Workshop on Buoyless Fishing Gear Location Marking Methods

Report on Stakeholder Engagement Meetings

August 2021

Mark Baumgartner (Woods Hole Oceanographic Institution), Leah Baumwell (The Pew Charitable Trusts), Elizabeth Baker and Sean Brillant (Canadian Wildlife Federation)

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Abstract

Identifying the location of fixed fishing gear on the sea floor to avoid gear conflict is one of the principal technical challenges in the development of buoyless fishing. Agreement on a single gear location marking method that can be developed by multiple manufacturers is needed, so a workshop will be convened in September 2021 to allow fishers, enforcement, regulators, and other stakeholders to (1) agree on a list of requirements for a gear location marking system for buoyless fishing, (2) evaluate various methods with respect to those requirements, and (3) choose a method that best meets the requirements. Interviews were conducted with stakeholder groups between August 2020 and March 2021 to develop a list of preliminary requirements, and an initial assessment of the four methods of gear location marking with respect to the preliminary requirements was completed. This report describes the workshop goals and process, stakeholder interviews, preliminary requirements, gear location marking methods, and the initial assessment of those methods. The report is intended to facilitate discussion and efficient decision making during the September 2021 workshop.

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1. Introduction and purpose

Buoyless (also called ropeless or on-demand) fishing systems eliminate the need for persistent surface buoys and vertical end lines from trap/pot fishing gear. For buoyless fishing systems to be suitable for commercial fisheries, they must replace the role that persistent surface buoys play in marking the location of fishing gear on the seafloor.

Since 2018, there has been considerable progress in the development of buoyless fishing systems (e.g., bottom-stowed rope, lift bags). There has, however, been less progress in the development of technology to mark the location of buoyless fishing systems on the seafloor. Gear location marking is required to prevent conflict between fishers using buoyless systems, and between different fisheries (e.g., mobile and fixed-gear). NOAA Fisheries identified gear location marking as the principal challenge to advancing buoyless fishing in 2010, and it remains largely unsolved today.

The greatest obstacle to developing a commercially viable gear location marking system is the universal adoption of a single method to locate gear on the seafloor. There are several proposed methods, including the use of GPS marking, acoustic ranging, directional acoustic ranging, and acoustic self-localization. GPS marking has been implemented by several manufacturers of buoyless fishing systems, but none of the proposed methods have been rigorously reviewed to determine if they meet the needs of industry, enforcement, and regulators. Furthermore, there has been no formal comparison of the various gear location marking options to determine which best meets those needs.

The decision of which gear location marking method to adopt must be made as a community of fishers, enforcement, and regulators, with input from engineers, scientists, conservationists, and gear manufacturers. It is unlikely that any government agency will impose a specific method in the near term. Moreover, it is undesirable for any single manufacturer to choose and implement a proprietary method for their gear alone, because cross-communication among different buoyless systems is crucial for preventing gear conflict and for keeping the technology affordable for fishers through manufacturer competition. Choosing an appropriate gear location method is the joint responsibility of fishers, enforcement, regulators and other interested stakeholders (e.g., manufacturers, conservationists, scientists, engineers).

In September 2021, we will host a workshop for members of this community to discuss and select a single gear location marking method that will meet the needs of fishers, enforcement and regulators and can ultimately be developed by technology companies for use in buoyless fishing. Prior to the workshop, we conducted 17 interviews with groups of stakeholders to understand the requirements of a gear location marking system. These interviews focused on how buoy-based gear location marking works today for fishers and enforcement, as well as how buoyless gear location marking might work in the future. This report (1) explains the workshop process, (2) summarizes the interviews, (3) provides a preliminary list of requirements for gear location marking based on the results of the interviews, (4) describes the available gear location

marking methods, and (5) offers an initial assessment of these gear location marking methods relative to the preliminary requirements.

2. Workshop

Workshop goals

The Workshop on Buoyless Fishing Gear Location Marking Methods is intended to be an opportunity for the community to discuss and to decide which gear location marking method will work best. Through this Workshop, we seek to gather fishers, enforcers, regulators, engineers, scientists, conservationists, and gear manufacturers from the U.S. and Canada to:

(1) Discuss and agree upon the requirements for gear location marking

(2) Evaluate various gear location marking methods to decide which method best meets the requirements identified by users and stakeholders

(3) Form a technical working group to formally develop and document the specifications for the adopted method

Workshop process

Preliminary requirements

Prior to the workshop, a preliminary list of requirements has been compiled through interviews with stakeholder groups. **This report describes the preliminary requirements identified during these interviews.**

Final requirements

The preliminary requirements will be collectively reviewed and discussed at the workshop to establish a final list of requirements for a gear location marking system for buoyless fishing.

