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Application of radio frequency identification tags for marking of fish gillnets and crab pots: Trials in the Norwegian Sea and the Barents Sea, Norway

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ABSTRACT

Marking of fishing gear is an important step in reducing abandoned, lost, and discarded gear, thereby reducing the amount of plastic pollution in the sea. With the help of fishers in their daily work on the Norwegian coast, we have performed several trials using radio frequency identification (RFID) tags to mark crab pots and gillnets. The results show that RFID tags are well suited to mark individual crab pots without affecting the daily work of fishers, and there is no evidence that the tags affect the catch. However, the trials uncovered that the tags easily entangle in the fish gillnets, creating much hassle for the fishers. Also, the heavy stress on the tags while hauling the gillnets damaged several tags. Therefore, we can not recommend marking gillnets with RFID tags before more appropriate tags have been identified and tested.

1. Introduction

The focus on plastic pollution in the sea has increased in recent years, and lost or abandoned passive fishing gear undeniably contributes significantly to this pollution. In addition, fishing gear conflicts and ghost fishing have boosted the focus on abandoned, lost, or otherwise discarded fishing gear (ALDFG). ALDFG is a genuine environmental problem, and it is in the interest of all nations to help reduce it (Macfadyen et al., 2009). Marine animals entangled in lost and abandoned fishing gear is a serious problem affecting many species (Derraik, 2002; Gregory, 2009). Fur seals are particularly prone to entangle in nets (Laist, 1987; Pemberton et al., 1992; Jones, 1995), but sea turtles (Carr, 1987), whales (Neilson et al., 2004; Stewart et al., 2021) and seabirds (Schrey and Vauk, 1987) are also threatened. Ingestion of microplastics is another problem widely discussed in the literature, affecting all marine life (Pawar et al., 2016; Gregory, 2009). A comprehensive list of species affected by entanglement in nets and ingestion of plastic debris is given by Laist (Laist, 1997). Finally, lost and abandoned fishing gear continues to catch fish for a long time (Lively and Good, 2019; Brown and Macfadyen, 2007), and in an attempt to overcome the problems with ghost fishing, researchers are working on using biodegradable nets that dissolve after a period in the sea (Kim et al., 2016; Bilkovic et al., 2012).

A first step towards solving the problems associated with ALDFG is to mark the fishing gear with the boat or owner, for instance, by name, IMO number or vessel registration number. The Food and Agriculture Organisation of the United Nations (FAO) has been concerned about marking passive fishing gear for many years. The original idea of marking fishing gear is for informal purposes, to resolve who owns the fishing gear and avoid conflicts. The work by FAO has resulted in the publication of voluntary guidelines for marking of fishing gear (FAO, 2019), however, these guidelines are rather general and do not specify how to mark the fishing gear. Therefore, the implementation-specific details can still vary. An expert group at FAO will provide a technical manual for marking of fishing gear as a supplement to the voluntary guidelines, expected to be published in 2022 (FAO, 2021).

There are several stakeholders in a future gear-marking system, with fishers being the most important ones. They are responsible for marking the gear properly and are affected by it in their daily work. Therefore, the tags must not limit or disturb their daily routines or cause additional work that reduces the overall efficiency. On the contrary, increased efficiency should be one of the benefits of such a system. Putting a mark on each gear requires additional work but is a one-time job. For the fishers, there are two significant drivers: The opportunity to gain from the

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system and the recognition of the problems related to lost and abandoned gear.

The authorities are also important stakeholders, as they monitor the fishery and check that everything is according to the law. The police, coastguard, and environmental agencies are all searching for illegal fishing gear, and a marking system can be of significant help. The Norwegian Directorate of Fisheries annually conducts special cruises to remove lost and abandoned fishing gear (Norwegian Directorate of Fisheries, 2020), and similar cruises are reported in other countries (Cho, 2011).

Next, fishing gear producers are also stakeholders. If marking of fishing gear becomes mandatory, fishing gear producers may provide such marking during the gear production, for example, by putting an electronic tag into the gear, which can be activated when the gear is sold. Selling new gear encompassing tags eases the fisher's work and provides a competitive advantage for the gear producer.

