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Hazard and catch composition of ghost fishing gear revealed by a citizen science clean-up initiative

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ABSTRACT

Ghost fishing, the continued catch of fishes and invertebrates by lost fishing gear, represents an animal welfare issue as well as a waste of both potential food and ecosystem resources. Fishing gear is lost by both commercial and recreational fishers, and management authorities often lack an overview of gear loss and subsequently potential impact on coastal populations. To investigate the hazard and catch composition of lost fishing gear along the Norwegian coast, recreational divers in collaboration with scientists conducted systematic reporting of retrieved lost fishing gear. Through this citizen science project, a total of 12,101 gear items were retrieved and reported, including traps, gillnets and fyke nets. Combining both data on the catch ratio of the gear and its relative quantity, we identified the five most hazardous gear types to be parlor traps, gillnets, fyke nets, wrasse traps and square collapsible traps. The parlour trap was the most hazardous trap, due to high catchability and quantity. The correct classification of gear type could not be confirmed in 2.8 – 6.1% of the pictures taken by divers, depending on reporting format, and divers reported the wrong gear type in 1.4% of the reports. Brown crab (*Cancer pagurus*) was the species most often found in retrieved gear. Furthermore, the vulnerable species European lobster (*Homarus gammarus*) and Atlantic cod (*Gadus morhua*) were also common. These results can inform future clean up-initiatives and management responses to ghost fishing, including preventive measures against gear loss and gear restrictions and customization.

1. Introduction

When fishing gear is abandoned, lost or discarded at sea, it can persist in the marine environment for long periods of time, posing a prolonged threat to the marine life, as a source of litter, entanglement or capture [1]. Ghost fishing is the continued catch of fishes and invertebrates by lost fishing gear [1-4]. It is often related to static fishing gear including gillnets, trammel nets and traps that are left to fish passively on the seabed [5]. Abandoned, lost and discarded fishing gear (ALDFG) is a repercussion from fishing that makes up a large fraction of marine litter: in European waters lost fishing gear account for 34% of litter observed in video and trawl surveys [6] and 46% of the litter in the Great Pacific Garbage Patch is fishing nets [7]. Overall, estimates of the quantity of lost fishing gear are mainly limited to local geographies [8]. Based on local studies, a recent meta-analysis estimates overall gear loss rates of 5.7% for fishing nets, 8.6% for traps and 29% for lines [9].

Fishing gear may be abandoned, lost or discarded, both intentionally and unintentionally, as a result of several processes. Some fishing gear is never retrieved due to lost marker buoys, which can get cut off by propeller strikes or ice, or because they were moved by bad weather [10]. Fishing gear may also be towed away by active gear or passing vessels [11] or become lost due to inadequate maintenance, gear failure or improper fishing methods, the latter including gear not being retrieved [2,5,12]. Historically, fishing gear was made up of degradable materials with shorter lifetime [13]. Today, synthetic materials have largely replaced degradable material making fishing gear both more effective and with higher durability, consequently resulting in more intensive ghost fishing. Static fishing gear, such as pots and traps, are generally considered to have less impact on habitat and biodiversity compared to mobile gear such as trawls [14]. As the fish needs to actively swim into the fishing gear, it can impact different species at different levels depending on which habitat the gear is lost, active

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fishing season and the species' movement patterns [15].

Ghost fishing has shown to cause mortality of marine species such as fish, crustaceans, sea birds and marine mammals [1] and may have severe effects on both target and non-target species [5,11]. One major problem concerning ghost gear is the process of "rebaiting", also called the "self-baiting cycle"; when an organism is caught in the ghost gear, eventually dies and decomposes, and release odors attracting more organisms [3,16]. Animals that are captured in ghost traps for longer periods of time are subject to various stress factors such as crowding, cannibalism, starvation, injuries and predation [10,12,17,18]. The long-term confinement of animals in ghost gear is also a welfare issue, and animals may be subjected to physiological stress, injuries, reduced growth rates, behavioural changes and mortality also after they manage to escape [18,19].

Estimates of gear loss rates and ghost fishing mortality rates for different gear types are of interest to fishers, fisheries managers, gear producers and the general public. Out of 1000 retrieved snow crab (*Chionoecetes opilio*) pots, 43% were still fishing and contained on average three snow crabs per trap after being abandoned 1.5 years earlier [16]. There was evidence of limb-loss and indication of rebaiting and cannibalism, demonstrating both poor animal welfare and unaccounted mortality. Due to the likelihood of poor animal welfare, long-term ghost fishing studies are controversial [16]. However, some studies document ghost fishing over longer time periods. Annual mortality rate reached 95% for snow crabs left in traps in the Gulf of St. Lawrence, Canada, adding up to 48 kg of dead snow crab per trap per year given local fishery catch rates [20]. In the Florida Keys, an estimated 637,622 (± 74,367 SD) spiny lobsters (*Panulirus argus*) die in ghost traps annually, based on investigations of both the magnitude of lost gear in the region [21] and the number of lobsters found dead in monitored ghost fishing traps during one year [22]. Additionally, 66 fish species and 13 other invertebrate species were observed in the monitored traps [22]. Deepwater gillnets to fish Greenland halibut (*Reinhardtius hippoglossoides*) deployed and left to fish as ghost nets had a 20–30% catch efficiency after 45 days [23]. Ghost fishing may also have economic impacts. Commercial losses of American lobster (*Homarus americanus*) due to capture by ghost fishing traps may exceed 175,000 CAD annually in studied Canadian lobster fishing areas, depending on the trap loss rate in the fishery [17]. For blue crab, a conservative estimate of commercial losses in Virginia waters is 300,000 USD [24].