Evaluation of gear location marking methods

Each method of gear location marking (described in Section 5 of this report) will be presented and examined with respect to the final requirements. The evaluation will use a matrix identical in format to Table 4 in Section 6 of this report. Based on the results of this evaluation, workshop participants will decide which method best meets the requirements.

Technical working group

The last task of the workshop is to form a small technical working group. The purpose of this group is to develop detailed specifications for devices that can meet the final requirements using the agreed-upon gear location method. It is expected that the working group will enlist the help of technology experts to complete the specifications.

The specifications will be documented and circulated to the workshop participants for feedback, and once approved by the workshop participants, these will be made publicly available for manufacturers to begin research and development (R&D) activities.

The workshop is intended to spur innovation and development of a gear location marking solution, but it is recognized that this may take several years and an investment of time and resources to design, prototype and test. As a result, it is also expected that interim gear location marking solutions that may not meet all of the community's requirements will be necessary in the short-term to allow continued development and testing of buoyless systems in small-scale experimental fisheries. The workshop is intended to focus solely on the long-term solution for buoyless gear location marking.

3. Stakeholder engagement meetings

To develop the preliminary list of requirements for a gear location marking system, 17 meetings were held between August 2020 and March 2021 with stakeholder groups that included fishers from different sectors (e.g., inshore, offshore, lobster, snow crab, mobile), fisheries associations, fisheries regulators, enforcement, scientists, engineers, non-governmental organizations and gear manufacturers from both Canada and the United States. A total of 76 people participated in the interviews. The meetings were held virtually, and participants were informed that the organizers were not acting on behalf of any government agency nor being funded for their effort.

A set of standard questions were posed to each group (Table 1), recognizing that some groups may not have the ability to answer all questions. Participants were encouraged to reflect on the fisheries with which they were most familiar, but to also give responses appropriate for a gear location marking solution that could be used for all fisheries. Participant names can be found in Appendix 1. Notes from the interviews (Appendix 2) are available upon request from the report authors; no participant names have been attributed to any comments in the notes.

Table 1. Questions posed during stakeholder interviews.

Function	**Question**
Detection distance	At what distance away from gear do you want/need to be able to detect it?
Location accuracy	What location accuracy is needed for localizing the position of the gear? How far apart is gear typically set in your area? How far apart does gear need to be to avoid gear conflict among fixed fishers in your area?
Data display at sea	When at sea, how do you want to view the location of gear on the sea floor (e.g., chart plotter, separate fixed display, tablet, smartphone)?
Additional information to collect and share	What information do you want/need from a marking system besides the location of gear?
Data sharing	Should information about currently set gear be available in a shore-side database? If information about currently set gear was available in a shore-side database, who should have access to that information? Do you want/need access to gear location information when not at sea? If you are a fisher, do you want/need information on the location of your gear when not at sea?
Lost gear	Do you want/need the marking system to assist in locating lost gear? If so, how?
Environmental impacts	What environmental impacts of a gear location marking system are acceptable? Which impacts are not acceptable? What impacts, if any, should be minimized?
Battery endurance	For gear location marking devices that are attached directly to trawls/traps, how long do you need/want them to work before the batteries need to be replaced or recharged?

4. Preliminary requirements

The following briefly summarizes what we learned from each set of interview questions, and reports the preliminary requirements we developed based on participant responses. The preliminary requirements are summarized in Table 2.

We have not included cost as a preliminary requirement, as that is very difficult to assess at this early stage of development. Additionally, most gear retrieval devices use an acoustic device to trigger the release of stowed rope or a lift bag. This acoustic device can be used for gear location marking, and the additional cost of including a localization method in this device may be minimal.

Detection Distance

Discussion: Fishers need to detect both ends of a trawl simultaneously to understand the entire trawl's location and orientation, so detection distance is related to the trawl length.

Requirements:

- For inshore fisheries where trawl lengths are shorter (e.g., 0.25 miles), a minimum detection distance of 0.5 nautical miles is required.
- For offshore fisheries where trawl lengths can reach 1.5 miles, a minimum detection distance of 2 nautical miles is required.

