Project Period 7/01/2016 - 12/31/2017

Project Location Description (from Proposal) Half Moon Bay Harbor, Gulf of Farallones, California.

Project Summary (from Proposal) Develop and test a prototype device that can communicate the location and identification of lost Dungeness crab traps back to shore. Project will demonstrate the ability to locate traps that have been lost or entangled in marine life, which enables their retrieval more quickly and thereby reduces the long-term impact of the derelict gear.

Project Status and Accomplishments

The Project entitled "Remote Detection and Location of Lost or Derelict Crab Traps" was completed on Dec. 31, 2017. All activities were successfully completed, and capabilities exceeded those originally planned.

Accomplishments related to the proposed activities include:

1. The initial prototype device was designed, assembled, and documented.
2. The initial prototype was tested off the dock. Successful operations were confirmed, with lessons learned to aid in improving the design.
3. The first round of design iterations was completed, with improvements made for complying with the California Department of Fish and Wildlife recommendations, and to improve the hardware and software of the design for better location accuracy and ability to withstand the marine environment.
4. Two ocean-going devices were assembled, implementing the above design improvements. All engineering documentation for hardware and software was maintained. The two units were tested off the dock, once in Half Moon Bay and once in San Francisco. The Half Moon Bay dock test confirmed system operations in a controlled marine environment, and the San Francisco dock test confirmed the system could be operated by the fishing boat's hauling equipment.
5. Three open water field tests were conducted with fishing boats owned and operated by commercial crab fishermen. One boat test was performed off the coast of Point Reyes near Stinson Beach with commercial fisherman John Mellor. This area did not have adequate cellular coverage for conducting successful communications tests, but the devices were able to be operated on the boat, and the water-tightness of the units was confirmed with no water leakage. The boat tests in Bodega Bay were more successful, with adequate cellular coverage. The units demonstrated consistent communications of time, location, and speed data, along with alerts if the gear moved beyond a threshold from its original deployment location, which serves as a simulated gear loss event.
6. Following these initial tests, the design was iterated upon again, using both information gathered from the testing plus feedback from the fishermen. In order to address the issue of operating in areas that lacked GSM coverage, two additional communications methods were implemented: satellite and long-range/low-power radio. The radio units were networked to the satellite unit, creating a mesh network of devices for data from all units to be sent to the fisherman onshore. In addition, a graphical user interface was developed to display the location of the networked buoys on a Google map that can be accessed on a smart phone device or computer. The data communicated in the messages from the buoys to shore was also updated to reflect useful information for the fishermen.
7. Three additional units were assembled to complete the total of five for this project. The initial two were equipped with GSM communications, and the final three consisted of two with radio communications, and one with radio and satellite communications. All designs were documented by Blue Ocean Gear.
8. The new Smart Buoys were tested incrementally off the dock, as well as off boats in the open water. These tests demonstrated the ability of the units to communicate as designed over water.
9. The final test with a fishing vessel involved a deployment of all 5 Smart Buoys in Bodega Bay, CA. The user interface was used by a colleague onshore, who was able to confirm when a buoy was moved (simulating loss of gear) and where to retrieve it.

These accomplishments have led to the following outcomes for this project:

1. Five ocean-going Smart Buoy units were developed using an innovative location and communications system design. All units were tested in typical fishing operations to demonstrate compatibility, robustness of design, and usefulness of data transmitted.
2. The Smart Buoy devices have been shown to be applicable in finding lost Dungeness crab

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gear. Local fishermen were engaged in the testing, as well as an onshore colleague to simulate the ability to note lost gear from onshore. Earlier detection of gear loss will facilitate recovery by providing coordinates for retrieval.

This project demonstrated the proof-of-concept design for being able to locate lost or derelict crab gear via GPS location devices coupled with onboard processing of buoy motion and communications to a user. The design is compatible with fishing operations, the data is useful for fishermen, and the networked system design makes the potential for future costs of goods to decrease significantly to ensure affordability by fishermen.

