SeaXChange: A Blockchain Driven App for Tuna Supply Chain Management

A Special Problem

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Declaration

We, Jeff Rouzel Bat-og, Maxinne Gwen Cahilig and Zyrex Djewel Ganit, hereby certify that this Special Problem has been written by us and is the record of work carried out by us. Any significant borrowings have been properly acknowledged and referred.

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Dedication

“Hello, world.”

Acknowledgment

“Hello, world.”

Abstract

The tuna supply chain faces critical challenges regarding traceability, transparency and sustainability, particularly due to certain issues such as illegal, unreported and unregulated (IUU) fishing. Ensuring the traceability within the tuna supply chain is a critical role in enhancing consumer confidence, transparency and promoting adherence to environmental and legal standards. This research explores the application of blockchain technology as a solution to these given issues. By combining qualitative insights gathered from different key stakeholders across the supply chain, the researchers evaluated the potential of blockchain to improve product traceability, accountability, and trust. The findings suggests that blockchain offers a secure and transparent method of recording the journey of tuna products from catch to market, helping to combat IUU fishing and promote sustainable practices. However, successful implementation requires overcoming barriers related to technological integration, cost, and stakeholder collaboration. This study provides valuable insights into the feasibility and impact of blockchain adoption within other fish supply chains, contributing to the development of more transparent, responsible, and sustainable tuna industries.

Suggested keywords based on ACM Computing Classification system can be found at `https://dl.acm.org/ccs/ccs_flat.cfm`

Keywords: Blockchain, Traceability, Smart Contract, Supply Chain

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Chapter 1

Introduction

1.1 Overview

The tuna supply chain faces critical issues that affect both the industry and its consumers. Illegal fishing, overfishing, and poor traceability threaten the sustainability and ethical trade. A lack of transparency compromises product quality and misleads consumers. Blockchain technology can address these challenges by tracking the tuna's journey from ocean to plate through a secure, tamper-proof ledger. This system also holds stakeholders to comply to legal standards.

Although blockchain integration in the tuna sector is underway, gaps remain in its implementation. This study helps to address the industry's need for transparent and secure tracking of tuna products from ocean to consumer, while assessing the feasibility of implementing blockchain at scale in the seafood sector.

1.2 Problem Statement

Fish is one of the most consumed protein products in the Philippines. Before the COVID-19 pandemic, fish was the most consumed animal protein in the Philippines with annual per capita consumption of 40 kg (Agriculture and Agri-Food Canada, 2022). Among the wide variety of fish, tuna stands out as a particularly significant commodity due to its high demand and economic value. Although the nation is gifted with an abundance of aquatic resources, the methods of dispersal of the product usually leads to inefficiency in terms of sales, pricing, and overall product quality for the consumers. The problem arises with the introduction of a supply chain from several middlemen between the fish farmer or producer and wholesaler in the coastal and aquatic regions towards the consumers with less access to fresh fish. Consequently, both consumers and suppliers struggle to ensure transparent and fair pricing, accurately track tuna products, and maintain consistent quality. These challenges stem from inefficient methods of product dispersal and the presence of multiple intermediaries between fisherfolks in coastal municipalities and consumers. This fragmented supply chain introduces delays, obscures product origin, and opens opportunities for mishandling or mislabeling. To address this, the study focuses on the absence of a reliable, real-time traceability system that allows stakeholders to verify the origin, novelty, handling processes, and adherence to ethical sourcing practices of tuna at every stage. Without such a system, the tuna supply chain and industry lack the transparency and accountability necessary to build consumer trust and improve supply chain efficiency. By introducing a blockchain-driven solution, this study aims to streamline the traceability process and reduce the negative impact of intermediary-heavy distribution.

1.3 Research Objectives

1.3.1 General Objective

The general objective of the study is to design and develop a blockchain-driven application that improves the traceability of the tuna supply chain. Given the timely issues regarding illegal, unreported and unregulated (IUU) fishing and lack of product traceability and transparency, this study addresses these challenges through an application that has the capability to provide an immutable ledger and tamper-proof records. The result of this study serves as a framework for integrating blockchain technology in the fish supply chain, specifically for tuna. This also supports future researchers and developers facing similar challenges in the industry.

1.3.2 Specific Objectives

To further specify the research objectives, the study focuses to:

1. develop a smart contract framework using blockchain technology for data verification and transaction recording, ensuring secure and tamper-proof data for the stakeholders,

2. design and develop a blockchain-driven application with a user-friendly interface that allows stakeholders to access and input data while enhancing traceability in the tuna supply chain through a tuna asset record for the supply chain participants, and

3. deploy the application after completing all necessary preparations for software development and to evaluate its overall results and effectiveness in enhancing the tuna supply chain, as discussed in the fourth and fifth chapters of the study.

1.4 Scope and Limitations of the Research

The scope of this study focuses on how blockchain technology can be applied to enhance traceability and transparency within the tuna supply chain. It involves features such as smart contracts for recording the transactions and user interface for stakeholders. The study also focuses exclusively on whole, small-sized caught tuna products in the supply chain, excluding processed forms such as canned or packaged tuna. The research examines the traceability of whole tuna from capture to market sale, specifically centering on a supplier based in Miagao and San Joaquin, Iloilo.

This study focuses solely on the supply chain in within the specified municipalities of Iloilo, so findings may not fully represent global practices. As it concentrates on blockchain's role in traceability, other potential functions of the technology fall outside of the scope of this research.

1.5 Significance of the Research

This study serves a significant purpose for several stakeholders in the tuna supply chain. This study aims to solve the problems related to the management of tuna supply chain, particularly with regards to product traceability.

- The Stakeholders
  - This study enhances transparency and accountability, allowing stakeholders such as fishers, suppliers, and retailers to access tamper-proof and accurate information, thereby promoting a more ethical and authentic supply chain. By providing a digital record of the product's history, this study helps ensure compliance with environmental and legal standards. In cases of anomalies such as oil spills, red tide occurrences, and illegal fishing activities, stakeholders can be involved in identifying and addressing these issues, fostering a collaborative approach to sustainability. Similarly, the record of a tuna asset can be utilized for accountability purposes when problems such as damaged products, mislabeling, or contamination arise, allowing stakeholders to trace and resolve them efficiently.

- The Consumers
  - This study helps consumers verify the history of the tuna product from its origin up until its journey to the consumers, therefore increasing trust and transparency. By promoting traceability, it offers a more detailed and verifiable record of the supply chain, enabling consumers to assess sustainability practices and identify stakeholders responsible for any potential issues affecting the tuna product. This, in turn, encourages critical evaluation of the tuna supply chain, driving improvements in accountability, resource management, and ethical sourcing.

- For Future Researchers
  - As blockchain technology continues to grow, this study contributes to the application of blockchain in the supply chain management and the insights regarding its benefits and limitations. This research can be helpful in the growing knowledge on digital solutions for traceability and transparency for future research.
- The Policy Makers
  - This study provides policy makers a reliable and data-driven foundation in monitoring and regulating the tuna supply chain. By leveraging tamper-proof and transparent records, policymakers can more effectively enforce compliance with fishing quotas and environmental protections. This research also aids in lessening the illegal, unreported and unregulated (IUU) fishing practices, contributing to the national sustainability goals.

Chapter 2

Review of Related Literature

This chapter reviews existing literature related to the traceability of the tuna supply chain and the potential application of blockchain technology. In purchasing goods, one important consideration is the product quality. An important factor of determining the quality is to know the traceability of the supply chain. Traceability refers to the ability of tracking the journey of the product from its source until its destination. The term "traceability" is now more utilized in both the food and production industry (Islam Cullen, 2021). In the context of the tuna supply chain, it can be used not only to promote transparency to consumers but to also ensure compliance with environmental and legal standards. With blockchain technology, the status of tuna at each stage could be recorded in the blockchain which could be used for traceability. This paper aims to address the following research question: How can blockchain technology improve the traceability of the tuna supply chain management? To explore this, the chapter reviews literature on the state of the tuna industry in the Philippines, fishing regulations, and the structure of the tuna supply chain, including its stages and the roles of key actors. It also examines factors that affect the efficiency and transparency of the supply chain. The discussion then turns to blockchain technology and its potential applications in supply chain management, with examples from the Philippines and Indonesia. Finally, the chapter reviews existing traceability technologies and systems and concludes with key insights that inform the development of this study's proposed solution.

In purchasing goods, one thing to consider is the quality of it. An important part of determining the quality is to know the traceability of the supply chain. Traceability refers to the ability of tracking the journey of the product from its source until its destination. The term "traceability" is now more utilized in both the food and production industry (Islam & Cullen, 2021). In the context of the tuna supply chain, it can be used not only to promote transparency to consumers but to also ensure compliance with environmental and legal standards. With blockchain technology, the status of tuna at each stage could be recorded in the blockchain which could be used for traceability. This paper aims to address the following research question: *How can blockchain technology improve the traceability of the tuna supply chain management?*

2.1 State of Tuna Industry in the Philippines

In 2014, the Philippines became the top global producer of tuna according to Llanto, et. al. (2018) . The tuna is caught in domestic and international fishing grounds near the country through various fishing methods such as purse seines, gill nets, handline (hook and line) and ring net. Among the tuna species, the skipjack tuna accounted for the largest portion of the catch by 40%. The study of PCMARD (1993 as cited in Nepomuceno et al., 2020) stated that skipjack tuna are often caught out in open waters or in offshore areas. In addition, Nepomuceno et al. (2020) mentioned in their study that the dominant production of skipjack tuna, together with yellowfin tuna, was recorded in South Cotabato. The tuna supply has declined since 2000 due to various factors including overfishing, climate change, and the laws and regulations imposed by different governing bodies for the tuna fishing ground such as the Regulation No. 56, released by the Indonesian Maritime Affairs and Fisheries Ministry in November 2014. The regulation imposed a moratorium on issuance of fishing licenses from 3 November 2014 to 30 April 2015 to eliminate illegal, unreported, and unregulated fishing in Indonesian waters near Mindanao where tuna are known to thrive (Llanto et al, 2018) . The regulation imposed for the protection of tuna fishing grounds in the western and central pacific ocean also lead to the decline of local tuna production which requires the fishing operators of the Philippines to invest in the manufacturing and processing of fish particularly tuna in Indonesia which includes hiring Indonesian crew to be deployed in the Philippine fishing vessels (Llanto et al, 2018) .

2.2 Fishing Regulations in the Philippines

A study of Asche et al. (2018) divided the fishing management strategies that include right-based fishery management like territorial use of rights, access rights and harvest rights. It discussed that a rights-based system could support the sustainability of global fisheries by taking in account the three pillars of sustainability (economic development, social development, and environmental protection) rather than focusing on their trade-offs. A restriction on the fisherman's behavior by harvest rights and catch shares could be a profit problem for them in the short-run but in the long-run, this could help both in the fish stock and the fishermen's profit. Lack of restriction could lead to overfishing. Access rights limit the entry to fishery through permits which can also reduce the effect of high harvest levels. A sustainable fishing management system in the Philippines is important in order to preserve marine resources. To preserve these resources and protect the livelihood of local communities, various fishing management strategies should be implemented. A collaboration between the fishermen, local government and other stakeholders often happens to manage marine resources (Pomeroy & Courtney, 2018) . The study of Pomeroy and Courtney discussed that marine tenure refers to the rights and responsibilities in terms of who can access the marine and coastal resources. The 1998 Fisheries Code paved the way for local government units (LGUs) to be involved in the management of municipal waters. LGUs are given the responsibility to overlook and regulate fisheries and establish marine tenure rights for fishers within 15 km from shore and these rights are applicable for municipal fishers and their respective organizations that are listed in the registry (Pomeroy & Courtney, 2018) . In this way, it resolved problems in terms of fishing rights between small-scale and commercial fishing.

