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EXPERT CONSULTATION ON THE MARKING OF FISHING GEAR
ROME, ITALY, 4 – 7 April 2016
Venue, FAO HQ Mexico Room
NEW TECHNOLOGIES FOR MARKING OF FISHING GEAR

DRAFT

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Executive summary

Fishing gears are marked to establish and inform origin, ownership, capacity management, and for position. Traditionally physical marking, inscription, writing, color, shape, tags have been used for ownership and capacity purposes, and 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 location by owner vessels but less easy for others. This report reviews recent advances in gear marking technology with focus on coded wire tags (CWT), radio frequency identification tags (RFID), Automatic Identification Systems (AIS), advanced electronic buoys for pelagic longlines and fish aggregation devices (FADs). The report also includes new lighting technology, especially light-emitting diode (LED) lights for fishing gear marking, and re-location technology if the gear becomes lost.

Coded wire tags (CWTs) have been successfully used for tagging fish to better understanding their migration routes and to their stock structure. CWTs have been tested for tracing the origin of fishing gear components, especially fishing ropes, when they become entangled in marine mammals, turtles and other large marine animals in the United States. Miniature CTWs can be reliably implanted in fishing ropes with no effect on their performance. The large number of tags needed in order to provide reliable data on the origin of the rope has limited their application.

Radio frequency identification tags (RFID) are widely used in supply chain and logistics management, and in the retail industry. RFID systems consist of a tag and a separate reader that can wirelessly provide information when the tag is within the range. Tests on RFID tags implanted in fishing ropes for identification of origin were 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 more potential as a management and research tool. Longer-range active RFID tags that were tested for indicating the position of the gear need further testing and technological development.

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. An AIS system consists of a transmitter (transponder) and a receiver. The use of AIS transponder as a fishing gear marker is in a grey area in terms of legality, but the technology is mature and affordable. The use of AIS markers for fishing gear has potential for automatic identification of fishing gear position to the owner vessel and other vessels passing by to provide navigational aids and to reduce potential gear conflict.

Advanced electronic buoys (radio buoys) have been available for last thirty years for pelagic longlines and fish aggregation devices (FADs) operated by purse seiners. The buoys for both fishing sectors are very similar in many ways, but also have differences. Radio buoys for longlines do not require a long range. Buoys for drifting FADs require longer transmitting range, longer batter life, and encrypted signs. Satellite buoys with solar power are now commonly used for industrial purse seine operations, proving unlimited range and extra long operating time.

Lights have been an integral part of fishing gear markers for the night. Due to their energy efficiency and long life, LED lights are increasingly used for gear marking. Solar panels are fitted in some LED lights, but space required for the solar panel has made them less suitable for compact lights for small vessels. Many large radio buoys for pelagic longlines and FADs have installed solar panel to recharge batteries to prolong operating time for electronics and lighting. The use of wave and tidal energy to power lights for fishing gear markers is in early development.

Fishing gear can become lost due to various reasons and some of lost gear (e.g., gillnets and pots) continues to catch fish, causing ghost fishing. Technologies for re-locating 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. As a result, most fishers resort to ‘creeping’ for lost gear with grapnels, a cheap but often time consuming process. Research and development of cost-effective devices for relocating lost fishing gear is still needed.

1 Introduction

Fishing gears are marked to establish and inform their origin, ownership, capacity management, and position. Traditionally physical marking, inscription, writing, color, shape, tags have been used for ownership and capacity purposes, and buoys, lights, flags, and radar reflectors are used for positional marking. More recently, electronic devices have been installed on marker buoys for easier location from a distance.

There is a need to identify the origin of fishing gear or its components when they become lost or entangled on marine animals. Understanding the area and fishery the gear component originally came from would provide valuable information in fishing gear modification, area/season closure and other management measures to reduce entanglement and potential mortality of venerable animals such a whales, porpoises, turtles, and other animals. This is especially applicable to fixed gears such as pots[1], gillnets, longlines, and traps. A study by Johnson et al (2005) revealed that only 45% of gear components entangled on North Atlantic right whales (*Eubalaena glacialis*) and humpback whale (*Megaptera novaeangliae*) on the US side of the North Atlantic could be identified for its origin (region/fishery). Currently, US National Marine Fisheries Services uses a scheme of colored rope sections to for different regions and fisheries to aid the identification of origin if they become entangle on an animal (NOAA, 2015). The International Whaling Commission (IWC) also consider fishing gear marking as an important issue in protection of cetaceans and recommended that Committee on Fisheries (COFI) complete its work on gear marking (IWC, 2014).

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 is regulated by many states and Regional Fishery Management Organizations (RFMO) to either limit fishing effort, or to reduce probability of gear loss. 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 (e.g., gillnets) or attached to the buoy (e.g., 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 illegal fisheries.

Gear marking for position not only provide quick recovery of gear by its owner but also aid to navigation to other users, and reduce gear conflict between gear sectors (e.g., fixed and mobile gear sectors). Flags, lights, and radar reflectors are still the main position markers for coastal fisheries. More advanced gear markers have been used by offshore longlines and purse seines using fish aggregation devices (FADs). There are more than 100,000 drifting FADs in use by world's tuna fisheries, primarily tuna purse seines with an estimated production of 47,500–70,000 satellite-tracked advanced FAD buoys per year (Baske et al., 2012). With advances in electronics technology and satellite communication, the use of advanced longline and FAD

[1] Pots and traps have been interchangeably used in many literatures. In this document, a pot is referred to small baited enclosures (e.g., lobster pot, crab pot), while a trap is referred to a large un-baited structure (e.g., Newfoundland cod trap).

buoys not only increases catch per unit effort, but also has implications in effort monitoring and in combating illegal fishing by various levels of authorities.

Fishing gears become lost due to various reasons; some of these lost gears (e.g., gillnets and pots) continue to catch fish, causing ghost fishing (Breen, 1978; Macfadyen et al., 2009). There are a few measures to deal with ghost fishing issues of lost, abandoned or otherwise discarded fishing gear, 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 as well as gear marking technologies that aid recovery of lost gear.

This report was written as a part of the preparation for the FAO Expert Consultation on the Marking of Fishing Gear held on 4-7 April 2016 in Rome, Italy. This report reviews recent advances in gear marking technology with focus on coded wire tags (CWT), radio frequency identification tags (RFID), Automatic Identification Systems (AIS), advanced electronic buoys for pelagic longlines and fish aggregation devices (FADs). The report also includes new lighting technology, especially light-emitting diode (LED) lights for fishing gear marking, and relocation technology if the gear becomes lost.

2 Coded Wire Tags

2.1 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). Binary codes replaced colored codes in 1971, then by decimal numbers around the turn of the century when laser-etching technology became available (Nandor et al., 2009). The standard tags are 0.25 mm in diameter and typically cut at 1.1 mm in length (Figure 1), but shorter (0.5 mm) and longer (1.6 and 2.2 mm) versions are also available. The tags are made of stainless steels and can be detected by specialized electronic detectors, and read under a microscope. Coded wire tags and associated injection and detection devices are manufactured by Northwest Marine Technology Inc. based in Shaw Island, WA, USA (http://www.nmt.us).

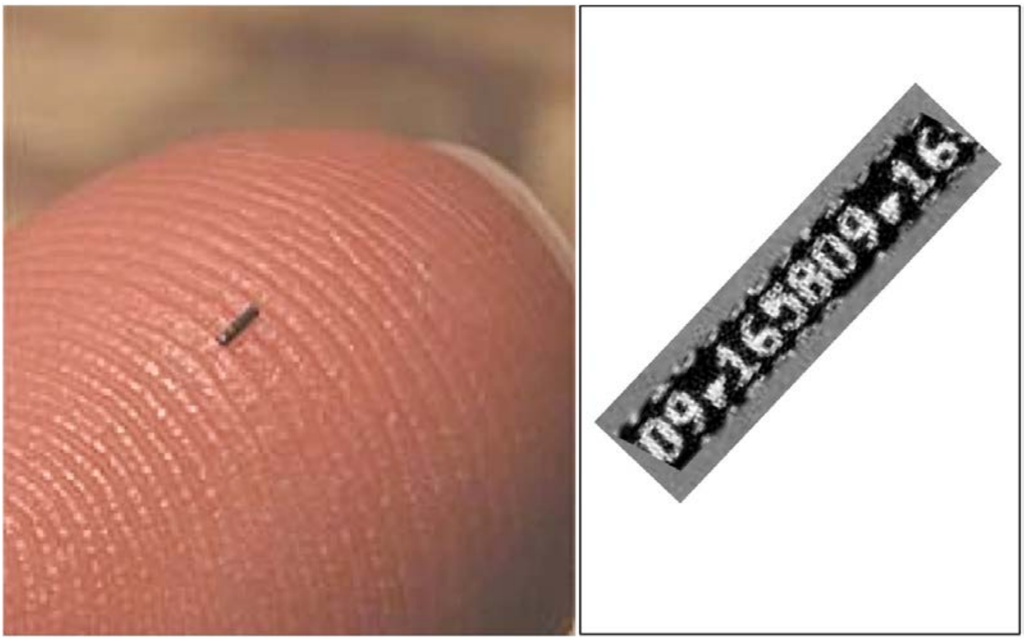

Figure 1. The standard coded wire tag (1.1 mm x 0.25 mm) as it appeared in a fingertip (www.nmt.us/products/cwt/cwt.shtml).

Coded wire tags may come with a unique code number 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.

2.2 Coded Wire Tags for Identification of Origin of Fishing Gear

The single study that has tested the feasibility of using CWTs for marking the origin of fishing gear, specifically ropes for use in fixed gear (pots, gillnet and longlines) was conducted in Massachusetts (USA) by Krutzikowsky et al. (2009). Information presented in this section was mostly from that study, unless otherwise stated.

The purpose of the study was to determine how CWTs could be implanted into fishing ropes, whether the tags would be retained in the rope after extensive use (simulated), and how the tags could be extracted and read. The project also evaluated costs of implementing such techniques for identification of ropes entangled in whales in eastern USA.

Type of coded wire tags tested

The project used standard size (Φ0.25 mm x 1.1 mm) pre-cut sequential CWTs. Sequential CWTs have three repeating numbers followed by one unique 5-digit sequential number (Figure 2). This allows the identification of region, fishery, license number and individual location of the rope when it was set by the fisher.

