Technologies for the marking of fishing gear to identify gear components entangled on marine animals and to reduce abandoned, lost or otherwise discarded fishing gear

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Abstract

Fishing gears are marked to establish and inform origin, ownership and position. More recently, fishing gears are marked to aid in capacity control, reduce marine litter due to abandoned, lost or otherwise discarded fishing gear (ALDFG) and assist in its recovery, and to combat illegal, unreported and unregulated (IUU) fishing. Traditionally, physical marking, inscription, writing, color, shape, and tags have been used for ownership and capacity purposes. Buoys, lights, flags, and radar reflectors are used for marking of position. More recently, electronic devices have been installed on marker buoys to enable easier relocation of the gear by owner vessels. This paper reviews gear marking technologies with focus on coded wire tags, radio frequency identification tags, Automatic Identification Systems, advanced electronic buoys for pelagic longlines and fish aggregating devices, and re-location technology if the gear becomes lost.

Keywords: gear marking; ALDFG; gear recovery; ghostfishing; marine litter

Introduction

Fishing gears are marked to establish their ownership and legality of their use. Gear marking has been considered as an important tool to reduce abandoned, lost, or otherwise discarded fishing gear (ALDFG) and to fight illegal, unreported, and unregulated (IUU) fishing (FAO, 2016; 2018). Fishing gears are also marked to inform the origin of the gear when entangled in marine animals, and to indicate position to reduce gear conflicts and improve safety at sea. Traditionally physical marking, inscription, writing, color, shape, and tags have been used for ownership and legality purposes, and buoys, lights, flags, and radar reflectors are used for marking of position. More recently, electronic devices including radio and satellite transmitter have been use in some fisheries for easier location from a distance or unlimited tracking, even from the land.

From the purely technical point of view, there is a need to identify the origin of fishing gear or its components (and where it was fished) when they become lost or entangled on marine animals (Johnson et al., 2005). Understanding the origin (area, fishery and gear type) would provide valuable information for fishing gear modification, area/season closure, and other management measures to reduce entanglement and potential mortality of venerable animals such a whales, porpoises, and turtles (Wilcox et al., 2015). This is especially applicable to fixed gears such as pots[1], gillnets, longlines, and traps. While the United States has invested considerable effort to identify fishing gear remnants entangled in marine megafauna species, yet only 45% of entangled gear materials on North Atlantic right whales (*Eubalaena glacialis*) and humpback whales (*Megaptera novaeangliae*) could be identified for its origin (region/fishery) (Johnson et al., 2005). It is likely that less proportions of entangled gear have been identified in other regions. Currently, a scheme of colored rope sections for different regions and fisheries is implemented by the United States to aid the identification of origin if they become entangled on an animal (NOAA, 2015). The International Whaling Commission (IWC, 2014) considered fishing gear marking as an important issue in protection of cetaceans and encouraged the Food and Agriculture Organization of the United Nations (FAO) complete its work on the guidelines for the marking of fishing gear (FAO, 2016). The Voluntary Guidelines on the Marking of Fishing Gear have just been approved by the Technical Consultation on the Marking of Fishing Gear of FAO Members States (FAO, 2018).

Gear marking for ownership, legality, and capacity management is especially important in capacity-controlled fisheries such pots and gillnet fisheries. The maximum amount of gear that is allowed for each licensed fisher or fishing enterprise is regulated by many nations, states or Regional Fishery Management Organizations (RFMO) to either limit fishing effort, or to reduce gear loss. Traditionally, various physical tags have been used, usually inscribed with the permit number of its owner. In some fisheries, tags are fixed in the gear itself (e.g., gillnets) or attached to its surface markers (e.g., buoy of a pot). These physical tags can only contain limited information (e.g., license number). More advanced tags that contain static information (e.g., license number, owner, vessel, etc.) as well as dynamic information (such as time in water, location deployed, etc.) would have advantages both for fishers and for management. Advanced tags that can be detected over a longer distance would help fishery enforcement in combating IUU fishing.

Gear marking for position not only aids in the quicker recovery of gear by its owner, but also aids to navigation to other users, and reduces gear conflicts between gear sectors (e.g., fixed and mobile gear sectors), reducing the probability of gear loss. Flags, lights, and radar reflectors are still the main position markers for coastal fisheries. More advanced gear markers have been used by offshore longliners and purse seiners using fish aggregating devices (FADs). There are more than 100,000 drifting FADs (dFADs) in use by world's tuna purse seine fisheries (Baske et al., 2012). With advances in electronics technology and satellite communication, the use of advanced longline and FAD buoys not only increases catch per unit effort, but also has implications in effort monitoring and in combating IUU fishing by various levels of authorities (Agnew et al., 2009).

[1] Pots and traps have been interchangeably used in many literatures. In this paper, a pot refers to a small baited enclosure, while a trap refers to a large un-baited structure.

Fishing gears become lost due to various reasons; some of these lost gears (e.g., gillnets and pots) continue to catch fish, causing ghostfishing (Macfadyen et al., 2009). There are a few measures to deal with ghostfishing issues of abandoned, lost, or otherwise discarded fishing gear (ALDFG), including measure to prevent gear loss, retrieval of lost gear, and mechanisms to reduce fishing efficiency of lost gear (de-ghosting technology) (DFO, 1995; Macfadyen et al., 2009). Prevention of ghostfishing includes measures for proper gear marking to prevent loss and to discourage intentional abandonment or discard of gear. Gear marking technologies that can help relocating lost gear facilitate quicker recovery.

The FAO Code of Conduct for Responsible Fisheries requested that "*fishing gear should be marked in accordance with national legislation so that the owner of the gear can be identified*" and "*gear marking requirements should take into account uniform and internationally recognizable gear marking systems*" (FAO, 1995, Para. 8.2.4). Only few governments or Regional Fishery Management Organizations (RFMOs), however, have properly implemented or enforced this requirement. Accordingly, ALDFG is often impossible to identify to the owner of the gear, and to fishery of origin. Appropriate marking of fishing gear would be beneficial in many respects. Among others, it would assist in the prevention and reduction of ALDFG and ghost fishing, assist recovery of ALDFG, improve the safety at sea, and enhance the ability to apply fisheries regulatory measures, including those for the control of fishing capacity and the prevention or elimination of IUU fishing (FAO, 2018).