Retrieving lost fishing gear from the sea floor is an activity that is both costly and time consuming. Retrieval may be performed by commercial and recreational divers [8], by towing grapple hooks after a vessel [17] or by using remotely operated vehicles (ROVs) with gripper claws [25]. Citizen science, data collection performed by volunteers with no formal training [26,27], is cost-effective and has the potential to collect more data in space and time than a research group usually can within given budgets. Citizen scientists have been involved in monitoring of marine litter, e.g. in the tidal zone [28] and volunteer divers collecting data about marine litter on the sea floor [29]. Despite the advantages mentioned above, citizen science may have varying accuracy [27,30], for example because of participants' lack of experience, the complexity of sampling and reporting, and limited training [31]. However, several studies show that valid data can be collected through citizen science initiatives and accuracy increases for easy tasks and experienced volunteers [27]. Seeking out volunteers that are personally invested in the topic at hand have been shown to produce better data quality rather than the general population [30].

In this study, we investigate gear and catch composition for different gear types retrieved by recreational divers along the Norwegian coast through a citizen science initiative. We estimate the relative hazard of different fishing gear based on their abundance and catch rates. This can inform management in their efforts to reduce the impact from ghost fishing on populations of fish and crustaceans and guide prioritization in future clean-up efforts. Lastly, we comment on the value of citizen science participation in this project and provide suggestions for enhancing reporting and data quality through artificial intelligence techniques.

2. Materials and methods

2.1. Study area and data collection

The search and retrieval of lost fishing gear by recreational divers was mainly conducted through regular recreational dives along the Norwegian coast (Fig. 1). The recreational divers were organized through the Norwegian Diving Association. For every gear retrieved the divers filled in a report including a picture of the gear. The local dive clubs received an economic compensation of ~22 USD for small gear items and ~45 USD for large gear items. The diving clubs also organized diving events with special focus on lost fishing gear. Divers chose the diving locations, so areas covered are not representative for the Norwegian coast. Also, depths covered mainly reflect diving practices, which in recreational diving normally means depths down to a maximum of 40 m. However, some participants retrieved gear at deeper depths using dredges, remotely operated vehicles (ROVs) and technical diving with specialized equipment.

All diver reports (n = 12,228) included a photograph of the retrieved gear, and all photos and forms were quality checked by the authors to check if the three different gear types (traps, gillnets and fyke nets) were correctly identified. In cases where the user had reported a wrong gear type in relation to what was seen in the photograph, the data was corrected to the right gear type. In cases where the diver reported several fishing gear types within one registration, all gear types that were possible to identify in the photograph were kept in the dataset, while items that could not be identified or were not visible in the picture were labelled as not classified and removed from the datasets and analysis (n = 598). All photos of traps were checked and classified into nine different trap-types: parlour trap, round collapsible trap, square collapsible trap, wooden trap, large square trap, circular kelp forest trap, crayfish trap, wrasse trap and other traps (Fig. 2). "Other traps" include traps that could not be categorized into the eight trap types, for example because they were homemade.

Data was reported in two different ways within the period. From June 2015 to December 2018, paper forms with pictures were sent to the Norwegian Diving Association and then to the Institute of Marine Research either by mail or e-mail (n = 4129). These reports included depth and GPS coordinates for the retrieved gear. From September 2017, a mobile app report system, "Fritidsfiske" ("Recreational fishing"), was launched by the Norwegian Directorate of Fisheries (see supplementary material S. 2 for screen captures from the app). Data reported through the app until June 2020 is included in this study. In the app, it appeared that some reported findings were added twice by mistake. If identical, the duplicated entry was removed from the dataset and analysis (n = 127), resulting in 7374 reports. Since the app also includes a report system for lost fishing gear, the divers can use the app to get information on where to conduct searches. Within the app, divers could deliver reports connected to their diving club. After an app update in March 2019 divers that were associated with a diving club supplied more detailed reports than other participants (n = 4185). All diver reports included GPS coordinates for the retrieved gear. However, detailed reports also included information on depth, bottom conditions, slope, presence of rope and buoy, and whether there were alive or dead animals found in the equipment. Catch was reported as number of live and dead individuals separately within five categories: brown crab (*Cancer pagurus*), European lobster (*Homarus gammarus)*, wrasse family (Labridae), Atlantic cod (*Gadus morhua*) and other fish. It was assumed that divers had sufficient knowledge of coastal species to identify these species/ species groups. The paper forms used in the beginning of the study contained fields for reporting catch as free text, but this data was not used due to missing instructions on how to report the catch. This led to a variation in whether catch was reported as species or in species groups. A standard operation involves divers releasing both live and dead catch