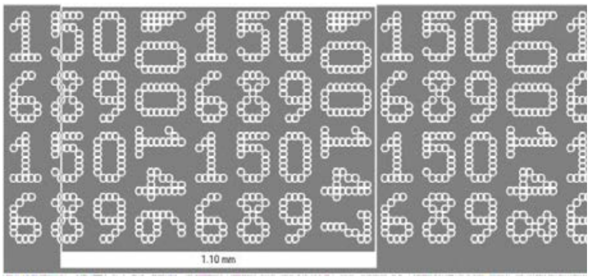

Figure 2. Numbers in the coded wire tags (Krutzikowsky et al. 2009).

Methods of implanting tags to ropes

Two methods for implanting CWTs to ropes were used: 1) injection with adhesive, and 2) implanting within a braided twine.

Two types of adhesives were used for implanting CWTs directly into ropes:

1. 3M Scotch-Weld 2216 translucent adhesive (http://multimedia.3m.com/mws/media/153955O/3mtm-scotch-weldtm-epoxy-adhesive-2216-b-a.pdf)
2. Bostik marine grade 920 urethane sealant (http://www.bostik-us.com/sites/default/files/920fs.pdf)

The tags were injected to the rope strand together with one of the adhesives with handhold syringe with a 20-gauge 13 mm long needle (Figure 3 A).

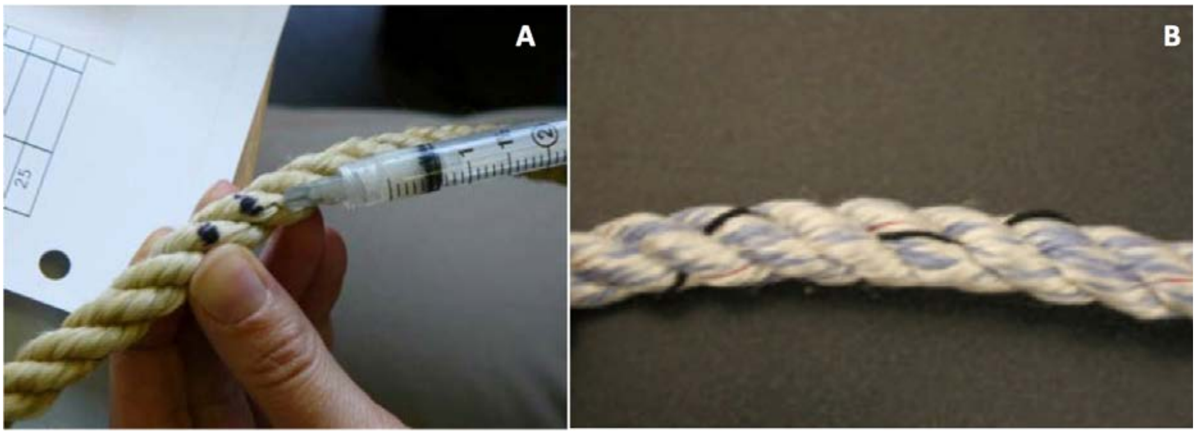

Figure 3. Coded wire tags (CWTs) that were injected into the rope (A) or tucked inside a braided twine, then spliced into the rope (B) (Krutzikowsky et al. 2009).

The second method used a braided nylon twine as an intermediate for which the CWTs were first implanted. The braided twines were then spliced into a rope at a desired interval (Figure 3 B). For this method, a 25 cm long #18 braided nylon twine was used as the intermediate. Pre-cut CWTs were injected into the twine using a standard single-shot tag injector manufactured by Northwest Marine Technology Inc. One CWT was injected into one piece of 25 cm long twine. For test purposes, pieces of twine were either treated with a clear rope-whipping compound or without.

<u>Fishing trials</u>

Ropes treated with both implanting methods, each with two different adhesive treatments were tested at sea in the Gulf of Maine and on the US Mid-Atlantic coast on board five pot-fishing vessels targeting American lobster and black sea bass. None of the vessel skippers reported issues with the marked ropes using either method.

<u>Longevity test</u>

The ropes implanted with CWTs using both implanting methods went through accelerated longevity testing under laboratory conditions. Two types of ropes commonly used in New England fixed gear (pot, gillnet and longline) were used for the test: Polysteel and Ever Haul. Polysteel ropes (http://www.polysteel.ca/index2.php?menu=comm1#) are a type of high strength, low elongation polypropylene rope that is commonly used as buoy ropes. Another type of rope tested was Ever Haul blue rope (http://www.orionropeworks.com/fishingeverhaulmed.htm) which is commonly used as ground rope linking a string of pots when fishing as a fleet. This is a sinking rope as required by National Oceanic and Atmospheric Administration (NOAA) for use as groundrope. Both types of ropes were tested in a rope-testing machine (see 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 4).

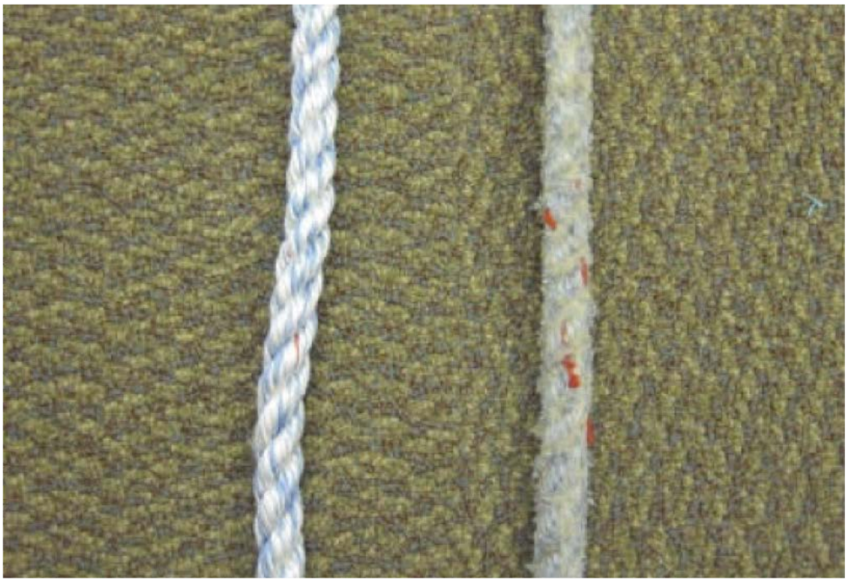

Figure 4. Comparison of sink rope used for accelerated longevity testing of CWTs. Left: new rope, right: run in the machine to simulate 5 years of hauling in offshore commercial fishing operations with CWTs in a red braided twine. From Krutzikowsky et al. (2009).

Tag retention, detection, extraction and reading

There seemed no differences in retention between two different adhesive treatments. Overall about 75% of tags were retained in ropes after one fishing season. For tags implanted in braided twines, coated twines were better in retaining tags than those uncoated twines. Between direct injected tags and those implanted using braided twines, the latter retained tags better.

Coded wire tags were detected using a handhold T-Wand tag detector manufactured by Northwest Marine Technology Inc. (http://www.nmt.us/support/TWandSpecSheet.pdf) from returned ropes or twines segments. CWTs in braided ropes were much easier to extract than those directly implanted into ropes with adhesive. About 90% of extracted tags were readable under a Leica S60 dissecting microscope. For a set of double-blinded treatment, 100% of ropes were correctly identified after tags were read.

Costs and other practical considerations

The material costs for each tag was projected to be $0.17 USD from the study if continuous standard CWTs were used. The real costs for identifying ropes entangled on whales depending on the linear density of tags in a rope. Based on the length of ropes recovered from entangled whales between 1997 and 2003, the length of rope on whales ranged from 1.5 to 366 m. If ropes were tagged every 12.2 m, 9 out of 10 ropes on entangled whales would be likely identifiable. The cost for marking ropes would thus be about $18 USD per km ropes if per tag cost is $0.25 and with the probability of identifying an entangled rope at 90%. The cost increases as tag price increases, or when higher probability of identification is required.

Coded wire tags seem to be a possible means for tagging ropes for identification of ropes entangled on marine mammals or for fishing gear lost or otherwise disposed. No further work on the concept has been carried out since the 2009 Massachusetts study, probably due to prohibitive costs considering the length of rope in use in the fishery (E. Burke, Massachusetts Division of Marine Fisheries, personal communication, January 26, 2016).

3 Radio Frequency Identification Tags

3.1 Introduction to Radio Frequency Identification tags

Radio Frequency IDentification (RFID) refers to technologies that automatically identify objects through the use of radio waves (RFID Journal, 2016). A generic RFID system includes a reader containing an antenna that sends out electromagnetic waves and a tag also containing a microchip and an antenna that is tuned to the wave from the reader. The microchips can be read-only or read-write. Typically a basic RFID tag can carry 2 KB of data. More advanced read-write tags may be linked to different sensors and store information such as temperature or GPS coordinates with a time stamp.

There are two basic types of RFID tags (or called transponders): passive tags and active 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 also exists; it 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.

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

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

RFID systems operate in four frequency bands: low frequency (LF, around 125 KHz), high frequency (HF, 13.56 MHz), very high frequency (VHF, 100 MHz), ultra-high frequency (UHF, 433 and 868 MHz, and 2.4 GHz). Lower frequency systems typically use less power; they can better penetrate high water content objects, but frequencies less than 100 MHz only work at close range due to its dependence on inductive coupling (Savi Technologies, 2007). On the other hand, higher frequency systems have better range; but they use more power, are less capable to penetrate material, thus work when the tags can be "seen" by the reader.

Frequency of 433 MHz was recommended as the best choice for active RFID tags (Savi Technologies, 2007).

Generally speaking, RFID tags can only be read within a short distance. The read range is affected by many factors such as the frequency of operation, the type of tag (passive or active), the power of the reader, and interference from metal objects or other RF devices (RFID Journal, 2016). 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 use batteries to boost reading range for up to 100 m (RFID Journal, 2016).

3.2 RFID Technology for Identification of Origin of Fishing Gear

RFID technologies have been used for identification of the origin of the items that contains a RFID tag, and its movement history. It has been widely used in supply chain and logistics management. In fisheries research, the technology has been used for tagging and tracking fish to understand stock structure, migration, and movement. For example, the use of Passive Integrated Transponder tags, or commonly called PIT tags, have revolutionized marine and terrestrial animal research in the past 30 years.