Gear Marking for the Identification of Origin

One of the important benefits of proper gear marking is the identification of origin of gear components, especially fishing ropes, entangled on marine mammals and other marine megafauna species that are also often endangered and/or threatened species (NOAA, 2015). Here the word "origin" means the region, fishery, and gear type that the gear was used before it became ALDFG or entangled on an animal. Understanding the origin of gear component on dead or impaired marine mammal is important for spatial and tempo management of gear use. Currently, colored ropes or tracers are being implemented in the northeastern water of the United States (NOAA, 2015). There are limited color shades that can easily be distinguished after rugged use in the sea. Embedding codes or more advanced identification tags in fishing ropes would provide much more information, including gear ownership, set location, time, fishery, and specific component of the gear. More recently, coded wire tags (CWT) and radio frequency identification tags (RFID) have been tested for possible inclusion in fishing ropes to provide additional information.

<u>**Color coding and tracers**</u>

Colored coding of buoy lines used in stationary gears is enforced by NOAA (2015). Colored marks may be applied by seizing colored twines, by spraying colored paint, or by attaching colored tapes to the rope. The colored sections have 25.4 cm minimum length, and marked at the surface and bottom ends, and at the middle of the rope. Different regions in the United States are assigned different colors or color combinations (NOAA, 2015).

Tracer yarns or strips may be woven into ropes or twines. The tracer may bear different colors, and information such as manufacturer, batch number, and/or material specification can be printed on to the tracer before it is woven into the rope or twine (P. He, personal observation). Tracers embedded as center core of braided ropes or twines may be less likely to wear off and would retain information for the life of the rope or twine. With corresponding book-keeping, the rope or twine with specific batch number may be traced or tracked from its manufacture, shipment, usage, recycle and disposal. Ropes or nets made of these twines recovered from sea or entangled in marine animals can thus be traced to the owner/operator of the gear, and location they were deployed or lost. This would aid in gear modifications and/or management measures that would reduce gear entanglement on animals (Henry et al., 2017).

Coded wire tags

Coded wired tags (CWTs) are minute magnetized tags that were invented over half a century ago for tagging juvenile salmonids on the US west coast (Jefferts et al., 1963). The tags are made of stainless steels and can be detected by specialized hand-hold electronic detectors, and read under a microscope. Coded wire tags may be assigned a unique code for each tag, called sequential CWT, thus allowing identification of individual tagged objects. For the purpose of fishing gear marking, these numbers may be associated with region/nation, license number, gear type, and other characteristics.

Only one study has tested the feasibility of using CWTs for marking the origin of fishing rope, specifically ropes for use in fixed gears (pots, gillnet and longlines) in Massachusetts (USA) (Krutzikowsky et al., 2009). They tested how the CWT tags might be inserted into ropes that are used as buoy lines in pot and gillnet fisheries, their durability under stimulated operating conditions, as well as handling in normal fishing operations.

Two methods were used to implant CWTs to ropes: injection with adhesive and implanting within a braided twine (Figure 1 A & B). Direct injected tags were better in retention than those implanted using braided twines (Krutzikowsky et al., 2009).

Both types of ropes were tested in a rope-testing machine (Lyman et al., 2005) to simulate five-year fishing effort under normal fishing conditions. Severe wear was evident after five years simulated fishing, with some tag-implanted twines completely worn off (Figure 1 C).

Coded wire tags seem to be a possible means for tagging ropes for identification of ropes entangled on marine animals, or recovered ALDFG. No further work has been carried out since the 2009 Massachusetts study, probably due to prohibitive costs to mark the gear that would result in a satisfactory degree of identification in the fishery (E. Burke, personal communication).

Radio frequency identification tags

Radio Frequency Identification (RFID) refers to technologies that automatically identify objects through the use of radio waves (RFID Journal, 2016). They are often used in retail and logistic/shipping industries. In fisheries research, the technology has been used for tagging and tracking fish to understand stock structure, migration, and movement. More advanced read-and-write tags may be linked to different sensors and store information such as temperature or GPS coordinates with a time stamp.

There are three basic types of RFID tags (often called transponders): passive, active and hybrid tags. A passive tag does not contain a battery and is powered by the electromagnetic field generated by the reader. An active tag contains its own power (e.g., batteries) to run the microchip and/or to broadcast a signal. A hybrid type, or called semi-passive tag uses its own battery to run its microchip, but use power from the reader for communication. Active tags have better range, but cost more than passive tags (RFID journal, 2016). A comparison between passive and active tags can be seen in Table 1.

Generally speaking, RFID tags can only be read within a short distance. Typically, low-frequency tags can be read from 30 cm or less, high frequency tags can be read from about 1 m, and ultra-high frequency tags can be read for up to 6 m (Theiss et al., 2005). Active tags can use batteries to boost reading range for up to 100 m (RFID Journal, 2016).

Tests were carried out on its possible use in identification of fishing gear components, specifically fishing ropes if they become lost, abandoned or discarded (Brickett and Moffat, 2004; La Valley et al., 2010). The main issue of using RFID tag for rope identification is the implantation of tags in the rope (Brickett and Moffat, 2004). These authors used a molded apparatus that houses a RFID tag which was then implanted into the ropes. The ropes showed significant wear at the points where the RFID chip was imbedded in a simulated rope-hauling machine to an equivalent of 40 years of hauling. The ropes were more easily broken at the area where the tags were implanted, but RFID tags were still readable at the end of test, even after submerged to a depth equivalent to 1400 m in a hyperbaric chamber (Brickett and Moffat, 2004).

Another issue of using RFID tags is the readability, and ease of reading when the ropes are recovered or retrieved. La Valley et al. (2010) tested a passive RFID tag that was typically used for tagging fish. The “naked” RFID tags before being embedded into the rope could be read at 20.3 cm by its reader, but the detecting distance was reduced to 13.7 cm when the tags were imbedded in nylon molds, then inserted in the twisted fishing rope.