Alternatives: Some offshore fishers suggested a detection distance of 3 miles would be best, but current detection distances of buoys, high fliers or radar reflectors are sometimes less than 3 miles.

Potential Solutions: For acoustic-based gear location marking, source level (i.e., the loudness of the acoustic transmissions) could be user-configurable so that in areas with longer trawls, the source level could be increased to increase detection range.

Location Accuracy

Discussion: Requirements for location accuracy are related to the density of fishing effort (i.e., the number of trawls in a given area, or equivalently, the distance between trawls). The denser the fishing effort, the higher the accuracy required. Mobile fishers do not need any higher accuracy for a fixed gear location marking system than required by fixed fishers. In some of the densest areas, fishers are setting trawls within tens of feet of other trawls.

Requirements:

- Location accuracy of at least 25 feet (~8 meters) is required.

Alternatives: In areas with low gear density, lower accuracy (50-100 feet) is likely acceptable; however, setting different accuracy standards in different zones may be difficult to manage.

Data Display at Sea

Discussion: All fixed fishers expressed a preference to see gear location information at sea on their chart plotter.

Requirements:

- Gear location information, including location and orientation of trawls, must be displayed on a chart plotter.

Alternatives: There was very modest support among fishers for displaying gear location data on a computer, and almost no support for viewing these data on a smart phone or tablet (although other groups, such as enforcement, may like to have the option of displaying data on a computer or tablet).

Additional Information to Collect and Share

Discussion: The gear location marking system should transmit not only gear location information, but other information important to gear owners, enforcement, and regulators.

Requirements:

- The gear location marking system must provide ownership information (state/federal permit/license numbers, owner identity), gear type, unique system identifier, number of traps on trawl, length and orientation of trawl, and date/time gear was deployed (from which soak time can be calculated).

Alternatives: Some fishers expressed interest in collecting and transmitting environmental data, such as information on water temperature and ocean currents.

Data Sharing

Discussion: The gear location marking system will collect data on gear location, ownership, configuration, etc., that will be helpful for gear owners, enforcement and fishery regulators. Fishers and enforcement need access to some or all of these data

when at sea and when on shore as well. Fishery regulators will want access to some form of these data on shore, but they do not require immediate access, and anonymized and summarized versions will likely suffice for them. Clear distinctions between public (e.g., gear location, trawl orientation) and private data (e.g., owner name) should be made, with private data encrypted for access only by gear owners and enforcement.

Requirements:

- Gear location information must be available to fishers and enforcement in real time on scene at sea (i.e., within the detection distance of the system) to avoid gear conflict.
- Real-time location information must mirror reality (i.e., locations must be associated with actual gear on the sea floor, and a lack of locations must be associated with no gear on the sea floor).
- The ends of trawls must be marked in a way that is not voluntary.
- All data (including location, state/federal permit/license numbers, owner identity, gear type, unique system identifier, number of traps on trawl, length and orientation of trawl, and date/time gear was deployed) must be available to enforcement in real time on scene at sea (i.e., within the detection distance of the system) as well as shared in near real time (within some prescribed time after deployment; e.g., 18 hours) with enforcement on shore (e.g., in an enforcement-accessible cloud database).

Alternatives: Some (but not all) fishers expressed an interest in seeing the location of their gear while they are on shore (note that providing location information access to gear owners is required for recovering lost gear; see "Lost Gear" section below).

Some fishers expressed an interest in knowing where their and others' gear was located while on shore prior to going to sea to save time and fuel when planning where to set/move gear. However, most fishers had serious reservations about making the location of their gear accessible to other fishers.

Some fishers expressed an interest in knowing the owner's identity of other fishers' gear to resolve gear conflicts or territoriality issues, and some fishers expressed a willingness to provide that information.

Potential Solutions: Layers of access together with encryption should be implemented so that data is only shared with appropriate parties. For example, all data is to be shared with gear owners and enforcement, whereas gear location and trawl length/orientation information is to be shared with all users when on scene at sea. Encryption can be used to keep owner data private and accessible only by the owner and enforcement.

A solution to fishers sharing gear ownership or location data with other fishers is to make sharing voluntary (default is no sharing, but fishers can "opt in" to sharing their ownership data).