According to the study conducted by Mullon et al. (2017) , the five major species of tuna: yellowfin *Thunnus albacares*, bigeye *Thunnus obesus*, bluefin *Thunnus thynnus* or *Thunus orientalis*, albacore *Thunnus alalunga*, and skipjack *Katsuwonus pelamis* are harvested to meet the global supply chain demand which causes those group of tuna fishes to be heavily exploited and threatened. The study conducted by Paillin et al. (2022) states that there are multiple risk agents in the supply chain assessment of tuna, these include the lack of standard environmental management system, lack of maintenance management, and lack of quality control from suppliers. The usage of efficient boats and good quality catching technology can also lead to fisheries depletion which causes various agency such as BFAR (Bureau of Fisheries and Aquatic Resources), the local government units, and the Philippine Coast Guard to enable policies for upholding closed fishing season to restrict large scale fishing vessel to minimize the fishing activities in the identified areas (Macusi et al, 2023) . The implementation of closed fishing season caused delay or lack of fish supply, which led to higher fish prices.The growing demands and depleting population of tuna fishes coupled with the rapid increase in fuel costs can have a negative impact on the future of the supply chain in tuna fisheries (Mullon et al., 2017) . With factors concerning the slow decline of tuna catches in the Philippines and surrounding nations, the future of the global supply chain of tuna must be addressed.

2.3 Tuna and Fish Supply Chain

According to Macusi et al (2023) , the implementation of traceability programs in the agricultural product commodities and value chain in the Philippines is slower than its competing nation for tuna production. The Philippines has been steadily responding to the market innovation and integration of cost-effective and smart technologies for the traceability of various commodities. Accurate catch data is crucial for determining the attributes of the fish health, size, volumes, and maturity (Grantham et al, 2022) which can be used as a basis for the transparency of the traceability of the fish product. Illegal, unreported, and unregulated (IUU) is another concern for the fish industry. In the 2000s, the persistent IUU became a global crisis affecting the biological, ecological, and socio-economics factors revolving around marine livelihood in Southeast Asia (Malinee et al, 2020) . IUU fishing is known to cause short- and long-term problems in the socio-economic opportunities which affects food security and results in the possible collapse of the fish industry and stocks due to overfishing (Malinee et al, 2020 .

The establishment of marine protected areas in the Davao Gulf (MPAs) affected the management of small-scale fisheries due to the growing population and demands for seafood products. The closure of a wide range of fishing areas hosting diverse and marine organisms has affected the socio-economics and livelihood of the local and small-scale fishermen (Macusi et al, 2023) , this in turn resulted in IUU fishing. To ensure that fish stocks in the gulf are sustainably managed, the implementation of GPS for tracking the movement and activities of fishers through logbook and habitat monitoring can provide data and insights for tracking, monitoring, and understanding the condition of the marine resources (Obura et al, 2019; Macusi et al, 2023) .

2.4 Tuna Supply Chain Stages and Roles

The study conducted by Delfino (2023) highlights the roles of different actors involved in the supply, production, distribution, and marketing of skipjack tuna in Lagonoy Gulf in the Philippines. The study showcased a total of eleven interconnected value chains but are generalized into four major stages or roles - fishers, wholesalers, retailers, and processors. The fishers are the initial players responsible for catching fish using boats or fishing vessels equipped with purse seines, gillnets, and handlines(hook and line). Wholesalers are the actors for selling freshly caught fish locally and regionally, they receive the fish supply directly from the fishers. The next stage after wholesalers are the retailers, these intermediaries sell the fish product to local markets, house-to-house (*libod"* in Visayan languages), and other local medium such as *talipapa* or fish stands. Another intermediary is the processors, they convert fresh skipjack tuna into products like smoked tuna. The given stages also overlapped in some cases as there are fisher-wholesalers who catch and sell the fishes directly to retailers and there are also retailer-processors that both sell whole and processed products. Despite having a firm system to transport fish from sea to table, all the actors face problems during seasonal challenges involving the availability of the tuna product. The fishers also need to consider strict local regulations such as RA 10654 and RA 8550. The strict implementation of RA 10654 and RA 8850 at the local level or the Fisheries Code of the Local Philippines aims to curb the problem encountered during season of deficit tuna supply by limiting fishing activities and implementation of 15-km boundary lines in the municipal waters of each municipality (Delfino, 2023) . The study suggests that improving conditions for value chain actors, particularly through support services and government involvement could lead to a stable and sustainable exchange of skipjack tuna and other seafood products from sea to table.

A study of Digal et al. (2017) discussed one of the value chains which was the purse seine or the skipjack tuna value chain in the Philippines. Purse seining is the method of catching a school of fish wherein it uses a large net around it, trapping them and pulling the bottom of the net like a purse-like (Digal et al.,

2017) . This type of catching often targets dense fishes like tuna. Skipjack fishes that weigh 300 grams and above are often sold to canneries, while the smaller ones are sold at local markets, often used for consumption by Filipinos. Purse seiners are usually employees of a fishing company and they have a fixed salary. They could reach international waters so they need to bring their passports with them. Jamboleros, who act as distributors, often buy from different fishing companies per *banyera* or tub. They will then pack the fish and sell it to traders/truckers who go to General Santos fishport. These traders will deliver it to the retailers across Kidapawan who contacted them. There is no formal contract between the jambolero and traders/truckers. One of the issues of the retailer is for everyday that a fish is not sold, they would have a ₱10.00 less per kilogram.

2.5 Factors Affecting the Tuna Supply Chain

The tuna supply chain faced several factors and challenges for the safety and quality of the product (Mercogliano & Santonicola, 2019) . Without the proper handling of the tuna after catching it can lead to various food-borne diseases and outbreaks. The most frequent and mitigated food-borne causing compound is Histamine(HIS) which causes Scombrotoxin fish poisoning (SPF) outbreaks related to food allergies when consumed (EFSA, 2017; Peruzy et al., 2017). Tuna species are known for having high presence of amino acid histidine concentrations which are converted to HIS by bacterial enzyme histidine-decarboxylase or HDS (Aponte et al., 2018; Verkhivker & Altman, 2018) . To combat the risk of SPF and other food-borne diseases caused by tuna consumption, several safety hazards and protocols were imposed to the tuna supply chain management. The term cold chain refers to the storing of fish in temperatures less than 5°C after it was caught (Yang & Lin, 2017). According to the article published by Mercogliano and Santonicola (2019), implementing a cold chain from the time the fish is caught until it is consumed is crucial for mitigating the outbreak of HIS poisoning. Additionally, the article also states that using high-quality raw tuna, cold chain maintenance, pre-cooking, and cooking can also reduce HIS development.

According to the study conducted by Pacoma and Yap-Dejeto entitled "Health Risk Assessment: Total Mercury in Canned Tuna and in Yellowfin and Frigate Tuna Caught from Leyte Gulf and Philippine Sea", examines mercury contamination in both canned and locally caught tuna in the Philippines. Methylmercury, a potent neurotoxin, presents risks especially to vulnerable groups like pregnant women and children. The study reveals that canned tuna generally has higher mercury levels (0.07 µg/g) than locally caught tuna (0.002–0.024 µg/g). Based on the Food and Agriculture Organization's fish consumption data, the mercury intake from locally caught tuna is within the World Health Organization's safe limits, whereas canned tuna may exceed these limits for some groups. This highlights the need for monitoring of the mercury levels in the Philippine tuna supply chain, as tuna is a dietary staple and economic asset in the region, to mitigate health risks from chronic exposure.

Risk management is important for tuna supply chains to analyze the root of the risk and to assess the probability of such cases through the information taken from the different locations or sorting states where the tuna product is handled before being purchased by the consumer or end-use state (Parenreng et al, 2016) .

2.6 Technology of Blockchain

According to Zheng et al. (2017) , the idea of blockchain was first introduced in 2008 and was first implemented in the Bitcoin business which deals with cryptocurrencies. This kind of technology tracks transactions and stores it in a list of blocks. According to Sarmah (2018) , it acts as a database of transactions which is overseen and verified by distributed nodes. Blockchain works by linking blocks (where data is stored). When a transaction is initiated, it is then broadcasted to a network of computers that verifies the transaction and if the verification is successful, it will then be grouped and linked with the previous transactions that will be added to the blockchain (Zheng et al., 2017) . It does not require a middleman because it operates on a peer-to-peer transaction. This eliminates the traditional way of a central authority like the bank (Sarmah, 2018) .

Automated process of transactions is also one of the salient features of blockchain which is executed automatically based on predefined rules involving no third parties. These predefined rules are conditions that need to be met in order for the transaction to proceed. Given this, blockchain is described to be a "trust-free technology" since it reduces the number of trusted individuals instead they trust the machine itself which is difficult to manipulate given its cryptographic security (Ali et al., 2023). Blockchain also ensures immutability with its data. Once the data has been added to the blockchain, it is difficult to change since each block has a cryptographic link to other blocks, which guarantees that the data is tamper-proof and permanent (Ali et al., 2023). This also brings back to the essence of blockchain being trustworthy. Immutability and tamper-proof enhances data management. It also helps prevent fraudulent activities especially with finances.

Transparency with transactions is one of the features of blockchain which makes the chances of data being tampered less because it is accessible to anyone on the network (Ali et al., 2023).

According to Nasurudeen Ahamed et al. (2020) , Blockchain technologies are classified into 3 types: Public Blockchain, Private Blockchain,. Consortium Blockchain. In Public Blockchain, all public peers can join together and have equal rights (for example, read, write, and execute) on the public node. In Private Blockchain, only Authorized Private Peers have access to the network. The access to the node in the private peer is limited to the specific node. In Consortium Blockchain, only the authorized team can access and join this blockchain, and all operations in the node must adhere to the access. Their paper, Sea Food Supply Chain Management Using Blockchain, gave the idea that with the purpose of creating a blockchain-driven application, a public blockchain approach could be appropriate for handling consumer-based information as users can verify non-sensitive data like prices, freshness and availability. While handling sensitive information such as internal works and logistics, a consortium blockchain where authorized users such as fish owners, distributors, manufacturers, etc. can handle the core supply chain operations, like tracking the movement of tuna from catch to market.

2.7 Opportunities of Blockchain Technology for Supply Chain Management

Supply chain is the term used for understanding the business activities for designing, developing, delivering, purchasing, and using a product or service (Hugos,

2024) . Companies and various industries are heavily relying on supply chains to achieve their business objectives. The purpose of supply chain began to be more significant in the last century as firms discovered that supply chain can be used for competitive advantage instead of just a cost driver as believed in the bygone days (Snyder & Shen, 2019) . Following the supply chain paradigm can demonstrate the delivery of a product or service while strongly emphasizing the customer's specifications. With the increasing studies conducted and published for supply chain, many companies adopted this practice for the benefit of their longevity, as such the term supply chain management has come into place. The Council of Supply Management Professionals or CSCMP (2024) defines supply chain management as the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities; essentially, supply chain management integrates supply and demand management within and across the company. Supply chain management is also involved with the relationship with collaborators and channel partners such as suppliers, intermediaries, third party providers, and customers (CSCMP, 2024) .

In the article of Cordova et. al (Cordova et. al, 2021) , the role of supply chain management and the growing opportunities for blockchain technology in supply chain management was discussed. According to Cordova (2021) , the recent innovation and globalization has given rise to the idea of using a data innovation framework for supply chain management. Technologies such as blockchains and enterprise resource planning (ERP) are among the highly contested platforms for supply chain management to operate in a seamless interaction and distribution with the product while heavily relying on modern technology and innovations. The logistic business of the supply chain market is wide and complex, the distribution and flow of products is not a simple job, and it heavily relies on paperwork (Georgiou, 2019; Cordova et. al, 2021) . The usage of paperwork for logistic business can be at higher risk for lack of transparency, complex or unreliable tracking, deficiency of information, and possible dispute due to the tendency of paper to disappear or tear down, this can in turn delay the process and delivery of the item/product. With the issues encountered in the supply chain market, businesses, people and enterprises are eyeing toward the application of blockchain technology on supply chain management (Cordova et. al, 2021) .