Patton and Cromhout (2011) tested tag inlays with different self-adhesive protective backing materials which would provide some cushioning when exposed to great pressure (e.g., going through pulleys and winches). Two types of RFID inlays were tested: a UHF tag (915 MHz) and a Near Field Communication (NFC) HF tag (13.56 MHz). The UHF tags had longer detection range measured in meters, while UF tags could be detected in less than 3 cm. Though NFC tags have short detection range, they could potentially be read by NFC-enabled mobile phones, allowing researchers, authorities, or fishers to access tag information in the field. It seems that RFID tags themselves are viable devices that offer potential for rope identification, but more research is needed on the method of attaching or embedding them to fishing ropes (Patton and Cromhout, 2011).

In summary, while RFID tags can potential provide vast amount of information on the rope and the fishery that was used, and potentially time of deployment and environmental conditions, imbedding RFID tags to ropes still face great challenges in terms of durability of the tags and the ropes they imbedded. More durable and smaller size RFID tags are yet to be produced and tested for rope-imbedding purposes.

Gear Marking for Capacity Management and Monitoring

In many fixed gear fisheries such as gillnet and pot fisheries, the amount of gear permitted for use is restricted by regulations to either limit fishing effort, to reduce probability of gear loss, and to indicate legality of the gear so as to combat or eliminate IUU fishing. Traditionally various physical tags have been used, usually inscribed with the permit number of its owner. In some fisheries, the tags are fixed in the gear itself, while in others, the tags are attached to the surface buoys, and while still others, both underwater and surface components of the gear are tagged or marked.

Electronic tags using RFID technology are being tested to allow for automatic monitoring, and when they are used with other devices such as GPS sensors, allow for identification of location of fishing activities. The draft guidelines for the marking of fishing gear (FAO, 2016) calls for reporting of lost or abandoned fishing gear and its tags so that the gear may be more easily recovered and replacement tags may be issued.

Physical tags for capacity management

The maximum number of gillnets and pots that can be used are controlled in many fisheries. In these cases, physical tags bearing license (or permit) number, serial number, and other identification number/codes are issued by authorities, and have to be attached to the gear when they are used.

RFID tags for capacity management

More advanced RFID tags are used in British Columbia (Canada) crab pot fisheries as a part of the electronic monitoring effort (McElderry, 2008). RFID tags are inserted into foam cores of each buoy and are read with a custom-made RFID reader when the pots are hauled. Currently, in addition to some Canadian crab pot fishery that use the RFID technology to manage gear capacity limit and inventory control (EcoTrust, 2015), some US west coast Dungeness crab fisheries are also using the technology (NWIFC, 2015; QIN, 2015). The RFID tags were used together with video cameras, and had a license number on each quarter-size tag that was attached to the pot's buoy (QIN, 2015). These systems not only serve as permit tags, they are designed to reduce the theft of gear and catch (NWIFC, 2015). EcoTrust Canada is also partnering with Gulf of Maine Research Institute in Portland, ME to institute similar electronic monitoring systems in Maine lobster fishery (EcoTrust, 2015).

RFID tags for fishing effort and catch monitoring

RFID tags are used in Scottish creel and pot fisheries for crabs and lobsters (Course et al., 2015), together with other electronic monitoring equipment for capacity management. In that case, two RFID readers were used; one for detecting tags on the buoy during deployment, and the other for tags on the creel/pot during retrieval (Course et al. 2015), so that fishing effort (soak time) can be determined.

RFID tags were also tested in conger eel pots in Japan for determining fishing effort and location of fishing (Uchida et al., 2005). These researchers attached RFID tags inside conger eel pots (tubes), and was read by two RFID readers during retrieving. When a pot did not contain any conger eel, the pot only passed the first reader. When a pot contained a conger eel, the port passed two readers. In all cases, GPS location was obtained when a RFID tag was read. In this way, catch information on a specific pot and at a specific location could be recorded. While the system served as a research tool rather than a capacity management or enforcement tool, similar system can be adapted for documenting fishing effort (number of pots used by a vessel) and catch.

Gear Marking for Location Tracking and Surveillance

Gear marking for location provides quicker retrieval of the gear, reduce gear conflict, and improve safety at sea. Location marking also aids in monitoring, control and surveillance by authorities.

Active RFID tags for positioning marking and tracking

Active RFID tags are battery-powered radio transmitters, and can be used in monitoring containers through gates, trains through specific points in the railway track, or vessels passing through a narrow waterway with stationary receivers installed at known locations (Crafts, 2007). If the receiver is installed in a low-flying airplane (whether manned or unmanned), the area of monitoring can be greatly increased (Appler, 2009). Similarly, tags can be installed on fishing gears such as buoys or hyflyers of gillnets and longlines as gear marks, provide means for enforcement and combat IUU fishing, as well as for re-locating gear by fishers.

The only RFID technology test for fishing gear position marking was a pilot study by Irish Fisheries Board (BIM, 2007). The BIM system consisted of several elements, but the tags and readers were all off-the-shelf and commercially available products. The specifications are listed in Table 2.

The tag could be detected up to 240 m. Heavier weather in exposed locations had slightly shorter detection range. It was concluded that RFID technology could be a useful approach for locating fixed gear buoys in adverse conditions and at night when the visibility of buoys was reduced (BIM, 2007).

AIS technology for position marking and tracking

The Automatic Identification System (AIS) is an automatic ship position and tracking system that has been used by vessels, port authorities and maritime security agencies worldwide. Vessels greater than 300 gross tons or passage vessels of any size are required to install an AIS system by the International Maritime Organization (IMO). More recently, European Union has implemented compulsory AIS use for fishing vessels 15 m or longer since 2014, and allowed EU member countries the use of AIS data for monitoring and control purposes (EC, 2017).