Lessons Learned

1. It is critical to take the fishermen's feedback and advice into account when designing smart fishing gear. It takes 60-90 seconds to haul, empty, re-bait, and reset a trap, and then it is time for the next one. Any additional devices on the gear must not interrupt these operations.
2. Communications must be operable in typical commercial fishing regions for effectiveness. The initial design utilizing GSM communications only is inadequate for fishermen operating in regions without adequate cellular service. A large percentage of fishermen fall into this category. As a result, satellite communications were implemented in the second generation Smart Buoys, with successful communications from a much broader region.
3. Cost is a large factor in designing smart fishing gear, as fishermen typically have between 100-800 traps per boat and do not want to invest excessive funds into gear devices. While satellite communications are superior in coverage area, putting satellite receivers and antennae on every buoy would be cost- prohibitive for the fishing community. As a result, a networked design involving radio communications from individual buoys to a central Smart Buoy equipped with a radio receiver and satellite transmitter was developed. This design also takes advantage of the configuration of trap fishing gear, where traps are typically set in strings, or sets of 10-20 in a row. These strings can be networked together with one satellite buoy per string. This allows reduced costs for the majority of buoys, and has the more costly components only on the central communications buoy of each string.

In general, the Lessons Learned in this project are rooted in the requirements of the fishermen for making this a device that is feasible for their budget as well as their operations. Getting their input and buy-in was critical. In addition, a greater understanding of the impacts of lost gear was acquired, as two of the field tests in Bodega Bay took place while the captain of the boat was looking for lost gear. The final designs have successfully addressed the fishermen's inputs on operations and cost.

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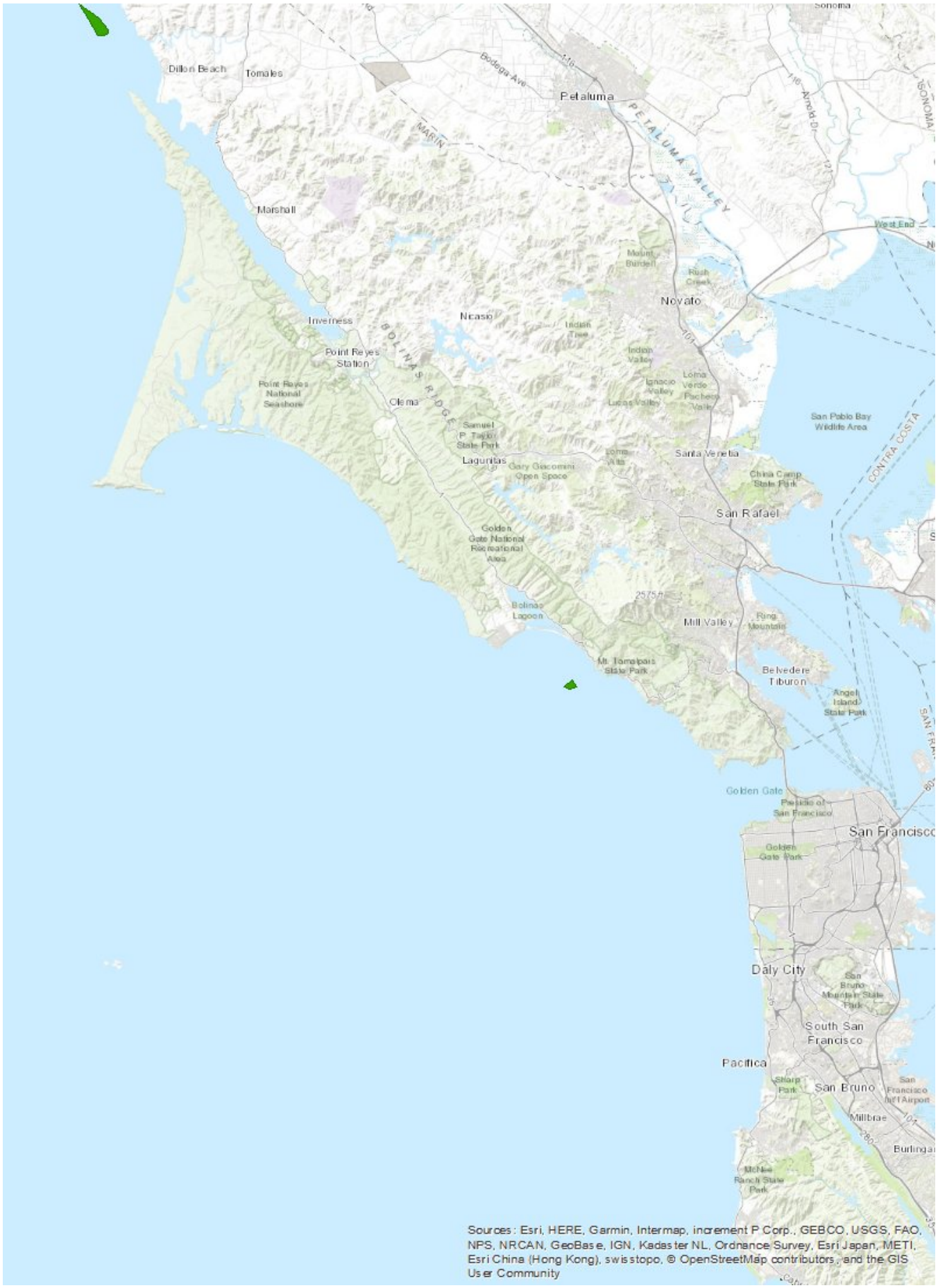
Activities and Outcomes