Today, in areas where marking is mandatory, fishers typically label only the buoy attached to the fishing gear by a name or boat number. However, what happens if the buoy detaches from the fishing gear? This frequently happens, resulting in lost fishing gear with no indication of ownership. Another issue is that the gear owner sometimes deliberately dumps his old fishing gear in the sea instead of bringing it to a deposit (Macfadyen et al., 2009). During their annual expeditions in the Barents Sea, the Norwegian Directorate of Fisheries finds lots of lost fishing gear (Norwegian Directorate of Fisheries, 2020), but as the fishing gear is not marked, they cannot trace the owner. Thus, fishing authorities now investigate the possibility of marking each part of the fishing gear rather than the buoy, meaning marking each gillnet and each crab pot in a string.

Several technologies are available to mark fishing gear. He and Suuronen (He and Suuronen, 2018) (FAO, 2016) provide a comprehensive summary of possible technologies, split into static and dynamic information systems. Static systems cannot change the information, like writing the name on a label. On the other hand, active systems are flexible and add possibilities beyond storing the owner's name. We do not detail each of these technologies but briefly mention that they include text signs, coded wire tags (Coded Wire Tag (CWT), 2019), colour-coded ropes, engraved metal stamps, QR-coded tags, and RFID tags. For the latter, three primary frequency bands exist with different characteristics. The 125–135 kHz band has a read range of up to 1 m, the 13.56 MHz band has an even shorter read range, and the 865–915 MHz band, based on the EPC standard (ISO/IEC JTC 1, 2017), has a read range of up to 20 m.

Although the technology exists, very little has been reported in the literature on trials and how to perform such marking. In 2017–2018, FAO conducted a pilot project in Indonesia intending to test the marking of gillnets based on the draft guidelines for marking of fishing gear (Dixon et al., 2018). They selected two pilot sites on the Island of Java involving gillnets for lobster and fish. Simple, low-cost tags were made from different materials, like metal, plastic, wood, bamboo, coconut shell, and Septillion FibreCode tags. All tags had a readable printed unique ID, and the Septillion tag incorporated a QR code. The results showed that many tags were lost during the trial, specifically the bamboo and coconut shell tags, whereas the plastic tags remained intact. Eventually, the fishers refused to use tags other than the Septillion ones, mainly because the others entangled in the net and caused problems for the fishers. The Septillion tags, however, were flexible, adapting to the ropes and causing less trouble. The fishers considered metallic tags dangerous (Dixon et al., 2018).

The MARELITT project also tested marking gillnets with RFID tags (Grabia et al., 2019). In this test, low-cost UHF RFID tags were placed inside 3D-printed float elements, which were then mounted to the gillnets. The main focus was on reading the tags and not so much on the practical problems that may arise during fishing, although the authors mention that the fishers expressed concern about entanglement.

The English company Succorfish has developed an RFID-based gear marking system ("RFID Tags for Gear identification," 2019). The system is tested by small-scale crab fishers in south-west England and uses the low-frequency RFID band. The tags are mounted to the crab pots using plastic strips through the centre hole, and the read range is about half a meter. However, an essential lesson learned from the tests is that seawater, over time, tears on the reader equipment, even though precautions are taken (Rossiter, 2019).

In 2005, researchers from Japan reported testing RFID tags in conger-eel tube fishery to monitor the fishing effort and effectiveness (Uchida et al., 2005). RFID tags using the 13.56 MHz band adhered to each tube at the fishing gear, and readers were fitted onboard for reading the tags during setting and hauling. Unfortunately, the read range was only about 55 cm, short for our purpose. However, the test went well, and the authors also mention using the system for gear marking to prevent abandoned fishing gear.

The technology that stands out is RFID using the EPC standard. Such tags perform the same way as bar codes but with an extended read range and without the demand for visibility. This paper describes the results from a series of trials using RFID tags to mark different types of fishing gear. In these experiments, fishers fastened RFID tags directly to their fishing gear, not only on the buoy at the surface. The study's primary goal is to determine how the tags affect the fishers in their daily work, but any additional information is of concern, like how well the tags withstand stress caused by onboard haulers, rough treatment, and the pressure caused by immersion in deep water.