Nets and ropes set in the aquatic environment can often accidentally entangle whales and other megafauna species. Sometimes the animals stuck in the gear and die, while in other cases the gear can be towed away, which can also cause injury and mortality. In order to assess which fishing gear types and seasons/locations are posing the greatest risk to these animals, it is necessary to determine the origin of fishing gear components (e.g. rope sections) remained on animals after accidentally entangled with the gear. This would provide scientific basis for implementing technical measures for specific gear types, at specific locations and in specific fishing seasons. Determining the origin (ownership and gear type) is also necessary for identifying fishing gear lost at sea for assessment of ghostfishing capacity and owner responsibility.

Currently, different colored traces are implemented for different fishing areas and gear segments in the US Atlantic coast (NOAA, 2015). NOAA has also been supporting research for advanced gear marking technologies using RFID technology since 2004, in addition to coded wire tags described in the last section. Since 2004, three studies have been carried out in the US on the feasibility of attaching RFID tags to fixed gear ropes. However, up to now, there are no known RFID tag uses in ropes or netting in commercial fisheries in the US or any other countries.

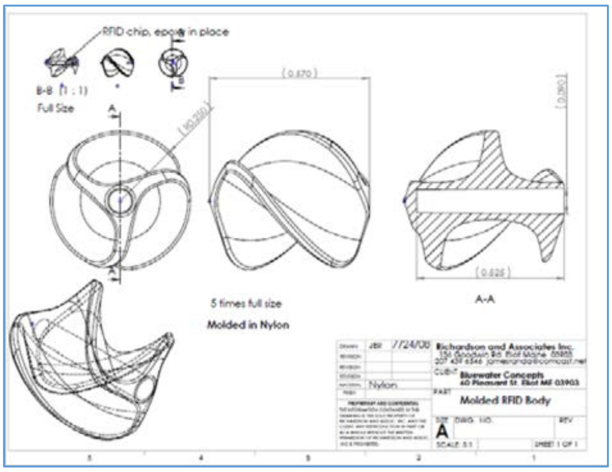

Figure 5. Drawing of the patented molded components for inserting RFID tags in rope (Brickett and Moffat, 2004).

The 2004 study by Whale safety Products, Inc. (Kittery, ME, USA) was probably the first attempt to implant RFID tags to fishing ropes for identification of its origin (Brickett and Moffat, 2004). They use a molded apparatus that houses a RFID tag. The apparatus was then inserted in the ropes.

The subsequent study by La Valley et al. (2010) was to refine the rope-tagging method and further evaluate its applicability for fixed gear fisheries. The passive RFID chips used was typical PIT tags used for tagging fish and was produced by BioMark Inc. (Boise, ID). The tag was enclosed in a proprietarily designed molded nylon (Brickett and Moffat, 2004) that was then implanted in the ropes (Figure 5). The tagged ropes (11 mm diameter Polypropylene and Polyester mix and 13 mm Polysteel PP) were tested in a simulated rope-hauling machine to accelerate the rope wear to an equivalent to 40 years of hauling. The ropes showed significant wear at the points where the RFID chip was imbedded (Figure 6). These "worn" ropes were tested for strength and for the integrity of the chip functionality. The ropes broke at the area where the tags were implanted, but RFID tags were still readable at the end of test. The tagged ropes also went through hydrostatic pressure tests for depths down to 335, 1034, 1400 m in a hyperbaric chamber. All RFID tags were still readable at each depth tested.

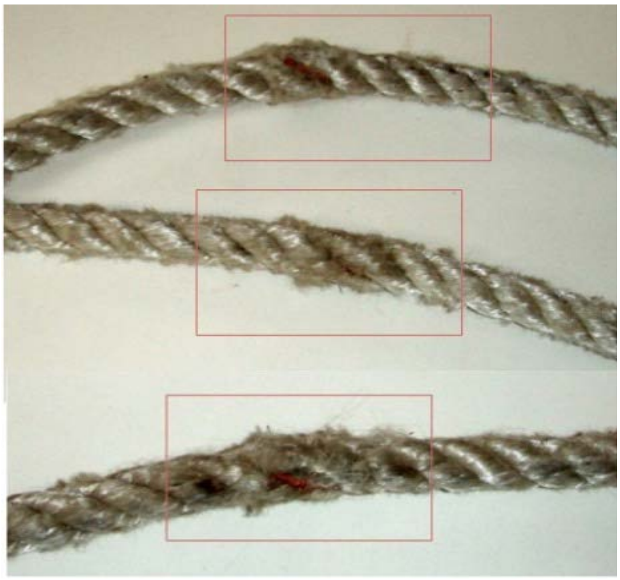

Figure 6. Severe wear of rope at the tag insertion points after a simulated 40-year hauling (La Valley et al., 2010).

The tagged ropes were sent to offshore lobster pot fishery (Georges Bank) and inshore gillnet and lobster pot fisheries (Gulf of Maine) for field-testing. All RFID tags after inshore gillnet and lobster pot field use were still readable, but only 54% of those tags from offshore lobster pot fishery could be read. Offshore lobster pot fishing on Georges Bank is usually conducted with tens of pots in a fleet, and experience much rough weather and sea conditions, compared with inshore Gulf of Maine pot fishery where usually one pot is attached to one buoy line and one float.

The “naked” RFID tags used in this study 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 the nylon molds. The imbedded tags inserted in the twisted fishing rope did not reduce detection distance, but interestingly, the detecting distance was increased to 15 cm when the rope was wet with seawater. In addition, La Valley et al. (2010) found that the best material to mount the reader antenna was either wood or high-density polyethylene, while aluminum and stainless steel had too much interference, rendering them unsuitable for mounting the reader antenna.

The other study on attaching RFID tag was conducted by RFID Research Center of Walton College of Business, University of Arkansas (Patton and Cromhout, 2011). Initially “weave-in” tag types were tried (Figure 7), but were proven unsuitable for the deck machinery that handles the ropes. They then 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). The devices looked similar to electrical tapes with RFID inlays. The tag inlays were made water resistant and were tested in seawater. 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 would have longer detection range measured in meters, while UF tags can 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 or fishers to access tag information in the field.

However, none of the devices attached to 11 mm diameter ropes survived simulated test runs (Figure 8), though the UHF tags fared better than NFC tags. They concluded that RFID tags themselves are viable devices that offer potential for rope identification, but more research would be needed on the method of attaching them to fishing ropes.

In addition, NOAA was also supporting research on what is called “Super Smart Tape” techniques consisting of a brightly colored tape with a RFID chip that is easily attached to a rope (NOAA, 2010). No further information on this development is currently available.

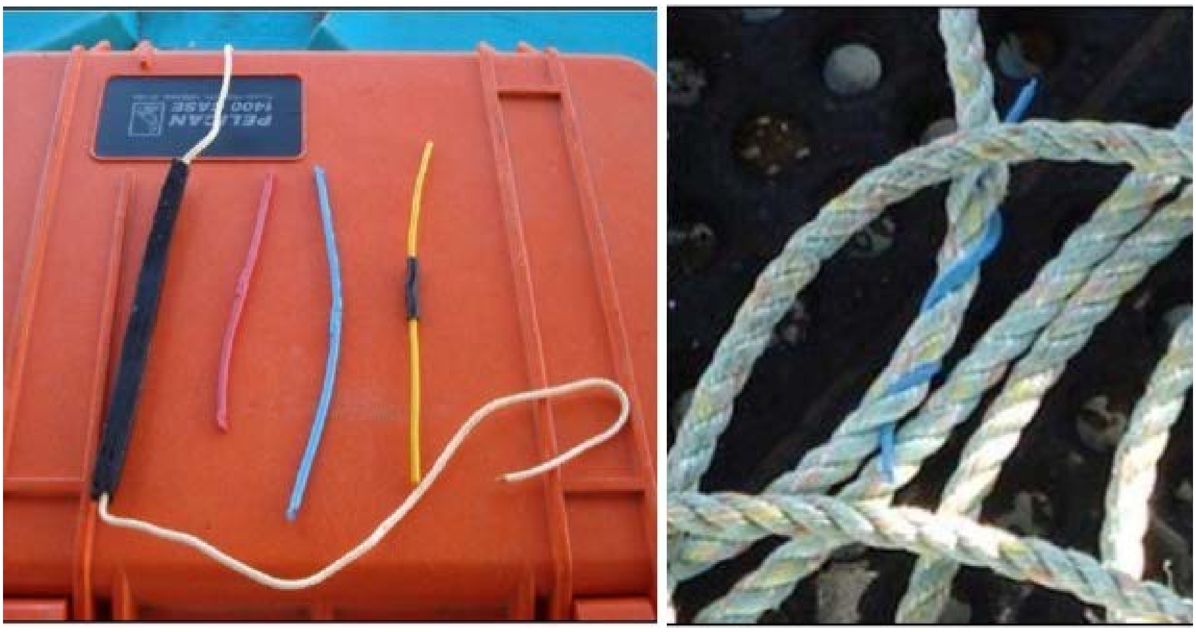

Figure 7. RFID tags inside rubber tubes (left) and then “weaved” in ropes (Patton and Cromhout, 2011).