There are several types of AIS systems: Class A (range 20-25 nautical miles), Class B (7-8 NM), search and rescue transmitters (SARTs) (3-4 NM), and aid to navigation (ATON). As AIS systems use VHF radio frequency channels, its range of reception is affected by line-of-sight between transmitter and receiver. However, recently-developed satellite-based AIS (S-AIS) systems have much greater range of coverage.

The use of AIS system in the fishing vessels is increasing. While only about 1% of about 1.3 million fishing vessels carry AIS Class A system (Selbe, 2014), many countries are requesting their fishing vessels to carry Class B system. While these requirements are primarily for safety at sea and for port security, there is a potential for use AIS as fisheries monitoring system for combating IUU fishing (Robards et al., 2016), thought there are challenges in infrastructure, resource, as well as privacy concerns. However, the notion of privacy, or “secret fishing spots” has started to change as the public demands for transparency of public resource utilization as well as conservation of the ocean (McCauley et al., 2016). For example, the Global Fishing Watch (globalfishingwatch.org) project provides very much needed “near real-time” information of fishing activities around the globe (Merten et al., 2016).

There is no known implementation or formal discussion of using AIS systems for the marking of fishing gear. However, the system architecture has several unused data slots could be used for specific purposes related to fishing such as the position of fishing gear (Selbe, 2014).

As AIS system was primarily developed for vessel collision avoidance, the use of AIS system and its frequency as fishing gear markers is in a grey area in terms of governmental approval. Some countries allow Class B AIS devices for non-ship uses, while others put restriction on its use. The potential use of AIS devices as fishing gear markers needs substantial national and regional elaborations and international agreements. Nonetheless, there are a few examples that AIS marker buoys may be used for fishing gear marking.

The advantage of AIS-based transponder for fishing gear markers is that many vessels already have AIS receivers, therefore, no additional onboard equipment is necessary. The positions of transponders can also be seen on land-based receivers, mobile phones or personal computers, allowing real-time monitoring of fishing activities and fishing effort by authorities.

The AADI’s AIS drifter marker buoy uses AIS Class B communication protocol and was designed to track the range of oil spills (Aanderaa Data Instruments AS, Norway). The size of the buoy (30 cm diameter) is comparable to many marker buoys used in fixed fishing gears such as pots and gillnets. Signals from the buoy can be received by Class A and Class B AIS receivers and shore-based stations. The range is 7-10 NM from the buoy to a ship, and 25 NM from the buoy to a shore station. The rechargeable battery lasts about 7 days after a full charge. Similarly, some of AIS identifiers intended for small crafts such as speedboats and kayaks may also be suitable as fishing gear markers.

There are several versions of AIS buoys that are marketed as “fishing net tracking buoys” or other similar names, for example, “Matsutec” (Huayang Electronic Technology, China) which provides detailed information and specification. The buoys use the AIS Class B communication protocol, and with a range of 12 NM and last for 10 days. The small size submersible buoy makes it suitable as a part of highflyer for inshore gillnets, longlines and pots, as well as for the marker buoy for Danish seines. Its use in fisheries are not well documented, but they are reported uses in gillnet and Danish seine fisheries in Norway (K. G. Aarsather, personal communication) and Iceland.

Virtual AIS ATON markers (or called eATON) can mark underwater obstacles where it is difficult or costly to install physical ATON devices (CNET, 2014). Position coordinates of the “virtual marker” are sent by an AIS transmitter installed on other locations, or by an existing shore-based AIS station as a part of AIS ATON data. The virtual marker information can be received and displayed on AIS device screens by vessels in the area, but no physical markers exist at these locations. This technology may be utilized for marking fishing gear in the future. For example, the position of a large-scale trap or weir may be "virtually" marked with longitude and latitude data so that the position of the gear is displayed on AIS devices of passing vessels. This would be especially useful for gears set permanently or for an extended period of time, e.g., several months, or years.

Radio buoys for pelagic longlines

The pelagic longline is a major fishing gear used to catch large pelagic fish in oceanic waters and is set near the surface without attachments to the seabed. The gear can thus "drift" with ocean currents. Typical Japanese tuna longliners use up to 3,200 hooks, stretching up to 70 nautical miles (Robertson, 1998). As pelagic longlines are not attached to the bottom, surface buoys and markers are thus very important to keep the hooks in specific depths and for relocation of the "drifting" longline gear. Intermediate buoy lines and buoys are used about every 300 m to reduce sagging of the mainline so that the hooks can be kept in relatively narrow depth strata to target specific species and to reduce bycatch. While end markers use most sophisticated technologies to help relocation, as many as 14 radio beacons were used along the mainline to help steering the vessel during hauling, and to locate the mainline after line breakage on a Japanese longliner (Robertson, 1998).

Longline markers and buoys went through technological changes since the introduction of pelagic longlines in the middle of the 19th Century (Watson et al., 2006). Wooden and glass floats with flagged bamboo poles were used in early days. Carbide lamp or battery powered lights were then used to increase visibility at night. Aluminum and then plastic floats replaced wood and glass floats thereafter.

Modern industrial pelagic longlines are equipped with radio buoys. There are basically two types of radio buoys: radio beacons that constantly transmit signals at specific frequencies, or radio buoys that only transmit signals when they are called (select call or Sel-Call). The former is a transmitter while the latter is a transmitter and receiver system. Other sensors such as GPS receiver, temperature sensor, and acoustic listening device can be attached to the radio buoy, and these parameters can be transmitted to the receiver on the vessel.

Radio beacons (Radio buoys): Radio beacons are radio transmitters that were originally developed in 1920s to indicate a vessel's position (range and direction) by shore- or vessel-based Radio Direction Finders (RDFs). Longline radio beacons are battery-power transmitters attached to a buoy or a highflyer of longlines so that a RDF on a longliner can be tuned to the frequency and determine its direction and distance. Simple radio beacons emit radio signals at a predetermined interval depending on its applications. These buoys have ranges beyond a couple of hundreds nautical miles depending on the height of antenna and the power of receiver.