Funding Strategy: Planning, Research, Monitoring
Metric: FIF - Tool development for decision-making - # tools developed
Required: Optional
Description: Examples: risk pools, modified/improved fishing gear, improved fishing practices, voluntary avoidance methods, electronic monitoring devices (cameras), software systems/applications, etc

Starting Value	0.00 # tools developed
Value To Date	5.00 # tools developed
Target value	5.00 # tools developed

Note: Five Smart Buoys were developed for the Fishing for Energy project. 3 different communications methods were implemented, and a user interface was developed to display buoy locations.

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Final Programmatic Report Narrative

Instructions: Save this document on your computer and complete the narrative in the format provided. The final narrative should not exceed ten (10) pages; do not delete the text provided below. Once complete, upload this document into the online final programmatic report task as instructed. **Please note** that this narrative will be made available on NFWF's Grants Library and therefore should provide brief context for the need of your project and should not contain unexplained terms or acronyms.

1. Summary of Accomplishments

In four to five sentences, provide a brief summary of the project's key accomplishments and outcomes that were observed or measured. This can be duplicative to the summary provided in the reporting 'field' or you can provide more detail here.

2. Project Activities & Outcomes

Activities

- Describe the primary activities conducted during this grant and explain any discrepancies between the activities conducted from those that were proposed.

Outcomes

- Describe progress towards achieving the project outcomes as proposed. and briefly explain any discrepancies between your results compared to what was anticipated.
- Provide any further information (such as unexpected outcomes) important for understanding project activities and outcome results.

3. Lessons Learned

Describe the key lessons learned from this project, such as the least and most effective conservation practices or notable aspects of the project's methods, monitoring, or results. How could other conservation organizations adapt similar strategies to build upon some of these key lessons about what worked best and what did not?

4. Dissemination

Briefly identify any dissemination of project results and/or lessons learned to external audiences, such as the public or other conservation organizations. Specifically outline any management uptake and/or actions resulting from the project and describe the direct impacts of any capacity building activities.

5. Project Documents

Include in your final programmatic report, via the Uploads section of this task, the following:

- 2-10 representative photos from the project. Photos need to have a minimum resolution of 300 dpi. For each uploaded photo, provide a photo credit and brief description below;
- Report publications, Power Point (or other) presentations, GIS data, brochures, videos, outreach tools, press releases, media coverage;
- Any project deliverables per the terms of your grant agreement.