Implementing blockchain innovation in ERP systems and companies that use digital platforms can provide opportunities and contribute greatly for business processes (EOS Costa Rica, 2019 as cited by Cordova et al, 2021) . The ability of blockchain technology to append new transactions to an existing block containing data can be thought of as a decentralized ledger (Cole et al, 2019) . The method of blockchain to behave like a decentralized ledger can serve as a single unified source of data which in turns create a clear and consistent audit trail involved in the manufacturing, assembly, supply, and maintenance processes. According to Cole et al (2019) , blockchains provide data to the movement and relation of products from its origin, inventory, shipment, and purchase. One potential of blockchain for supply chain management (Hackius & Petersen, 2017) is the ease of paperwork processing, specifically in ocean freight. When IBM and Maersk settled for a permissioned blockchain solution, they were able to connect a global network of shippers, carriers, ports, and customs. Another potential of blockchain in SCM is to identify counterfeit products. In the pharmaceutical industry and healthcare setting, blockchain could improve patient safety and hazard through establishing supply chain transparency from manufacturers through wholesale and pharmacies to the individual patients (Hackius & Petersen, 2017) . Using blockchain can make it harder to tamper or alter the products chain of origin with illegal and counterfeit products. Blockchain have the potential to facilitate origin tracking. According to Cordova et al (2021) , blockchain allows organizations to input relevant data inside a chain which would have constant updates and tracking, this supports visibility and traceability of the origin of the product. Smart contracts, an executable code and a feature of blockchain, serves as a computer protocol made between participants to digitally facilitate, execute, verify, and enforce an agreement or terms of contract which is then stored in the blockchain (Khan et al, 2021) .

2.8 Supply Chain Model with Blockchain Technology of Fishing Industry in Indonesia

Larissa and Parung (2021) who explored the application of blockchain and designed a supply chain model based on it, specifically for the Indonesian fishing industry, aimed to mitigate the challenges in the fishery industry such as product quality (perishability), long shipping times ,and data manipulation. The model they developed of using QR codes for each player in the supply chain then tracking it by scanning the QR code, could inspire our approach in building a blockchain-driven application for the tuna supply chain in the Philippines.

2.9 Existing Technology Intended for Traceability and Supply Chain

A study of Shamsuzzoha et al. (2023) discussed the feasibility of implementing a blockchain driven application called 'Tracey' for monitoring the fish traceability in supply chain management. The study utilized the theoretical framework developed by Islam & Cullen (2021) for improving the understanding and effectiveness of implementing a food traceability system. The framework consists of four principles as a basis for the supply chain management: identification, data recording, data integration, and accessibility (Islam & Cullen, 2021) . The Tracey application utilized a public-private hybrid blockchain-based conceptual framework by Mantravadi and Srai (2023) to uphold the transparency, traceability, and certification of the sea food produce, specifically shrimp. The prototype being studied by Shamsuzzoha et al. (2023) called Tracey focuses on the mobile-based solution approach, the study found that the most widely used smartphone type in the Philippines is the android phone which is where the Tracey prototype is intended to be used. The Tracey app allows fishermen to log their catch details and buyers to verify and update transaction history (Shamsuzzoha et al., 2023) . The Tracey app uses a central database for storing fish trading data and a decentralized ledger or blockchain for traceability purposes. The decentralized ledger acts as a tamper-proof copy of the data recorded by fishermen and buyers. The result of the study finds that fishermen are open to using digital methods for payments and confidentiality which is required for exporting the fish product to maintain high standards for traceability, catch certification, and product quality. The usage of blockchain as exemplified by the Tracey project can be used for upholding the restriction for IUU due to its ability to ensure transparent trade, consistent records, and accessibility. The result and discussion of the study of Shamsuzzoha et al. (2023) provides a solution for improving the sustainability of tuna fishery and ensures that Filipino fishermen receive fair compensation. For the study limitation of the Tracey project, although there is a high acceptability of potentially using the app for fishermen, there are still constraints in terms of proper incentives, connectivity issues, technology usability, and education for using the app.

A study of Cocco and Mannaro (2021) proposed a blockchain-based technology in the traceability of the supply chain management of a traditional Italian food product, Carasau bread, which is made from durum wheat flour, salt, yeast and water. Since the production of this product is traditional, consumers would demand for transparency on the methods used in the Carasau bread production to ensure authenticity. The proposed model involves the combination of the application of Internet of Things (IoT), specifically the Radio Frequency Identification (RFID) sensors and Interplanetary File System (IPFS) with Blockchain (Cocco & Mannaro, 2021) . RFID is a technology that uses radio frequencies to identify and track a tagged object while IPFS allows files to be stored and tracked over a decentralized and distributed file system. Cocco and Mannaro (2021) also stated that using RFID tags that will be integrated with different sensors to monitor food quality will be useful in their study. These sensors include freshness indicators to monitor the food quality when packaged, biosensors to detect degradation molecules, time temperature indicator to measure and record temperature and humidity sensors to detect the amount of water vapor in the atmosphere. The integration of IoT and blockchain technology can have a huge impact in increasing traceability in agri-food supply chain. Moreover, this study proposed to have a generic agri-food traceability system which will be based on Ethereum blockchain, Radio-frequency identification (RFID), Near Field Communication (NFC), and Interplanetary File System (IPFS) technology. Moreover, the model proposal also includes sensor network devices, smart contacts, optical cameras and an external database. Each IoT device will be connected to Raspberry Pi and interfaces with blockchain implementing smart contracts and IPFS which authorities can inspect every node and batch online through the uploaded files in IFPS; hashes of the uploaded files on IFPS are also stored on blockchain (Cocco & Mannaro, 2021) . In this way, users along the chain supply can view and trace each batch using the NFC tags promoting transparency and traceability. Overall, the proposed model is a combination of two subsystems. The first one is an on-chain system which is the blockchain implementing smart contracts and will be developed using Solidity, an object-oriented language. The second one is an off-chain system that will be implemented in Javascript using Node.js (to interact with the smart contracts) and Web3.js packages (to interact with blockchain) and these packages should be installed on the Raspberry Pi. However, the purpose of this study is to examine the traceability systems of the agri-food industry and further provide possible solutions.

2.10 Developing a Traceability System for Tuna Supply Chains

The study of Kresna et al. (2017) , proposed an IT-based traceability system for tuna supply chain as opposed to the traditional paper based traceability system which has several limitations such as the potency to be manipulated, error by the human, language barrier, and physical damage. The architecture comprises several layers: infrastructure, data, application, communication, and user layers. The infrastructure layer includes computer hardware, network infrastructure, and sensing devices like CCTV, GPS, and RFID for data acquisition. The data layer serves as the system's database, featuring both a main system database and an emergency database for critical situations. The application layer consists of various modules—admin, tracing, transporter, supplier, and government—that registered actors can access through different interfaces. Finally, the user layer consists of the registered actors who utilize the system.

The journal article of Tiwari (2020) called Application of Blockchain in Agri-Food Supply Chain conducted two case studies for a blockchain driven app built for supply chain related to food, fishing, and agriculture. The first case-study is the usage and effectiveness of the Provenance system for tuna tracking certification. The objective of the Provenance system is to enhance transparency in the tuna supply chain by ensuring certification and standard compliance across all roles(e.g. supplier, retailer) in the chain. The system is built using six modular programs: registering, standards, production, manufacturing, tagging, and user-interface. The usage of blockchain in the Provenance system allows transactions to be recorded to allow shared ledger for transparency and smart contracts for secure exchanges of money or information. The usage of the Provenance system is to solve the issues encountered in the tuna fishing industry affected by various factors such as illegal, unregulated, unauthorized (IUU) fishing, fraud, and human rights abuses. The solution of the Provenance system is to allow tracking, tracing, and certification of tuna using blockchain. The Provenance system has a smart tagging feature that allows fishermen to use SMS for digital assets on the blockchain to track where the fish, in return, all supply chain stakeholders can access the data that was sourced from the SMS. The second case-study is the usage of the IBM Food Trust for transparency in the food supply chain. The IBM Food Trust aims to solve the problems in the food supply chain, specifically in product safety. Locating supply chain items in real-time using identifiers like GTIN or UPC is the primary feature of the IBM Food Trust. The app also provides end-to-end product provenance, real-time location and status, and facilitates rapid product recalls. The IBM Food Trust also provides insights and visibility for the freshness of the product to reduce losses and spoilage. Lastly, the IBM Food Trust provides certifications from the information taken when handling and managing the products in the supply chain. The case studies conducted by Tiwari (2020) illustrates the potential of blockchain technology in improving transparency, efficiency, and ethical practices within supply chains.

2.11 Chapter Summary

2.11.2 Research Gaps and Problem

Given the advanced existing technologies in blockchain-based traceability systems for agri-food supply chains, significant gaps remain in understanding the user experience and integration challenges faced by the fishermen. While the study by Shamsuzzoha et al. (2023) highlighted the feasibility and benefits of the mobile application, Tracey, they overlooked possible issues related to technology adop-

2.11.1 Comparison Table of Related Studies

Study	Technology Used	Focus Area	Application	Key Findings	Limitations
Shamsuzzoha et al. (2023)	Blockchain (hybrid model)	Fish traceability	Mobile app (Tracey) for fishermen and buyers	Demonstrated feasibility for traceability, certification, transparency; high user acceptability among fishermen	Connectivity issues, technology usability, need for proper incentives and education
Cocco & Mannaro (2021)	Blockchain, IoT (RFID, IPFS), NFC, Ethereum	Italian traditional food (Carasau bread)	Agri-food supply chain traceability system	Proposed a model combining IoT and blockchain to enhance traceability and transparency	High complexity; requires integration of multiple technologies (RFID, IPFS, NFC)
Kresna et al. (2017)	IT-based system, RFID, CCTV, GPS	Tuna supply chain	Digital traceability system (IT-based)	Identified weaknesses in traditional paper-based systems; proposed IT layers for comprehensive tracking	Infrastructure requirements (CCTV, GPS, RFID); limited detail on blockchain
Tiwari (2020) - Provenance	Blockchain, smart contracts, SMS	Tuna tracking certification	Provenance system for tuna supply chain	Enhanced transparency, certification compliance; addressed IUU fishing, fraud, human rights abuses	Limited to specific regions and roles within supply chain
Tiwari (2020) - IBM Food Trust	Blockchain, GTIN/UPC identifiers	Food supply chain	Real-time tracking, product recalls	Improved transparency, efficiency; enabled real-time status, freshness insights	Focused on general food products; high dependency on IBM ecosystem

Table 2.1: Comparison of Studies on Technology for Traceability and Supply Chain Management

tion, digital literacy, and connectivity.

Furthermore, existing technologies have primarily focused on large-scale implementations and theoretical frameworks without adequately considering the practical implications and user experience needed for effective system integration. This study aims to address these gaps by exploring real-world challenges faced by users, especially fishermen, in adopting blockchain technology for traceability.

2.11.3 Summary

The literature reviewed highlighted the critical challenges and opportunities regarding the tuna supply chain, particularly in the areas of traceability and sustainability. Existing supply chain technologies, especially those utilizing blockchain, present solutions but also come with limitations in terms of blockchain adoption. The application of blockchain technology in the tuna supply chain has shown potential for enhancing traceability from ocean to consumer.

Through this paper, a blockchain-driven solution could contribute to providing a more efficient and transparent supply chain. However, further studies are necessary to assess the long-term sustainability of blockchain in such systems.