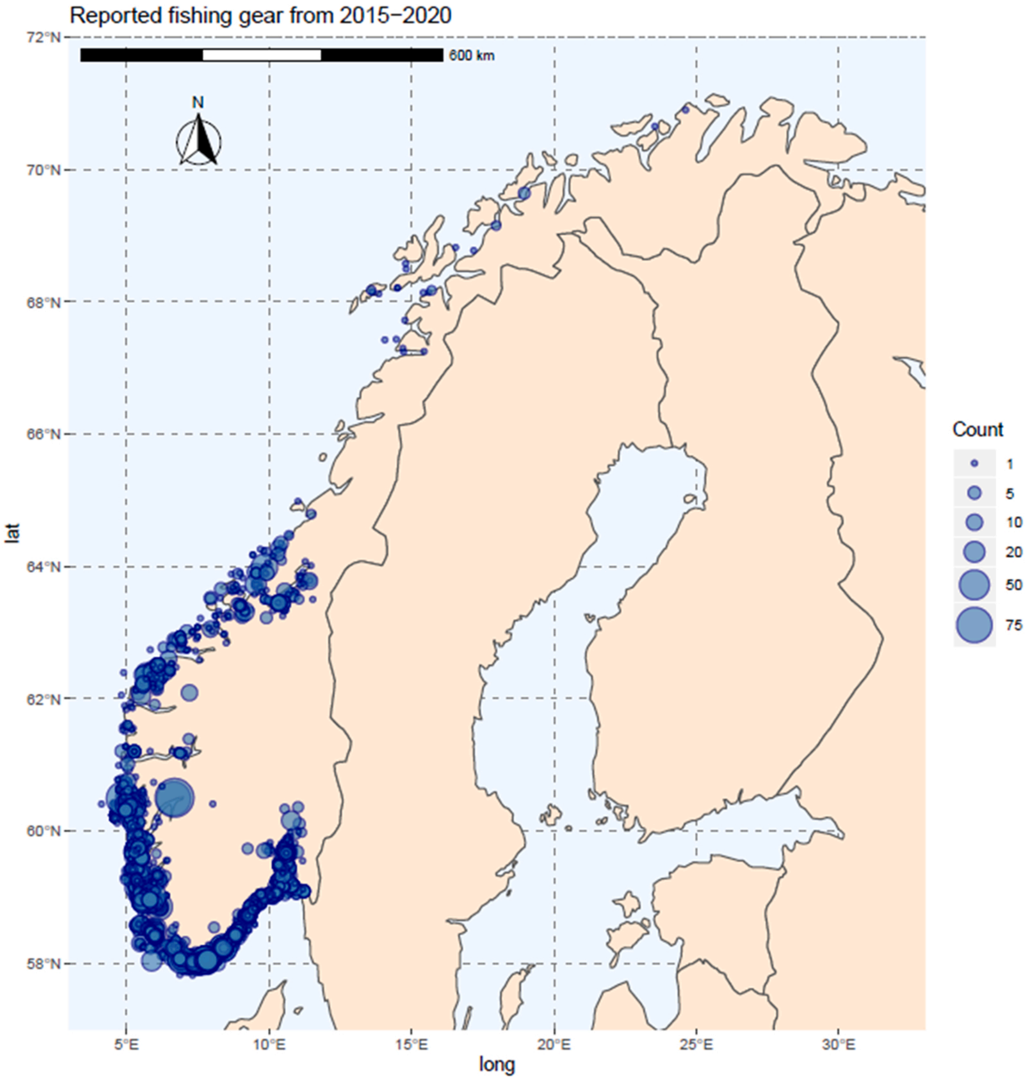

Fig. 1. Retrieved fishing gear reported by divers from June 2015 to June 2020. Point sizes represent number of retrieved gear reported at a given location.

where the trap was found. For live catch, this is done to avoid sudden pressure differences for fish while raising the gear and to avoid removing individuals from their home area.

2.2. Study species

The four species/species groups reported as caught in lost fishing gear are valuable species in the Norwegian recreational and/or commercial fishery. European lobster, hereafter referred to as lobster, is mainly fished using parlour traps and collapsible traps (square and round) with two escape vents with a diameter of 60 mm, allowing small individuals to escape. The fishery is open from October 1st to November 30th/December 31st, depending on location, and commercial fishers can use 100 traps, while recreational fishers can use up to 10 traps. Brown crab is mainly fished using parlour traps and collapsible traps (square and round), and in most regions, there is a requirement of two escape vents with a diameter of 80 mm. The fishery is open all year and a there is no limit on number of traps for commercial fishers, while recreational fishers can use up to 20 traps. Wrasses are captured alive and used as biological delousers in salmon aquaculture in Norway. Species targeted are mainly ballan wrasse (*Labrus bergylta*), goldsinny wrasse (*Ctenolabrus rupestris*) and corkwing wrasse (*Symphodus melops*), but rock cook (*Centrolabrus exoletus*) and cuckoo wrasse (*Labrus mixtus*) are also used [32]. They are mainly fished by commercial fishers using fyke nets or wrasse traps, the latter with escape vents of 12 × 70 mm. The fishery is open from July 12th/July 26th to October 20th, depending on location, and fishers can use 100 traps in southeast Norway and 400 traps along the rest of the coastline. Atlantic cod, hereafter referred to as cod are targeted using nets [33] and may be targeted using fyke nets and large square traps but are otherwise not mainly fished using the gear types described in this study.