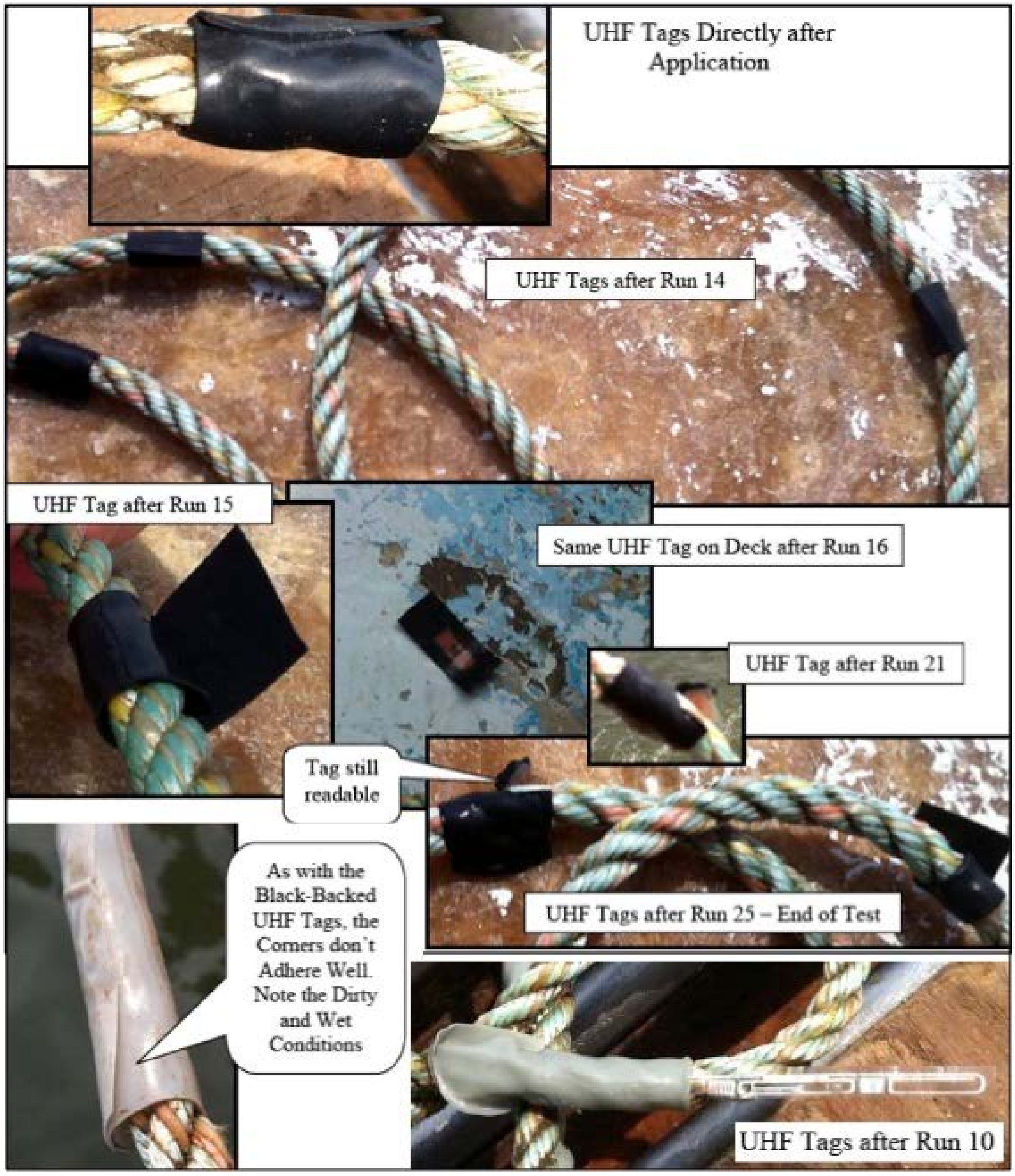

Figure 8. Wear and tear of some UHF tags attached to ropes after simulated hauling (Re-arranged from Patton and Cromhout, 2011).

3.3 RFID Technology 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, or to reduce probability of gear loss. Traditionally various physical tags have been used, usually inscribed with the permit number of its owner (Figure 9). In some fisheries, the tags are fixed in the gear itself (e.g., gillnets), while in others, the tags may be attached to the buoys (e.g. lobster pot), and while still others, both underwater and surface components of the gear are tagged. More recently, electronic tags using RFID technology are being tested. RFID tags allow for automatic monitoring, and when they are used with other devices such as GPS sensors, allow for identification of location of fishing activities (more details in the next section).

RFID tags were tested in conger eel pots in Japan for determining fishing effort and location of fishing (Uchida et al., 2004; 2005). These researchers attached RFID tags inside conger eel pots (tubes). The tags used were high frequency (13.56 MHz) Omron V720-D13P07 (36 mm x 75 mm) and V720-D52P01 (84 mm x 134 mm) with nominal read distance of 45 cm and 60 cm respectively when using Omron V720-BC5D4 RFID reader. The standard tags were laminated before they were attached to the pots so that they would be waterproof during fishing. When the tags were wet inside the pot, the tag reading distance was about 15 cm (Uchida et al., 2005).

Figure 9. Cable-tie style tags typically used in lobster pots in Maine, USA. From http://www.ellsworthamerican.com/maine-news/political-news/lobster-trap-tag-limits-bill-founders.

In this particular research, two RFID readers were used 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. The system served as a research tool rather than a capacity management or enforcement tool. However, similar system can be adapted for documenting fishing effort (number of pots used by a vessel) and amount of catch.

The study found that the ability of reader to detect RFID tags was reduced when the pot was filled with water and with the RFID tags drenched with water. RFID tags were also not suitable for wire mesh pots due to interference of metal on reading success.

RFID tags were used in British Columbia crab pot fisheries as a part of the electronic monitoring effort (McElderry, 2008). In that fishery, the pot was fished as single pot operation, i.e., one pot for one buoy. In that application, one RFID tag was inserted into foam core of each buoy. The buoys were scanned with a custom-made RFID reader when the pots were 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 have also started 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 (Figure 10). These systems not only serve as permit tags, "they are designed to lessen the theft of gear and catch" as quoted in the source (NWIFC, 2015). EcoTrust Canada is also partnering with Gulf of Maine Research Institute in Portland, ME to institute similar electronic monitoring systems with RFID tags in Maine lobster fishery (EcoTrust, 2015).

Figure 10. The quarter-size RFID tag used for crab pots by Quinault Indian Nation (NWIFC, 2015).

RFID tags were also used in Scottish creel and pot fisheries for Nephrops, crabs and lobsters (Course et al., 2015). The RFID tags were used with other electronic monitoring equipment for capacity management. RFID tags were attached to marker buoys and on each individual pot/creels. 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 (Figure 11, Course et al. 2015).

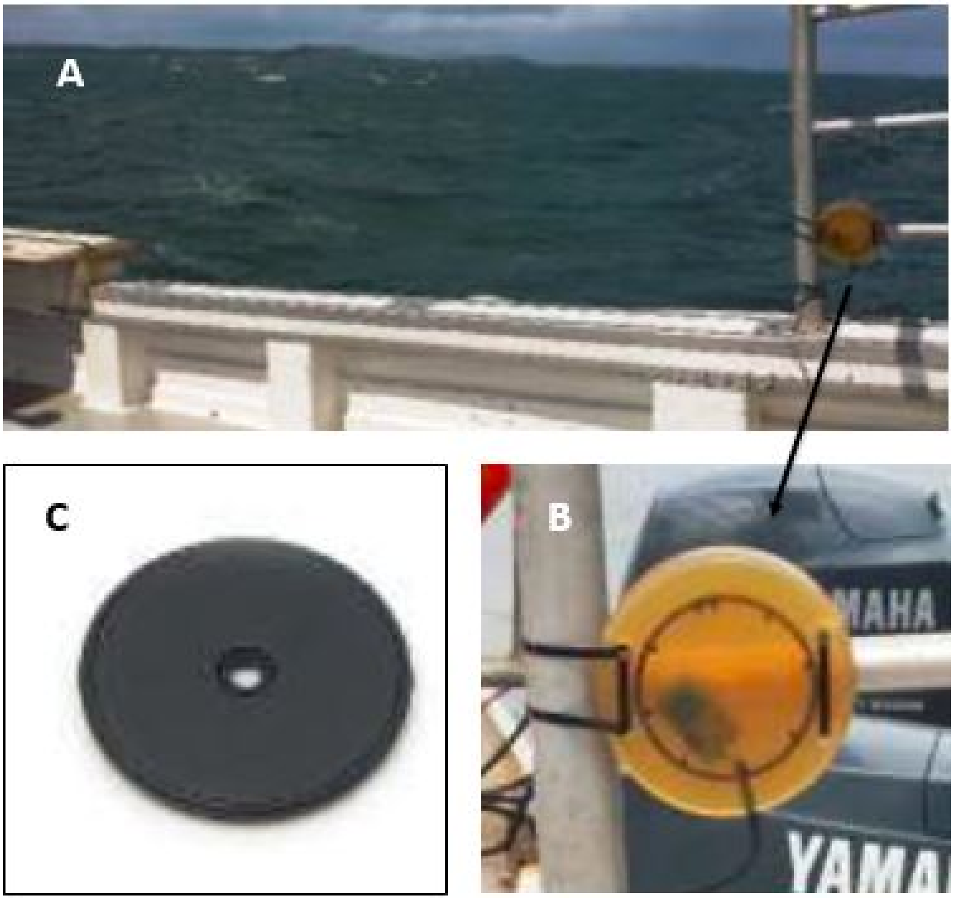

Figure 11. RFID reader (A & B) and the tag used by Course et al. (2015) in the Scottish creel/pot fisheries for Nephrops, lobsters and crabs.

3.4 RFID Technology for Location Tracking and Surveillance

As discussed above, there are two basic types of RFID tags: passive tags and active tags. Passive tags can only be read within a very short range, while active tags have much better range. For location tracking of tagged objects, active tags are more suitable.

Crafts (2007) installed active tags in small vessels in a small waterway and attempted to track these vessels from the shore while these vessels passing through a channel. The RFID tags used for the study were Savi Data-Rich Tag (ST-654) with operating frequency of 433.92 MHz. It had an advertised ranged of 122 m using UHF transceiver in outdoor line-of-sight conditions (www.**savi**.com/wp-content/uploads/Hardware_Spec_Sheet_**ST_654**1.pdf*)*. The tags were reliably read within 100 m, but they were detected as far as 400 m. Appler (2009) tested an aerial vessel monitoring system using the same RFID tag and receiver system. The receiver was installed on a small airplane that flew over a tagged vessel up to 274 m above sea surface. The tag was detected by the reader at the range between 484 and 982 m. While these tags were installed on small vessels, not on the fishing gear, they have potential applications for marking fishing gear. Such system would help enforcement and combat illegal fishing.

The only RFID technology test for fishing gear position marking was a pilot study by Irish Fisheries Board (Bord Iascaigh Mhara) (BIM, 2007). The BIM system consisted of several elements as shown in Figure 12. The tags and readers were all off-the-shelf commercially available products that were assembled together by a Spanish company AdActiv Ltd. The tags had two frequencies: LF 125 KHz for activation and to received data for storing in its internal memory. UHF 868 MHz was used to transmit signals to the receiver onboard the vessel with a range of 50 m when the tag is in the line of sight. The internal battery was to last for 3 years with 2 million operations. Other specifications are listed in Table 2.

