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Tracing Atlantic Sea Scallops Using Radio Frequency Identification (RFID) Technology

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A capstone project in partial fulfillment of the requirements for the degree of Master of Arts in Marine Science at the Virginia Institute of Marine Science, William & Mary

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List of Abbreviations

Chain of Custody (CoC)

European Article Number (EAN)

Global Pocket Reader (GPR)

Institut Technologique de Maintenance Industrielle (ITMI)

International Council for the Exploration of the Seas (ICES)

Illegal, Unreported, and Unregulated (IUU)

Marine Stewardship Council (MSC)

New England Fishery Management Council (NEFMC)

Passive Integrated Transponder (PIT)

Quick Response (QR)

Radio Frequency Identification (RFID)

Stock Keeping Unit (SKU)

Supply Chain Management (SCM)

Universal Product Code (UPC)

Executive Summary

Traceable seafood can be linked back to its origin and method of catch. Improving the traceability of marine organisms involves establishing a transparent Chain of Custody (CoC) by collecting data at checkpoints throughout the supply chain, from ship to shore to store. This report explores the feasibility of integrating Radio Frequency Identification (RFID) technology into the United States Atlantic sea scallop (*Placopecten magellanicus*) fishery in order to improve traceability. This report serves as a forward-looking evaluation of RFID technology that is intended to inform interested stakeholders of its functionality and capabilities. It is not intended to serve as a management proposal.

At a basic level, RFID technology consists of two hardware components: a tag and a reader. The reader activates the tag using a radio wave. The tag then responds with a radio wave of its own, which contains data. The data from the tag is then loaded into a software system by the reader. The data in the software system can then be accessed and managed by a user. There are many different variations of both the hardware and software components in an RFID system, which are explained in more detail in this report.

In fisheries, RFID technology has the potential to benefit fishery managers, the fishing industry, and seafood consumers. This report explores the use of RFID technology by implementing a ‘bag tag’ system for the United States Atlantic sea scallop fishery. In this system, RFID tags would be affixed to the bags that store scallop meats aboard fishing vessels. The first scan of the tag would occur at sea once a bag of scallop meats has been filled, a subsequent scan occurs when the scallop meats are offloaded in port and transferred to another entity. These two bag tag scans could provide fishery managers, such as the New England Fishery Management Council (NEFMC) and National Marine Fisheries Service, among others with data on where scallops are being caught, how many are being caught, who is catching them, and where they are being landed.

An RFID-based traceability system would benefit the fishing industry because it has the potential to serve as an enforceability measure to prevent Illegal, Unreported, and Unregulated (IUU) fishing, and it can assist fishermen in keeping an accurate, real-time inventory of the scallops being caught during a trip. Additionally, the data that is recorded by the traceability system would bolster the trip reporting that currently takes place.

From a consumer perspective, RFID provides an opportunity to gain a clear understanding of the origin of their seafood. The certification of sustainably sourced seafood, commonly referred to as eco-labeling, has become a complicated and convoluted process. The data provided from RFID bag tags has the potential to streamline the eco-labeling process by providing third-party certification entities with precise data relating to the CoC of products in the fishery.

This report concludes that a need and a technological framework exist to establish an RFID-based traceability system in the Atlantic sea scallop fishery. The proposed system, as evaluated in the context of this report, utilizes 12mm Passive Integrated Transponder (PIT) tags attached to bags of scallop meats. These tags would seamlessly collect data regarding where scallops are being caught, who is catching them, and where they are being landed.

I. Introduction

Problem Statement

In 2021, the U.S. Atlantic sea scallop fishery landed 43 million pounds of meats, with a value of $670 million making it one of the most valuable fisheries in the country (NOAA, 2021). The success of the scallop fishery in United States is largely due to a series of successful fishery management decisions since the 1990's, including a rotational harvest strategy that now accounts for approximately half of the total commercial landings (Rheuban et al., 2018; Rudders et al., 2020). The individuals on the advisory team for this project play critical roles in the continued success of the Atlantic sea scallop fishery's management strategy. Their suggestion to conduct this project indicates the importance of this work, which will provide insight regarding the potential future of Radio Frequency Identification (RFID) technology being implemented in the scallop fishery to improve traceability.