2.3. Data analysis

The proportion of retrieved items containing catch was calculated for each gear type. Here, catch was assessed as a binary variable, being either present or not. Both alive and dead catch was included. To evaluate the risk of ghost fishing from different gear types depending on both catch ratio (data from detailed diver reports submitted in 2019–2020) and quantity (all data), we calculated a hazard ratio for each gear type (GT) (Eq. 1),

$$Hazard\ ratio_{(GT)} = Proportion\ with\ catch_{(GT)} \times \frac{Number\ of\ retrieved\ items(GT)}{Total\ number\ of\ retrieved\ items} \quad (1)$$

where “Proportion with catch” refers to the proportion of retrieved items containing catch for a given gear type. Then, the hazard ratio was

Fig. 2. Examples of the different trap types retrieved and reported by divers. From top left: A) Parlour trap, B) crayfish trap, C) round collapsible trap, D) circular kelp forest trap, E) large square trap, F) wrasse trap, G) wooden trap and H) square collapsible trap. The parlour trap shown in this figure has two chambers, while some traps in this category had similar design but only one chamber.

normalised to a scale of 0–1 in accordance with Gilman et al. [34] (Eq. 2). Following this, the gear type with the lowest hazard ratio will have a normalised hazard ratio of 0 and the gear type with the highest hazard ratio will have a normalized hazard ratio of 1.

$$Hazard\ ratio_{(nGT)} = \frac{Hazard\ ratio_{(GT)} - Hazard\ ratio_{(\min)}}{Hazard\ ratio_{(\max)} - Hazard\ ratio_{(\min)}} \qquad (2)$$

Further, temporal changes in composition of retrieved gear were investigated for the five most hazardous gear types. Lastly, the average number of individuals caught per gear item was calculated for each species/species group and each gear type. This was calculated separately for live and dead individuals.

3. Results

In total, 12,101 items of lost fishing gear were retrieved and reported by divers from June 2015 to June 2020, where the gear type could be identified in 11,503 of them (Table 1). For retrievals reported using paper forms, gear type could not be identified in 2.8% (n = 118) of the pictures. For retrievals reported using the app this was the case for 6.1% (n = 480) of the pictures. Participants assigned the wrong gear type (three levels: traps, gillnets and fyke nets) in 1.4% (n = 114) of the reports. The depth range of retrieved gear was 0–200 m (mean = 22.4 m ± 14.5 m SD, Table 1). The distributions of different gear types across different bottom conditions and slopes are presented in the supplementary material (S.1, Fig. S1, S2). There was no rope on 34.4% of the retrieved gear, only rope on 42.4% of the gear and both rope and buoy on 23.2% of the gear.

Table 1
Total and yearly number of gear retrieved (N) and depth (mean ± SD) for each gear type. Only full years are included.

Gear type	N total	N 2016	N 2017	N 2018	N 2019	Depth (mean ± SD)
Parlour trap	2550	351	312	670	920	25.9 ± 13.2
Gillnets	831	107	57	168	353	24.3 ± 13.5
Fyke net	1201	240	115	257	431	17.7 ± 9.4
Wrasse trap	641	38	18	124	293	19.0 ± 13.7
Collapsible trap, square	3201	830	334	574	1031	18.8 ± 11.8
Other traps	1243	256	102	224	531	24.8 ± 14.9
Collapsible trap, round	889	184	88	235	231	19.7 ± 10.4
Crayfish trap	360	35	4	59	161	46.1 ± 30.5
Large, square trap	92	9	2	17	49	43.2 ± 29.9
Wooden trap	357	59	21	65	125	30.5 ± 16.4
Circular kelp forest trap	138	86	14	20	9	13.2 ± 11.0
SUM	**11,503**	**2195**	**1067**	**2413**	**4134**	

The most common types of retrieved fishing gear were square collapsible traps (27.8%) and parlour traps (22.2%) (Fig. 3, left panel).