POSTING OF FINAL REPORT: *This report and attached project documents may be shared by the Foundation and any Funding Source for the Project via their respective websites. In the event that the Recipient intends to claim that its final report or project documents contains material that does not have to be posted on such websites because it is protected from disclosure by statutory or regulatory provisions, the Recipient shall clearly mark all such potentially protected materials as "PROTECTED" and provide an explanation and complete citation to the statutory or regulatory source for such protection.*

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1. **Summary of Accomplishments:** Blue Ocean Gear developed a Smart Buoy device to detect and locate lost crab traps. As a result, the project demonstrated the ability of these devices to detect and locate lost fishing gear. Fishing traps are at high risk of loss or entanglement, resulting in devastating financial and environmental impacts such as ghost fishing. Five Smart Buoy devices were assembled and successfully tested off a fishing boat in typical operations to demonstrate operational compatibility, robustness of design, and utility of data transmitted. A lost fishing gear simulation was successfully conducted with an onshore user, showing how the device can be useful to fishermen in knowing that their gear is at risk of becoming lost and where to find it, even if they are not on the water themselves.

2. **Project Activities and Outcomes:**

Activities:

a. Initial Prototype: An initial prototype Smart Buoy device to locate lost Dungeness crab traps was designed, assembled, and documented. The device works with a standard Dungeness crab trap that is connected to a main buoy via a length of rope from the seafloor to the water surface. A trailer buoy that is designed to hold the Smart Buoy electronics is then connected by a short length of rope to the main buoy. The electronics are designed to sense and communicate the location of the buoy, along with an identifier signal indicating the specific trap. This information is transmitted on a periodic, adjustable schedule via text message to the user whether they are onshore or on the water.

- **i.** Mounting components: This first prototype utilizes an IP-68 rated electronics enclosure mounted on a PVC frame on a ring buoy.
- **ii.** Electronics components: The electronics are comprised of a GPS receiver and antenna, a microprocessor, and a cellular transmitter with antenna, plus batteries for power.
- **iii.** Microprocessor logic: The device is turned on when it is deployed to allow the microprocessor to determine the deployed coordinates via the GPS. The microprocessor then samples the GPS periodically, determines the distance moved by the buoy, then sends that information over the GSM network via text message. If the buoy has moved beyond a threshold distance from the original location, an alert is sent. The initial threshold was set based on input from fishermen.

This unit was tested at the subsystem level, as well as the complete system, on land to confirm functionality. The California Department of Fish and Wildlife inspected the equipment prior to testing.

b. Initial Prototype Testing: The initial prototype was tested off the dock in San Francisco with fisherman John Mellor.

- **i.** Deviation from proposed activity: The initial plan was to test off the dock in Half Moon Bay, but it was helpful to have Mr. Mellor engaged in these tests so the location was changed to San Francisco. As the test was independent of location, and did not require a permit, this was a reasonable modification.
- **ii.** Results: Successful operations were confirmed, as text messages with the buoy location information were received once an area with adequate cell coverage was determined.
- **iii.** Lessons learned: There was minor water intrusion into the electronics enclosure, and there was a challenge in keeping the ring buoy upright in case of an inversion. These would be addressed in the design iterations following the testing.

c. Design Iterations: The first round of design iterations was completed to improve the hardware and software of the design for performance and ability to withstand the marine environment. These improvements were:

i. An improved electronics housing was implemented, rated to 100m depth to ensure there would be no water intrusion if the buoy was somehow dragged underwater.

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ii. A bullet-shaped buoy, similar to a standard crab trap main buoy, was used. This allows for assessment of the design that will eventually be mounted on a main buoy. A hole was created in the center of the buoy to mount the enclosure, with a PVC cap to secure it at the base.
iii. The batteries were mounted in a manner to provide a counterweight that would always keep the device antennae upright for sensing and communications.

d. Assembly of two devices: Two ocean-going devices were assembled, implementing the above design improvements. All engineering documentation for hardware and software was maintained. The two units were tested off the dock, once in Half Moon Bay and once in San Francisco. These tests confirmed system operations in a controlled marine environment, and that the counterweight design held the buoy upright for adequate communications. The data sent by the Smart Buoys includes an identification number, timestamp, the GPS coordinates of the buoy, the distance traveled, and the buoy speed. An alert is also included if the buoy moves greater than the threshold value.