The traceability of seafood products has emerged as an important issue for the fishing industry, fishery managers and seafood consumers. Seafood companies have taken steps to document supply chains in recent years to address the issue (Rahman et al., 2021). Parallel efforts by the NEFMC have identified the development of measures to improve enforceability of landings limits (bag tags) as a possible work priority for 2023. A project exploring the use of RFID technology and its applications in fisheries has broad applicability as well as addressing an identified, emerging need. This project and its resulting report will relate specifically to Atlantic sea scallop traceability, with a focus on RFID technology and its applicability in the scallop industry. NEFMC has maintained an interest over the years in investigating RFID, but it has not been directly evaluated by the Council since its presentation in Amendment 10 in 2003. The advisory team for this project expects that improvements in technology and implementation have improved significantly since 2003, and RFID is much more likely to be applicable to the scallop fishery today.

At its core, the goal of integrating RFID technology into the scallop fishery is to allow a mechanism for any interested party to trace scallops from harvest through sale. From the consumer viewpoint, it provides verification of both where their seafood was caught and who caught it. Consumers have continued to have an increased interest in the sustainability of the food that they eat. This has paved the way for organizations like the Marine Stewardship Council (MSC), the Monterrey Bay Aquarium's Seafood Watch, and Friend of the Sea, which have emerged in recent years to offer certifications for sustainable fisheries. These sustainability certifications, commonly referred to as eco-labels, exist to provide customers with assurance that the product was harvested in a sustainable manner (McIlveen et al., 2019). An added benefit of this practice is that eco-labels can act as financial incentives for the fishery to improve its management practices and sustainability efforts. Seafood certified as sustainable has a stronger position in the marketplace and can be sold at a higher number of retailers at a higher price point. Additionally, an increasing number of retailers are requiring that the seafood they sell is certified as sustainable. (Goyert et al., 2010). However, the legitimacy of the certification process used by these organizations, MSC in particular, has been called into question by critics. MSC certification requires a significant financial contribution by the fishery, up to $300,000 in some cases, a possible conflict of interest for a non-profit organization offering eco-labels (Goyert et al., 2010). There is therefore a need for a reliable, equitable, method by which seafood can be certified as sustainable to consumers. RFID technology provides an opportunity to do so.

RFID technology, if properly utilized, has the potential to drastically improve the SCM and CoC in the scallop fishery (McIlveen et al., 2019; Rahman et al., 2021). While the improvement of accurate SCM and CoC will benefit seafood consumers by providing verification of who caught their scallops and where, it will also help fishery managers to accurately track and enforce landing limits (bag tags). Increased accuracy of catch (where and when) and landings (how much) data allows managers to better understand fishery harvest spatially and temporally and would provide a more complete census of total removals. The continued success of the scallop fishery's management plan requires continued innovation in stock monitoring technology, emphasizing the importance of this project and its broad application across many aspects of the fishery.

Radio Frequency Identification Technology - Basics

Technological advances that occurred during World War II produced significant improvements in radar technology. Radar functions by emitting radio waves, then detecting an object's position based on how those radio waves are reflected back to their source. These technological advances likely played a major role in the development of RFID technology as we know it today (Landt, 2005). H. Stockman's 'Communication by means of reflected power', published in 1948, is thought to be the first published work exploring Radio Frequency Identification technology. It wasn't until the 1980's, however, that RFID technology was implemented at scale. In the United States, the transportation sector took a particular interest in the technology. In the late 80's, The Port Authority of New York and New Jersey and the Dallas North Turnpike implemented large-scale RFID systems for toll collection (Landt, 2005; Landt & Catlin, 2001). These systems attached RFID tags to individual vehicles, allowing those vehicles to pass through an RFID scanning checkpoint without stopping to pay their toll. In the decades since, research and innovation have continued to find more applications for RFID technology, as well as making it both smaller and more affordable. Today, RFID is utilized by many different sectors for a diverse of purposes, including logistics, supply chain, asset tracking, and healthcare (Munoz-Ausecha et al., 2021).

RFID functions by utilizing three main components: a transceiver, a transponder, and an antenna (Figure 1). The antenna and the transceiver are commonly combined into one piece of equipment, which this report will refer to as the 'reader'. This report will refer to the transponder as the 'tag'. The reader emits radio waves that serve as a signal for the tag, which then transmits its data, in the form of radio waves, back to the reader (Cui et al., 2019). The reader then translates the signal it received from the tag into data, which can then be uploaded to a network. That network can then be accessed using a computer that has been granted access to the network in order to view and manage the collected data.