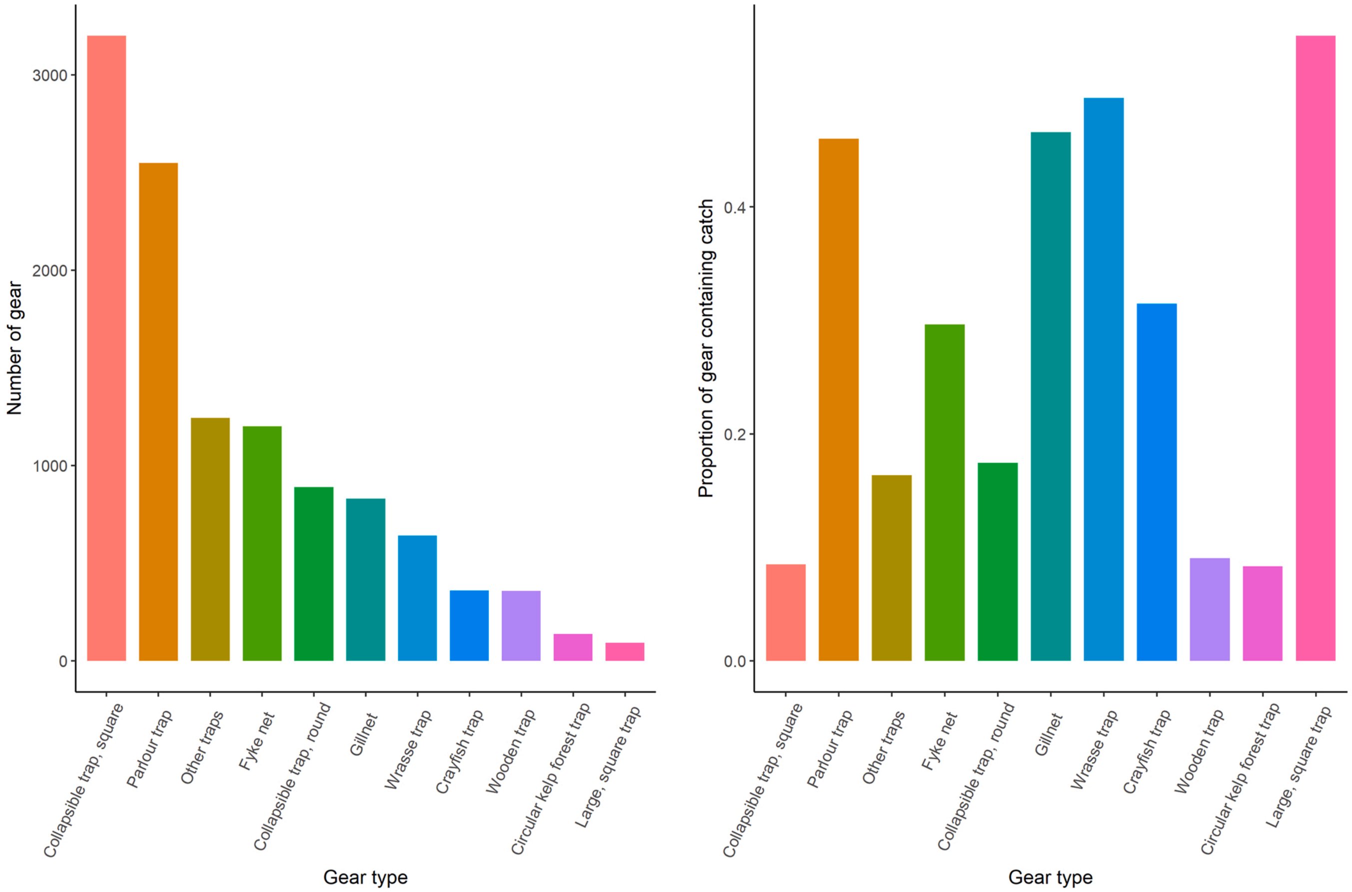

Fig. 3. Number of retrieved lost fishing gear for each gear type (left panel, total n = 11,503) and the proportion of gear containing catch by gear type (right panel, total n = 4185).

Comparing these two gear types, the parlour trap contained catch more than 5 times as often as the square collapsible trap (Fig. 3, right panel). In addition to the parlour trap, the gear types that most often contained catch were large square traps, wrasse traps and gillnets. Wrasse traps contained the most live individuals on average, with wrasses and brown crab accounting for a large proportion of the catch (Fig. 4, left panel). Brown crab was the species most often found in retrieved gear, both among live and dead individuals. It especially dominated the dead part of the catch, where gillnets contained the most dead catch per gear item (Fig. 4, right panel).

The normalised hazard ratio, combining both data on catch ratio and quantity, was highest for parlour traps (Fig. 5). They were three times more hazardous than the next gear type on the list, gillnets, which were followed by fyke nets, wrasse traps and square collapsible traps. There was a temporal change in the composition of retrieved gear for the five most hazardous gear types, with increasing proportions of wrasse traps and gillnets (Fig. 6).

4. Discussion

Here, we provide evidence of which gear types have been responsible for the most ghost fishing in Norwegian coastal waters on diveable depths from June 2015 - June 2020. Given their popularity and catchability, parlour traps top the list and have been 3 times more hazardous than the next gear type on the list, gillnets. Wrasse traps and gillnets also had a high catchability, and wrasse traps had the highest catch per item when measured as number of live animals captured. Note that wrasse traps have the smallest escape openings. Wrasse traps and gillnets also increased in proportion over time relative to other gear types, indicating that they may be responsible for more ghost fishing in the future and reach a higher hazard ratio. To battle ghost fishing, management measures can be directed towards the most hazardous gear types to reduce their effect on local populations. Further, gear retrieval efforts can be directed towards the gear types with the highest catch rate to most effectively reduce mortality and suffering. However, management measures have recently been implemented to reduce ghost fishing from several of the gear types studied herein. An escape panel, closed with a degradable cotton thread with a maximum thickness of 3 mm, was made mandatory in the lobster fishery (2018), the recreational crab fishery (2019), the wrasse fishery (2021) and the crayfish fishery (2022). Note that these panels are additional to the escape vents mentioned above. The degradation time for the cotton thread is expected to vary, but a thickness of 3 mm was chosen to ensure at least a 3-month durability [35]. The catch data used to calculate the hazard ratios in this study are from the detailed diver reports collected in 2019–2020, and many of the retrieved gear items are likely to have been lost before the change in regulations. Hazard ratios are expected to reduce over time as a response to the introduction of escape panels. However, mortality and suffering may be substantial also within shorter time periods when fishing gear has high catchability (see below).