Lost Gear

Discussion: Buoyless fishing causing an increase in the amount of ghost gear was a concern raised by most stakeholders. For some fishers, losing gear is not a serious problem in their area, so having a means to locate and recover lost gear was not a priority. For other fishers, lost gear and lost catch was a significant problem and a significant cost. Some fishers also suggested that the elimination of buoy lines would greatly reduce the chances of gear moving, so lost gear would become less of a problem. Enforcement agencies recover derelict gear; with a means for owners to relocate and recover their own gear, this may relieve enforcement of this task and free up resources for other tasks. The rate of gear loss is frequently quoted to be 10% per year, and at the very least, a suitable gear location marking system should be no worse than this.

Requirements:

- The gear location marking system must be able to provide an accurate location for gear even if the gear has moved (e.g., because of storms or being dragged by a mobile fisher).
- The gear location marking system should provide a means for gear that has moved to be relocated and retrieved by the owner.

Potential Solutions: An on-shore cloud database that makes gear location data accessible to gear owners in near real time would allow owners to be alerted if their gear was encountered by other fishers in someplace other than the location at which it was deployed.

Environmental Impacts

Discussion: Concern was expressed by most stakeholders over the introduction of noise into the environment by acoustic-based gear location marking systems. Concerns were also expressed over potential pollution from plastics, batteries, toxic components and heavy metals if gear was lost (this concern is addressed in the "Lost Gear" section above).

Requirements:

- The gear location marking system should (1) minimize the use of disposable plastics, (2) minimize acoustic noise, (3) choose acoustic frequencies and source levels that minimize effects on marine mammals, fish, and shellfish.

Battery endurance

Discussion: Devices attached to the ends of trawls will need to be serviced, and in particular, batteries will need to be replaced or recharged. Interviewed fishers provided a range of values for minimum battery life, from 3 months to over a year (depending on their fishing seasons). Battery life is likely going to be a feature with which device manufacturers compete against one another (similar to battery life on smartphones).

Requirements:

- Any gear location marking device that is affixed to submerged fishing gear must have an endurance of at least 6 months.
- Battery condition (e.g., voltage, charge status) of the gear location marking device must be easily interrogated.

Alternatives: Endurance of over a year would be preferred.

Other

Discussion: Other requirements emerged from the interviews that were not part of the original question list.

Requirements:

- Acoustic-based gear location marking devices must be able to activate whatever gear retrieval mechanism to which the device is attached (e.g., lift bag, bottom-stowed rope).
- The gear location marking system must be capable of sharing data in real time across international boundaries to avoid gear conflict and assist enforcement in these sensitive areas.
- A manufacturer's gear location marking device must be able to communicate with all other manufacturers' gear location marking devices using adopted standards.

Alternatives: Ultimately a registry for gear location marking devices will likely be needed so that their ownership can be tracked for enforcement purposes.

Table 2. Summary of preliminary requirements for a gear location marking system.

Function	**Preliminary requirement**
Detection distance	For inshore fisheries where trawl lengths are shorter, a minimum detection distance of 0.5 nautical miles is required. For offshore fisheries where trawl lengths can reach 1.5 miles, a minimum detection distance of 2 nautical miles is required.
Location accuracy	Location accuracy of at least 25 feet (~8 meters) is required.
Data display at sea	Gear location information, including location and orientation of trawls, must be displayed on a chart plotter.
Additional information to collect and share	The gear location marking system must provide ownership information (state/federal permit/license number, owner identity), gear type, unique system identifier, number of traps on trawl, length and orientation of trawl, and date/time gear was deployed.
Data sharing	Gear location information must be available to fishers and enforcement in real time on scene at sea (i.e., within the detection distance of the system) to avoid gear conflict. Real-time location information must mirror reality (i.e., locations must be associated with actual gear on the sea floor, and a lack of locations must be associated with no gear on the sea floor). The ends of trawls must be marked in a way that is not voluntary. All data (including location, ownership information, etc.) must be available to enforcement in real time on scene at sea (i.e., within the detection distance of the system) as well as shared in near real time (within some prescribed time after deployment; e.g., 18 hours) with enforcement on shore (e.g., in an enforcement-accessible cloud database).
Lost gear	The gear location marking system must be able to provide an accurate location for gear even if the gear has moved (e.g., because of storms or being dragged by a mobile fisher). The gear location marking system should provide a means for gear that has moved to be relocated and retrieved by the owner.