Chapter 3

Research Methodology

This chapter outlines a clear and detailed description of the research methods and processes used in the development and evaluation of SeaXChange: A Blockchain Driven App for Tuna Supply Chain Management. The algorithms, systems, theories, framework and models are described in detail in which this chapter establishes the foundation of this study .This chapter also explains the data collection method used ensuring the validity and reliability of the results.In addition, the chapter discusses the considerations and potential limitations of this study. Overall, this will serve as a guide for the readers in understanding the structured process of developing the SeaXChange.

3.1 Software Development

Scrum is a framework within the Agile development that prioritizes flexibility. It is an iterative software development approach that lets a project be broken down into phases and emphasizes continuous improvements. For this study, the researchers opted to use Scrum because it involved many stakeholders and it operated in a ever-changing environment. Scrum allowed the team to adapt to new requirements through structured sprint planning, weekly reports, and sprint reviews, ensuring continuous alignment with project goals.

3.2 Research Activities

For this study, the researchers opted for interviews because it enabled in-depth exploration of stakeholder perspectives and experiences. The identified fisher and supplier client interface was tested within the perimeters of Barangay Sapa, Miagao, Iloilo, Philippines. The identified retailer testers were the vendors who reside in Barangay Mat-y and Barangay Sapa in Miagao. The identified consumer testers were situated in Miagao. The researchers chose the local fishermen, retailers and suppliers within Miagao because they wanted to focus on the small-scale fishing.

3.2.1 Feedback Collection Method

The feedback was collected through a combination of structured interviews and assessment forms. Participants were asked to complete an assessment rubric evaluating the SeaXChange app across key criteria such as functionality, end-user needs, performance, usability, ease of use and feasibility. Moreover, follow-up interviews were conducted to gather deeper qualitative insights and obtain suggestions for system improvement.

The feedback gathered from fishermen, suppliers and retailers, and consumers was analyzed based on the SeaXChange assessment rubric, which evaluated six major categories: Functionality, End-user Needs, Performance, Usability, Ease of Use and Feasibility. The collected data were analyzed using descriptive statistics, through the computation of mean scores for each assessment criterion. These mean values were used to summarize stakeholder perceptions of the system. Mean ratings were calculated based on the 1-5 Likert Scale where 1 = Poor and 5 = Very Good.

3.2.2 Data Gathering

- **Primary Data:**
  - Stakeholder(Fishermen, Supplier, Retailers, and Consumers) interviews were conducted to identify the use-case and user requirements, interface usability, and adoption challenges.
  - Observations were made of existing tuna supply chain processes in local settings.
- **Secondary Data:**
  - Literature review was conducted on blockchain applications in supply chain management and product traceability.
  - Industry reports and regulatory documents related to tuna fishing and supply chain operations.

3.2.3 Designing and Developing the System

1. **Software Development Methodology:** The project followed a Scrum framework to ensure continuous iteration, stakeholder involvement, and flexibility in adapting to feedback.

2. **Technology Stack:**

   - Front-end Development: Used React for creating a secure and user-friendly interface for stakeholders, prioritizing simple and responsive user-interface.
   - Back-end Development: Used Node.js along with Express for managing back-end processes and API integration. Express is a flexible we application framework for Node.js used to build APIs for web applications. Docker for containerization of the project and Window Subsystem for Linux (Ubuntu as the Linux distribution) for setting up the network.
   - Cloud Infrastructure: Used Google Cloud to host backend services and manage the databases, where the app could be accessed globally. It also ensured the app could scale smoothly as more data and users were added.
   - Blockchain Framework: Used Go language for developing smart contracts and providing an immutable ledger for transaction data.
   - Database for Accounts: Used Firebase managing user accounts and authentication.

3. **Blockchain Development Platform:**

- Used Hyperledger Fabric for its permissioned nature and scalable architecture.
- The open-sourced resources and timely updates of Hyperledger Fabric components is ideal for creating a distributed ledger for tuna supply chain.

3.2.4 Implementing Algorithms and Services

The system for this study is built on top of a Hyperledger Fabric project, it also utilized combinations of algorithms to facilitate the work flow of data or asset as well as ensuring high security with encryption and decryption configuration techniques.

1. **Consensus Algorithm**

   The project followed Raft(Leader-based consensus) for handling organizations or nodes. Raft is intended for managing a replicated log in a blockchain network. Raft is a Crash Fault Tolerant (CFT) protocol, is designed to handle non-malicious node failures (e.g., hardware crashes, network issues) In Raft, one node is elected as the leader, and it coordinates the ordering of transactions (Xu et al, 2022) . The leader replicates log entries (transactions) to follower nodes, ensuring consistency across the network.

2. **Cryptographic Algorithm**

   The project employed several cryptographic algorithms to ensure security and privacy. These cryptographic data served as digital signatures and identity verification for the project. ECDSA (Elliptic Curve Digital Signature

Algorithm) was used for generating digital signatures while X.509 certificates are intended for identity management and authentication of participants (Anitha & Sankarasubramanian, n.d.) . For the encryption, AES (Advanced Encryption Standard) was used for encrypting data at rest and in transit. TLS (Transport Layer Security) secured communication between network nodes. SHA-256 (Secure Hash Algorithm-256) ensured data integrity by generating unique hashes for blocks and transactions.

3. **Membership Service**

   The implementation of the Membership Service Provider (MSP) requirement involved a set of folders added to the network configuration. These folders defined an organization both internally, by specifying its administrators, and externally, by enabling other organizations to verify the authority of entities attempting specific actions. While Certificate Authorities (CAs) are responsible for generating the certificates that represent identities, the MSP included a list of permitted identities. The MSP specified which Root CAs and Intermediate CAs are authorized to define members of a trust domain. This was achieved by either listing the identities of their members or identifying the CAs allowed to issue valid identities for those members.

4. **Ordering Service**

   The ordering service in this study played a crucial role in maintaining the integrity and functionality of the blockchain network. Its primary responsibilities included ensuring that transactions are processed in the correct sequence (transaction ordering), grouping transactions into blocks based on configurable parameters like size or timeout (block creation), and distributing these ordered blocks to peers for validation and commitment (block distribution) (Nassar et al, 2024). Additionally, the ordering service provided fault tolerance to ensure the network remains operational even in the presence of node failures through Raft.

5. **Endorsement Policy**
   Fabric employs endorsement policies to specify which peers must validate a transaction before it's committed. The algorithm involved multi-signature schemes where a transaction is valid if it receives endorsements from the required peers as per the policy.

6. **Chaincode (Smart Contract)**
   The handling and flow of business logic agreed to by members of the tuna supply chain in the blockchain network is executed by a chaincode or smart contract. The chaincode of the app was written in Go language. Docker container was used for enabling the chaincode to securely run along with the overall hyperledger fabric configurations. Chaincode initializes and manages ledger state through transactions submitted by applications (Hyperledger Fabric Documentation, 2024) . The chaincode followed the object-oriented paradigm for creating classes and objects necessary for the tuna supply chain.

3.2.5 Modeling the System Architecture

The system architecture of the project were consisted of many nodes that communicated with each other. The chaincode enabled the system to run algorithms, particularly, holding state and ledger data, and executes transactions such as asset transfer in the tuna supply chain.

- **Blockchain Architecture**

  The project involved peer, ordering services, ledger, and client application to perform various transaction such as tracing the origin and the stop points of a tuna asset. Peers are nodes in the blockchain network that maintained a copy of the distributed ledger and execute chaincode (smart contracts). The ordering service is the central component of the blockchain for ordering transactions and creating blocks to distribute to peers through consensus mechanism. The ledger is the immutable record of all transaction in the tuna supply chain network, stored across all peers. The client application is the interface through which users or tuna supply chain participants interact with the blockchain network.

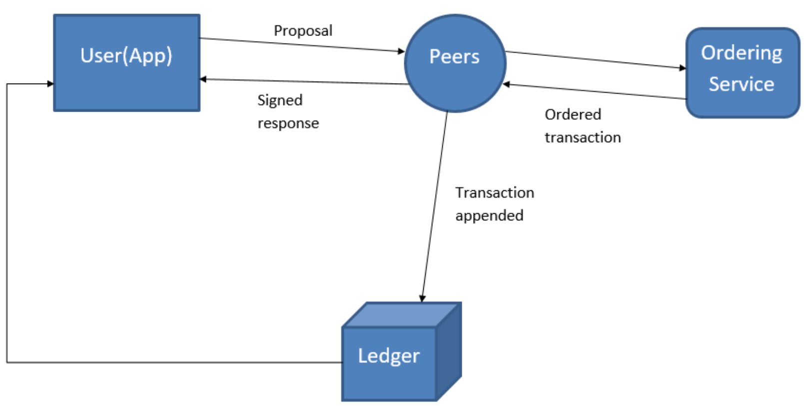


Figure 3.1: Blockchain Architecture of SeaXChange

- **Overall System Architecture**

  The overall system architecture contains a web application built with Next.js for the frontend, utilizing Firebase for user authentication and account management. The application follows a role-based access model (Fisher, Supplier, Retailer, Consumer) where each role has specific permissions for interacting with tuna assets in the supply chain. The backend runs on Google Cloud Platform, consisting of an Express.js API that interfaces with a Hyperledger Fabric blockchain network (containerized in Docker) which stores and manages the immutable record of tuna assets and their transfers between supply chain participants. This architecture enables secure tracking of tuna from creation by fishers through the supply chain to consumers, with appropriate viewing and transfer capabilities assigned to each role in the process.

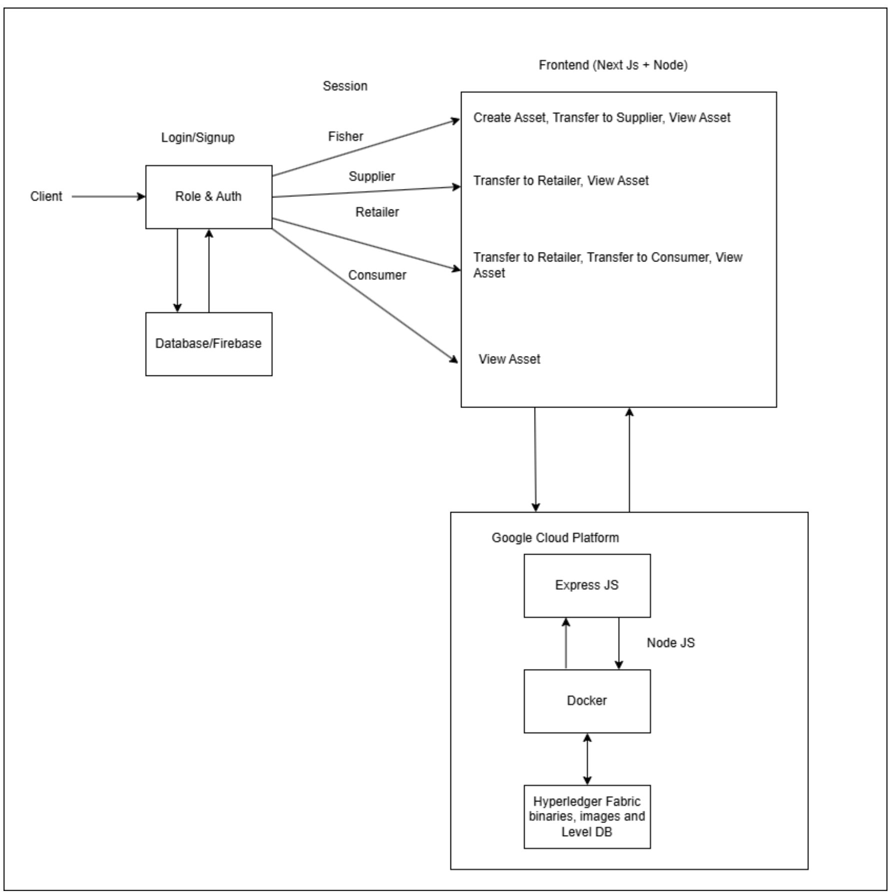


Figure 3.2: Overall System Architecture of SeaXChange

- **Use Case**

The use case shows the outline on how the user will interact with the SeaX-Change App. It followed the major stages or participants in the tuna supply chain.