Sel-Call radio buoys: Because of extensive use of radio beacons by Japanese longline vessels in the 1960s and 1970s, interference between beacons on a crowded fishing ground makes it increasingly impossible to reliably find a vessel's own buoys. The select-call beacon, introduced by Japanese longliners in 1980s, only transmits signals when it receives a specific signal from its owner vessel and was (Miyake, 2004; cited in Ward and Hindmarsh, 2006).

Sel-Call buoys also use less energy so that they can last much longer, sometimes 10 times longer, than comparable continuous emitting radio beacons.

Radio buoys with GPS: Many advanced radio buoys, whether regular radio buoys or Sel-Call radio buoys, can attach position sensors such as GPS sensors (or other satellite location sensors). The location of the buoy can then be transmitted either continuously, at set intervals, or when called in an encrypt format so that only the owner vessel can decrypt the location or other sensitive data.

Solar-powered radio buoys: Typically, longline radio buoys are powered by batteries. Larger battery packs are need for powerful systems (longer range, frequent transmission, additional sensors) for longer service durations. Since the turn of the century, solar power together with rechargeable batteries has made the system last almost indefinitely. This is especially useful for drifting fish aggregation devices as described below.

Marks and buoys for fish aggregating devices

Fish aggregating devices (FADs) have been used in the last 50 years as an aid for purse seine fishing. Purse seine fisheries targets schooling fish, either free schooling fish or schools concentrated around floating objects are targeted. At first, the floating objects were naturally occurring logs and/or debris without ownership. Then, markers were attached to the floating objects so that the vessels could locate the object when they returned. The first commercial man-made floating objects with the purpose to attract and gather fish, thus called fish aggregating device, were deployed in the Philippines in the 1960s (Greenblatt, 1979), but widespread use of purposely-built FADs was not practiced until early 1990s (Davis et al., 2014). Today, the majority of FADs are purposely built and deployed by individual vessels or enterprises. Gradually sophisticated markers, buoys, and electronic devices are attached to FADs for longer-term and exclusive use by the owner vessel. However, there are much confusion about ownership, loss, discard and abandonment of FADs as reported by Gilman et al (2018).

There are basically two types of FADs: anchored (or tethered) FADs (aFADs) and drifting FADs (dFADs). Anchored FADs are mostly deployed nearshore in shallow waters, and in small-scale fisheries. Drifting FADs are deployed in oceanic waters, and typically associated with large industrial operations. Today, about half of tuna catches are from FAD-associated operations (Miyake et al., 2010). Both anchored and drifting FADs are marked for ownership, for position, and for real-time tracking of position (dFADs). The use of sophisticated marking systems significantly increased the number of FADs a vessel can handle, and speed of detection. While there is no reliable assessment, it is estimated that about 105,000 drifting FADs are in use by the world's tuna fisheries, primarily tuna purse seines (Baske et al., 2012). Commercial FAD manufacturers produce 47,500–70,000 FAD buoys per year, primarily for European Union purse seine fleets (Scott and Lopez, 2014), indicating that many FADs are not recovered and left at sea.

Radio buoys were first used in dFADs in 1984 (Lopez et al., 2015). Global positioning systems (GPS) were installed in radio buoys in 1996, with the first generation of echo sounder buoys in 1999. Starting in 2013, multi-frequency echo sounders were installed in FAD buoys (Lopez et al., 2014). The development and introduction of progressively advanced instrumented buoys is shown in Table 3 (Scott and Lopez, 2014). These advances in radio buoy technology contributed greatly to fishing effort and fishing efficiency. Radio buoys and other advanced versions used in pelagic longlines can also be used for FADs; however, marker buoys used for FADs require longer battery life, greater range, and more discrete (privacy) in signal transmission.

Sel-Call buoys. Continuous transmitting radio buoys (or radio beacons) are considered less suitable for dFADs than for longlines because they can easily be detected by other vessels, and thus possibly be “stolen” with signal frequency re-setting, swapping of buoys (Itano, 2002), or unauthorized fishing. Continuously transmitting buoys are also energy intensive, thus have short battery life. Sel-Call radio buoys are much more discrete; only respond to command signals from their owners. Typically, batteries in Sel-Call buoys last 10 times longer than equivalent continuous transmitting buoys, but the battery usage is affected by the power of transmission (affecting range), and frequency of transmission.

Satellite buoys. Using satellite communication technology, the range of communication becomes global, anywhere in the ocean and on the land with satellite coverage. The signals transmitted via satellite is discrete, much like the satellite phone, though there is a cost for transmitting the signal. A GPS sensor is essential for satellite buoys so that the position of the buoy can be transmitted, along with environmental data such as water temperature. Another advantage of satellite buoy is that there is no need for a long antenna, thus reducing detection by radars of other nearby vessels.

Solar-powered buoys. Buoys for FADs are less limited by size, thus are ideal for installing solar panels to recharge batteries. The first solar-powered FAD buoys appeared during the turn of the century (Pino, 2012). Today, most industrial dFAD buoys are equipped with solar panels.

Gear Marking to Aid Recovery of Lost Gear

Abandoned, lost or otherwise discarded fishing gear has become a major issue in terms of their contribution to marine litter, and their impact on marine animals. It is estimated that 10% of marine litter are a result of ALDFG (Wilcox et al., 2015). Some ALDFG such as gillnets and pots continue to catch fish, causing ghostfishing, which wastes valuable marine resources and harms vulnerable marine animals including some of the most endangered species (Macfadyen et al., 2009; Gilman et la., 2016; Stelfox et al., 2016). There are a few measures to deal with ghostfishing of ALDFG, including measure to prevent gear loss and abandonment, retrieval of ALDFG, and mechanisms to reduce fishing efficiency of lost gear (de-ghosting technology) (DFO, 1995; Macfadyen et al., 2009).

Prevention of gear loss and abandonment includes measures for proper gear marking for identification of ownership as well as for position (FAO, 2016). Limits on the amount of gear that can be deployed is also an important measure so that vessels have extra capacity for retrieving gear under adverse conditions. Technologies to reduce or deactivate gear include degradable panels or degradable nets. Recent research on degradable nets has showed good promise for gillnet and pot fisheries (e.g., Kim et al., 2012; 2016). Proper gear marking, and mandatory reporting of lost and/or abandoned gear (amount and position) by fishers would help recovery by the industry and by government authorities. Technologies that allow for relocating lost fishing gear will aid speedy recovery of lost gear.