2. Materials and methods

2.1. RFID tags

The RFID tags used in the trials are shown in Fig. 1. They are moulded and large enough to provide a good read range, which were the two main reasons we chose them. They are all passive tags based on the EPC standard operating at a frequency of 868 MHz. All the tags are anonymized and hence referred to as Tag-A to Tag-F. To ensure an acceptable read range, all tags were tested outside in a controlled

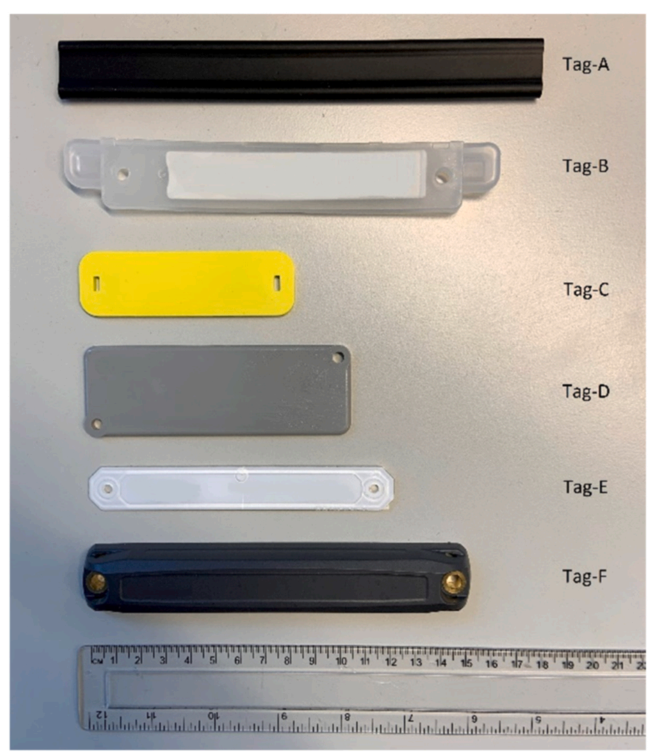

Fig. 1. RFID tags used in the trials.

environment prior to the trials. The tags were fixed to a snow crab pot, and the read range was registered by taking 20 samples from different angles, occasionally altering the pot's position slightly. The read range was measured using an Orca-50 handheld reader at maximum effect (30 dBm).

2.2. Trial overview and study area

In cooperation with the Norwegian Directorate of Fisheries, we decided on the number of tests and the type of fishing gear to mark. The most critical gear to mark is crab pots, which are often lost during fishing and therefore regarded as one of the worst when it comes to ghost fishing. Also, marking gillnets is interesting as they stress the RFID tags much more than crab pots. The study comprises six test scenarios using different fishing gear, and we arranged them into two main groups; gillnets and crab pots. The first group comprises commercial fishing for Greenland halibut and cod and small-scale fishing for monkfish, whereas the second group comprises commercial fishing for King crab and Snow crab and small-scale fishing for crab and lobster. 20 fishers helped perform the trials in an authentic environment during their regular fishing activity. All trials were carried out on the coast of Norway, in the Norwegian Sea and the Barents Sea, from 3rd August to 20th November 2020. Table 1 summarizes the six test scenarios, and Fig. 2 shows the geographical study area in the northern part of Norway. Two areas are not shown in Fig. 2; Snow crab is caught in the Barents Sea, close to the ice edge east of the island Hopen, and the small-scale test area (monkfish and lobster) in the south-western part of Norway, at the archipelago west of Bergen.

2.3. Gillnet trials

The gillnet trials comprise three types of fish gillnets; Greenland halibut, cod, and monkfish. Fig. 3 shows the principal locations of the tags on gillnets. There are six locations: foot- and headrope at the beginning of the string (P1 and P2), foot- and headrope on net number 4 in the string (P3 and P4), and foot- and headrope at the end of the string (P5 and P6). Net number 4 is chosen because the first nets in a string tend to tangle; hence we seek to avoid them.

In Norway, fishing for Greenland halibut is regulated and performed for short periods, one of which starts at the beginning of August. This fishing is at a depth of 600–800 m, creating heavier stress on the nets and ropes during hauling than any other fishing gear. The involved fishing boat is in the 11 – 15 m range, operated by two fishers, and it has a hydraulic net hauler, where the ropes and nets are squeezed between two plates. The nets are linked together in a string of 25. Since the fishing period was short, the fishers had only three hauls. Four different tags are used in this trial, each with five duplicates, hence 20 tags in total. Each gillnet string has five tags at positions P1 – P4 and P6, and four strings are marked.