Of the two primary RFID components, tags are more simple, smaller, and inexpensive compared to the reader. Tags can be powered independently by batteries, or they can be powered by returning the radio signal send by the reader (Landt, 2005). Tags that are powered by their own batteries, commonly referred to as active tags, have a signal availability of over 100 feet, meaning that they require a lower signal strength from the reader and can be read from greater distances (Ishtiaq, 2019). Passive tags do not contain an internal power source, instead they are powered by the radio wave that they receive from the reader through a process known as backscattering (Cui et al., 2019). The fact that passive tags do not contain a power source makes them both smaller and more inexpensive compared to active tags, but they have a significantly shorter range and require a relatively powerful reader. Biomark, a distributor of passive tags, cites the range of their passive tags as being about 30 cm. Finally, semi-passive tags look very similar to passive tags in size and complexity, but they do contain a small power source attached (Ishtiaq et al., 2019). Due to the fact that they contain an internal power source, active tags can be used in the broadest range of applications. The RFID-based traceability system described in this report (see 'Implementation' section) uis predicated on passive tags. Table 1 identifies the differences between active and passive RFID tags.

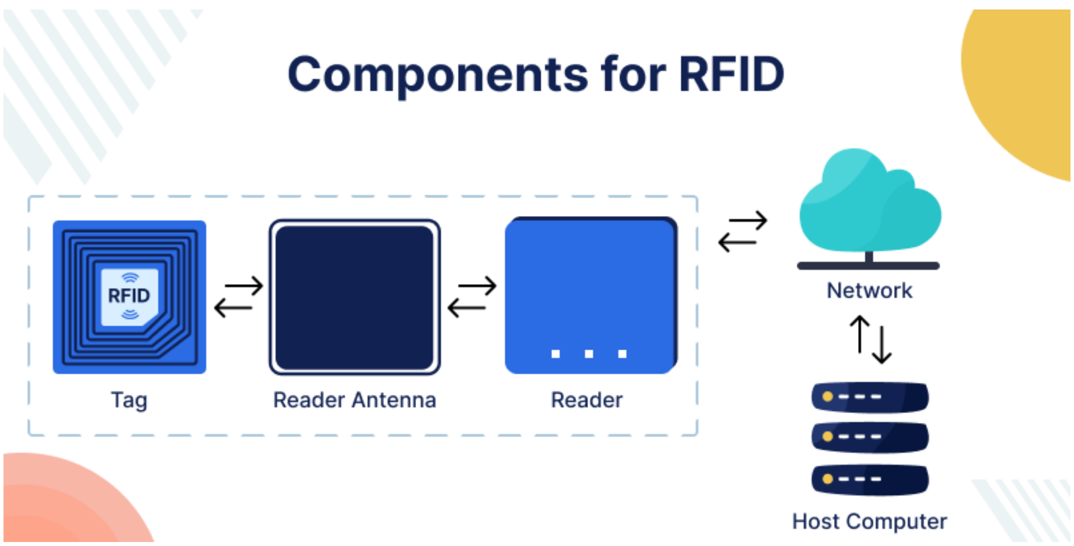

Figure 1: Basic functionality of an RFID system. RFID hardware consists of a transponder, commonly referred to as a tag, a transceiver, commonly referred to as a reader, and an antenna. The reader and antenna are contained in a single device in most RFID systems. RFID data is then uploaded to a network, which an end user can access through a host computer. (webkul.com).

Data collection occurs when a reader scans a tag. When a scan takes place, the data from any tags in the scanner's range will be downloaded and stored on the scanner. Once the scanner is connected to a network, a process that can occur through a wired or wireless connection, the data will be processed through middleware software. Middleware processes the information produced by the RFID components and manipulates it into a format that can be utilized by end users (Baballe, 2021). Once the data has been converted, it is uploaded to a network and can be accessed using host computers.

Table 1: Technical and functional differences between passive and active RFID tags (He & Suuronen, 2018; adapted and modified from SAVI Technologies (2007))

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

Current Uses of RFID Technology

RFID technology was first used on a large scale during the 1980's to collect electronic tolls on turnpikes and in tunnels (Landt, 2005). Since then, the technology has continued to evolve and is now used in many different industries. RFID has become especially helpful in the monitoring of SCM. Thanks to RFID technology, businesses have been able to reduce their labor costs, streamline procedures, and maximize efficiency (Sriram et al., 2021). Within SCM, RFID is most commonly used in asset tracking and monitoring (Casella et al., 2022). Tracking inventory in a retail store provides an opportunity to showcase how RFID differs from traditional inventory tracking methods. There are several advantages of RFID technology that make it preferable to other traceability technology (Figure 2).

Figure 2: Advantages of RFID technology. (Cui et al., 2019).