Apart from gear marking and associated reporting mechanisms that would reduce ALDFG and assist in its recovery, specialized devices can be used to aid recovery of lost fishing gear. Successful retrieval of lost gear is an important consideration in oil explorations, subsea surveys, naval excises, and ocean research. Equipment used in these fields are usually much more expensive than those in fisheries.

Gear relocation devices typically use acoustic technology, taking advantage of superior sound transmission property in the sea water. There are basically two types of technologies: active pingers (or transponders) and passive sonar reflectors. The first method is based on detecting specific frequencies of sound from the locator tag using a receiver hydrophone, and the second is based on enhanced target strength of the locator using an echo sounder or a sonar.

Pinger/transponder locator markers

Pingers (also called beacons) continuously emit acoustic signals at certain frequencies once in the water. A hydrophone is used to listen to the acoustic signals from the pinger to home in its position. A transponder listen to the acoustic signal from a commend unit via a hydrophone. Once it has detected a certain signal, the transponder sends an acoustic signal back to the hydrophone, so that the location of the transponder can be determined. Many marine technology companies manufacture acoustic pingers and transponders for offshore oil and gas related activities and for ocean explorations (e.g., AUVs).

Acoustic pingers are required in gillnets in many jurisdictions around the world to reduce the interaction between gillnets and marine mammals. These pingers typically operate at 10 KHz, but some are up to 160 KHz. “Pinger detectors” have been developed for enforcement purposes – to check if pingers are attached to required gillnets in the area and if they are working. These pingers and the detectors can be used for locating gillnets (or any other gear with a pinger) if they become lost. German researchers tested a long-range pinger detector which could detect both analog and digital pingers between 10 and 160 KHz, and with the help of an onboard GPS, to calculate the distance between the pingers installed in gillnets (ICES, 2008).

One of the specialized lost fishing gear locator devices is the Gearfinder manufactured by Notus Ltd (St. John’s, Canada) some twenty years ago when deepwater gillnets fishing for Greenland halibut off Newfoundland and Labrador started to experience gear loss. The Gearfinder 700 is a transponder/receiver system that is marketed to the fishing industry as seen in Figure 2 (Notus, 2018). The transponder can operate down to 1300 m in depth, and with horizontal distance of up to 2 NM.

More recently, another gear locator that was developed (France. www.scatri.com). The Deepsea Launcher System (DLS) consists of an underwater buoy system and an onboard command unit has potential for relocating small scale fixed gears (Scatri, 2016). The buoy is submerged about 15-40 m below surface when the gear is in fishing conditions so that it will not interfere with passing vessels. The buoy line breaks when an unauthorized person tries to haul the gear from the buoy line, preventing unauthorized hauling of the gear. When the owner vessel with the command unit approaches the gear, and emits an encoded acoustic signal, the buoy will release a section of rope that is tucked inside the buoy, and emerge from the surface. The buoy will also rise automatically if water leaks into its watertight compartment or the battery operating its electronic components becomes too low, preventing accidental failure of the system.

Passive sonar reflectors

Enhancing or reducing reflectivity of objects underwater comes at the same time the echo sounder was invented. For marking objects underwater, measures have been taken to enhance reflectivity of objects, including the size, shape, material, and other features (Islas-Cital et al., 2013).

One notable passive sonar reflector device that has recently attracted attention is the SonarBell (Subsea Asset Location Technologies, UK). SonarBell is a passive, omni-directional sphere with proprietary design (Smyes, 2011). Looking like a bowling ball, it utilizes the different materials in the shell and core to create a constructive interference to result in a return signal significantly greater than that from a solid reflecting sphere (Proctor et al., 2010).

The SonarBell comes with different sizes (50, 100, 200, and 275 mm diameter) and designed for different frequencies from 8 to 140 KHz. SonarBells work with a wide range of sonars (including echo sounders), but the best result would be achieved when the frequency of sonar can be tuned to resonate that of SonarBell. Locating lost fishing net is listed as one of the applications in its website (www.cesalt.co.uk), though no detailed information is available.

Summary and Conclusions

Abandoned, lost or otherwise discarded fishing gear (ALDFG) is a significant part of marine litter which pose navigational hazard, destroy living marine resources through ghostfishing, and endangers marine magefauna and other protected species. Fishing gear marking is one solution to combat ALDFG and ghostfishing. Globally a systematic and standardized gear marking that fulfils requirements of indicting ownership and position, serving as a tool for capacity management and control, combating IUU fishing, and preventing of ALDFG and ghostfishing is required. Proper and advanced gear marking and associated reporting system also provides a means for successful recovery after the gear have been lost. Various gear marking technologies exist and new technologies are being developed and implemented. Different technologies described in the previous sections have their own advantages and disadvantages, and are suitable for specific uses. Table 4 summarizes and compares different technologies that are used as gear marking in world fisheries.

Coded wire tags have been tested for tracing the origin of fishing gear components, especially fishing ropes after they become entangled in marine mammals. Miniature CTWs can be implanted in fishing ropes with no effect on their performance; however, an excessively large number of tags is needed in order to provide reliable data on the origin of the rope. Implanting RFID tags in fishing ropes for identification of origin was less successful due to difficulties in securing the tag inside the rope. RFID tags attached to gear components that identifies ownership and for capacity management have potentials as a management and research tool. Longer-range active RFID tags for indicating the position of the gear need further testing and technological development. The use of Automatic Identification System (AIS) transponders as fishing gear markers is in a grey area in terms of legality, but the technology is mature, affordable, and has potential for avoiding gear conflicts, location-tracking, capacity management, and for combating IUU fishing. The potential use of AIS devices as fishing gear markers needs substantial national and regional elaborations and international agreements. Advanced electronic buoys (radio buoys) have been available for last thirty years for pelagic longlines and fish aggregation devices. Solar-powered satellite buoys are now commonly used for large-scale offshore aFADs, proving unlimited range and long operating time. Technologies for relocating lost gear are widely available in offshore oil and gas sectors, and for ocean exploration, but these technologies are generally too expensive for fisheries applications, especially in small-scale fisheries in developing countries. Further research and development of cost-effective devices for relocating lost fishing gear is still needed.