Brown crab was the species most often found in lost gear and it was present in all gear types. Annual official landings of brown crab have been stable for the last two decades and average around 5000 tons, while landings in the open, recreational fishery are unknown [36]. Even though the population does not show signs of decline, the welfare issue is self-evident. Further, European lobsters are listed as vulnerable on the Norwegian red list [37], and ghost fishing adds to the populations' burden. Commercial fishers' official landings were 41 tons in 2019 [38], but the sum of total commercial landings (both reported and unreported) and recreational landings is estimated to be 14 times higher

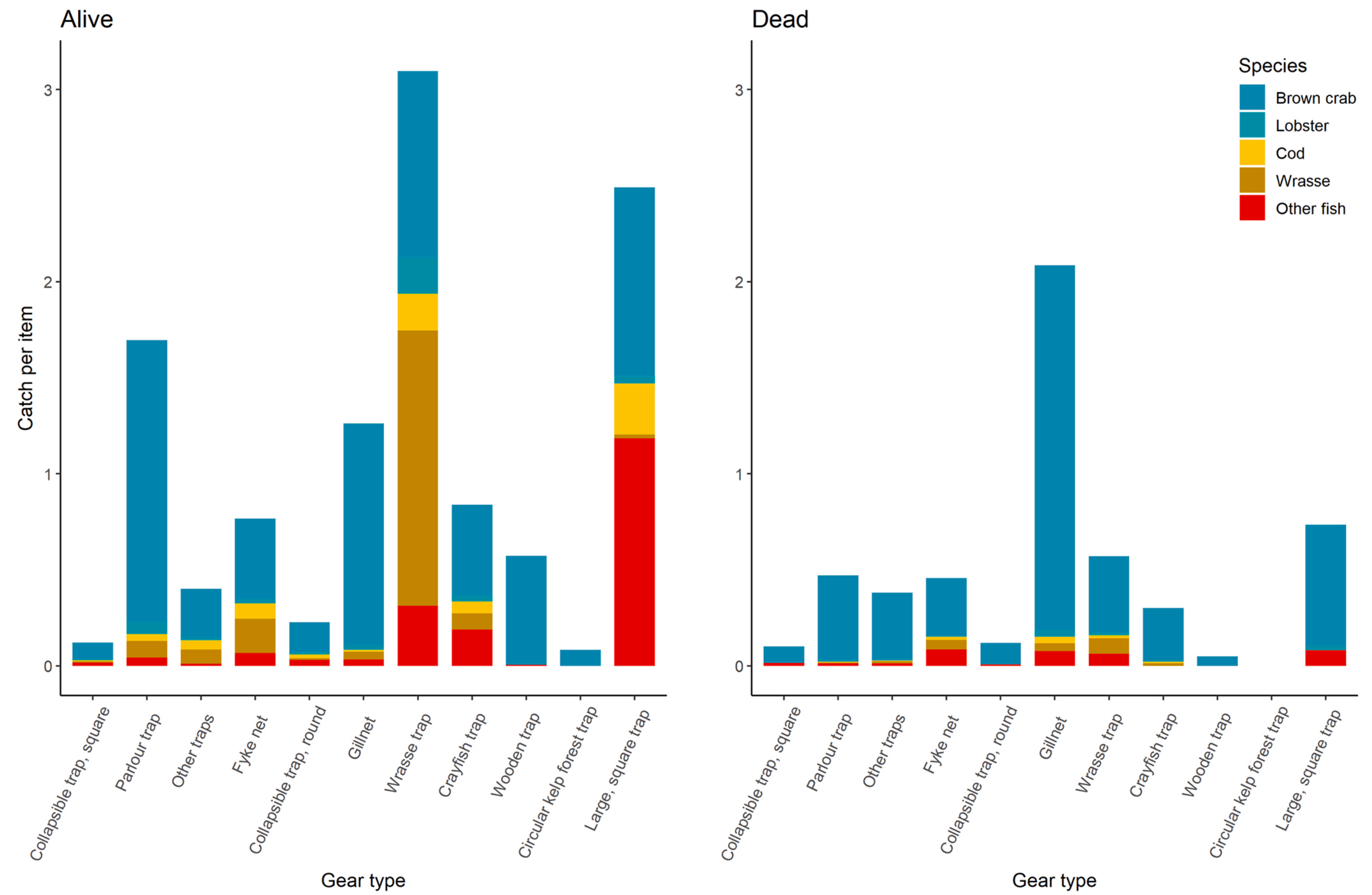

Fig. 4. Average number of live (left panel) and dead (right panel) individuals caught per gear item for all gear types. Colors represent species/animal group.