1. **Fisher**

   - Encodes tuna I.D. of fish.
   - Encodes the date when the fish was captured.
   - Encodes the location where the fish was captured.
   - Encodes the fishing method used.
   - Query the origin and exchange of the tuna asset.

2. **Supplier**

   - Encodes when the product was transferred from fisher to supplier.
   - Query the origin and exchange of the tuna asset.
   - Generate supplier's location during retrieval of tuna asset.

3. **Retailer**

   - Encodes when the product was retrieved from the supplier or another retailer.
   - Query the origin and exchange of the tuna asset.
   - Generate retailer's location during retrieval of tuna asset.

4. **Consumer**

   - Retrieve data from retailer.
   - Query the origin and exchange of the tuna asset.

There are four (4) types of users that will use the app. The first user type is the Fisher, which will be the starting point of the blockchain. It will encode the catch details of a tuna product such as the date of capture, location, and fishing method. The second user type is the

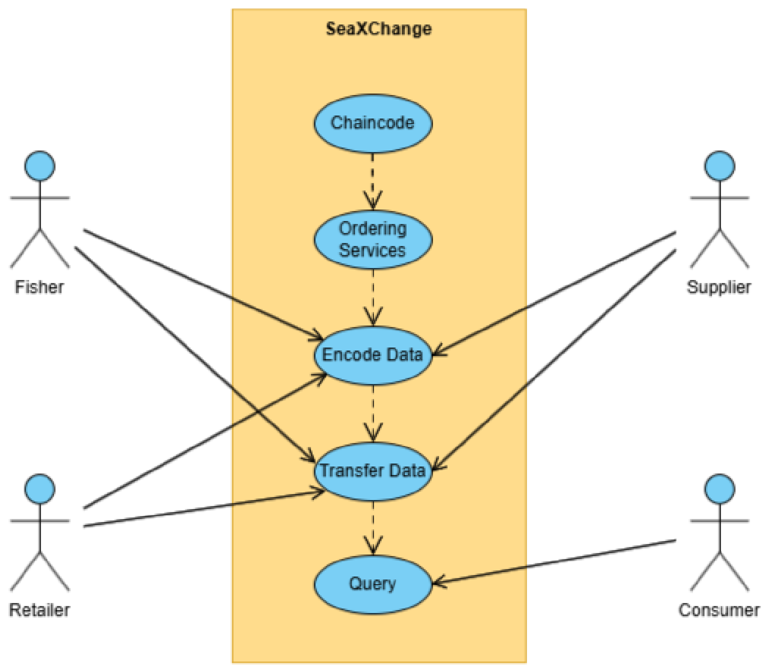


Figure 3.3: Use case diagram for SeaXChange.

Supplier, which will encode when the product was transferred from the fisher to the supplier, as well as generate their location during the retrieval of the tuna asset. The third type is the Retailer, which will encode when the product was transferred from the supplier to the retailer or in the case of multiple retailers, from the previous retailer to the current retailer, their location is also generated during the retrieval of the tuna asset. Lastly, the Consumers, which can only query the origin and exchange of tuna assets.

Chapter 4

Results and Discussions

4.1 Overview

This chapter presents the results of the system. Included in this chapter are screenshots and the discussion of results. The tuna supply chain management smart contract on Hyperledger Fabric has been initiated and tested within a controlled blockchain environment. Results indicated that the system was functionally robust and reliable, having managed assets, transaction integrity, and the ability to query and update the ledger in the blockchain. This chapter presents the details of the major steps executed during the process, results for those steps, and the current status of the system's operations.

4.2 Smart Contract Deployment and Installation

4.2.1 Hyperledger Fabric Prerequisites

Before executing a smart contract framework and blockchain system, it is crucial to first install and set up the necessary tools and technologies. This includes setting up Hyperledger Fabric, which involves installing the Fabric binaries, configuring the network, and ensuring all necessary dependencies like Docker, Docker Compose, and Node.js are installed and properly configured. Additionally, setting up the required certificates, defining the channel configurations, and ensuring that peer nodes and orderers are correctly connected and synchronized are all essential steps in preparing the environment for blockchain and smart contract operations.

- **Software Requirements:**
  - **Docker and Docker Compose:** Hyperledger Fabric needs to have Docker installed and running on the system. Docker is required to run the peer and ordering services of the blockchain system.
  - **Node.js:** Required for the Fabric SDK for client application integration with JavaScript libraries such as react.
  - **Go:** Ensure Go is installed, and the GOPATH environment variable is set up. This is essential for building and running chaincode(smart contract) written in Go.
  - **Fabric Samples:** Clone the official Hyperledger Fabric's fabric-samples repository from GitHub:

```
git clone -b release-2.4 --single-branch
https://github.com/hyperledger/fabric-samples
cd fabric-samples/test-network
```

- **Binaries and Docker Images:**

```
curl -sSL https://bit.ly/2ysbOFE | bash -s
```

- **Network Setup:**
  - Run the `test-network` script to start the Hyperledger Fabric test network:

```
./network.sh up
```

  This script starts a peer, an ordering service, and a CA (Certificate Authority) on the local machine.

  - After starting the network to docker in the same directory (test-network), a channel must be created:

```
./network.sh createChannel
```

- **Deploying Chaincode (Smart Contract):**
  - Step 1:

```
export PATH=${PWD}/../bin:$PATH
```

– Step 2:

```
export FABRIC_CFG_PATH=$PWD/../config/
```

– Step 3:

```
export CORE_PEER_TLS_ENABLED=true
export CORE_PEER_LOCALMSPID="Org1MSP"
export CORE_PEER_TLS_ROOTCERT_FILE=${PWD}/organizations
/peerOrganizations/org1.example.com/peers/peer0.org1.example.com
/tls/ca.crt
export CORE_PEER_MSPCONFIGPATH=${PWD}/organizations
/peerOrganizations/org1.example.com/users
/Admin@org1.example.com/msp
export CORE_PEER_ADDRESS=localhost:7051
```

4.2.2 Invoking the Blockchain System

After setting up the prerequisites, including Docker containers, the test network, and chaincode, the tuna supply chain system can now be invoked for creating, transferring, and querying tuna assets. The figures provided below demonstrate the processes involved in invoking the blockchain system.

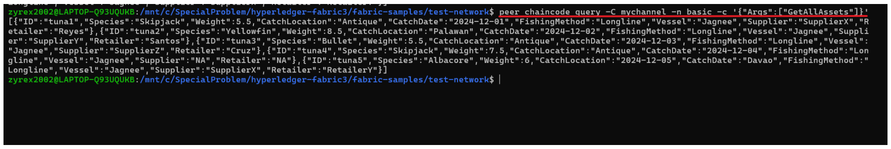


Figure 4.1: Query Smart Contract: Check assets

- **Adding new tuna assets:**

  Here, a new tuna asset is created and registered on the blockchain. This involves invoking the smart contract to add a new entry, which includes details such as the type of tuna, quantity, and any other relevant information. This step ensures that newly caught or acquired tuna can be tracked throughout the supply chain.

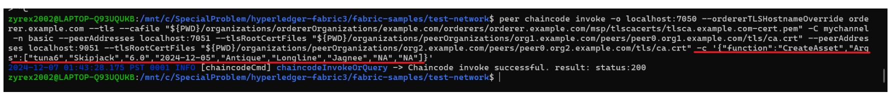


Figure 4.2: Invoke Smart Contract: Create/Add new tuna asset

- **Check all assets after adding a new tuna asset:**

  After adding a new tuna asset, the smart contract is queried again to verify that the asset has been successfully added. This step confirms that the new asset is part of the current inventory and that no discrepancies exist in the recorded data.

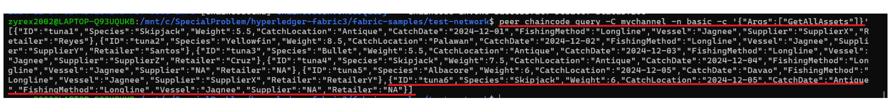


Figure 4.3: Query Smart Contract: Check assets with new tuna asset

- **Transfer tuna asset to Supplier:**

  This step involves transferring ownership of a tuna asset from the current holder (e.g., a fisherman or a trader) to a supplier. The smart contract is invoked to facilitate the transfer, ensuring that the transaction is securely recorded on the blockchain and that the asset's new owner is updated accordingly.

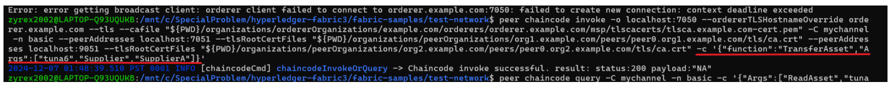


Figure 4.4: Invoke Smart Contract: Transfer asset to a supplier

- **Check the updated tuna asset:**
  After the transfer, the smart contract is queried once more to check if the asset details have been updated correctly. This step verifies that the asset's new owner is now the supplier and that all relevant information is correctly updated on the blockchain.

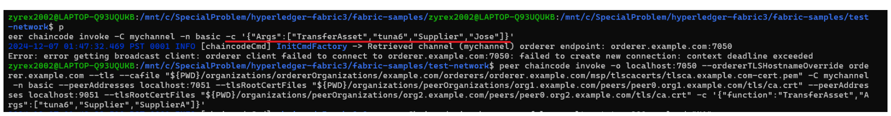


Figure 4.5: Query Smart Contract: Check asset after transfer

- **Transfer tuna asset to Retailer:**
  Similar to the supplier transfer, this step involves transferring the tuna asset from the supplier to a retailer. The smart contract facilitates this transfer, ensuring that ownership is correctly updated and that the retailer has control over the tuna asset. This step is crucial for the supply chain as it moves the tuna from bulk supply to retail.

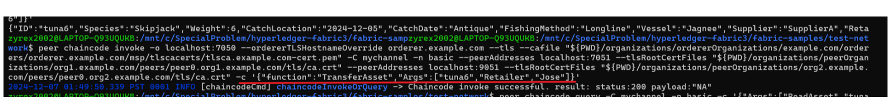


Figure 4.6: Invoke Smart Contract: Transfer asset to a retailer

- **Check the updated tuna asset:**

  After the transfer to the retailer, another query is made to verify the updated asset details. This step ensures that the transaction was successful and that the retailer now has ownership of the tuna asset. It confirms that the asset has moved through the supply chain correctly.

Figure 4.7: Query Smart Contract: Check asset after transfer

- **Query Smart Contract and check updated assets:**

  The final step involves querying the smart contract to get a complete overview of all the assets in the supply chain. This includes all tuna assets from fishing to retail, allowing stakeholders to monitor and manage inventory effectively. It provides traceability in the supply chain, helping to maintain freshness and authenticity of the tuna as it moves through the market.

Figure 4.8: Query Smart Contract: Check updated assets

4.3 Backend Security Analysis (Hyperledger Fabric on GCP)

4.3.1 System Architecture and Deployment Overview

The backend of the system's tuna assets was developed using a containerized Hyperledger Fabric deployed on Google Cloud Platform (GCP). The network of Hyperledger Fabric consists of a peer node, an ordering node, and Certificate Authorities (CAs).

4.3.2 Blockchain Network Security

The blockchain network leverages Hyperledger Fabric's security model to ensure authenticated transactions and controlled access. A Membership Service Provider (MSP) manages identities and issues certificates based on a Public Key Infrastructure (PKI) model, ensuring that only verified participants can interact with the network.