Function	Preliminary requirement
Environmental impacts	The gear location marking system should (1) minimize the use of disposable plastics, (2) minimize acoustic noise, (3) choose acoustic frequencies and source levels that minimize effects on marine mammals, fish, and shellfish.
Endurance	Any gear location marking device that is affixed to submerged fishing gear must have an endurance of at least 6 months. Battery condition (e.g., voltage, charge status) of the gear location marking device must be easily interrogated.
Other	Acoustic-based gear location marking devices must be able to activate whatever gear retrieval mechanism to which the device is attached (e.g., lift bag, bottom-stowed rope). The gear location marking system must be capable of sharing data in real time across international boundaries to avoid gear conflict and assist enforcement in these sensitive areas. A manufacturer's gear location marking device must be able to communicate with all other manufacturers' gear location marking devices using adopted standards.

5. Gear location marking method descriptions

A gear location marking system must fulfill two primary functions: (1) provide gear location information to fixed fishers to help them avoid laying trawls over one another and to mobile fishers to help them avoid trawling or dragging through fixed fishing gear and (2) provide gear location, ownership and other pertinent information to enforcement for monitoring and at-sea inspection. Depending on how the gear location marking system is designed, another possible function may be to provide fishing effort information to fishery managers.

Currently, there are four methods of gear location marking that have the potential for application in buoyless fishing: (1) GPS marking, (2) acoustic ranging, (3) directional acoustic ranging and (4) successive acoustic receive time (SART) self-localization. To provide a base of understanding of the available methods, we include a brief explanation of each of the gear location marking methods below as well as their pros and cons. A comparison among the different methods is provided in Table 3.

GPS marking

System requirements: (1) A GPS, (2) real-time at-sea data communications (e.g., cellular, satellite) and (3) on-shore data system to collect, store and distribute location, ownership, and enforcement data.

Localization principle: The location of each end of the trawl is measured as the GPS locations of the vessel when each end of the trawl is deployed (i.e., the surface location when they leave the vessel's deck). That location data must be transmitted to the on-shore data system along with ownership and enforcement data so that the location data is immediately accessible to other fishers, and ownership and enforcement data is accessible to enforcement.

Pros:

- Very simple and makes use of a well-understood technology (GPS).
- Produces no acoustic noise whatsoever.
- No device is attached to the ends of the trawl, so no maintenance of a trap marker is required (e.g., there are no batteries to replace).

Cons:

- No actual marker or physical device is attached to the gear to communicate its location; the marker is virtual and must rely on some other means of communicating the location of the gear in real time (e.g., an at-sea internet connection).
- If GPS data acquisition is not automatic for marking (i.e., marking is user-controlled), this method can be "gamed" such that virtual markers are set for gear that is not present, or virtual markers are absent for gear that is present.
- The initial accuracy of the location information will vary by depth and current, since the end of the trawl will drift laterally with the current as it descends to the sea floor.
- If the gear moves (e.g., because of a storm or dragger), its location will be unknown and it will contribute to increased gear conflict.
- If the gear moves beyond the acoustic range of the retrieval mechanism trigger (e.g., because of a storm or dragger), it will be impossible to relocate and retrieve the gear.
- This method alone does not transmit any information, so an on-shore data system capable of collecting, storing and sharing (with appropriate parties) data, including gear location, ownership information, gear type, number of traps per trawl and other essential information, is needed.
- Delivery of location information to avoid gear conflict requires real-time at-sea data communications (e.g., cellular or satellite internet connection).

Ranging

System requirements: (1) An acoustic device, called here the vessel transponder, affixed to a vessel's hull, (2) a complementary transponder (called here the trap transponder) affixed to one end of a trawl, (3) a vessel's GPS, (4) a computer or microprocessor to carry out the localization calculations, and (5) an on-shore data system to collect, store and distribute ownership and enforcement data.

Localization principle: The vessel transponder regularly (e.g., once a minute) emits a sound and records the exact time and location when the sound was emitted. When the trap transponder detects the sound, it immediately emits a sound of its own. When the vessel transponder detects this sound, it records the exact time of detection. A two-way travel time is calculated by subtracting the emission time from the detection time, and this two-way travel time is used to estimate the slant range to the trap transponder using the speed of sound in seawater. When slant ranges are collected at several different locations distributed around the trap transponder, the position of the trap transponder can be calculated. Accuracy largely depends on the spatial distribution of slant ranges measured around the trap transponder.