The codfish gillnet fishing is at depths below 200 m, resulting in less strain put on the tags than for Greenland halibut fishing. This test comprises four different tag types, each having four duplicates, hence 16 tags in total. Four strings are marked at positions P1 – P4 in Fig. 3. P3 and P4 are at net number four, and there are 16 nets in the string. The hauler on this fishing boat is of the drum roller type, being gentler to the net than the net hauler. The boat is below 11 m and operated by two fishers.

For small-scale fishing, there are fewer nets in a string, and fishing is at a lower depth, causing less stress to the tags. The specific gillnet is used for monkfish, and positions P3 and P4 are at the second net in the string. Five different types of tags are tested, each having six duplicates. The six identical tags represent positions P1 – P6 in Fig. 3, thus marking 5 different strings with a total of 30 tags. The boat is below 11 m and operated by one fisher.

The tags are tied to the net and ropes using a short nylon thread at each end of the tag, see Fig. 4. For Greenland halibut and cod gillnets, half of the tags are tied with 5–7 cm slack (Fig. 4-A), leaving a small space from the tag to the rope. During hauling, the ropes are squeezed between the plates at the net hauler, and this space may prevent the tag from squeezing. The other half of the tags are tied tightly to the rope. The idea is to observe if the different ways of fastening the tags make any difference.

2.4. Crab pot trials

The crab pot trials include King crab, Snow crab, and lobster pots. King crab fishing is usually around 100–200 m in depth close to the shore. The pots are rectangular and collapsible, and the tags are placed inside the roof of the pots, see Fig. 5-B. This location ensures the tags do not entangle in other pots when stacked together. The tags are tied tightly to the pot using a nylon thread at each end, but a few tags are also fixed using plastic strips. Two boats at different locations are used for this trail. Each boat has six different types of tags, each type having 4 duplicates, hence a total of 24 tags per boat. These 24 tags are split between 8 pots with 3 tags in each pot. For the two boats together, this means 16 pots marked with a total of 48 tags. Both boats are below 11 m and operated by one fisher.

Snow crab pots are not collapsible but still stackable, and the tags are fitted on the sidewall's inner side, as shown in Fig. 5-A. A string of snow crab pots can consist of several hundreds of pots, but for the trial, we only mark the first and last pot. When the pots are stacked, the first and last pot are put aside, making it easy to identify them. Snow crab fishing takes place in the Barents Sea, close to the ice edge, and the boat is usually out for a month. Thus, we had help from colleges at the boat monitoring and performing the test. The boat is large (58 m) with a factory to process the catch, and altogether 12 fishers gave their

Table 1
Overview of the six different test scenarios.

Fishing gear	Trial period 2020	Sea depth (meter)	Number of hauls	RFID tags involved	Duplicate tags	Number of gear and strings marked
Greenland halibut gillnet (commercial fishing)	3rd – 6th Aug.	600 – 800	3	Tag-A, Tag-B, Tag-C, Tag-E	5	4 strings 5 tags in each
Cod gillnet (commercial fishing)	1st Sep. to 20th Nov.	130 – 180	19	Tag-A, Tag-B, Tag-C, Tag-E	4	4 strings 4 tags in each
Monkfish gillnet (small-scale fishing)	1st – 7th Oct.	80 – 100	2	Tag-A, Tag-B, Tag-C, Tag-D, Tag-E	6	5 strings 6 tags in each
King crab pot (commercial fishing)	5th Aug. to 20th Oct.	100 – 190	15	Tag-A, Tag-B, Tag-C, Tag-D, Tag-E, Tag-F	8	16 pots 3 tags in each
Snow crab pot (commercial fishing)	2nd Oct. to 20th Nov.	250 – 300	6	Tag-A, Tag-B, Tag-C, Tag-D, Tag-E	6	3 strings 6 pots 5 tags at each pot
Crab / Lobster pot (Small-scale fishing)	1st Oct. to 16th Nov.	10 – 30	40	Tag-A, Tag-B, Tag-C, Tag-D, Tag-E	6	5 strings 10 pots 3 tags at each pot.