Compared to traditional practices, primarily barcoding and Stock Keeping Units (SKU) (see ‘Other Relevant Technologies’ section), RFID is able to capture much more information without as much human time and effort. Due to the fact that RFID is contactless and wireless, and the scanning of active tags does not require line-of-sight in order to function (Cui et al., 2019). In practice, that means that an employee could be able to walk down the aisle in a retail store with an RFID reader in hand, collecting real-time RFID-based inventory data without scanning any individual items. This saves businesses from labor costs, while simultaneously increasing the frequency, and therefore the accuracy, of their inventory practices.

The applicability of RFID technology extends beyond logistics and supply chain contexts. There are a broad range of animal applications for RFID tags as well. The microchips that are inserted into dogs, for example, are RFID-powered. In addition to identifying a lost dog for its owners, these chips can store the dog’s vaccination record (Gillenson et al., 2019). This example demonstrates a situation in which passive (non-battery powered) RFID tags are beneficial. Because the tag is powered by backscattering the radio wave from an RFID reader, it can be used for much longer without needing to be replaced.

II. Background

RFID in Fisheries

The broad range of RFID functionality has allowed for it to be utilized in a broad range of fisheries applications in both fisheries science and fisheries management. RFID-based traceability systems have been used in both aquaculture and wild-caught fisheries SCM (Rahman et al., 2021). The specific applications have been broad, from using wireless tracking to measure environmental factors in the facilities involved in seafood transit to ensure food safety (Zhang et al., 2019), to RFID tags being implanted in live fish to track them in a restaurant setting (Hsu et al., 2008). This report identified the United Kingdom as being the primary location to have utilized RFID technology with scallops. The International Council for the Exploration of the Seas (ICES) Scallop Assessment Working Group (WGScallop) conducted a pilot project in 2018 where scallops were tagged with RFID chips then released back into the habitat. The project intends to investigate the efficiency of commercial scallop dredges, but no data or reports have been released yet (ICES, 2018). The UK Seafood Innovation Fund is conducting a similar project, which is ongoing, and no data or reports have been published.

A Canadian project, led by the Institut Technologique de Maintenance Industrielle (ITMI), is utilizing RFID technology to track and trace fishing gear. ITMI researchers have teamed up with Axem Technology to develop and RFID-based system that allows fishing gear to be uniquely and clearly identifiable by managers and owners, as well as determining if and where that gear has been lost. The ITMI project utilizes passive RFID tags attached to fishing gear in a marine environment, validating the technology that has been identified by this report as being viable for a scallop traceability system (see ‘Proposed Solution’ section).

RFID technology has been used in Scottish crab and lobster pot fisheries to determine fishing effort by detecting tags during deployment and retrieval (He & Suuronen, 2018). A similar project was attempted with the Japanese conger eel pot fishery, which recorded GPS data in addition to soak time (fishing effort) data (He & Suuronen, 2018). While the primary focus of these projects was to determine fishing effort, there may be an opportunity to use similar data to address Illegal, Unreported, and Unregulated (IUU) fishing.

The utilization of RFID in the ITMI project as well as the pot fisheries in Scotland and Japan have shown the ability of the technology to monitor fishing gear in wild-caught fisheries. There is real potential to utilize the data gathered from these projects to address IUU fishing. If fisheries managers are able to track the owners and locations of fishing gear using verifiable data, it will make it much more difficult for fishermen to fish illegally. While this is a benefit to fisheries managers, it also benefits fishermen who are fishing legally. As such, the RFID-enabled traceability system outlined in this report may potentially be utilized as an enforceability measure as well as a traceability measure.

RFID in Eco-Labeling

Historically, markets for agricultural and food products have left consumers with a lack of information on the origin and quality of their food. Information for consumers regarding the control quality, origin, and food safety measures has come at a high cost or not been available at all (Heyder et al., 2012). In recent years, however, consumers have become increasingly aware of the importance of this information and have called for it to become more readily available. These concerns escalated during the COVID-19 pandemic, when food safety became a top priority for seafood importers and (Rahman et al., 2021). RFID technology has been implemented around the world in both capture fisheries and aquaculture operations in order to improve SCM and transparency, giving consumers and distributors more confidence in their seafood (Rahman et al., 2021). Improving SCM and transparency in tandem results in an increase in overall traceability of seafood products. Consumers and distributors are not the only entity that stand to benefit from enhanced traceability. Fisheries managers and the fishing industry are interested in the benefits of increased traceability because of the data generated and subsequent insight and data that it provides into fishing patterns and trends.