Key security features include:

Channel Privacy

Channels act as private communication subnets, isolating transaction data so that only authorized organizations can access and process specific transactions.

Policies and Access Control

Policies, including endorsement policies and access control lists (ACLs), govern how transactions are validated, how channel resources are accessed, and how changes to the network are approved. Endorsement policies specifically define which peer nodes must approve a transaction before it is committed to the ledger.

Secure Communication

Transport Layer Security (TLS) is enforced across node communications to protect data in transit. Mutual TLS is used for operational endpoints like monitoring services.

Identity and Role Management

Every network participant—peer nodes, orderer nodes, client applications (SeaX-Change Web Application)—has a cryptographically verifiable identity, with roles defined within the framework to control access and permissions within channels.

Hardware Security Modules (HSMs)

Critical cryptographic operations, such as signing transactions under the blockchain assets invocation, can optionally be handled by HSMs to secure private keys outside of the software environment.

These layered mechanisms collectively ensure the confidentiality, integrity, and authenticity of transactions in the blockchain network.

4.3.3 Smart Contract Automated Test Result

To validate the security and functionality of the deployed smart contracts on the Hyperledger Fabric network, an automated testing script (app.js) under asset-transfer-basic directory was executed. The script interacted with the blockchain network through the gateway application, utilizing the defined channel (mychannel) and chaincode (basic). The automated tests performed the following operations:

InitLedger Transaction

The ledger was initialized by creating a predefined set of tuna asset entries. The transaction was successfully committed, confirming the proper initialization of asset data. (See Figure 4.9 for initialization confirmation.)

Figure 4.9: Initialization Confirmation of the Ledger

GetAllAssets Query

A query operation retrieved all existing assets recorded on the ledger. The results displayed multiple tuna asset entries with details such as species, weight, catch location, catch date, fishing method, fisher, supplier, retailers, selling locations, and consumers. (See Figure 4.10 for the asset retrieval output.)

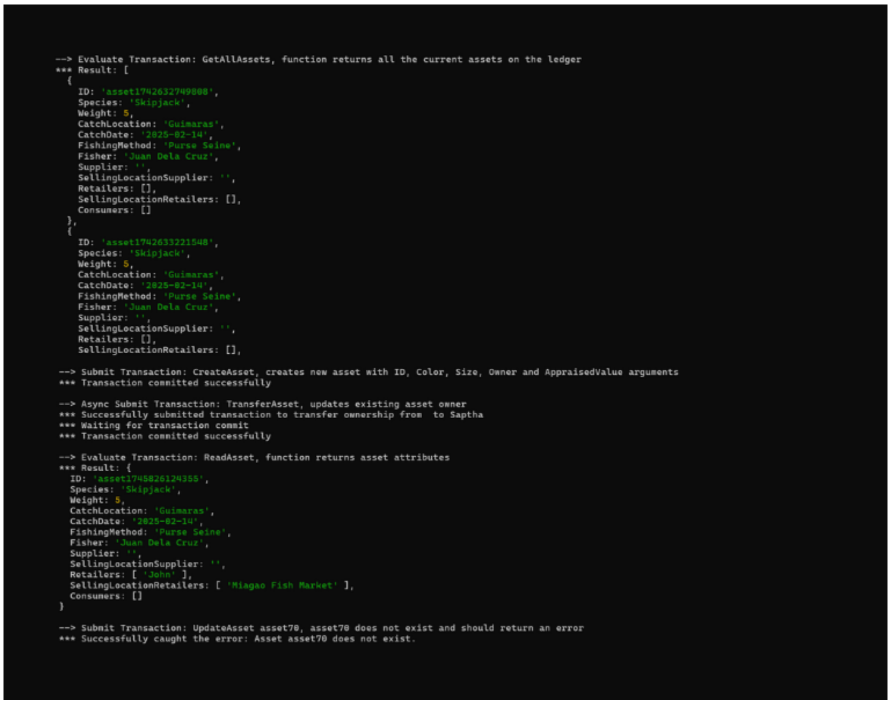


Figure 4.10: Initialization Confirmation of the Ledger

CreateAsset Transaction

A new asset was successfully created and appended to the blockchain. The transaction was committed without errors, validating the chaincode's ability to handle new data insertion.

TransferAsset Transaction

Ownership transfer of an existing asset was simulated. The transaction was successfully submitted and committed, demonstrating the correct application of asset updates in the blockchain ledger.

ReadAsset Query

The updated asset was retrieved and verified to ensure the correctness of the transfer. The retrieved asset data reflected the changes made through the previous transaction, confirming data consistency.

UpdateAsset Error Handling

An attempt to update a non-existent asset (asset70) was performed to test the smart contract's error-handling mechanism. The application correctly caught and reported the error, verifying that improper transactions are adequately handled and rejected.

Summary of Results

All positive transactions (initialization, creation, transfer, and reading) were successfully executed and committed. The smart contract exhibited robust error handling during invalid operations. Endorsement policies and Membership Service Provider (MSP) enforcement ensured transaction authenticity and integrity during the process. These tests confirm the functional reliability and transaction security of the smart contracts used within the tuna supply chain blockchain network.

4.3.4 GCP Infrastructure Security

The Hyperledger Fabric network deployment on Google Cloud Platform (GCP) was secured by leveraging multiple layers of Google's infrastructure security model, following best practices in network, identity, and data protection.

Firewall Rules and Network Control

Only essential ports (e.g., 7051 for peer communication and 7050 for the ordering service) were opened to minimize network exposure. GCP's VPC firewall rules, ingress and egress controls, and options like VPC Service Controls help further isolate services and prevent unauthorized access. Traffic between virtual machines and Google APIs is securely routed through Google's internal network infrastructure using Private Google Access when available.

IAM Roles and Access Management

The principle of least privilege was enforced by assigning minimal permissions to users and services through GCP Identity and Access Management (IAM). Access decisions involve authentication, authorization checks, and enforcement of policies through centralized services, helping reduce the risk of unauthorized actions or privilege escalation.

Encryption

GCP ensures that data is encrypted both at rest and in transit by default. Storage systems use multiple layers of encryption, with cryptographic keys managed by Google. For additional control, Cloud Key Management Service (KMS) enables customers to manage their own encryption keys. Data in transit between services is protected using Application Layer Transport Security (ALTS), and all external communication with Google services is encrypted via TLS.

Access Control

Access to virtual machines and services was restricted using secure access methods. Identity-Aware Proxy (IAP) or VPN connections were employed to safeguard SSH and administrative access. GCP's zero-trust model emphasizes verifying identity and device security rather than relying solely on network location, aligning with best practices for modern infrastructure protection.

Infrastructure and Operational Security

GCP's underlying infrastructure benefits from Google's proprietary hardware designs, including the Titan security chip, secure boot mechanisms, and service identity enforcement. Google's physical data centers use multi-layered defenses such as biometrics and intrusion detection systems. Operational security practices, including binary authorization and extensive monitoring, reduce insider risks and enforce software integrity throughout the lifecycle.

By deploying the blockchain network on GCP, the project leveraged a highly secure environment, benefiting from Google's layered security architecture across networking, identity management, encryption, access control, and operational practices.

4.3.5 Threat Model and Mitigations

Potential threats to the system were identified and mitigation strategies were applied, as summarized in Table 4.1.

Threat	**Mitigation**
Unauthorized access to network	Use of MSP and Certificate Authorities
Tampering with transactions	Endorsement policies and consensus mechanisms
Denial of Service (DoS) attacks	GCP Firewall and rate limiting rules
Data leakage	Private channels and access controls

Table 4.1: Potential Threat and Mitigation

4.4 Mockups

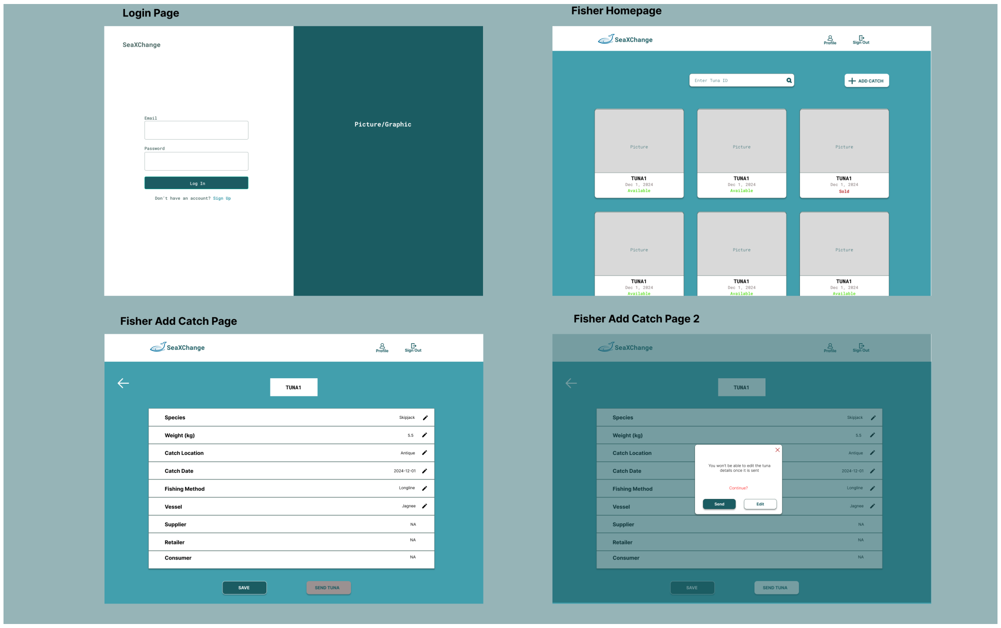
The mockups represent the preliminary design for the SeaXChange web application, created using Figma to facilitate collaboration and incorporate feedback efficiently. The visual design features a teal-based color scheme to evoke an oceanic theme, aligning with the app's focus on tuna products supply chain. This aesthetic choice reinforces the app's identity and enhances user engagement.

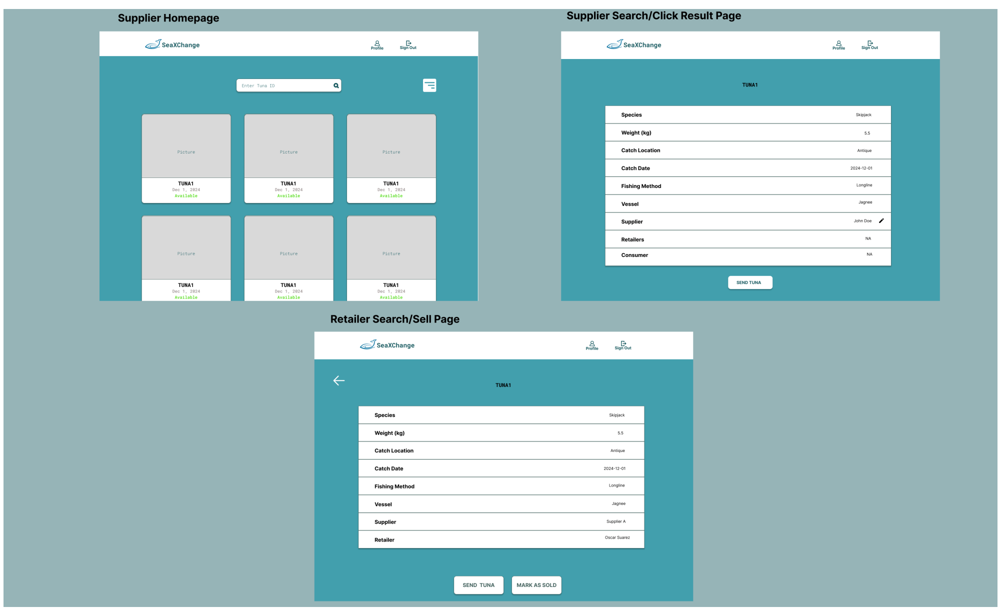
Upon launching the app, users are first directed to the Login or Sign-Up page, where authentication is required to access any data. This ensures security and role-specific access within the blockchain system.