e. Open water field testing: Three open water field tests were conducted with fishing boats owned and operated by commercial crab fishermen. One boat test was performed off the coast of Point Reyes near Stinson Beach with commercial fisherman John Mellor, and two subsequent tests were conducted in Bodega Bay with fisherman Dick Ogg. Prior to testing with fishing vessels, it was confirmed from the CA Department of Fish and Wildlife and the National Marine Sanctuary that as long as the testing operations were done in legal fishing waters during the commercial season, no permits were required. When testing extended into the off-season, permits from both organizations were obtained by Blue Ocean Gear.

i. Deviations from proposed activity: The initial plan was to test off in San Francisco Bay or the Gulf of the Farallones. Mr. Mellor indicated that the region close to Point Reyes would have calmer conditions for testing. In addition, Mr. Ogg indicated interest in helping with test activities, so Bodega Bay was added to the site list. All areas were cleared with permits and with NOAA's NEPA clearance.

ii. Results: The Point Reyes area did not have adequate cellular coverage for conducting successful communications tests, but the devices were able to be operated on the boat, and the water-tightness of the units was confirmed with no water leakage. The tests in Bodega Bay were successful, with adequate cellular coverage. The buoys were set in the water during normal fishing operations for several hours. The units demonstrated consistent communications of time, buoy location, distance traveled by the buoy, and buoy speed. The units did send alerts when the buoy moved further than the threshold value, indicating that the alert function was operational.

iii. Lessons learned: Since the buoys are typically dragged behind the boat for a period prior to deploying the trap itself, the original threshold value was determined to be too low for indicating a loss event and was increased for subsequent tests. The buoy would travel much further than that in the event of a storm or other cause of loss. In addition, the issue of cellular coverage needed to be addressed. The batteries of one unit did not last for one of the tests, so power management is also an issue for this design.

f. Design Iterations: Following these initial tests, the design was iterated upon again, using both information gathered from the testing plus feedback from the fishermen.

i. Communications methods: In order to address the issue of operating in areas that lacked GSM coverage, two additional communications methods were implemented: satellite and long-range/low-power radio. The radio units were networked to the satellite unit, creating a mesh network of devices for data from all units to be sent to the fisherman onshore. This allows the overall price for instrumenting a large set of fishing gear to be kept much lower.

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ii. User interface: A graphical user interface was developed by consultant Kevin Johnson to display the location of the networked buoys on a Google map that can be accessed on a smart phone device or computer. Note that the involvement of a new consultant was a deviation from the initial plan to have Professor Gabriel Elkaim as the sole consultant to this project. Approval was given by the FFE program for this, as it used the same consulting funds. Prof. Elkaim helped connect Blue Ocean Gear with Mr. Johnson for developing this interface and provided guidance during the development and testing. The data communicated in the messages from the buoys to shore was also updated to reflect useful information for the fishermen. This interface was implemented to improve the ease of use for the fishermen. Green markers on the map indicate the location of the Smart Buoys, and the markers turn red and indicat an alert status if the buoy moves beyond the threshold radius. Clicking on the marker displays the GPS coordinates, facilitating retrieval for a fisherman.

iii. Power management: The battery use was optimized in a newer version of the software in order to reduce power use when the unit was not sampling GPS or sending data.

g. Assembly of three devices: Three additional units were assembled to complete the total of five for this project. The initial two were equipped with GSM communications, and the final three consisted of two with radio communications, and one with radio and satellite communications. The radio/satellite buoy received data from the other two radio buoys, and transmitted data for all three via the Iridium network. All hardware and software designs were documented by Blue Ocean Gear.

h. The new Smart Buoys were tested incrementally off the dock, as well as off boats in the open water. Two tests were performed with the harbormaster team in Half Moon Bay and one test was conducted in Bodega Bay to test the communications distance of the radio and satellite buoys.