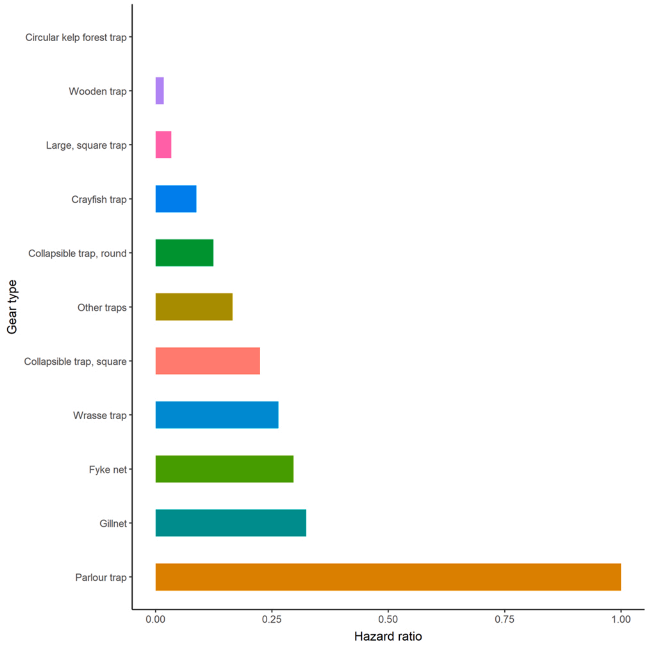

Fig. 5. Normalized hazard ratio for the different gear types.

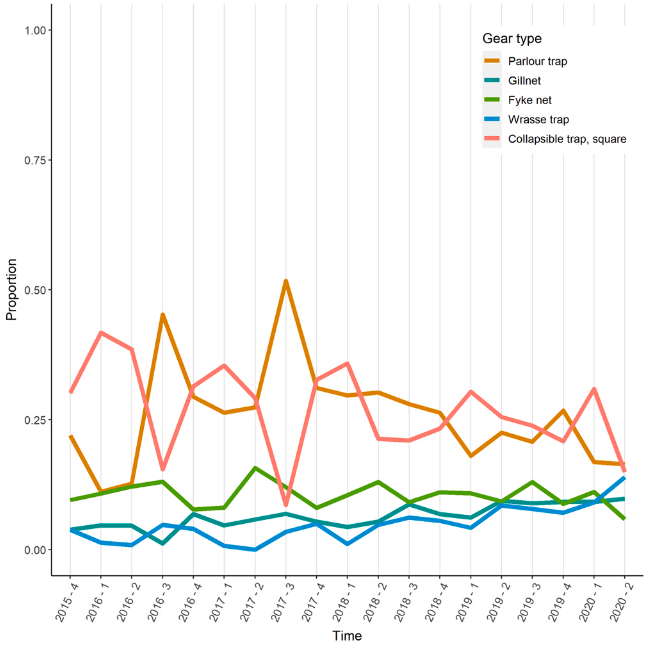

Fig. 6. Temporal change (quarters of a year) in relative amount of different gear types. Only the five most hazardous gear types are shown.

[39]. Lost wrasse traps, followed by parlour traps, had the highest catch rate of living European lobster (*Homarus gammarus*). Coastal cod is also a vulnerable species along the Norwegian coast, with the Skagerrak coastal cod having its effective population size reduced by a factor of 10^4 since medieval times [40]. Cod were most often found in large, square traps and wrasse traps. Wrasses were most often found in wrasse traps, followed by fyke nets. Wrasse catch rates change across seasons, with

catches in September and October being higher than in June [32]. This indicates that wrasse traps lost in the fishery (July-October) can cause high ghost fishing mortality on these species during the first months until the cotton thread has degraded. Cod [41] and lobster [42] increase their activity with temperature, potentially also increasing their vulnerability to capture by passive fishing gear in these periods [43].

The share ghost fishing takes from local populations of fish and invertebrates compared to commercial and recreational landings is of interest to fishers and fisheries management. Previous studies have shown loss rates of 7% for Dungeness crab [44] and 1.5% for monkfish [45] when comparing ghost fishing to commercial landings. To get an overview of ghost fishing mortality of different species along the Norwegian coast, information on gear loss rates or estimates of the density of lost gear is needed. Further, alive or dead animals found in lost fishing gear at retrieval time represent a snapshot and gives no information about previous catches, meaning that catches are underestimates of actual loss. Ghost fishing mortality rates may be especially difficult to estimate for fish, due to fast decay rates [17]. This may also explain the low number of dead fish in recovered gear. Brown crab made up a larger proportion of dead catch than live catch, indicating that its shell has a longer decay rate than the remains of the other animals studied. Some animals recorded in this study may not be captured in the gear but instead be using it as shelter. Another study from the Norwegian coast indicates that 11% of lost fishing gear containing catch was no longer capable of fishing [46]. These animals could be using the gear as shelter or be entangled. In the current study, we also do not know how long the traps have been lost. Interestingly, after the end of this study, the Norwegian Directorate of Fisheries implemented mandatory name and address tags on fixed fishing gear. Before, only the buoy had to be marked. Since very few gear items have been found with address tag before this regulation came into force, it can be viewed as a time shift that can be used to estimate the age of the gear. If information on date of loss is provided by the fisher, it can also enable data collection on time intervals of ghost fishing.