The integration of RFID technology in fisheries has the potential to streamline the eco-labeling process. Organizations such as the Marine Stewardship Council (MSC) offer to certify fisheries as sustainable, providing them with a label they can place on their seafood to signify responsible sourcing. This process provides fisheries with an economic incentive to meet the MSC's certification standards, as consumers are more likely to pay a higher price for seafood that has been labelled as sustainably sourced (Goyert et al., 2010). For example, a study conducted in the London metropolitan area of the UK found that consumers paid a price premium of 14.2% for MSC-labeled Alaska pollock products (Roheim et al., 2011). There is also evidence of price-premiums for MSC-labeled products at the ex-vessel level, directly in higher profits for fishermen. The MSC-certified artisanal common octopus fleet in Asturias, Spain received an ex-vessel price premiums of 15.2% - 24.6 % over uncertified octopus price (Sánchez et al., 2020).

The concept of eco-labeling emerged in the 1980's, when dolphin-friendly labels were applied to canned tuna products. Since then, a number of other entities have entered the eco-labeling market, including MSC. According to McIlveen et al. (2019), a central problem with the eco-labeling process is the varying credibility of the third-party labeling entities. The various channels that contribute to credibility can be seen in Figure 3. The importance of credibility in the eco-labeling process is paramount because it establishes the authority of the third-party organizations to determine whether a fishery is sustainable or not.

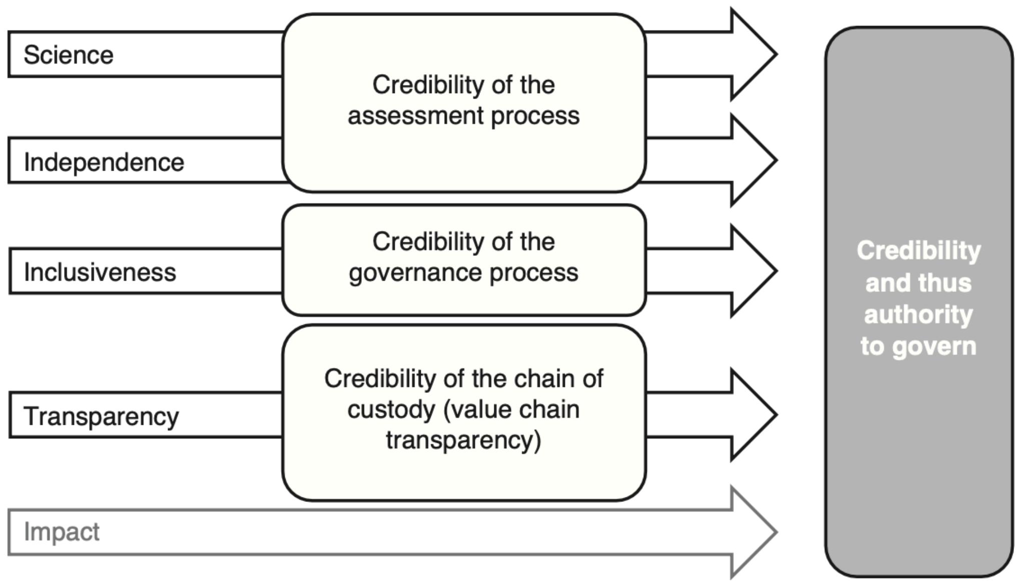

Figure 3: The four key practices for credibility. The RFID-focused work in this report explores the fourth key: transparency (McIlveen et al., 2019).

The RFID-based traceability system described in this report provides an avenue by which the scallop fishery would be able to clearly establish its transparency to third-party eco-labeling entities. If properly utilized, the data produced by an RFID-enabled CoC can clearly demonstrate where a product was caught, who caught it, and when. Establishing similar information through traditional fisheries data streams can be costly and time consuming, which may negate some of the benefits that a fishery hopes to gain by pursuing an eco-label certification (Goyert et al., 2010). So, while the traceability system established in this report (see 'Implementation' section) would not be a suitable replacement for third-party eco-labeling entities, it could help fishery managers in producing clear, transparent CoC data. This would simplify the process of establishing sustainability when applying for an eco-label.

Other Relevant Technologies

A few other technologies that could be relevant to improving a scallop traceability system are barcoding (Figure 4a), Quick Response (QR) codes (Figure 4b), and blockchain. Barcodes and

QR codes are hardware components, meaning that they are physical components of the system. Blockchain is a software component, which tells hardware what to do and how to do it.