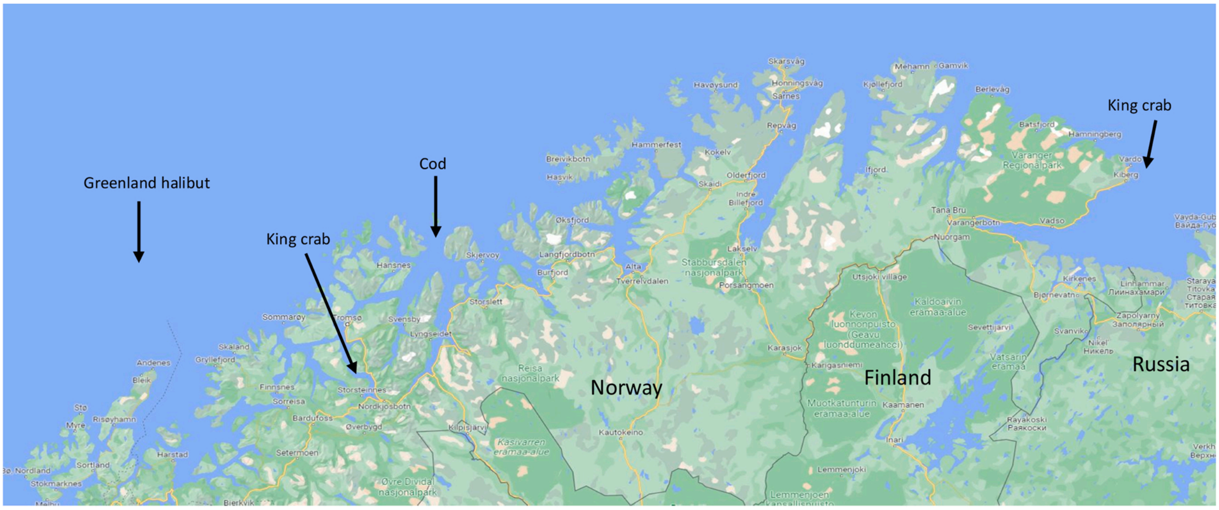

Fig. 2. Map of the study area.

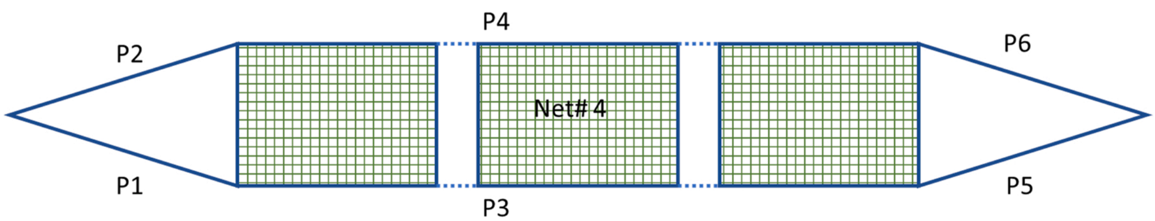

Fig. 3. Locations of tags on gillnets. Position P5 applies only to the monkfish gillnet trial, and P6 to Greenland halibut and monkfish gillnet trials. Net #4 is the fourth net in the string.

Fig. 4. RFID tag loosely tied to the Greenland halibut gillnet rope (A), tag tied to cod gillnet headrope (B), and tags (encircled) tied to the monkfish gillnet headrope (C).

opinions on the tags. Five different tags are tested in this trial, each with six duplicates, hence a total of 30 tags. All five tag types are fitted to the same pot, meaning that six pots are marked, or the first and last pot at three strings.

The number of pots in a string for the small-scale fishery is fewer than for commercial fishery, and the pots used for lobster and crabs can not be collapsed or stacked. As for the King crab test, the tags are fixed on the inside of the top wall, as shown in Fig. 5-C, shielding them from outside impact. Five different tag types are used, each having six duplicates, giving a total of 30 tags. The tags are split between ten pots having three tags each. The fisher has 5 strings with four pots each, so half of the pots are marked. The boat is below 11 m and operated by one fisher.