Gear marking technologies are fast evolving with the advance of electronics and computer technologies. With the broadening of national and international fisheries enforcement through monitoring, control and surveillance (MCS), advanced gear marking technologies may become an integral part of fisheries management in the future.

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Table 1. Technical and functional differences between passive and active RFID tags (modified from Savi Technologies (2007).

Technical/functional parameters	**Passive RFID tag**	**Active RFID tag**
Power source	From reader/no battery	Internal/battery
Tag battery	No	Yes
Availability of power	When within reader's range	Continuous
Signal strength from reader	High	Low
Signal strength to reader	Low	High
Detection range	Short (<3 m)	Long (up to 100 m)
Sensor capability	Very limited	Yes/multiple
Data storage	Very limited	Yes/multiple
Multi-tag readability	Limited	Yes
Tag size	Small	Large
Tag cost	Low	High

Table 2. Specification of the active RFID tag (ID-004) tested by BIM (2007).

Function	Parameter	Specification
Receiving	Band	LF
	Frequency	125 KHz
Transmission	Band	UHF
	Frequency	868 MHz
	Power	+2 dB
	Range	50 m
Data	ID	134 million possibilities
	Signalization	State of battery
Electrical	Source	Li battery 2.2 – 3.2 VDC
	Autonomy	2 million operations (~3 years)
Environmental	Storage temperature	-20° C to +60° C
	Working temperature	-10° C to +50° C
Mechanical	Dimension	106 x 76 x 12 mm
	Weight	72 g
	Protection	IP65

Table 3. Development of instrumented buoys and their introduction in tuna fisheries as well as their main detection and powering characteristics (Modified from Scott and Lopez, 2014). EDF – radio direction finder.

Type	**Year**	**Signal detection/ transmission**	**Detection range(NM)**	**Power**	**Notes**
Radio buoys	mid 1980s	RDF (constant transmission)	100	Battery	Detectable by other RDFs and radars
Sel-Call radio buoys	late 1980s	RDF (no constant transmission)	200	Battery	Detectable by other RDFs and radars
Radio GPS buoys	mid 1990s	RDF (no constant transmission) + GPS	700-900	Battery	First expansion of FAD fishing grounds
GPS tracking buoys	late 1990s	GPS position (continuous emitting)	1000	Battery	First with info on battery status and SST
Echo-sounder buoys	2000s	Satellite connection + light when approached	Virtually unlimited	Battery	First echo-sounder readings
2nd gen. echo sounder buoys	mid 2000s	Satellite connection	Virtually unlimited	Solar panels/ battery	First with on current speed and direction
3rd gen. echo sounder buoys	2012	Satellite connection	Virtually unlimited	Solar panels/ battery	Multi-frequency echo sounder transducers

Table 4. Comparison of different marking technologies and their applications.

Mark type	Detection distance	Usage and comments
Flags/floats	Visual range	Easy to fit; generally available; visible; easy to recognize from distance; cheap; generally accepted
Color marking	Visual range	Not unique but fishery-based identification; availability of colors limited; monofilament nets hard to re-color
Printable tracer	Visual range	Can be woven into ropes or twines; cheap
Physical tags	Visual range	Limited information on tags; good for individual gears
Chemical marking	Not visible	Cannot be removed; whole net is identifiable at manufacturing level; reusing the net may cause problems in the identification or tracking; high cost to entry
Coded wire tag	Under microscope	Small; need other marking to indicate the existence
RFID - passive	Within 3 m	Relatively cheap; generally available; informative; flexible use; widely tested in pot fisheries
RFID - active	100 m or more	More expensive; large size; need battery; longer detection range
AIS transponder	Up to 25 NM	Legal issues; for satellite-linked AIS, unlimited range; available existing infrastructure
Radio beacon	100-1000 NM	Large size; suitable for large buoys, e.g., pelagic longlines and FADs
Satellite buoy	unlimited	High detail of information; rapid recovery; relatively expensive; high service/use costs (data subscribe fee)
Acoustic transponder	Within 2 NM	Expensive; difficult to install; easy to remove (steal)
Passive acoustic reflector	Receiver dependent	Similar to the size of fishing floats; no need for battery; yet to demonstrate for fisheries use

Figure captions

Figure 1. Coded wire tags (CWTs) that were injected into the rope (A), or tucked inside a braided twine (black thread), then spliced into the rope (B), and Comparison of sink line used for accelerated longevity testing with the new rope on left, the worn CWT-embedded rope (simulated 5 years of hauling) on the right (C) (from Krutzikowsky et al. 2009, with permission from Center for Coastal Studies, Provincetown, MA, USA).

Figure 2. The principle of Gearfinder 700 manufactured by Notus Ltd in St. John’s, Canada (www.notus.ca). Inset: the components - the transponder, the hydrophone and the receiver with cable. Used with permission from Notus Ltd.