Barcodes are the simplest of the hardware components described in this report. Barcodes emerged in the 1970's as a tool to expedite the checkout process at grocery stores and have since become synonymous with inventory management (Chanda, 2019). They are limited to one horizontal line of code, meaning that they are 'one dimensional', which limits their potential functionality (Singh, 2016). Barcodes are read by shining laser light on the parallel black and white lines, a process that requires a specialized barcode reader. The most common type of barcode in the United States is UPC (Universal Product Code), while the rest of the world typically utilizes EAN (European Article Number) barcodes (Mishra & Mathuria, 2017). QR codes have emerged more recently and are made up of a more complex combination of black and white modules (Figure 4b). The position of the modules informs how the information is encoded. QR codes contain error adjustments allowing the code to be read even if it has been partially damaged (Ventura et a., 2016). QR codes can store data in two dimensions, also known as matrix code, allowing them to perform more complex functionality than barcodes. QR codes can be read by most smartphones on the market, making them easily accessible to a wide audience.

*Figure 4: (**a**) Traditional barcode. This barcode requires a barcode scanner to read (wired.com). (**b**) Quick Response (QR) code. This code, generated for free by the website QR.io, links to the NEFMC scallop management web page and can be scanned with a smartphone.*

Blockchain is an electronic database (software) that tracks every transaction that takes place on its network, using consensus protocols to verify data and reduce the risk of data corruption (Howson, 2020). In simpler terms, blockchain is a tamper-proof database that can ensure data security without the need for a trusted third party because it is able to verify itself. Blockchains are best known for their role in maintaining a secure record of transactions for cryptocurrency systems such as Bitcoin (Hayes et al., 2022). Blockchain can be generally categorized into permissionless public blockchains, permissioned public blockchains, and permissioned private blockchains (Cruz & da Cruz, 2020). These distinctions are relevant when database administrators are determining which parties should be granted access to the system. The principal strengths of blockchain are that it is generally resilient to data loss, and it utilizes shared governance in the establishment of its consensus protocol (Ruoti et al., 2019; Cruz & da Cruz, 2020). Essentially, the integration of blockchain technology into a supply chain allows all relevant parties access to the collected data, and it ensures the accuracy and security of data. A blockchain-based database ensures transparency in a traceability system, bolstering that system's credibility (Figure 3).

Technologies being used together

A comprehensive fisheries traceability system would ideally integrate both hardware and software components. The development of an information system (software) is not sufficient in itself to be a traceability system (FMRIC, 2008) In this report, a system is examined where RFID technology serves as the hardware, that would need to be paired with a software-based information system to effectively track CoC and establish traceability. While innovations in internet-based cloud computing systems have increased their accessibility, effective fisheries traceability systems would likely include additional components (Moga, 2017). For example, a complete RFID-based traceability system may utilize RFID tags and readers to capture data, a blockchain database to verify and store the data, and QR codes for consumers to access the data.

RFID has been identified as the hardware component of choice for this report due to its superior ability to identify and transmit data compared to technologies such as barcodes and QR codes (Cui et al., 2019). RFID is preferable due to the fact that it is a more complex technology with a wider applicability. For the purposes of fisheries managers, in this case the NEFMC, evaluation of the benefits and drawbacks of different hardware systems may be necessary. A comparison of the capabilities of these technologies can be seen in Table 2.

Table 2: Comparison of different hardware components associated with traceability systems.

Technology	RFID	Barcode	QR Code
Advantages	• Multiple tags can be scanned simultaneously • Read-write capabilities • Broad applicability • Line of sight not necessary	• Cheap • Simple • Commonly used	• Scannable by most smartphones • Cheap, easy to generate • Two dimensional
Disadvantages	• Require specialized readers • Comparatively expensive	• Line of sight necessary • One dimensional	• Line of sight necessary • Read only

In order for a traceability system to be effective, it needs to be complete, thorough, enforceable, and utilized by a significant portion of the fishery (Moga, 2017). The benefits that are provided by cloud-based computing systems and RFID tags rely on a consistent stream of data inputs. Maintaining reliable and consistent data inputs will require participation by fishermen in the sea scallop fleet.

Scallop Fishery Relevant Details

The Atlantic sea scallop is one of the most valuable single species fisheries on the east coast of the United States, with an ex-vessel value of $488 million in 2020 (Rudders et al., 2020; NOAA, 2020). There are roughly 350 full-time limited access vessels operating in the fishery (NEFMC, 2022). These vessels, along with the fleet of smaller vessels operating on trip limits, would be targeted for the implementation of this RFID-based traceability system. The fishery is managed using a rotational harvest strategy, which accounts for approximately half of the fishery's current annual landings (Rheuban et al., 2018; Rudders et al., 2020). Rotational harvest allows fisheries managers to 'close' certain geographical areas to commercial fishing, allowing juvenile scallops in that area time to grow and reproduce without being exposed to fishing pressure. Other areas in the fishery remain open to permitted fishing vessels.