2.5. Practical trial procedure

We performed all tests the same way: 1) First, we delivered tags to the fishers giving instructions on how to fit them to the gear. During this process, we assisted in fastening the tags. 2) Next, the fishers went out to set the gillnets or pots in the sea. 3) During the first hauling, we scanned the tags and inspected them for any damages or wear. 4) On subsequent trips, we aimed to be present to observe and discuss with the fishers, but sometimes the fishers were alone inspecting the tags only. They reported any damages or other relevant information back to us. 5) On the last trip, we boarded the boat, scanning and inspecting the tags.

We implemented simple software to ease the scanning using an Orca-50 RFID reader. Before the trials, we scanned and named all tags and

Fig. 5. RFID tag on a snow crab pot (A), tags (encircled) on a King crab pot (B), and tags on a lobster pot (C).

stored them locally in the reader so that when read, they were recognized and presented on the screen. Additionally, we stored each reading in the local database, allowing us to check when and how many times a tag has been read. Finally, we performed each test sequentially, although some overlapped in time.

3. Results

3.1. RFID read range test

Table 2 shows the measured average read ranges. The ranges for three of the tags are considerably longer than stated by the manufacturers, whereas Tag-F has a shorter range than expected. However, Tag-F is optimized for on-metal mounting, which may explain this deviation. Tag-C has the shortest read range, which is logical since it is the smallest. The most important observation is the high standard deviation caused by an extensive spread in the read ranges. The surroundings and small changes in the read angle significantly impact the read range, making it difficult to repeat the measurements.

3.2. Crab and lobster pots

Tag-F was not moulded as the others, and consequently, it did not withstand the water pressure at 200 m. This became evident at the King crab trial when 75 % of the tags stopped working. It was not entirely surprising, as we anticipated it might collapse under underwater pressure. Still, we had to try it out. Because of this, we did not include this tag type in the other trials.

The remaining tags performed well on crab pots. During the trial period, we did not notice any change in the read range, nor did the location of the tags on the pots seem to matter. It is also worth noting that none of the fishers reported that the tags affected the catch. The small-scale fisherman reported that for Tag-B, four out of six tags detached from the pots during the test period. We later learned they had not been tied to the pots correctly, using inappropriate knots and a rather thick rope. Table 3 summarizes the results of the crab pot tests.

Table 2
Measured read ranges for the RFID tags.

Type	Size [mm]	Manufacturer's specified read range	Average measured read range with standard deviation [m]
Tag-A	181 × 21 × 5	< 5 m	18.0 (SD 4.1)
Tag-B	162 × 25 × 6	< 8 m	13.7 (SD 5.6)
Tag-C	83 × 25 × 3	< 8 m	8.1 (SD 4.1)
Tag-D	105 × 36 × 3.5	< 8 m	12.6 (SD 4.6)
Tag-E	122 × 18 × 2	< 12 m	10.3 (SD 6.7)
Tag-F	155 × 26 × 14.5	< 16 m (on metal)	11.6 (SD 5.1)

3.3. Fish gillnets

The results were not as promising for the gillnet trials as for the pots. All fishers using gillnets reported that the tags quickly entangled in the nets, with an example shown in Fig. 6-A. The fishers had to disentangle the nets, creating much extra work and irritation. This was most prominent for the tags at positions P3 and P4 and those loosely tied to the net. Also, the small-scale fisher reported that the tags entangled in the nets when lying in the bin. All fishers regarded Tag-C as the best because it did not entangle as quickly as the others. At the other end of the scale, Tag-A was regarded as the worst as its sharp edges quickly entangled the nets. It was, however, an accepted agreement amongst the fishers that none of the tags were appropriate since they all seemed to mess things up and create much hassle. None of the fishers reported that the tags affected the catch. The practical problems and comments from fishers are summarized in Table 4.

All the trials showed that the mechanical stress imposed on the tags was very high, resulting in damage or breakdown of several tags. Particularly, Tag-E did not meet the expectations, as several broke during the cod gillnet trail. Also, one of Tag-B broke during this trial, as shown in Fig. 6-B. Several other tags had visible damage, specifically to the mounting holes. This observation was most evident during the

Table 3
Summary of tag performance during lobster, king and snow crab fishing.