Pros:

- This is a common localization method for high-value equipment deployed on the sea floor, so is well known by many acousticians and acoustic release manufacturers.
- Several retrieval mechanisms (e.g., stowed rope or lift bag) are designed to be triggered acoustically, so including an acoustic gear location marking method in the same acoustic device that triggers the retrieval mechanism is feasible.

Cons:

- The vessel transponder needs to collect two-way travel times at locations distributed 270-360 degrees around the trap transponder (a process called "surveying"). Fishing vessels do not have the time to survey every trap transponder they encounter, so will not be able to localize every trap transponder they encounter.
- The trap transponder emits a sound every time a vessel emits a sound so the vessel system can measure the two-way travel time. This method produces the most sound of any of the other gear location marking methods, and since sound emission consumes power, this method will cause the trap transponder to use up batteries more quickly than other methods.
- This method alone does not transmit any information in the sound emission, so another method would be required to capture ownership and enforcement information as well as to identify both ends of a trawl to allow trawl orientation to be viewed by passing vessels.
- Without a capability to transmit information, this method cannot facilitate relocation of gear that has moved further away from the original deployment location than the detection range of the system.

Directional Ranging

System requirements: (1) An acoustic device (called here the vessel directional transponder) affixed to a vessel's hull, (2) a transponder (called here the trap transponder) affixed to one end of a trawl, (3) a vessel's GPS, (4) a computer or microprocessor to carry out the localization calculations, and (5) an on-shore data system to collect, store and distribute ownership and enforcement data.

Localization principle: The vessel transponder is attached to a hull-mounted directional transducer (also known as an ultra-short baseline, or USBL, transducer). The vessel and trap transponders produce sounds in exactly the same manner as for ranging to estimate the slant range (described above). Additionally, the vessel transponder measures a bearing to the sound produced by the trap transponder using the directional transducer. Using the position of the vessel, the estimated slant range, the bearing, and an estimate of the trap transponder's depth, the position of the trap transponder can be calculated.

Pros:

- This is a localization method often used for high-value equipment or divers, so is well known by several acoustics manufacturers.
- The position of the trap transponder can be calculated with a single transmission from the trap transponder.
- Several retrieval mechanisms (e.g., stowed rope or lift bag) are designed to be triggered acoustically, so including an acoustic gear location marking method in the same acoustic device that triggers the retrieval mechanism is feasible.

Cons:

- The accuracy of the calculated trap transponder position varies with range (i.e., the distance between the vessel directional transponder and the trap transponder) such that the error in the position estimate is larger at long ranges and smaller at short ranges. Because the accuracy changes with range, a vessel will likely need to emit sounds several times as it approaches a trap transponder to achieve sufficient accuracy to avoid gear conflict.
- Because multiple sound emissions are required to improve accuracy, this method produces more sound than the SART method, but less sound than the ranging method. Consequently, the battery drain (i.e., power consumption) from sound emission will be more than the SART method and less than the ranging method.
- This method alone does not transmit any information in the sound emission, so another method would be required to transmit ownership and enforcement information as well as to identify both ends of a trawl to allow trawl orientation to be viewed by passing vessels.
- Without a capability to transmit information, this method cannot facilitate relocation of gear that has moved further away from the original deployment location than the detection range of the system.

Successive acoustic receive time (SART) self-localization

System requirements: (1) An acoustic device (called here the vessel modem) affixed to a vessel's hull, (2) a complementary acoustic device with included microprocessor to carry out localization calculations (called here the trap modem) affixed to one end of a trawl, and (3) a vessel's GPS.

Localization principle: The vessel modem is attached to a hull-mounted transducer which regularly (e.g., once a minute) emits a series of sounds in which the following data are encoded: location of the vessel's transducer at the time of the sound emission and the time of the sound emission. The trap modem detects and decodes these sounds and stores the information about where and when the sounds were sent from the vessel in a table. Each successive difference in transmission time and each successive difference in acoustic receive time is then calculated from the data in the table, and from these differences, the position of the trap modem can be calculated[1]. Hence, the trap modem can self-localize simply by listening for and decoding the transmissions from passing vessels. The trap modem communicates its calculated position to a passing vessel in a single message that contains unencrypted public data and encrypted private data; the public data might include a unique identifier, the location of the trap modem and the unique identifier of the trap modem located at the other end of the trawl, while the private data might include ownership information, permit/registration number, deployment date/time and number of traps on the trawl.