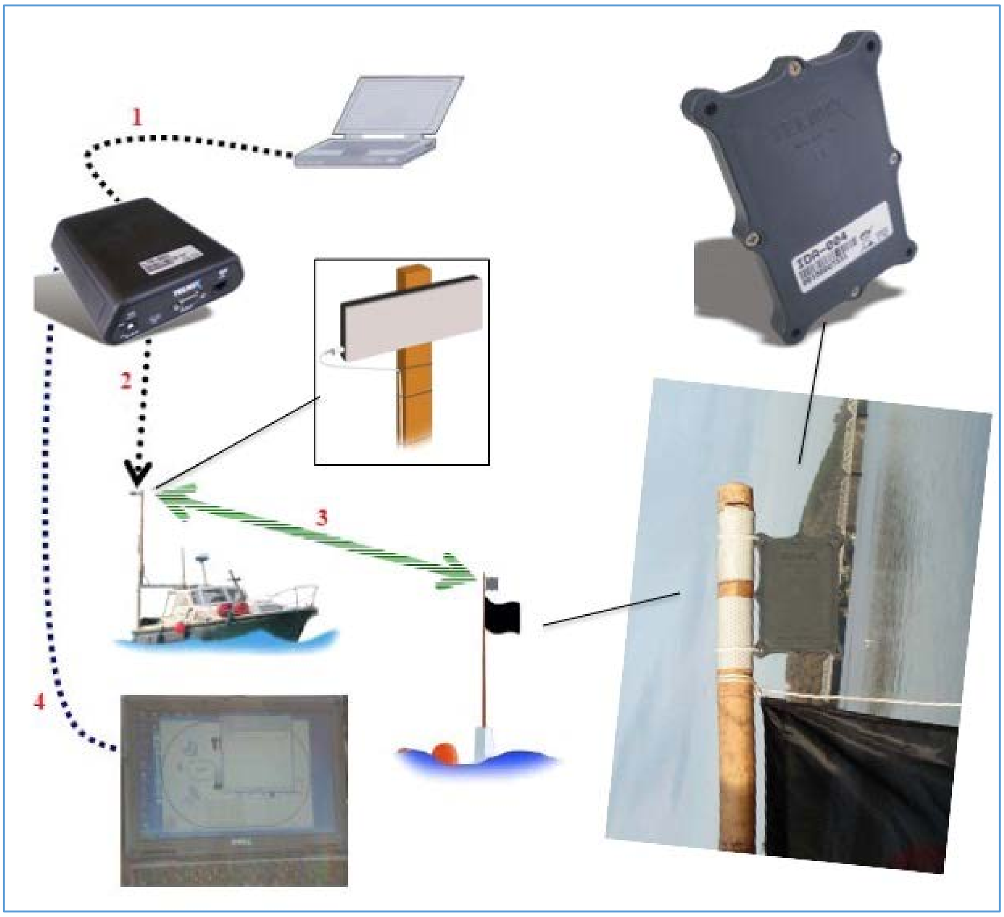

Figure 12. Equipment layout for testing active RFID tags for location of stationary gear (modified from BIM, 2007).

Table 2. Specification of the active 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

The receiver included an antenna and a tag reader. The antenna (Figure 13) was mounted on a pole 4.5 m above the waterline to provide better line-of-sight capability with the tag that was mounted on a highflyer 1.97 m above the water. The antenna was also above the radar scanning height to reduce interference. Two sizes of directional antennas were tested: 86 x 105 x 10 mm (45° detection angle) and 256 x 105 x 10 mm (25° detection angle). The tag reader was connected to the antenna and a notebook computer with plotting software.

Two tests were conducted. The results showed that the tag could be detected between 148 and 204 m. Heavier weather in exposed locations had slightly shorter detection range. No signals were received beyond 240 m.

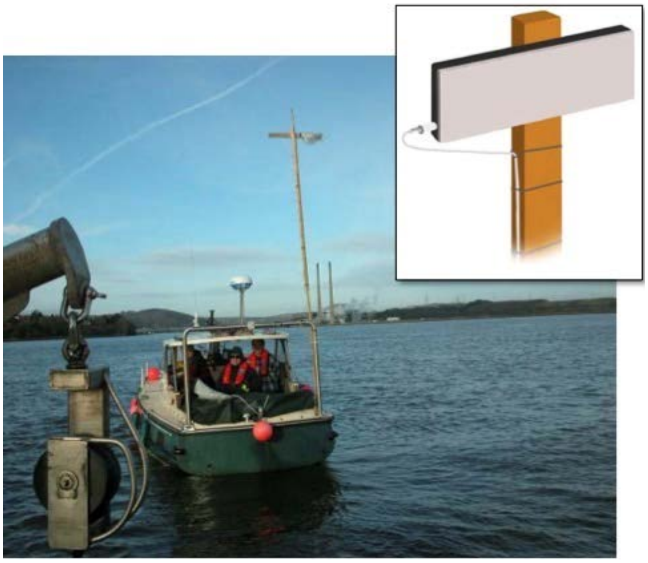

Figure 13. The unidirectional antenna installed on the stern of the test vessel (BIM, 2007).

The report 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. The report made several suggestions for improving the system, especially the directional antenna that was not suitable for marine application as vessel orientation constantly changed. The report also mentioned the inclusion of GPS signal in the transmitted data, and the use of AIS (Automatic Identification System) reception of GSM data.

4 AIS Technology for Position Marking and Tracking

4.1 Automatic Identification System (AIS)

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). Developed in 1990s for short-range identification and tracking, The AIS system is primarily for collision prevention and vessel control by port authorities. 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), aid to navigation (ATON), and shore-based stations.

AIS systems use VHF radio frequency channels (Channel A: 161.976 MHz, Channel B: 162.025 MHz). Thus its range of reception is affected by line-of-sight between transmitter and receiver. The higher the antenna, the higher its range. More recently, satellite-based AIS (S-AIS) systems have been developed, which will result in much large range of coverage.

The use of AIS system in the fishing industry is still very rare. Only about 1% of 1.3 million fishing vessels carry AIS Class A system (Selbe, 2014). There are potential for use AIS as fisheries monitoring system for combating IUU fishing, but it faces challenges in terms of infrastructure and resource, and there are privacy concerns. 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).

4.2 AIS Transponders for Position Marking and Tracking

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 may put restriction on its use. US Coast Guard only permit AIS devices on vessels, or for Aids to Navigation (ATON) (J. Arroyo, US Coast Guard, email communication, 2016-02-17). The potential use of AIS devices as fishing gear markers need substantial elaborations and international agreement.

Figure 14. The AIS Class B drift marker designed by Aanderaa Data Instruments AS (www.aadi.no) that was primarily used for tracking oil spills.

The owner/user will need to obtain a Maritime Mobile Service Identity (MMSI) number from a country's authority before an AIS device can be used. Regardless, there are a few examples of using AIS marker buoys for fisheries and other industries. The advantage of AIS-based transponder for fishing gear markers is that many vessels already have AIS receivers.

The AADI's AIS drifter marker buoy uses AIS Class B communication protocol and was designed to track the range of oil spills (Figure 14). The size of the buoy (30 cm diameter) is comparable to many marker buoys used in fixed 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. The brochure for this product is attached in the Appendix.

Figure 15. EM-TRAK's AIS identifier (www.em-trak.com).

Some of AIS identifiers intended for small crafts such as speedboats and kayaks may also be suitable as fishing gear markers technically. For example, EM-TRAK's I100 AIS Identifier by EM-TRAK Marine Electronic Ltd (www.em-trak.com) (Figure 15) measures 35 cm long and 6.3 cm diameter. It is battery-operated and lasts for 5 days after a full charge. There are many similar transponders by other manufacturers such as SRT Marine Technology (www.srt-marine.com) and True Heading AS (www.trueheading.se). These transponders sell for about $500 each.

4.3 AIS Fishing Gear Marking Transponders

There are several versions of AIS buoys that are marketed as “fishing net tracking buoy” or other similar names. One noticeable product with detailed information and specification is marketed as “Matsutec” and is manufactured by Huayang Electronic Technology in southern China (http://www.matsutecmarine.com) (Figure 16). The buoys use the AIS Class B communication protocol, and claim to have 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). These and other similar products sell for about $200 US on the Internet.

4.4 Virtual AIS Markers and Potential Use as Fishing Gear Markers

NOAA and some port authorities are currently testing virtual AIS ATON markers (or called eATON) to mark underwater obstacles or other locations 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 another 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, positions of large-scale traps and weirs 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.

Figure 16. One of few AIS identifiers marketed as "fishing net tracking buoy" (http://www.matsutecmarine.com).

5 New Development in Markers and Buoys in Pelagic Longlines

5.1 Modern Pelagic Longline Fishery

The pelagic longline is a major fishing gear used to catch large pelagic fishes in oceanic waters. Because of the water depth and epipelagic distribution of target species, including tunas, swordfishes, and in the past, large sharks, the gear is set near the surface and without attachments to the seabed. The gear is thus "drifting" with ocean currents when they are not in setting or retrieving operations. Typical Japanese longliners use up to 3,200 hooks, stretching up to 70 nautical miles (Robertson, 1998). Typically, line-setting starts before dawn and finishes in mid-morning (Ward and Hindmarsh, 2007). With a few hours waiting, hauling starts from the end that was deployed last (counter-retrieval). This makes it easier to find the end maker just deployed than the other end that is some 70 NM away, as well as saving time and fuel. Retrieval usually lasts 12 to 14 hours, but adverse sea and weather conditions, and high catch and bycatch rates can severely prolong retrieval process.

Much like bottom-set longlines, the basic elements of the pelagic longline is the bait, hook, snood, and the mainline. In pelagic longlines, snoods are usually called branch lines. Different from bottom-set longlines, pelagic longlines are not attached to the bottom, but rather to the surface structures. 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 much as 14 radio beacons were also used along the mainline to help steering the vessel during hauling, and to locate the mainline after line breakage according to an observation by Robertson (1998) on a Japanese longliner. A typical pelagic longline system is shown in Figure 17.