i. Deviations from proposed activity: The initial plan was to test all five units during these tests. However, with the development of the new radio network communications concept, it was deemed necessary from an engineering standpoint to test out the three new radio and satellite buoys together. The Half Moon Bay harbormaster team was engaged, as they are interested in this effort, and since it was much easier to go a short distance offshore with their boat and test communications without fishing traps attached. For the Bodega Bay test, the buoys were attached to crab traps and set in different locations. One buoy was sending data via radio to a radio receiver on the boat. The second buoy was equipped with a satellite transmitter. For the Half Moon Bay tests, the buoy equipped with satellite and radio was set, and one or two radio buoys were dragged behind the boat. Communications were checked periodically as the boat moved incremental distances away.

ii. Results: The first test in Bodega Bay resulted in successful communications from the satellite buoy, with consistent location and motion data sent. The data sent from the radio buoy was not received due to the boat's rapid motion. The first test in Half Moon Bay indicated a communication distance of roughly 0.4 miles. After some design modifications to the antenna, the second test showed a communications distance of 0.8 miles, though this was after the final test on the fishing boat. Note that subsequent software modifications that were tested on land after the period of performance for this project showed a distance of over 1 mile for successful radio communications, which will be used moving forward.

i. Final fishing boat test: The final test with a fishing vessel involved a deployment of all 5 Smart Buoys in Bodega Bay, CA. Two sent buoy location data via GSM text message, and three were networked with radio communications, with one of the three also equipped with satellite

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transmission capability to send data from all three to the user interface. A lost fishing gear event was simulated by moving one of the Smart Buoys (along with the attached trap) a certain distance away and testing whether or not a remote user could detect that event using the interface, and determine the coordinates where the Smart Buoy had moved to. This would be similar to what might happen if a storm washed gear away and it was no longer where the fisherman had originally. This would allow accurate retrieval instead of permanent loss of gear.

i. Results: The buoys using GSM communicated location and speed of the buoy consistently during the test. The user interface was accessed on the boat to demonstrate to the fisherman. The user interface was also used by a colleague onshore, who was able to confirm when a buoy was moved (simulating loss of gear) and where to retrieve it. The onshore user was able to tell when one buoy was moved roughly 80m away, as seen on the interface. However, the radio buoys were limited in their ability to communicate over greater distances for these tests (Note that the distance over which these buoys can communicate has since been increased via software and hardware modifications, as mentioned above). In a subsequent lost gear simulation test, the satellite buoy was moved. After a reboot needed due to a minor communications software bug, the user onshore was able to detect that it had been changed to an alert status on the interface. The indicator changes from green to red, and when the user clicked on the icon the current GPS coordinates are shown to facilitate retrieval.

ii. Lessons learned: The communications software has since been updated to allow more accurate timing between multiple networked buoys. The use case for the radio networked buoys was discussed with several fishermen. In the event that one of the radio buoys is lost, the central communications buoy (with radio receiving and satellite transmitting) would send the last-known coordinates for the lost buoy. This would provide a starting point for a retrieval search. By putting a receiver antenna on the boat, the line of sight to the lost buoy would enable receipt of a signal from further away, likely 10-20 km. Since the data signal contains the buoy coordinates, the gear could then be retrieved successfully.

Outcomes:

a. Development of prototype units of an innovative trap, buoy, and communications system: This outcome was successfully achieved. Five ocean-going Smart Buoy units were developed using a novel location and communications system design, in addition to the initial prototype unit. All units were tested in typical fishing operations to demonstrate compatibility, robustness of design, and usefulness of data transmitted. Beyond the original goals, a networked system of locator buoys to reduce costs was developed, and a user interface showing the buoys on a common mapping display was created and tested. These innovations will facilitate adoption of this technology as it becomes available to fishermen.

b. Results from the test protocols, indicating performance of the entire system as a whole and the ability to aid in the detection of lost or entangled Dungeness crab traps: The Smart Buoy devices have been shown to be applicable in finding lost Dungeness crab gear. Buoy location, distance from deployed coordinates, and speed were transmitted along with a timestamp and trap identification number. Received data was displayed either via text message or on a mapping interface, and alerts were indicated by either text or the buoy icon changing color. Providing coordinates can allow fishermen to know where their gear is located at all times. Local fishermen were engaged in the testing, as well as an onshore colleague to simulate the ability to note lost gear from onshore. Earlier detection of gear loss will facilitate recovery by providing coordinates for retrieval.