Pros:

- Communicating information is built into this method, so relocating lost gear by transmitting ownership information is feasible.
- The SART method creates the least amount of noise and uses the least amount of battery capacity to transmit sound of any other method since it localizes by listening to vessel modem transmissions (i.e., not transmitting sound itself).
- Several retrieval mechanisms (e.g., stowed rope or lift bag) are designed to be triggered acoustically, so including an acoustic gear location marking method in the same acoustic device that triggers the retrieval mechanism is feasible.

Cons:

- The localization method is new, so is therefore unfamiliar to nearly all acousticians and acoustic release manufacturers.
- Because SART requires acoustic time differences to be measured 270-360 degrees around the trap modem, the first vessel to approach the trap modem would receive the surface deployment location in lieu of a SART-derived location. After the first vessel passes the trap modem, the trap modem will be able to self-localize and send self-localized positions to all other passing vessels.

[1] Baumgartner, M.F. and J. Partan. 2021. Self-localization of buoyless fishing gear and other objects on the sea floor. JASA Express Letters 1, 086001. https://doi.org/10.1121/10.0005739. Also available at ropeless.org.

Table 3. Comparison of gear location marking methods.

Characteristic	GPS marking	Ranging	Directional ranging	SART
Detection range	Unlimited[1]	Depends on acoustic source level, frequency, and ocean conditions	Depends on acoustic source level, frequency, and ocean conditions	Depends on acoustic source level, frequency, and ocean conditions
Accuracy	Accuracy decreases with increasing water depth and currents	Can be high if a complete survey is done	Varies with distance; low at long range, higher at close range	High (independent of range, water depth or currents)
Requires survey?[2]	No	Yes	No	No
Acoustic noise	None	High	Medium	Low
Can buoyless systems be relocated if moved beyond detection range?	No	No, unless device has the capability to transmit data acoustically[3]	No, unless device has the capability to transmit data acoustically[3]	Yes
Other information required for localization	None	Device depth	Device depth	Device depth
Other requirements for gear conflict resolution	Requires an on-shore data system and real-time at-sea data communications (e.g., cellular, satellite) to provide location information	Requires capability to transmit data acoustically to identify device at other end of trawl and thereby share trawl orientation	Requires capability to transmit data acoustically to identify device at other end of trawl and thereby share trawl orientation	None
Other requirements for locating lost gear and facilitating enforcement	Requires an on-shore data system to provide ownership and enforcement data[4]	Requires capability to transmit data acoustically as well as an on-shore data system to provide ownership and enforcement data[4]	Requires capability to transmit data acoustically as well as an on-shore data system to provide ownership and enforcement data[4]	None; encrypted ownership and enforcement data are delivered locally by device attached to trawl

[1] Range will likely be limited in software so that only gear within some fixed radius around a vessel's current position can be viewed by a fisher.

[2] A survey is when the fishing vessel must travel in a circle around the device on the sea floor to determine its position.

[3] With the capability to transmit data acoustically, the trap transponder could send a unique identifier to the vessel, and this identifier could be used to access ownership data in an on-shore data system to alert the owner that the gear has moved.

[4] Data such as unique system identifier, state/federal permit/license numbers, owner identity, gear type, number of traps on trawl, and date/time gear was deployed must be accessible to appropriate parties.

6. Preliminary assessment of gear location marking methods

We have conducted an initial assessment of the four gear location marking methods relative to the preliminary requirements (Table 4). This assessment will be discussed and updated during the workshop to determine how each of the gear location marking methods compares to the agreed-upon final requirements. Methods that meet a requirement are indicated with a check mark, while methods that do not meet a requirement are indicated with an "X". Additional capabilities needed for a method to meet a requirement are included where appropriate.

Table 4. Matrix of preliminary requirements and the capability of each gear location marking method to meet those requirements.