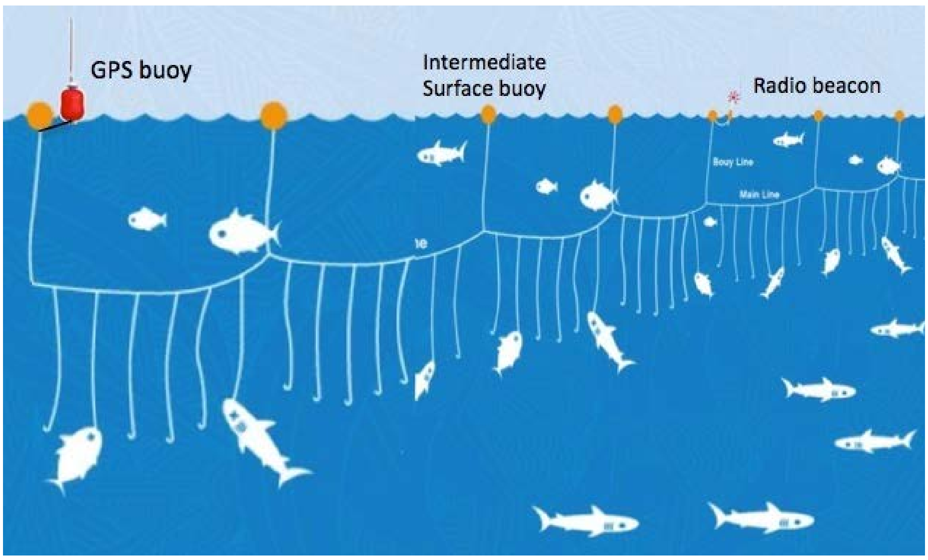

Figure 17. Typical longline system showing end markers and intermediate buoys and radio beacons. Modified from an image from http://www.kanuhawaii.org/.

5.2 Advanced Markers and Buoys for Pelagic Longlines

Longline markers and buoys went through technological changes since the reported invention 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 then plastic floats replaced wood and glass floats thereafter.

Modern industrial pelagic longlines are equipped with radio buoys at two ends and at intermediate locations (Figure 17). 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 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 intervals depending on its applications. For examples, Kato Electronics' KTR-17 and KTR-18 radio buoys (Figure 18) emit signals with 30 seconds repetition and 3 minutes rest. These buoys have ranges beyond a couple of hundreds nautical miles depending on the height of antenna and the power of receiver.

Figure 18. Examples of radio buoys for longlines from Kato Electronics Co. Ltd (Kaohsiung, Taiwan). Antenna not included. From: http://www.radiobuoy.com.

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 only transmits signals when it receives a specific signal from its owner vessel and was introduced by Japanese longliners in 1980s (Miyake, 2004; cited in Ward and Hindmarsh, 2006). Sel-Call buoys also use less energy so that they can last much longer than comparable continuous emitting radio beacons. For example, Sel-Call radio buoy produced by Dong Yang Engineering (Korea, www.radiobuoy.co.kr) PRSC-30 lasts 10 time longer than the regular radio buoy PR-30 with similar parameters (300 days vs. 30 days).

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 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.

Radio buoys with acoustic listening hydrophone:

Fish caught on longline hooks are often depredated by carnivorous toothed whales, sometimes up to 25% as reported by McPherson and Nishida (2010). Various mitigation measures have been tested to reduce depredation. McPherson et al. (2008) demonstrated that false killer whales (*Pseudorca crassidens*) depredate line-caught fish based on their active sonar system. They also found that whales exchange "whistles" between individuals during depredation to share food. Installation of whale "listening" devices could thus provide fishers with information on the presence of these whales so that they can alter fishing strategy (e.g., early retrieval or termination of operation in the area). McPherson and Nishida (2010) reported the installation of listening hydrophone on longline radio buoys, so that whale presence can be transmitted to owner vessels (Figure 19). Software was developed to distinguish whistles of different toothed whale species and during different activities. In essence, this is a type of sonobuoy that have been used by navy since World War II (Holler, 2014). Similar sonobuoys are also used by seabed mining industries.

Figure 19. A prototype Global Detection Systems (GDS) buoy as reported by McPherson and Nishida (2010).

<u>Solar-powered radio buoys</u>:

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. Solar power together with rechargeable batteries have started to be used by some companies since the turn of the century to make the system lasts almost indefinitely. This is especially useful for drifting fish aggregation devices (next section). Some notable solar radio buoys include those produced by Kato Electronic Ltd (Taiwan) and Marine Instruments S.A. (Spain). Some of their products are attached in Appendix.

6 New Development in Markers and Buoys in Fish Aggregation Devices

6.1 Fish Aggregation Devices and Purse Seine Fisheries

A purse seine is s wall of netting that encircles fish, and catch fish by closing the purse string on the bottom. Purse seine fisheries targets schooling fish. For small pelagics (sardines, anchovy, etc.), free schooling fish are targeted in the day and light fishing is employed at night. For medium and large pelagic species (tunas, and other tuna-like species), 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 can location the object when they returned. The first commercial man-made floating objects with the purpose to attract and gather fish, thus called fish aggregation device (FADs) were believed to have been 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 owned by individual vessels or companies. Gradually sophisticated markers, buoys, and electronic devices are attached to FADs for longer-term and exclusive use by the owner vessel.

Purse seining around FADs has become very important during the last thirty years. For example, only 20% purse seine sets were conducted around FADs in 1985 by Spanish purse seiners, compared with 75% in 2009 (Lopez et al., 2015). While purse seine fishing around FADs are now an integral part of many tuna fisheries, there is a growing literature on the possible ecological impact of FADs (e.g., Davis et al., 2014), which is not the focus of this report.

There are basically two types of FADs, anchored (or tethered) FADs and drifting FADs. In theory, artificial reefs deployed on the seabed are a type of FADs. In this document, we will primarily discuss surface and/or midwater FADs with surface markers or buoys attached to FADs to mark position (and ownership) (Figure 20).

Figure 20. A drifting FAD with a solar-powered radio buoy. From: http://www.theecologist.org/siteimage/scale/800/600/397596.png.

Anchored FADs are mostly deployed near shore 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 (drifting FADs). The use of sophisticated marking systems significantly increased the number of FADs a vessel can handle, and speed of detection. It is especially important for drifting FADs deployed in wider areas and for a longer time period.

There are 105,000 drifting FADs in use by the world’s tuna fisheries, primarily tuna purse seines (Baske et al., 2012). Information gathered by these authors from the five major FAD buoy suppliers indicated increased demand for satellite-tracked buoys. It was estimated that an output of 47,500–70,000 buoys per year from these manufacturers and a high proportion of these are used by fleets from European Union (Scott and Lopez, 2014).

6.2 Markers and Buoys for Fish Aggregation Devices

Radio buoys were first used in drifting FADs 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., 2015). 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.

Table 3. Development of instrumented buoys and their introduction in tuna fisheries as well as their main detection and powering characteristics. From Scott and Lopez (2014).

Type	Year	Signal detection/ transmission	Detection range	Power	Notes
Radio buoys	mid 1980s	Constant transmission Radio Detection Finder (RDF)	100	Battery	Detectable by other RDFs and radars
Select 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 position	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	Inmarsat 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	First with info on current speed and direction
3rd gen. echo sounder buoys	2012	Satellite connection	Virtually unlimited	Solar panels	Multi-frequency transducers

Radio buoys and other advanced versions used in pelagic longlines can also be used for FADs; however, there are differences between longline buoy markers and FAD markers, especially the advanced FAD versions. Typically, 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 drifting FADs than for longlines because they can easily be detected by other vessels, and thus possibly be stolen with signal frequency re-setting (Itano, 2012). Continuously transmitting buoys are also energy intensive, thus have short battery life. Sel-Call radio buoys are much discrete; only respond to command signals from their owners. Typically, batteries in Sel-Call buoys last 10 times longer than equivalent continuous transmitting buoys; of course the battery usage is affected by the power of transmission (affecting range), and frequency of transmission).

Satellite communication buoys

Using satellite communication technology, the range of communication thus 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 (Figure 21). 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 on board other non-owner vessels.

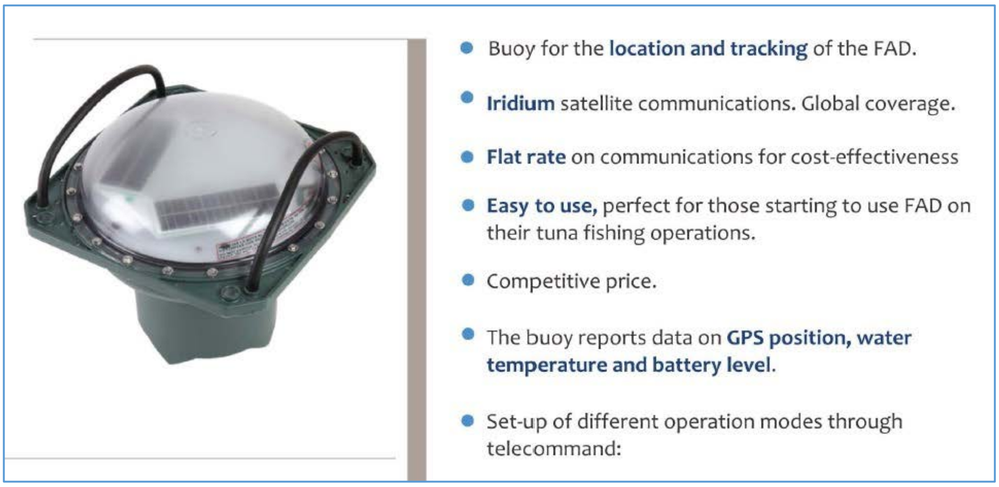

Figure 21. An example of a solar-powered satellite FAD buoy from Marine Instruments AS with some advertised features (www.marineinstruments.es).

Solar-powered radio buoys

Buoys for FADs are less limited by size, thus are ideal for installing solar panels to recharge batteries and extend battery life (Figure 21). In fact, some claim “unlimited battery life”. The first solar-powered FAD buoys started during the turn of the century by Zunibal of Spain (Pino, 2012). Today, many FAD buoys are equipped with solar panels.

Echo sounder buoys:

Many instruments and sensors can be attached to buoys to provide fishers with additional information about fish and environment. One of the noticeable and significant instruments is the echo sounder. The first radio buoy with echo sounder appeared in 1999 (Lopez et al., 2015). With improvement over the last 15 years, the technology has become very reliable. Today, multi-frequency echo sounders (Figure 22) are installed on some FAD buoys for wider range detection of fish schools under and around the buoys and for high-resolution species discrimination (Pino, 2012). With the echo sounder data, fishers would be able to know in advance if and how much fish under the FAD before the vessel reaches the site. In addition to Marine Instruments A/S (Figure 22), several other manufacturers also produce advanced buoys with an echo sounder and other sensors.