The hazard ratios presented herein are representative for Norwegian coastal waters and reflect fishing practices here. They can have relevance to areas where similar fishing methods are used, for example in the lobster fishery in Canada [17] and the USA [22] and the crustacean fishery in the United Kingdom [10]. Parlor traps are also commonly used in the Canadian lobster fishery and are responsible for ghost fishing of American lobster, crabs in the *Cancer*-genus and several fish species [17]. Escape panels are also mandatory here but were shown to take up to four years to fall off [17]. In Australia, catch rates of pots used in the fishery for blue swimmer crabs (*Portunus pelagicus*) decreased with time after trap loss, but could reach ~14 crabs/trap/year depending on pot type [47]. When combined with data on trap loss from the fishery, ghost fishing rates could be as high as 41,646 crabs/year [47]. In Sweden, lobsters are also fished with parlor traps [48] and fishers supply wrasses to Norwegian salmon aquaculture facilities using both wrasse traps and fyke nets [49]. Here, the wrasse traps are not equipped with escape openings, likely resulting in a larger ghost fishing mortality. Wrasses are also caught using traps in the UK and Scotland to provide Scottish salmon aquaculture.

The composition of gear retrieved in this study largely reflect recreational diving practices. Therefore, the mean depth of different gear types may be deeper than reported in this study. Gear is often displaced after being lost, for example due to currents [50] and bad weather, and may end up in deeper waters. Square, collapsible traps were most often retrieved by divers, indicating a high loss rate for this gear type. This could be because this gear type is relatively light weight and may more easily be displaced. Gear types that are more common deeper than 40 m, like the crayfish trap, are likely to be underrepresented in the data. Further, the choice of diving locations is also non-random, and includes for example searches for lost gear reported in the app. When using the app, it is possible that divers have prioritized searches for certain gear types, e.g. gear perceived as having a higher ghost fishing mortality, or large gear items yielding the largest economic compensation. Regional differences are not considered in the present study. The presence of rope and buoy may give some hints on the cause of gear loss; a missing buoy may indicate propeller cut, while intact rope and buoy may indicate displacement by currents or bad weather. In further studies, information on rope status (whether the rope was fringed or if a knot had loosened) can help identify propeller cuts while information from fishers on where the trap was lost can help identify displacements.

Retrieving lost fishing gear from the sea floor requires a specialized effort. There has been a large motivation among participants beyond the relatively small economic compensation, given the large amount of time spent by volunteers on retrieving gear. The result is a highly valuable dataset, presenting the current composition of both lost gear and its catch to citizens, policy makers and researchers. Participants were requested to identify gear type (three levels: traps, gillnets and fyke nets) and did so with high precision. Species were also identified by participants, but this data could not be verified. In a citizen science project where participants collected data on and identified different species of lady bugs, identification accuracy was 81–100% for the majority of species [31]. In the present study, we assume that European lobster and brown crab mostly have been correctly identified by participants, as there are no similar species in the Norwegian coastal zone. The identification of trap types was done manually from pictures by a researcher, but this task can be made more efficient through the use of artificial intelligence, more specifically machine learning. Machine learning is already enhancing data analysis in marine ecology through enabling rapid and reproducible analysis of large datasets [51]. There are many examples of studies integrating citizen science and machine learning, e.g. by citizen scientists reporting observations and researchers processing the data to be used by a machine learning algorithm [52]. Lost fishing nets have been detected from video using object detection (a machine learning-technique) with high precision [53]. Improving accuracy in citizen science reports includes continuous improvement of reporting forms, volunteer training and testing, expert validation (e.g. through verifying reported data in collected images) and accounting for random error and systemic bias [27]. The initial paper forms used in our study contained fields for reporting catch as free text. Instructions for how to report catch were vague, e.g. whether participants should report catch by species or species group (e.g. “crabs”, “fish”). This was improved in the app, where participants had to group the catch within defined categories.

Knowledge about the hazard to marine species from different gear types is important to effectively manage and reduce the impact from lost gear on local populations of fish and crustaceans. To reduce the impacts of ghost fishing, there is both a need to retrieve already lost gear and to reduce the number of gear being lost in the future. Gear retrieval efforts can be directed towards the gear types with the highest catch rate, and management measures can be directed towards the most hazardous gear types. Number of gear allowed per commercial or recreational fisher can be evaluated, as well as technical requirements on gear types used in different fisheries. The introduction of escape panels with a degradable opening mechanism is expected to reduce catch rates due to ghost fishing, and future studies can investigate the efficiency of this management measure, e.g. whether degradation time is acceptably short.

Conflict of interest

None declared.

Data Availability

Data are available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.8sf7m0csr

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2022.105431.

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