Function	Preliminary requirement	GPS marking	Ranging	Directional Ranging	SART
Detection distance	For inshore fisheries where trawl lengths are shorter, a minimum detection distance of 0.5 nautical miles is required.	✓	✓	✓	✓
Detection distance	For offshore fisheries where trawl lengths can reach 1.5 miles, a minimum detection distance of 2 nautical miles is required.	✓	✓	✓	✓
Location accuracy	Location accuracy of at least 25 feet (~8 meters) is required.	Depends on depth, currents and if gear moves	If survey is completed	✓	✓
Data display at sea	Gear location information, including location and orientation of trawls, must be displayed on a chart plotter.	N/A	N/A	N/A	N/A
Additional information to collect and share	The gear location marking system must provide ownership information (state/federal permit/license number, owner identity), gear type, unique system identifier, number of traps on trawl, length and orientation of trawl, and date/time gear was deployed.	Requires on-shore data system and real-time at-sea communications	Requires acoustic communication capability and on-shore data system	Requires acoustic communication capability and on-shore data system	✓
Data sharing	Gear location information must be available to fishers and enforcement in real time on scene at sea (i.e., within the detection distance of the system) to avoid gear conflict.	Requires on-shore data system and real-time at-sea communications	Requires acoustic communication capability and on-shore data system	Requires acoustic communication capability and on-shore data system	✓

Function	Preliminary requirement	GPS marking	Ranging	Directional Ranging	SART
Data sharing	Real-time location information must mirror reality (i.e., locations must be associated with actual gear on the sea floor, and a lack of locations must be associated with no gear on the sea floor).	Marker is virtual	✓	✓	✓
Data sharing	The ends of trawls must be marked in a way that is not voluntary.	Depends on implementation	N/A	N/A	N/A
Data sharing	All data (including location, ownership information, etc.) must be available to enforcement in real time on scene at sea (i.e., within the detection distance of the system).	Requires on-shore data system and real-time at-sea communications	Requires acoustic communication capability, on-shore data system and real-time at-sea communications	Requires acoustic communication capability, on-shore data system and real-time at-sea communications	✓
Data sharing	All data (including location, ownership information, etc.) must be shared in near real time (within some prescribed time after deployment; e.g., 18 hours) with enforcement on shore (e.g., in an enforcement-accessible cloud database).	N/A	N/A	N/A	N/A
Lost gear	The gear location marking system must be able to provide an accurate location for gear even if the gear has moved (e.g., because of storms or being dragged by a mobile fisher).	X	Requires acoustic communication capability and on-shore data system	Requires acoustic communication capability and on-shore data system	✓

Function	Preliminary requirement	GPS marking	Ranging	Directional Ranging	SART
Lost gear	The gear location marking system should provide a means for gear that has moved to be relocated and retrieved by the owner.	X	Requires acoustic communication capability and on-shore data system	Requires acoustic communication capability and on-shore data system	Requires on-shore data system
Environmental impacts	The gear location marking system should (1) minimize the use of disposable plastics, (2) minimize acoustic noise, (3) choose acoustic frequencies and source levels that minimize effects on marine mammals, fish, and shellfish.	Produces no acoustic noise	Produces highest amounts of acoustic noise	Produces moderate amounts of acoustic noise	Produces lowest amounts of acoustic noise
Endurance	Any gear location marking device that is affixed to submerged fishing gear must have an endurance of at least 6 months.	N/A	Uses most power for acoustic transmission	Uses moderate power for acoustic transmission	Uses least power for acoustic transmission
Endurance	Battery condition (e.g., voltage, charge status) of the gear location marking device must be easily interrogated.	N/A	N/A	N/A	N/A
Other	Acoustic-based gear location marking devices must be able to activate whatever gear retrieval mechanism to which the device is attached (e.g., lift bag, bottom-stowed rope).	N/A	✓	✓	✓
Other	The gear location marking system must be capable of sharing data in real time across international boundaries to avoid gear conflict and assist enforcement in these sensitive areas.	N/A	N/A	N/A	N/A

Function	Preliminary requirement	GPS marking	Ranging	Directional Ranging	SART
Other	A manufacturer's gear location marking device must be able to communicate with all other manufacturers' gear location marking devices using adopted standards.	N/A	N/A	N/A	N/A

Appendix 1: List of participants

Participant	Affiliation
Matt Abbott	Conservation Council of New Brunswick
Terry Alexander	Fisher (ME), NEFMC
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Andre Bezanson	Ashored Innovations
Kurt Blanchard	Rhode Island Division of Law Enforcement
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David Capotosto	DBV Technology
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Jane Davenport	Defenders of Wildlife
Marco Flagg	Desert Star
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CT Harry	International Fund for Animal Welfare
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Adam Kenney	Fisher (South shore Nova Scotia)
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Rob Morris	EdgeTech
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Sean Reilly	New York state enforcement
Meghan Rickard	New York Natural Heritage Program
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