RFID tag	Damage or wear	Fishers' opinions
Tag-A	No visible or measurable damage known	All fishers think it works well
Tag-B	Four out of six tags were lost into the pot due to inappropriate fastening by a small-scale fisher.	All fishers think it works well
Tag-C	No visible or measurable damage known	All fishers think it works well. 20 % remarked that the yellow colour is easy to see.
Tag-D	No visible or measurable damage known	All fishers think it works well, but 45 % also commented that the hard plastic might crack over time.
Tag-E	No visible or measurable damage known	All fishers think it works well.
Tag-F	75 % of the tags stopped working during the first King Crab test due to a lack of water resistance.	Inappropriate due to improper water resistance.

Fig. 6. Tag-A entangled in the net (A) and a broken Tag-B, tightly tied to the rope (B).

Table 4
Summary of tag performance during gillnet fishing. Tag-F was not tested.

RFID tag	Greenland halibut gillnet trial	Cod gillnet trial	Monkfish gillnet trial	Fishers' opinions
Tag-A	There were visible damage to mounting holes at several tags.	No visible damage	No visible damage	All fishers stated that this tag is unusable and considered the worst since it entangles quickly in the net.
Tag-B	No visible damage.	The tag at position P2 was broken, tightly tied. Two others had damage to mounting holes.	No visible damage	All fishers stated that this tag is unusable. It entangles very easy in the net, although not as bad as Tag-A.
Tag-C	One tag shows signs of pressure.	No visible damage.	No visible damage	All fishers regarded this tag as the best, but they are still sceptical since it entangles in the net, although not as quickly as the others. One fisher said it might work.
Tag-D	Not used	Not used	No visible damage	The small-scale fisher regarded the tag as inadequate since it entangles in the net during hauling and when lying in the net bin.
Tag-E	The tag at position P3 is broken.	Tags at positions P2, P3, and P4 were broken, all tightly tied. The tag at position P2 was broken, loosely tied.	No visible damage	All fishers stated that this tag is unusable since it entangles very easily. 50 % of the commercial fishers pointed out that it looks fragile.

Greenland halibut fishing, probably because of the extra stress caused by the extended depth. None of the tags broke down during the small-scale test, but unfortunately, this trial only included two hauls due to unforeseen incidents. An important observation was that all the broken tags were tied tight to the rope, whereas the slack ones did much better. A video showing hauling of Greenland halibut nets with RFID tags is available (Høybakken, 2020). Apart from those that broke, all tags performed well, even after several months, and we did not detect any reduction in the read range.

4. Discussion and conclusion

Our trials show that the RFID tags tested are inappropriate for marking gillnets. The main reason is that they entangle in the nets, creating much hassle and extra work for the fishers. We tried to avoid entanglement by not using the first nets in the string, but without success. Another issue is that some tags showed damage to the mounting holes caused by heavy stress. Although none of the tags fell off, they would likely have had the trials lasted longer.

The problem with entanglement was also observed during the FAO trial in Indonesia (Dixon et al., 2018). This implies that fitting tags on gillnets cause severe problems that probably must be solved by the involvement of gear producers. Alternatively, a soft tag that can be threaded inside the cords yet be large enough to have sufficient read range may be a solution. A thinner, more extended version of Tag-C could be a candidate. Therefore, a tag explicitly designed for gillnets is probably necessary. Also, small existing tags that we can stuff into the ropes are an alternative, but the read range, one of the advantages of RFID, will be significantly shortened. Another suggested solution is to use low-cost RFID tags encapsulated in float elements mounted on the gillnets (Grabia et al., 2019); however, this requires specific float elements. It may be an excellent strategy for gillnet producers to put RFID tags into the gillnet during production, but this requires regulations from the authorities calling for mandatory marking.

There are differences between commercial and small-scale fishers. For instance, the latter group use manual and simpler technology and mainly fish locally for food (Daw et al., 2009). Hence, we assumed that small-scale fishers would be less sensitive to any problems caused by the tags than the commercials, but the problems caused by tags entangled in the net seem severe. Although small-scale fishers can tolerate a bit more hassle, they still want things to flow easily, and the RFID tags create too many problems. Also, when the fisher stores the nets in bins, the tags entangle with other nets, causing much irritation. Although this is the opinion of only one small-scale fisher, it is easy to understand the frustration. Further studies involving several fishers must be performed before we can conclude on marking small-scale gillnets, but for now, it seems problematic.