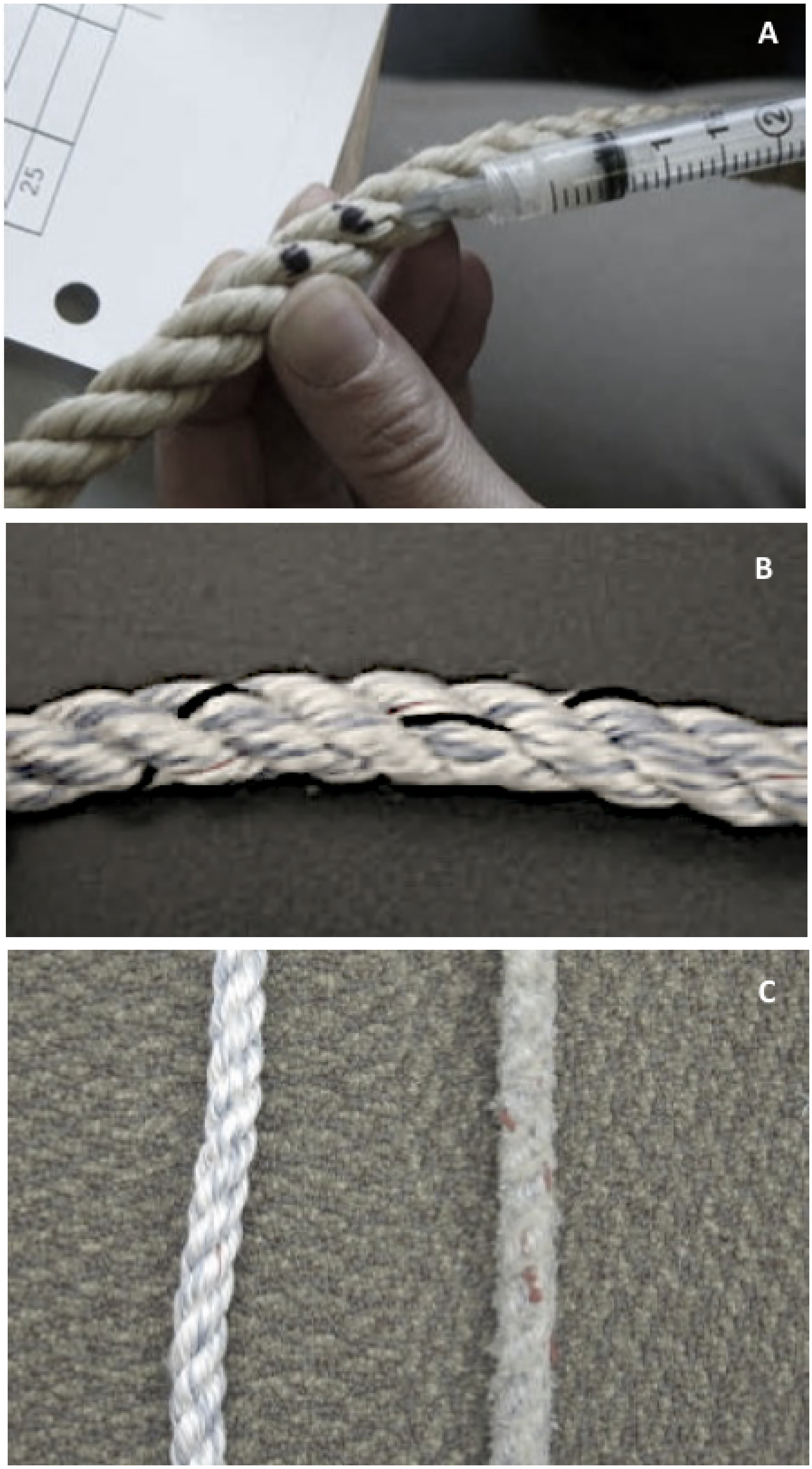

Figure 1

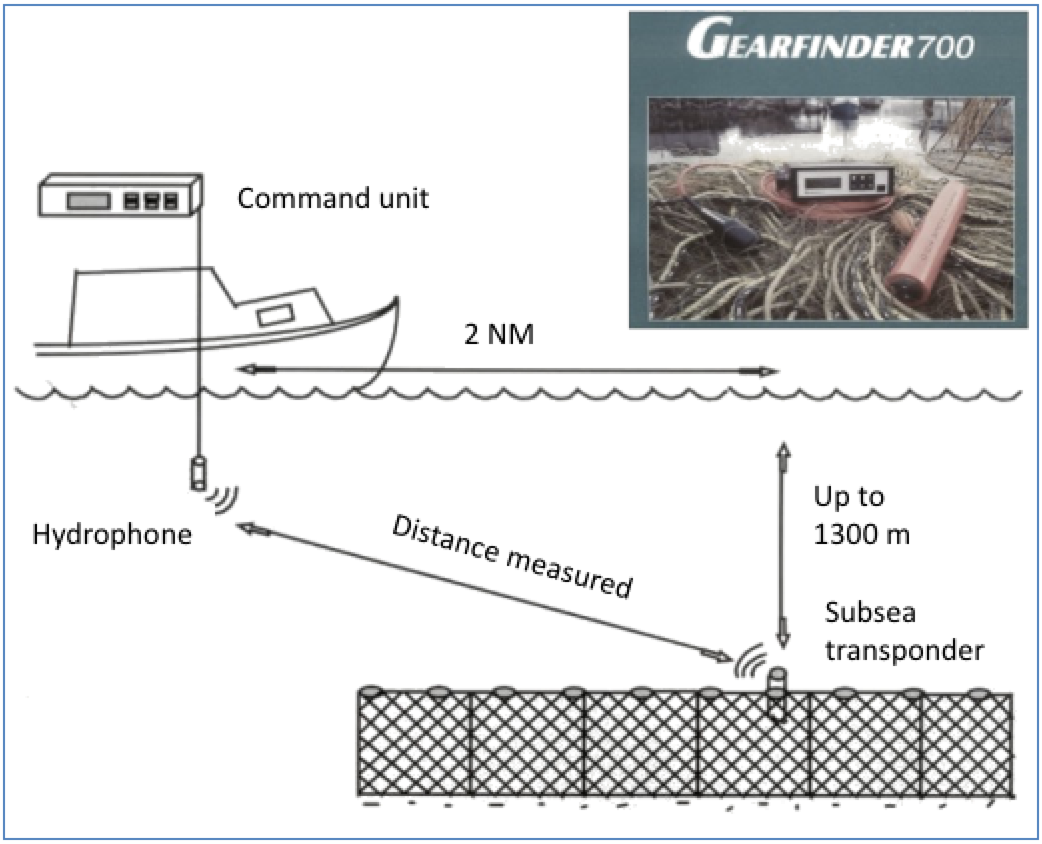
GEARFINDER 700
Command unit
2 NM
Up to
1300 m
Hydrophone
Distance measured
Subsea
transponder

Figure 2