A traceability system would need to be robust to future changes in the fishery to be beneficial through time. Climate change represents one such change, as it continues to affect marine ecosystems, fisheries managers will need to take steps in order to quantify those changes to understand potential future impacts (Stokesbury & Bethoney, 2020). RFID technology may be able to assist with this process, as an RFID traceability system has the potential to provide fine scale geographic data regarding where scallops are being caught. Although the rotational management strategy informs the areas in which limited-access vessels can catch scallops, the RFID system would provide fisheries managers with an increased level of data precision as to where scallops were being caught inside each area. Over time, this system could potentially show any population migration that may be occurring due to climate change or other environmental factors.

III. Proposed Solution & Implementation

Proposed Solution

One possible realization of an RFID-based bag tag strategy has been discussed with Biomark, a company that specializes in identification solutions in fish and wildlife communities. Roman Smith (roman.smith@merck.com) was the representative that assisted in identifying the technology that would be necessary in order to establish, and price, an effective traceability solution. Biomark recommends the use of 12mm GPT12 Passive Integrated Transponder (PIT) tags (Figure 5). The GPT12 tags are low-cost, waterproof, RFID-powered, provide tag number, time, and date data every time they are scanned, and are functional in a marine environment. Biomark sells batches of 100 GPT12 tags for $204, or $2.04 per tag. One tag would be affixed to each bag of scallops aboard a fishing vessel, which breaks down to an implementation cost of roughly $0.04 per pound of scallop meats. The advisory team for this report estimates that a full-time limited access vessel is likely to land around 400-500 bags of scallop meats in a given trip. This results in a maximum expense of about $816 - $1,020 for new GPT12 PIT tags per trip should all bags be equipped with a tag. Further details regarding ways by which this expense may be reduced are available in the 'Future Considerations' section.

Figure 5: 12mm GPT12 Passive Integrated Transponder (PIT) Tag. Unit cost $2.04 (Biomark).

Biomark offered three different options for RFID readers that are compatible with the GPT12 tags: the Global Pocket Reader Plus (GPR Plus) (Figure 6a), the HPR Lite (Figure 6b), and the HPR Plus (Figure 6c). The GPR plus is the most inexpensive reader, at $650 per unit. GPR plus is not waterproof or water-resistant, but Biomark does sell a water-resistant cover. The HPR Lite is $950 per unit, but it is both shock resistant and water-resistant. GPR Plus and HPR Lite scanners capture data from individual RFID tags, which does not include geographic position data. The HPR Plus, $3,670 per unit, has the same waterproof capabilities of the HPR Lite, but would assign geographic position data to each tag scan. For that reason, this report suggests the use of the HPR Plus model for at-sea scans. Each of these scanners are handheld and would capture data by simply waving them over the tags.

*Figure 6: (**a**) GPR Plus Handheld PIT Tag Reader. Records time, date, tag number. Not waterproof. Unit cost $650 (Biomark). (**b**) HPR Lite Handheld PIT Tag Reader. Records time, date, tag number. Waterproof and shock resistant. Unit cost $950 (Biomark). (**c**) HPR Plus Handheld PIT Tag Reader. Records time, date, tag number, geographic position. Unit cost $3,670 (Biomark).*

No internet connection is necessary in order to collect data at sea, as each of the recommended readers has the capacity to store data from at least 3,000 individual data entries (tags), which is far more storage than would likely be necessary during an individual fishing trip. All of the recommended scanners can be connected via USB or Bluetooth in order to download their data to the Biomark Device Management Software. Access to the management software would be provided for free upon the purchase of Biomark supplies. Once the data has been entered into the device management software, it can be downloaded and viewed in a .XLSX or .TXT format.

Other companies that sell similar RFID technology that could be used in the scallop fishery include Oregon RFID, William Frick & Company, and Unified Information Devices.

Implementation

This report has elected to focus on the implementation of an RFID-based bag tag traceability system aboard the fleet of full-time, limited access vessels accessing the Atlantic sea scallop fishery in the northwest Atlantic. While at sea, scallop fishermen remove the adductor muscles, or “meats” from the captured scallops and store them in bags of consistent size. The bags, made of a material similar to cheesecloth, hold between 40-60 pounds of scallop meat. Individual GPT12 tags would be affixed to the bags themselves. This tagging method has been selected due to the fact that the Atlantic sea scallop fishery is wild capture, so establishing traceability by tagging individual scallops would be prohibitively expensive and unnecessary.

Data collection to establish CoC begins with fishermen scanning the tag attached to a recently filled bag of scallop meat with a handheld RFID reader (HPR Plus, for example), establishing which fishing vessel caught the scallops and recording their geographic location. This process does not require an internet connection, as the RFID reader will store the data until it is connected to the device management software. Readers have the storage capacity for thousands of individual scans. The bag would then be put on ice in the hold of the vessel for the remainder of the trip.