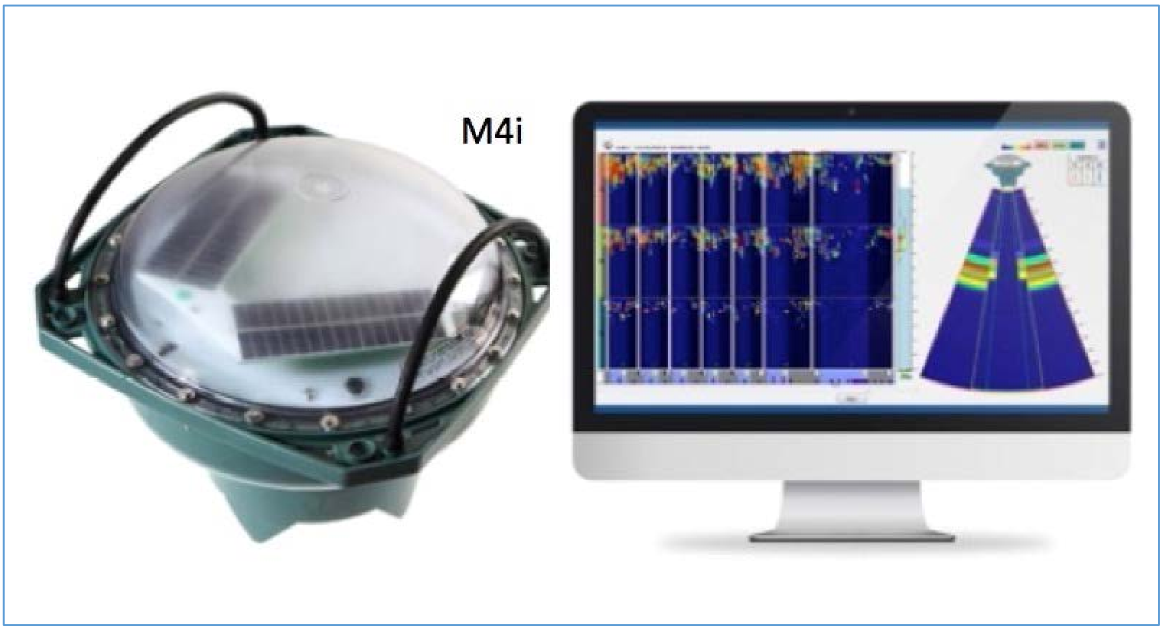

Figure 22. A example of the M4i solar-powered satellite FAD buoy with tri-frequency sounder (50, 120, and 200 KHz) from Marine Instruments AS (www.marineinstruments.es). The computer screen shown on the right is the information displayed on a vessel or shore-based receiving station.

7 New Development in Lights for Gear Marking

7.1 Use of Light in Fishing

The use of lights to attract and gather fish may be much earlier than the use of light to mark the position of fishing gear, as early lights needed constant addition of fuel (e.g. fire torch). While the exact time when lights were first used to attract fish is not known, it might be one of the most advanced and successful fishing methods utilizing fish behavior for controlling animals for capture purposes (Ben-Yami 1976). Throughout the years, fire torches, acetylene and kerosene lamps, incandescent lamp, mercury lamps, fluorescent lamps, halogen lamps, metal halide lamps have been used as light sources for scoop nets, lift nets, purse seines, and hook and line fisheries. Light emitting diode (LED) lights have been tested and used during the last ten years to extend battery life, and reduce energy costs and CO_2 emission (Okamoto, 2008; Inada et al., 2010).

Lights are used to indicate position of the gear at night; however, it is not universally required. For anchored or drifted nets and hook and line gear that are less than 2 m below surface and left over night, lights are required (FAO, 1993). These lights must be visible at least 2 NM in good visibility conditions. Traditionally incandescent lights in a watertight tube and with on/off switch controlled by a light sensor or a timer have been used.

7.2 LED Lights

Light-emitting diode (LED) lights were first used as instrument indicator lights in the 1960s, but it is not until 1990s that the first high-brightness LED was invented (Neubert, 2015). LED lights can be made in compact sizes and are much more energy efficient. For example, LED lights use six times less energy and last 40 times longer than incandescent lights for similar luminescence, but they are also 30 times more expense (http://eartheasy.com/live_led_bulbs_comparison.html). In other words, lights with LED bulbs have potentially six times longer battery life than its incandescent counterpart.

LED lights for light fishing have been widely tested and applied in countries such as Japan, Korea, China and southeast Asian countries where light fishing for squid, Pacific saury and other species (Okamoto, 2008; Inada et al., 2010).

Because of their energy efficiency and longevity, there is great potential for the use of LED lights in marine environment, especially in battery-powered applications such as marking lights for fishing gear, as battery life and bulb longevity are two very important factors.

Figure 23. An example of a purposely-designed LED marker light for fishing gear and aquaculture facilities. www.jotron.com

The exact date when LED lights were used as marker lights for fishing gear is not known, but LED lights are now widely used worldwide as fishing gear markers. An example of the LED lights that are marketed for fishing gear and for aquaculture industry is shown in **Error! Reference source not found.**. Another example that is specifically marketed as “buoy lights” is marketed by McDermott Light & Signal (http://www.mcdermottlight.com/catalog/buoy_lights_driftlights.html). Numerous manufacturers and retailers supply LED lights for fishing gear markers/highflyers that have different power, battery life, and characteristics (color, flash, on/off control, etc.).

7.3 Solar-powered Lights

Solar panels have been used to power fishing lights in small-scale light-based fisheries in lakes and in coastal waters as a replacement for fuel-based power source (Mills et al., 2014; McHenry et al., 2014; Kehayias et al., 2016). Due to limited power generation by solar power in a limit space, the light fishing system often use LED lights.

As mentioned in last two sections, radio buoys and FAD buoys have incorporated solar panels to power their electronics. The buoys often have lights; some of them only light up when the owner vessel approaches.

There are some purposely-designed solar-powered marker lights for small to medium sized vessels. Figure 24 is an example. Other similar solar-powered LED lights are available over the Internet, but none of them have been independently tested for quality and specification.

Figure 24. An example of solar-power LED light manufactured by C & R Countryroad Industrial & Trading Co., Ltd. http://www.country-road.cc/.

7.4 Wave-powered and Tide-powered Lights

While human interest to harness the power of waves and tides in the ocean have existed for many years, the concept of wave-powered LED buoys has emerged in recent years (http://earthtechling.com/2012/03/ahoy-its-a-wave-powered-led-lit-buoy/). It is conceivable that anchored FADs can be equipped with wave and tidal energy-harvesting devices to recharge batteries to power the ever-increasing electronic devices and lights.

The only one wave-powered marker light that may be suitable for small scale fishing gear has been found through this literature and Internet search, and is shown in Figure 25 (C & R Countryroad Industrial & Trading Co., Ltd, Anhui, China, http://www.country-road.cc/). The dimensions in the Internet seem to suit for small vessel uses, but its quality and function have not been independently verified.

Product Details:	
Place of Origin:	China
Brand Name:	OEM
Certification:	CE
Power:	sea wave

full automatic type wave power

emitting light colors: red, white, blue, green

Packing size: 360 mmx90mmx50mm

weight: 0.6 kg

Powered by sea wave

Operation Mode: Flash any time in sea.

Figure 25. Wave-powered LED light manufactured by C & R Countryroad Industrial & Trading Co., Ltd. http://www.country-road.cc/.

8 New Development in Gear Relocating Technologies

8.1 Gear Loss and Ghostfishing

Fishing gear becomes lost due to various reasons. Some of the lost gears such as gillnets and pots continue to catch fish, causing ghost fishing, which destroys valuable marine resources and pollute marine environment (Breen, 1978; Macfadyen et al., 2009). There are a few measures to deal with ghost fishing issues of lost, abandoned or otherwise discarded fishing gear, 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 gear loss includes measures for proper gear marking for identification of ownership as well as for position. Limitation of 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 by Koreans showed good promise for gillnet and pot fisheries (Kim et al., 2012; 2016). Proper gear tagging and marking, mandatory reporting of lost 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.

Not only fishing gear, but also many other marine devices that are deployed in the sea have a risk of being lost; some are much more expensive than fishing gear. Successful retrieval of lost gear is an important consideration in oil explorations, subsea surveys, naval excises, and ocean research.

Gear relocation devices typically use acoustic technology, taking advantage of superior sound transmission property in sea waters. There are basically two types of technologies: active pinger/transponders and passive sonar reflectors. The first method is based on 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.

8.2 Pinger/Transponder Locator Markers

Pingers (also called beacons) continuously emit sounds 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 sound from a commend unit via a hydrophone. Once it has detected a certain sound 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). Attached in the Appendix are specifications of some pingers and transponders from Teledyne Benthos (www.benthos.com).

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. Some authorities have developed “pinger detectors” for enforcement purposes – to check if pingers are attached to required gillnets in the area and if they are working. These pingers and pinger detectors can be used for locating gillnets (or any other gear with a pinger) if they become lost. In 2010, NOAA Fisheries has distributed four sets of pinger detectors to enforcement officers in four New England states (http://www.greateratlantic.fisheries.noaa.gov/prot_res/porptrp/pinger.html). The pinger detectors were produced by RJE International (Irvine, CA). Similarly, German researchers were also testing a long-range pinger detector which 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 (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 became loss. The Gearfinder 700 (Figure 26) is in fact a transponder/receiver system that is marketed for the fishing industry. The transponder can operate down to 1300 m in depth, and with horizontal distance of up to 2 NM.