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c. Long term outcomes: The long-term outcomes from this project have already begun in some instances.
    a. A project is just beginning with the Pacific States Marine Fisheries Council to develop and test a larger number of Smart Buoys with Dungeness crab fishermen. Additional sensors will be implemented to determine if it is possible to differentiate a whale entanglement in fishing gear from a weather-related loss event.
    b. Other fisheries have expressed interest in using Smart Buoys to track fishing gear, such as spot prawn (CA), lobster (Nova Scotia), and other crab fisheries (Nova Scotia and British Columbia).
    c. Other practical uses for Smart Buoys were discussed with fishermen as testing commenced. For example, strong currents often pull buoys underwater for days or even weeks at a time. When they make boat trips out to haul their gear, they are unable to hook the buoys if they aren't above the surface, which wastes time and fuel. If a Smart Buoy transmitted data when it was above the surface, the fishermen could time their boat trips better instead of trying to predict when the current would let up.
    d. As the number of deployed units increases over the next year, data will be recorded to track the number of lost or entangled traps retrieved using Smart Buoys.

3. Lessons Learned:

a. It is critical to take the fishermen's feedback and advice into account when designing smart fishing gear. It takes 60-90 seconds to haul, empty, re-bait, and reset a trap, and then it is time for the next one. Any additional devices on the gear must not interrupt these operations. The design of the prototypes aimed to minimize any additional steps being taken prior to deployment.
b. The design must take into account typical operating regions for fishermen with respect to appropriate communications. The initial design utilizing GSM communications only is inadequate for fishermen operating in regions without adequate cellular service. A large percentage of fishermen fall into this category. As a result, satellite communications were implemented in the second generation Smart Buoys, with successful communications from a much broader region.
c. Cost is a large factor in designing smart fishing gear, as fishermen typically have between 100-800 traps per boat and do not want to invest excessive funds into gear devices. While satellite communications are superior in coverage area, putting satellite receivers and antennae on every buoy would be cost- prohibitive for the fishing community. As a result, a networked design involving radio communications from individual buoys to a central Smart Buoy equipped with a radio receiver and satellite transmitter was developed. This design also takes advantage of the configuration of trap fishing gear, where traps are typically set in strings, or sets of 10-20 in a row. These strings can be networked together with one satellite buoy per string. This allows reduced costs for the majority of buoys and implements the costlier satellite components only on the central communications buoy of each string.

In general, the Lessons Learned in this project are rooted in the requirements of the fishermen for making this a device that is feasible for their budget as well as their operations. Getting their input and buy-in was critical. In addition, a greater understanding of the impacts of lost gear was acquired, as two of the field tests in Bodega Bay took place while the captain of the boat was

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looking for lost gear. The final designs have successfully addressed the fishermen's inputs on operations and cost.