In addition to capturing data for traceability purposes, fishermen will be able to utilize the RFID technology aboard their vessel to conduct real-time inventory management. The HPR Plus reader will maintain an active count of how many bags of scallops have been scanned during a given trip. Although they will be able to, fishermen will not need to download any data in order to see how many tags have been scanned. This information is available on the reader’s display.

Once the fishing vessel returns to port, the GPT12 bag tags are to be scanned again. Ideally, this scan would be done by whoever is taking physical control of the scallop meat. This would allow fishermen and fisheries managers to identify who is taking possession of their scallops and the next steps in the harvest/landing process, contributing to transparency and maintaining the CoC. If it were to be the fishermen doing it, this scan will still provide data regarding where scallop meat is being landed, how many pounds are being landed. This port scan will likely be the final scan that takes place in the portion of the supply chain under the purview of NEFMC. Any additional tag scans, or data being pulled from the network, would be utilized in order to benefit the distributor, wholesaler, or consumer of the scallops.

Despite the fact that additional scans are not enforceable or required by fisheries managers, there may be an economic incentive for retailers to continue utilizing the RFID system. Retailers could use the data from the CoC established in this traceability system to sell their scallops at a higher price. They would be able to show consumers where their scallops were caught, by who, and when. While this is much less stringent than the eco-labeling process, at MSC, for example, it has been shown to have a positive impact on individuals purchasing seafood. Consumers assign value in the understanding of where their food came from, resulting in price-premiums for certified-sustainable seafood (Rahman et al., 2021; Roheim et al., 2011; Sánchez et al., 2020).

Future Considerations

This forward-looking report covers the basic functionality of Radio Frequency Identification technology and discusses some of the ways in which it could benefit the scallop fishery. However, there are some components of this work that will require further investigation. In order to achieve the maximum potential of an RFID-enabled supply chain, data would ideally be collected from the point of harvest to the point of final sale. The proposed solution in this report focused on the portion of the supply chain from the point of harvest to the first transfer of the scallops. Collaboration with other entities involved in the supply chain may allow for the continuation of a transparent CoC.

One way to utilize the data gathered from the two RFID scans conducted in the Proposed Solution section would be to integrate QR codes into the traceability system. Similar to the methodology that Legit Fish uses, QR codes could be affixed to the final packaging of the scallops. Consumers would have the ability to scan those QR codes in order to access a summary of the RFID data that was collected at sea and at port: who caught the scallops, where, and when. An additional benefit of this methodology is that the RFID tags themselves do not need to be scanned throughout the CoC and would remain at fishing ports, where it is more likely that they can be reused in the fishing fleet.

There are two significant issues that need to be considered regarding the RFID tags before a full-scale implementation effort is attempted. The first consideration is the question of which entity would be responsible for purchasing the RFID tags and associated equipment. This answer to this question may result from the anticipated utility of enhanced traceability. If a traceability system is determined to be an effective enforcement measure for data collection and fisheries monitoring, there is assumed to be an incentive for fisheries managers to invest in the necessary supplies. If fishermen and the scallop industry determine that enhanced traceability results in benefits to on-vessel inventory management and an overall reduction of IUU fishing in the fleet, they may be incentivized to invest in the supplies.

The second consideration regarding the RFID tags is their continued use. Biomark notes that their PIT tags can last as long as 75 years and that they can be reused indefinitely. While the specification of the tags allows for continued use, the retention of the RFID tags in the traceability system becomes a question of logistics. If the full-scale implementation of a traceability system involves additional scans to the final destination of the scallops, it will be much more challenging for the tags to be returned to the fishery. If the only scans of the RFID tags take place at sea and in port, this process may be simpler.

In order to reduce the cost of this traceability system, bag tags may be affixed to a ‘lot’ of scallop meats instead of being affixed to each individual bag. For example, if a vessel lands 25 bags from a specific fishing spot, one bag tag could represent that 25-bag lot of scallops. This measure may decrease the overall data resolution of scallop traceability, but its reduced cost may increase the feasibility of the traceability system as a whole.

This report did not conduct an in-depth analysis of the challenges associated with housing or managing the data that would be gathered by the proposed traceability system. Utilizing the Biomark device management software, data from individual trips can be easily downloaded and converted to .XLSX or .TXT files. However, the size of the data files and the specifics related to data management remain unclear. The level of hands-on data management required will likely depend on how the traceability data is utilized.

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