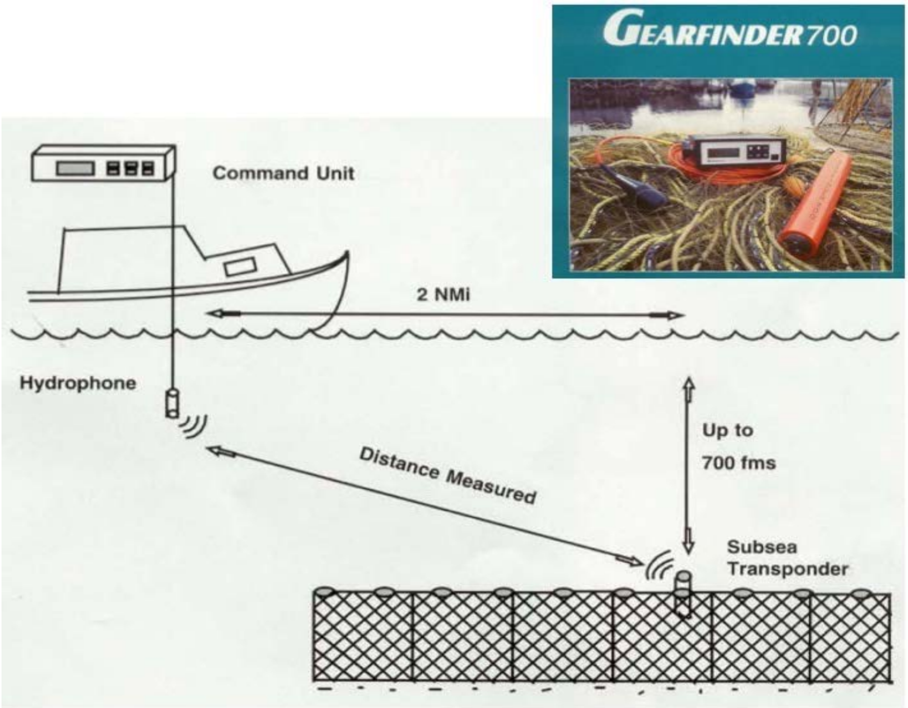

Figure 26. The principle of Gearfinder manufactured by Notus Ltd in St. John's, Canada (www.notus.ca).

Another gear locator that has potential for small scale fixed gears was recently developed by Scatri (France) as shown in Figure 27. The Deepsea Launcher System (DLS) consists of an underwater buoy system and an onboard command unit (http://www.scatri.com). 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 marker 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 the will emerge from the surface. The acoustic signal has a range of 500 m. The buoy will also rises automatically if water leaks into its watertight compartment or the batter operating its electronic components becomes too low, preventing accidental failure of the system.

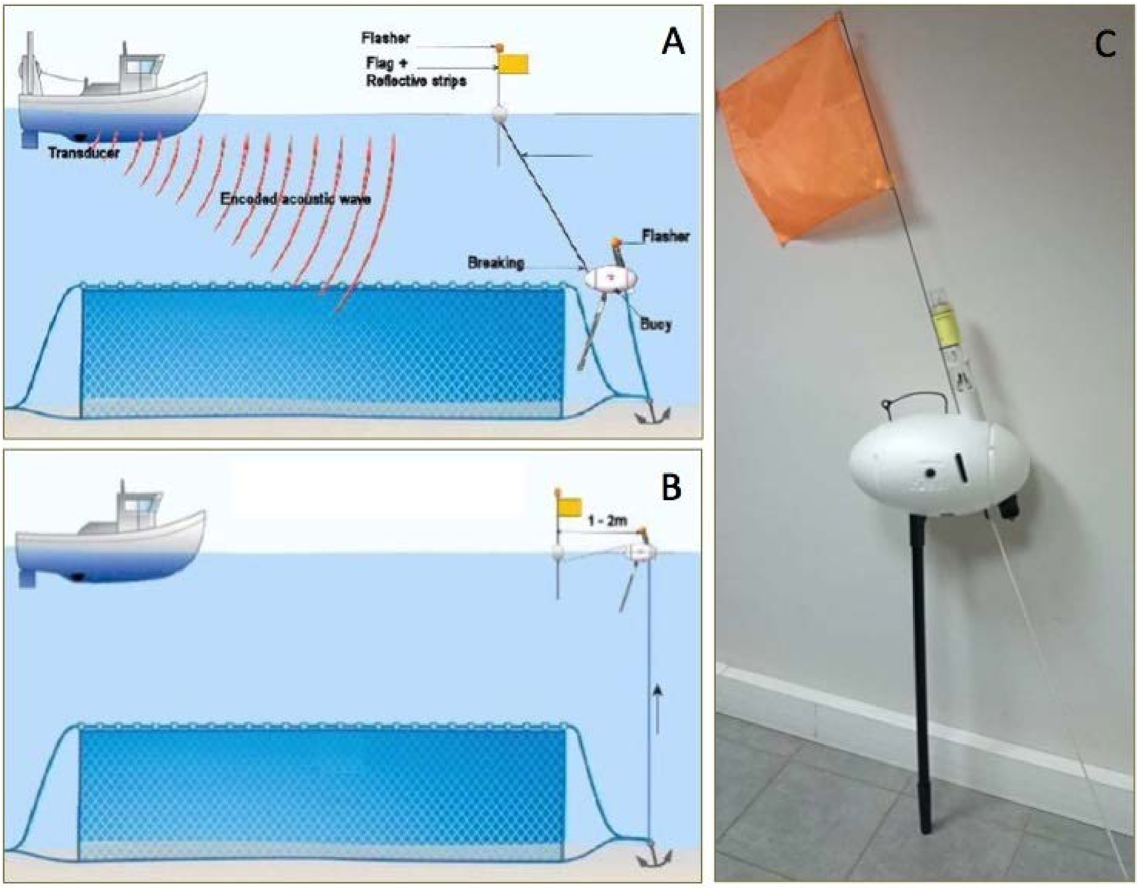

Figure 27. The Deepsea Launcher System (DLS) from Scatri of France. A. The gillnet in fishing condition (the buoy submerged 15-40 m the surface. B. The buoy emerged from underwater during retrieval. C. The buoy. From http://www.scatri.com.

8.3 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 manufactured by Subsea Asset Location Technologies Inc. (www.cesalt.co.uk). SonarBell is a passive, omni-directional sphere with proprietary design originated from UK Ministry of Defense, but now available for non-military use (Figure 28) (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 are supposed to 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, though no detailed information is available. Incidentally, if the balls do function as described by the manufacturer, they may be used as fishing gear performance monitoring device, e.g., the door spread of an otter trawl. Attempt was made to obtain price information of the SonarBell devices, but no answers have been received at the time of writing.

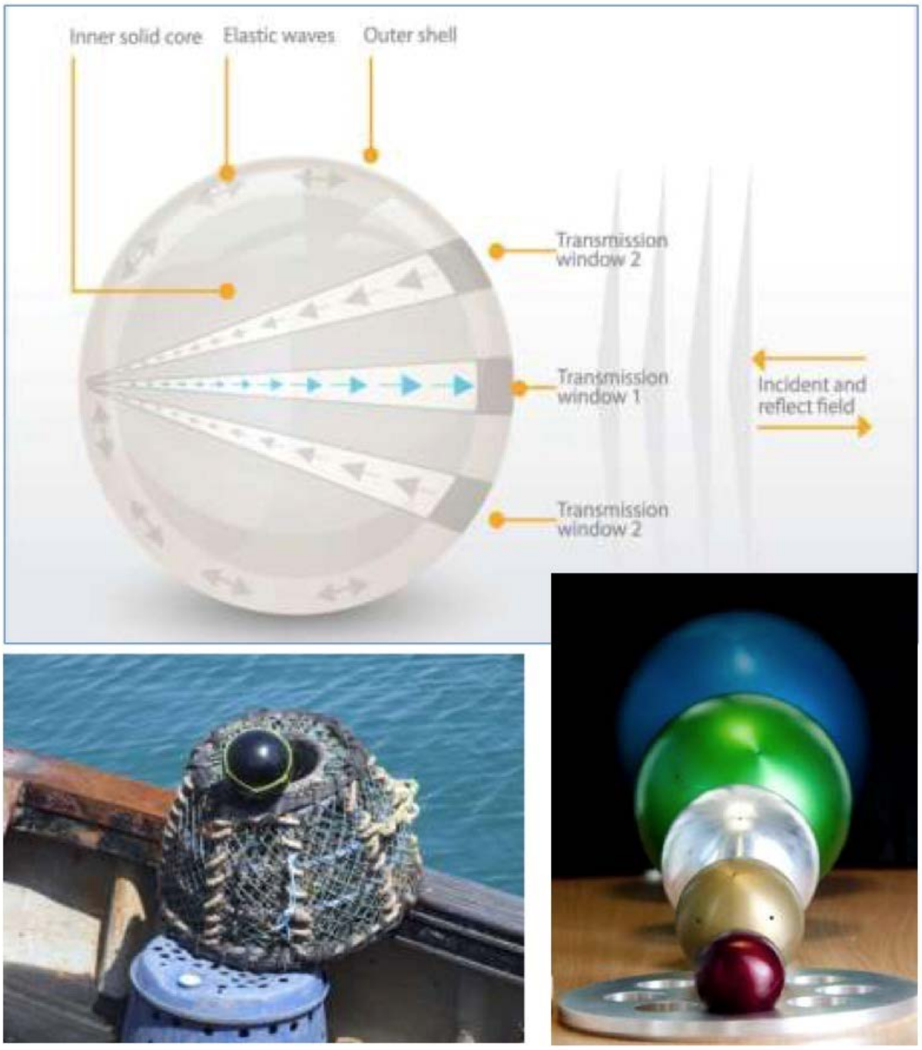

Figure 28. The SonarBell object location device produced by Subsea Asset Location technologies Inc. (www.ceasalt.co.uk). The lower left shows that the ball is attached to a pot.

9 Acknowledgement

The author would like to thank the following colleagues who provided valuable information for the report: Glenn Salvador and John Kenny (NOAA Fisheries, USA), Erin Burke, (Massachusetts Division of Marine Fisheries, USA), Jorge Arroyo (U.S. Coast Guard, USA), Joe Shoemacker (Quinault Department of Fisheries, USA), Kenneth J. La Valley (University of New Hampshire, USA), Farrell Davis (Coonamessett Farm Foundation, USA), Amanda Barney (Ecotrust Canada, Canada), Paul winger (Memorial University, Canada), Howard McElderry, (Archipelago Marine Research Ltd, Canada), Francis Parrott (Notus Ltd., Canada), Karl Gunnar Aarsæther (SINTEF Fisheries and Aquaculture, Norway), Daniel Stepputtis (Thuenen-Institute of Baltic Sea Fisheries, Germany), Seref Pinar (Biousse S.A.S./Scatri, France), Yoshiki Matsushita (Nagasaki University, Japan), Tadashi Tokai and Keiichi Uchida (Tokyo Univ. of Marine Science and Technology, Japan), Daragh Browne (Bord Iascaigh Mhara, Ireland), Liuxiong Xu (Shanghai Ocean University, China), Tim Huntington (Poseidon Aquatic Resource Management Ltd., UK), Grant Course (SeaScope Fisheries Research Ltd., UK), and John Thompson (University of St. Andrews, UK).

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