4. **Dissemination:** This project has led to two specific follow-ons: 1) presentation of the results to the 6th International Marine Debris Conference (6IMDC), and 2) follow-on work with the Pacific States Marine Fisheries Council (PSMFC) on using these devices to detect whale entanglements. These are described below.
    a. The NOAA representative assigned to this project, Sherry Lippiatt, encouraged participation in the 6IMDC as encouraging results were discussed. This conference highlights issues facing the oceans in terms of marine debris, and the efforts to address them. Several sessions are dedicated to marine debris caused by fishing gear, and the specific one that the results of this work will be presented in is the Innovative Advancements in Limiting the Impacts of Derelict Fishing Gear. The talk, entitled "Using Smart Buoys to Detect and Locate Lost Gear" highlights the issue of lost fishing traps, the Smart Buoy design and solution, and test results. The support of the Fishing For Energy program will be acknowledged. The presentation slide deck is attached in the Uploads section of this report.
    b. As the efforts of this project became known within the Dungeness crab fishing community, the PI, Kortney Opshaug, was invited to attend the Workshop on Crab Gear Innovations and Practices to Reduce Whale Interactions in March, 2017 in Portland, OR. Whale entanglements in fishing gear are a large problem off both coasts of the US and Canada, with the threat of shutting fisheries down in some regions. Interactions with some of the scientists led to discussions as to whether Smart Buoys could be used to differentiate a whale entanglement event from other types of loss events such as storms or strong current. A contract with the PSMFC has begun for 2018 to further develop these devices to test in this manner. Whales entangled in fishing gear are often seen only once, and never again, rendering rescue efforts ineffective. Detection of an entanglement event could provide rescue teams exact coordinates for the animal in trouble, reducing the amount of time to disentangle and improving chances of survival.
    c. Another follow-on is the recent membership of Blue Ocean Gear in the Global Ghost Gear Initiative (GGGI). We were invited to participate, as the Smart Buoy devices developed in this project have the same end goals as the organization is focused on. This provides a broader audience for this type of work and potential for larger pilot studies.

5. **Project Documents**: Included in the Uploads section are the photos itemized below, and the 6IMDC presentation slides.
    Photos:
        1. Credit: Kortney Opshaug. Description: This image shows the original prototype design for the Smart Buoy, which was an electronics enclosure mounted on a PVC frame and ring buoy. This design was improved upon through this Fishing for Energy project.
        2. Credit: Kortney Opshaug. Description: This image shows the follow-on design of the electronics and enclosure to the prototype above. This enclosure is rated to 100m depth to allow operations to continue even if it were dragged under for a period of time. The electronics include components GPS sensing, a microprocessor, and communications.

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3. Credit: Kortney Opshaug. Description: Smart Buoy with the electronics enclosure mounted inside a bullet buoy, such as typically used in crab or lobster fishing. The components are oriented such that the buoy remains upright for optimal positioning of the antennae sensing and communications.
4. Credit: Kortney Opshaug. Description: Smart Buoy setup with a crab trap prior to deployment off a fishing vessel. The Smart Buoy is attached as a trailer buoy to the standard main buoy.
5. Credit: Kortney Opshaug. Description: This photo shows a Smart Buoy being tested behind a boat in Half Moon Bay. These tests were demonstrating the communications distances achievable by the radio buoys.
6. Credit: Kortney Opshaug. Description: This photo is of the Fishing Vessel *Karen Jeanne*, owned and operated by Dungeness crab fisherman Dick Ogg out of Bodega Bay, CA. This vessel was used for several tests of the Smart Buoys.
7. Credit: Kortney Opshaug. Description: This is a photo of the deck of the F/V Karen Jeanne loaded with crab fishing gear prior to field testing. The 5 traps in the foreground are the ones equipped with Smart Buoys that were being tested that day.
8. Credit: Kortney Opshaug. Description: This image shows the Smart Buoy set up as a trailer buoy to the main crab buoy, deployed in Bodega Bay.
9. Credit: Kortney Opshaug. Description: All five Smart Buoys tested in the final field test in Bodega Bay. Two of the buoys use GSM communications, two have radio communications only, and one has radio to receive from the others plus satellite for transmitting.
10. Credit: Kevin Johnson. Description: This is a screenshot of the Graphical User Interface developed for the Smart Buoys that were transmitting via Iridium satellite. This was taken during the final field tests in Bodega Bay. The three green markers on the map reflect the location of the three Smart Buoys networked with radio/satellite communications. The blue circles around each one shows the 200m radius of typical buoy motion, outside of which an alert is generated and the marker would turn red. Clicking on a marker shows the latest GPS coordinates for that particular buoy.
11. Credit: Kortney Opshaug. Description: This is a screenshot of a text message sent from a Smart Buoy equipped with GSM communications. The data contains an identification number, timestamp, GPS coordinates, distance moved, and speed of the buoy. An alert is added on in the case of the buoy moving too far.

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