Once authenticated, users are redirected to their personalized homepages, which include their profile information and a dashboard showing relevant tuna product assets. The user experience is role-dependent:

- All users can view available assets on the blockchain.
- Fishermen are the only users who can create new assets, representing newly caught tuna.
- Suppliers and Retailers have the ability to pass on assets down the supply chain, updating the product's status, location, or freshness.

This role-based structure ensures traceability, accountability, and clarity across the supply chain, while maintaining a clean and intuitive interface tailored to each user type.


Login Page
SeaXChange
Email
Password
Log In
Picture/Graphic
Fisher Homepage
SeaXChange
ADD CATCH
TUNA1
Fisher Add Catch Page
SeaXChange
TUNA1
Species
Weight (kg)
Catch Location
Catch Date
Fishing Method
Vessel
Supplier
Retailer
Consumer
SAVE
SEND TUNA
Fisher Add Catch Page 2
SeaXChange
TUNA1
Send
Edit


Supplier Homepage
SeaXChange
TUNA1
Supplier Search/Click Result Page
SeaXChange
TUNA1
Species
Weight (kg)
Catch Location
Catch Date
Fishing Method
Vessel
Supplier
Retailers
Consumer
SEND TUNA
Retailer Search/Sell Page
SeaXChange
TUNA1
Species
Weight (kg)
Catch Location
Catch Date
Fishing Method
Vessel
Supplier
Retailer
SEND TUNA
MARK AS SOLD

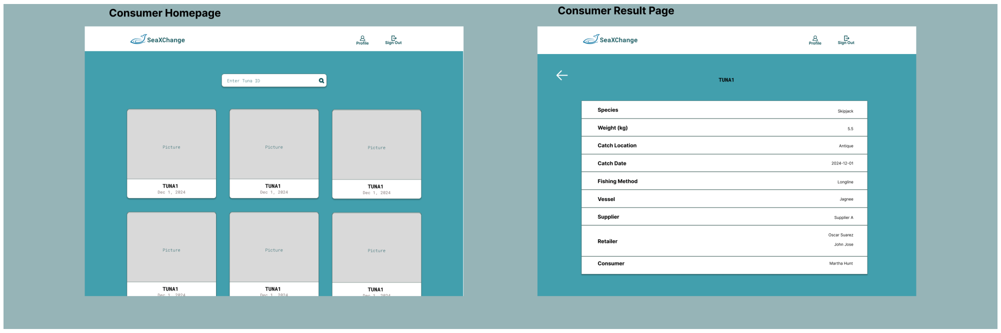


Figure 4.11: SeaXChange Mockups showing the Authentication Page, Role-Based Homepage, Asset Transfer Interfaces for Fishermen, Suppliers, and Retailers, and Asset Viewing page for the Consumers

4.5 Operational Flow of the Web Application

This section will discuss the flow in using the SeaXChange Web Application. It will show the respective interface for every page and how the users can interact with it.

4.5.1 Landing Page

Users are be greeted with the landing page, where it shows a ocean visuals and a tagline "Discover the Journey your tuna made from the ocean to your dinner plate". Users are given the option to Login, where they are redirected to the login page or Get Started, where they are redirected to the sign up page.

Figure 4.12: Landing Page

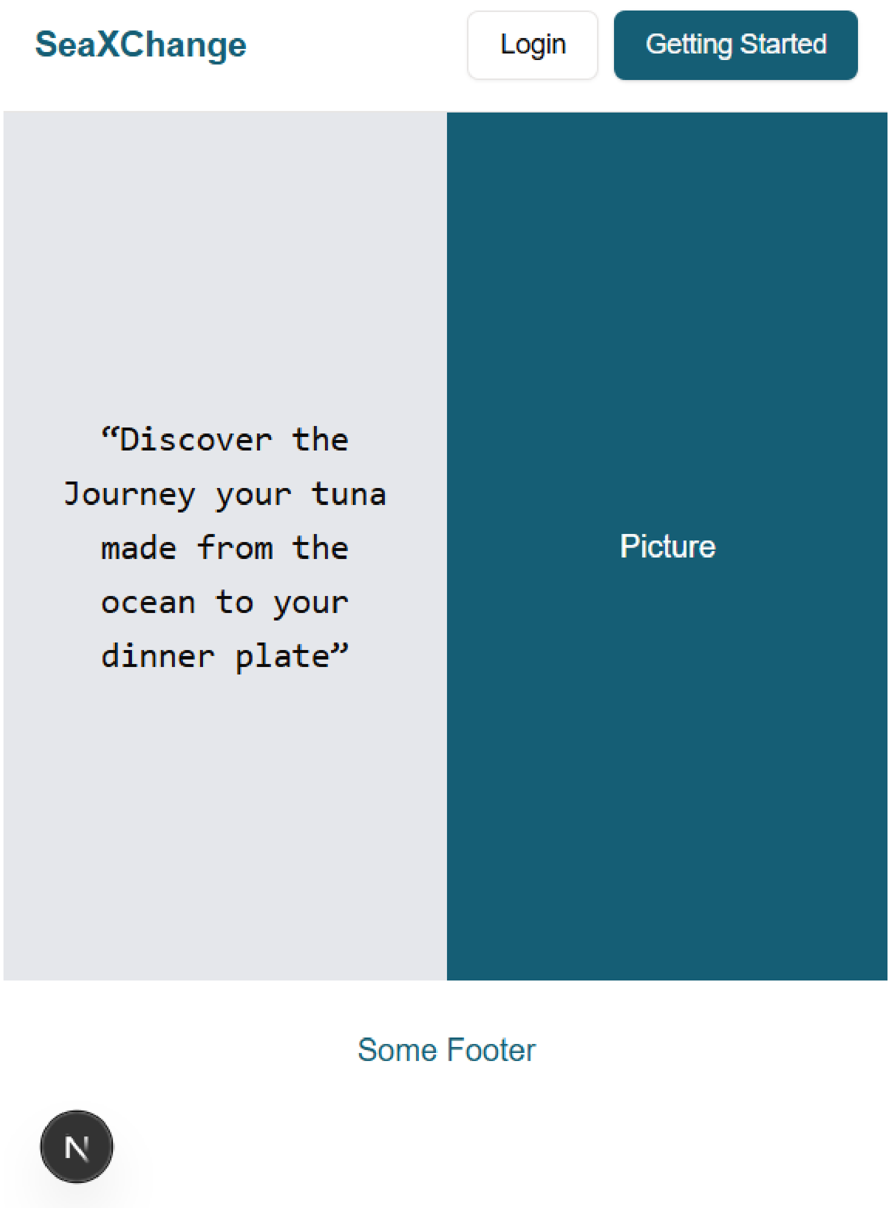


Figure 4.13: Mobile View: Landing Page

4.5.2 Sign Up Page

First time users will be required to create an account. They are to provide their name, email and password. For their user type, there are four roles to choose from: Fisher, Supplier, Retailer and Consumer.

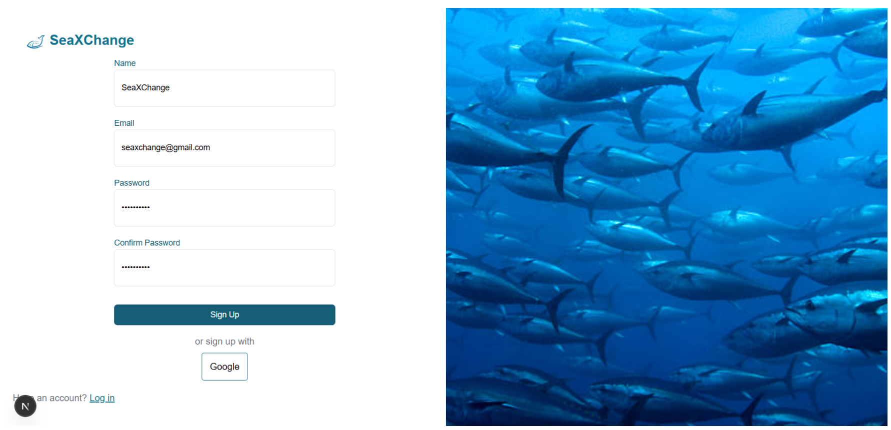


Figure 4.14: SignUp Page

4.5.3 Login Page

Returning user are required to login with their email and password.

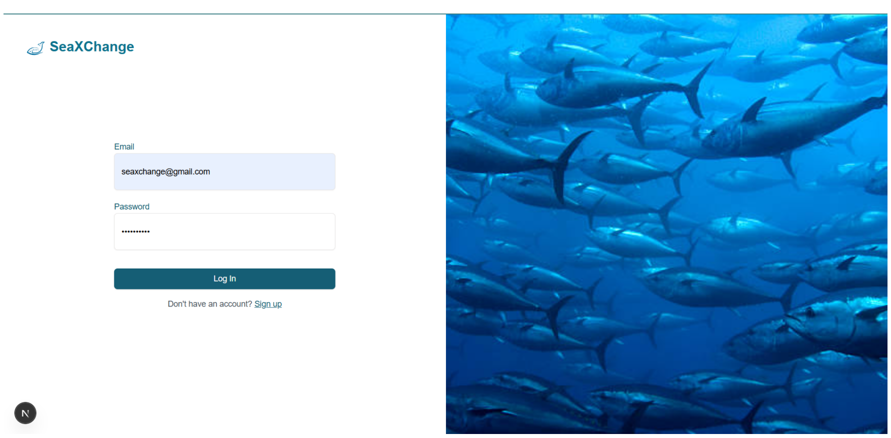


Figure 4.15: LogIn Page

4.5.4 Homepage

Each user type has their own respective homepages and features.

- **Fisher** Fishers can add a fish catch using the ”Add catch” button, where they are to input the species of the fish, weight in kg, catch location, catch date, fishing method used and vessel name. The remaining text fields like the Supplier name, Retailer name and Consumer name are left null and cannot be edited because they will be filled out by the other users receiving the tuna asset. Users can send a tuna asset to the Supplier. Users can also browse existing tuna assets.

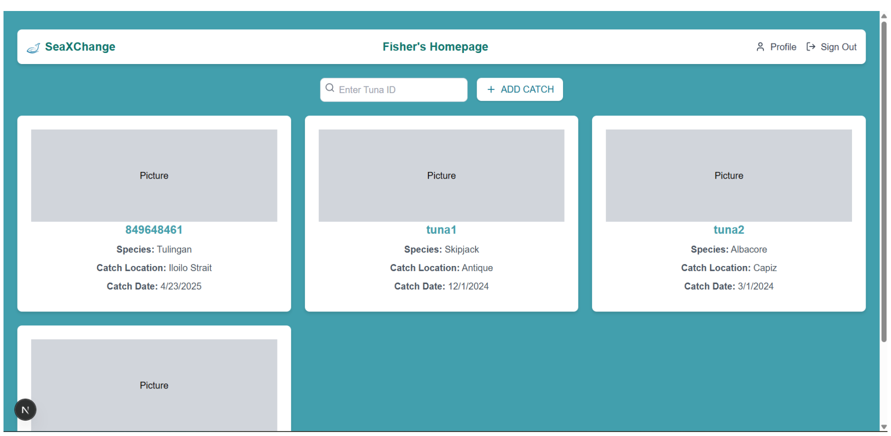


Figure 4.16: Fisher Homepage

- **Supplier** Suppliers can browse existing tuna assets. Upon clicking a tuna asset, the user can only edit the Supplier text field. They can send the tuna asset to the Retailer.