The test worked very well for crab pots, and both the commercial and small-scale fishers were positive. None of the fishers reported that the tags entangled the pots during storage. There was initially some concern amongst the crab fishers if the presence of the tags would affect the catch, notably if the crabs would climb into the pot decorated with different tags. This concern is justified by the fact that crabs are sensitive to the bait (Araya-Schmidt et al., 2019), and also that the color of the pot may impact the catch (Knott, 2017). However, the trials showed no evidence that the catch was affected. On the contrary, the catch was very good for Snow crabs in the Barents Sea and King crabs on the north-eastern coast of Norway. Therefore, we have no evidence that tags mounted to crab pots affect the catch, and RFID tags seem appropriate for marking pots.

Six tags broke during gillnet fishing, possibly due to the stress caused by the haulers. Five of them were tied tight to the rope, which suggests that fastening the tags with some slack to the ropes is the best way, but further trials must be performed to confirm this. However, tags that break in the hauler are a severe problem that must be solved before RFID tags can be recommended to mark fish gillnets.

The tags seem to resist stress if they are moulded and waterproof; however, our trials do not confirm the long-term effects on the tags caused by sea immersion. The fishers claim that tags made of hard plastic, like Tag-D, are not a good choice since they likely break. We did not observe this during the pot trials, but the tests did not last long enough. Crab pots are not affected by the hauler or other onboard equipment the same way nets are, and the stress put upon the tags is minimal. The fishers involved in the pot tests were confident about the system and welcomed it. Also, they were concerned about the loss of crab pots and the possible damage caused by ghost fishing and plastic pollution in the sea.

The purpose of testing the read range was to ensure that the tags could be read at a proper distance, not specifically to find the best tag. All tags worked well, but our test showed large deviations in the measured range dependent on the surroundings. This means we must try reading several times before detecting a tag.

We have not implemented a complete marking system, like, for instance, the BlueSenz system from Slovakia ("BlueSenz", 2019). We stored the data associated with the RFID tag locally on the reader only, and they were not accessible from the outside. In a finalized system, the reader will send the data to a centralized database. Thus, we can create an automated system that reads the tags when the fisher sets the pots or gillnets in the sea and automatically sends the data to a register that records all fishing gears. Such a register exists in Norway, and each fisher is responsible for reporting his fishing gear. RFID tags and readers can streamline this work, thus motivating the fishers.

A system using RFID tags has the potential to significantly reduce the time spent identifying lost gear found in the sea by the authorities. When they locate gear in the sea, it can easily be identified by an RFID reader with the proper software. However, fishers and others that find lost gear are not likely to have such readers, and we recommend including a readable label on the tags identifying the owner. This makes it easier to identify the gear for those who do not have the proper tools. Furthermore, one of the system's strengths is storing the information in a database and adding, deleting, or otherwise changing it if necessary, making it highly flexible with possibilities to extend the purpose and add new services over time.

A problem that arises is the need for standardization. It is unrealistic for the government to create and operate such a fishing gear register, but they are stakeholders in a system developed by others. Ideally, this should be solved in international fora, creating a standard way to identify, store and read the tag information, like the existing standard for animal identification (ISO, 1996). Several companies may offer a gear marking system based on a standard, but such a standard will not be available for many years. Therefore, the more powerful fishing nations should gradually incorporate a system for gear marking, possibly based on RFID technology.

Future research on the theme is necessary, specifically to investigate the long-term effects on the reliability of the tags. A reliability test on UHF RFID tags is reported in the literature (Saarinen and Frisk, 2013), but this test does not include moulded tags as we used in our trials. Also, finding more appropriate tags for gillnet fishing is a topic of great interest.

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CRediT authorship contribution statement

Tore Syversen: Conseptualization, Methodology, Software, Validation, Writing – original draft, Writing – review & editing, Project administration. **Jørgen Vollstad:** Conseptualization, Validation, Investigation, Writing – review & editing.

Declaration of Competing Interest

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

Data Availability

Data will be made available on request.

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