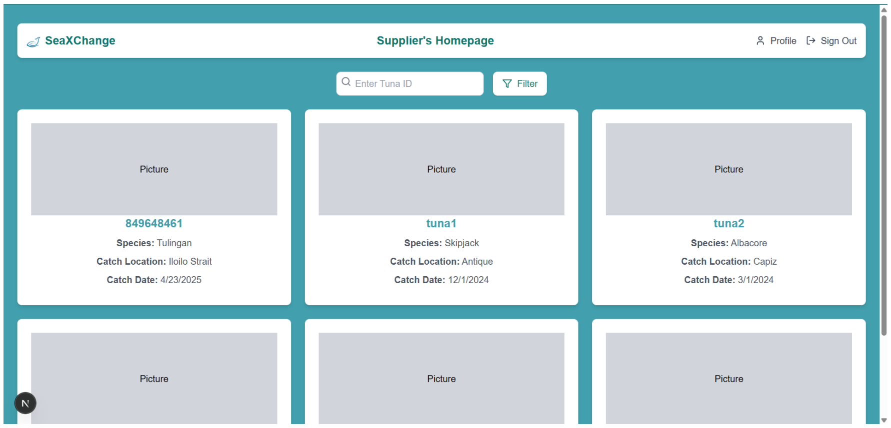


Figure 4.17: Supplier Homepage

- **Retailer** Retailers can browse existing tuna assets and can send it to the Consumer.

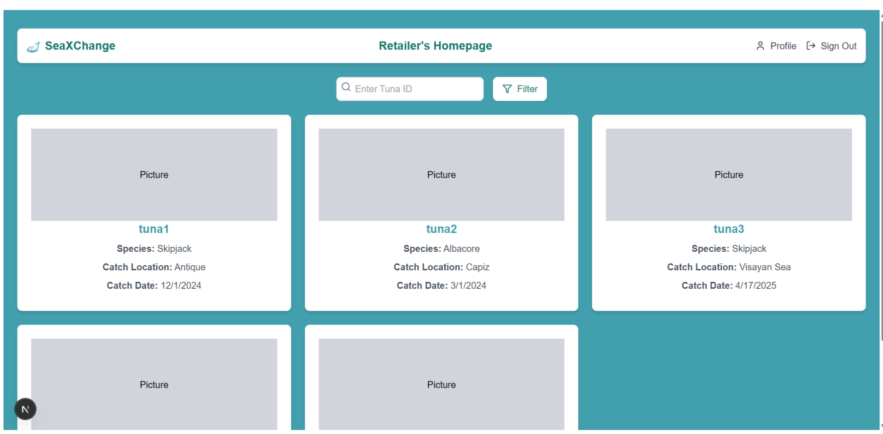


Figure 4.18: Retailer Homepage

- **Consumer** Consumers can only view the tuna asset and cannot edit anything else

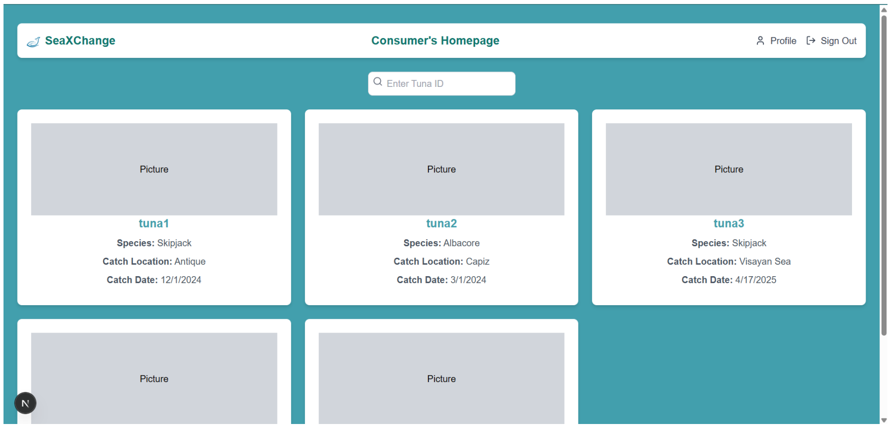


Figure 4.19: Consumer Homepage

4.5.5 Profile

The user's profile information is shown on the homepage through a pop-up. It shows the user's name and role.

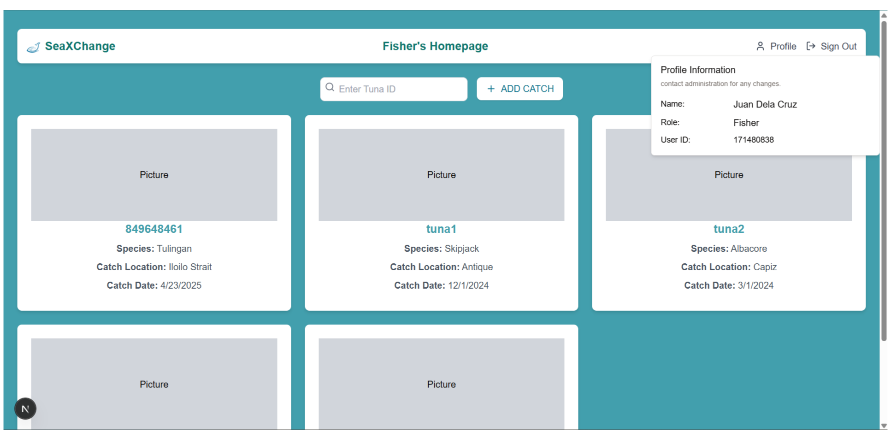


Figure 4.20: View Profile

4.5.6 Logout

Users can logout of their accounts and is redirected to the Signup Page.

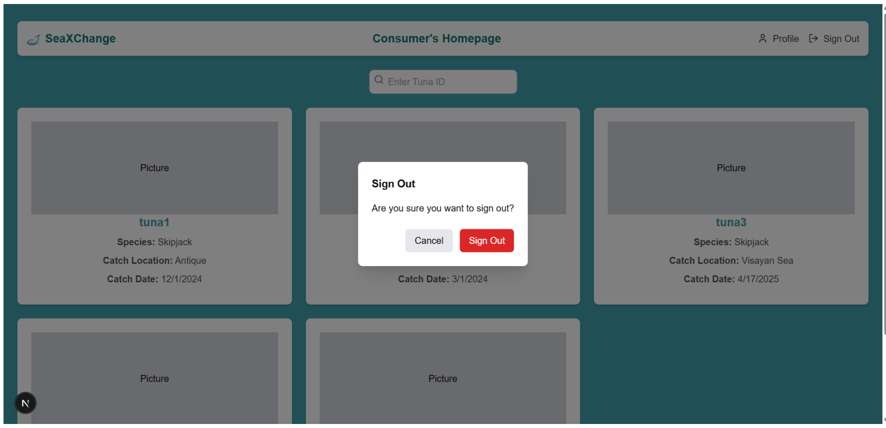


Figure 4.21: Log Out

4.6 System Discussion

After modifying the Hyperledger Fabric smart contract to assess necessary processes involved in the tuna supply chain, the blockchain is ready to be invoked wherein the smart contract can be activated. To start, a new tuna asset is added and registered to the blockchain. Each tuna asset has its attributes or details. Before proceeding to the transfer of tuna asset, the smart contract is queried to verify if the creation of the asset is successful and if it is part of the current inventory. After that, the tuna asset can be transferred from fisher to supplier and the asset's owner is updated. The smart contract is queried again to verify if the asset details have been updated successfully. With the same process, the tuna asset is transferred from supplier to retailer using the smart contract and the owner is updated again. To ensure that the asset details are successfully updated, the smart contract is queried again. The final step is to query the smart contract to show the overview of all the assets in the supply chain. With this, it can be seen all the tuna assets from fishing to retail. Overall, the steps and process provides transparency and traceability in the tuna supply chain.

4.7 User Demonstration and Feedback Results

4.7.1 Demo Setup and Scenario

During the demonstration of the system, the participants had a brief introduction of the key functionalities of the SeaXChange app. They were shown how to create an account, input and send tuna assets from one stakeholder to another. Participants were also shown how real-time updates were reflected on the app. Finally, they were introduced on how to view transaction histories and traceability information on each tuna asset. Throughout the demonstration, participants were encouraged to ask questions and provide feedback on the usability and functionality of the system. After the demonstration, they were given feedback forms in order to assess the SeaXChange app.

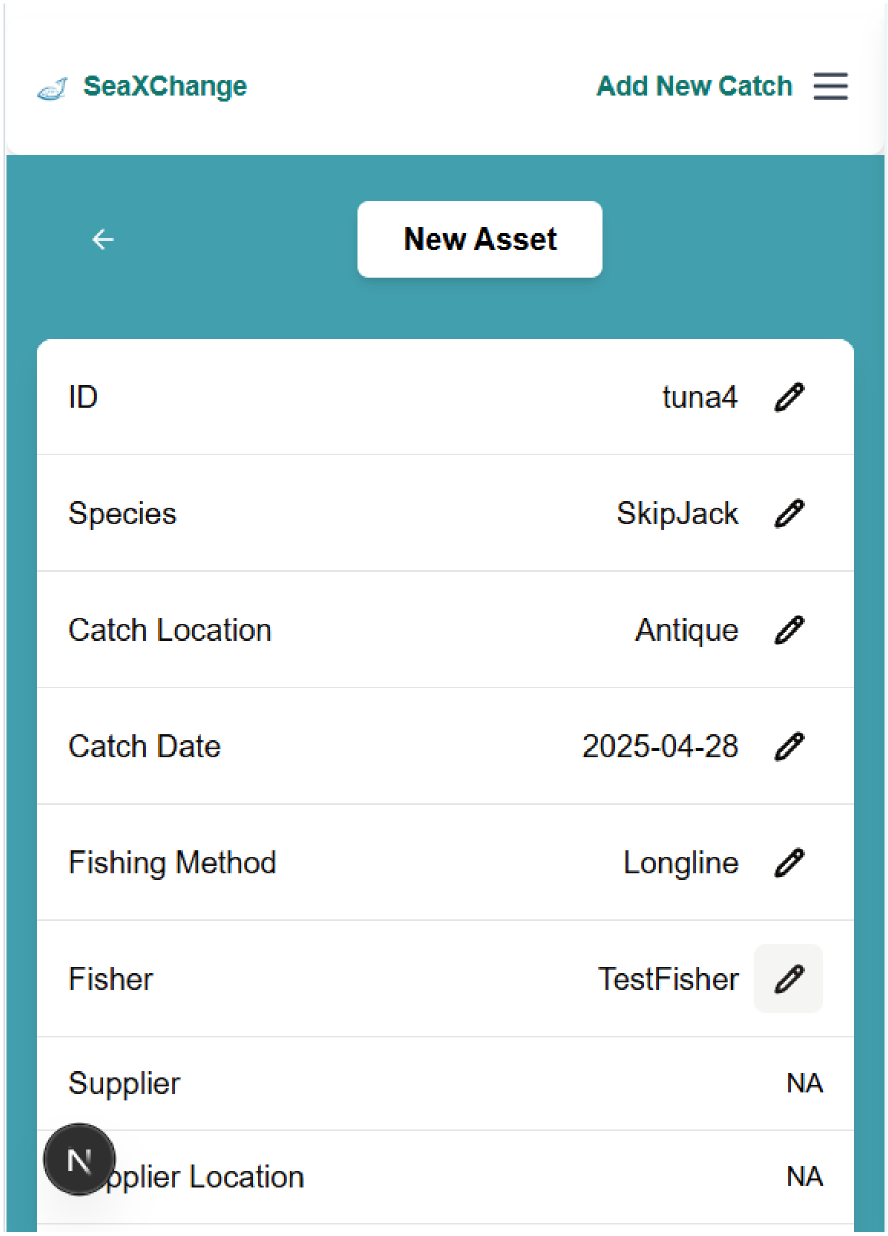


Figure 4.22: Add Catch (Asset)

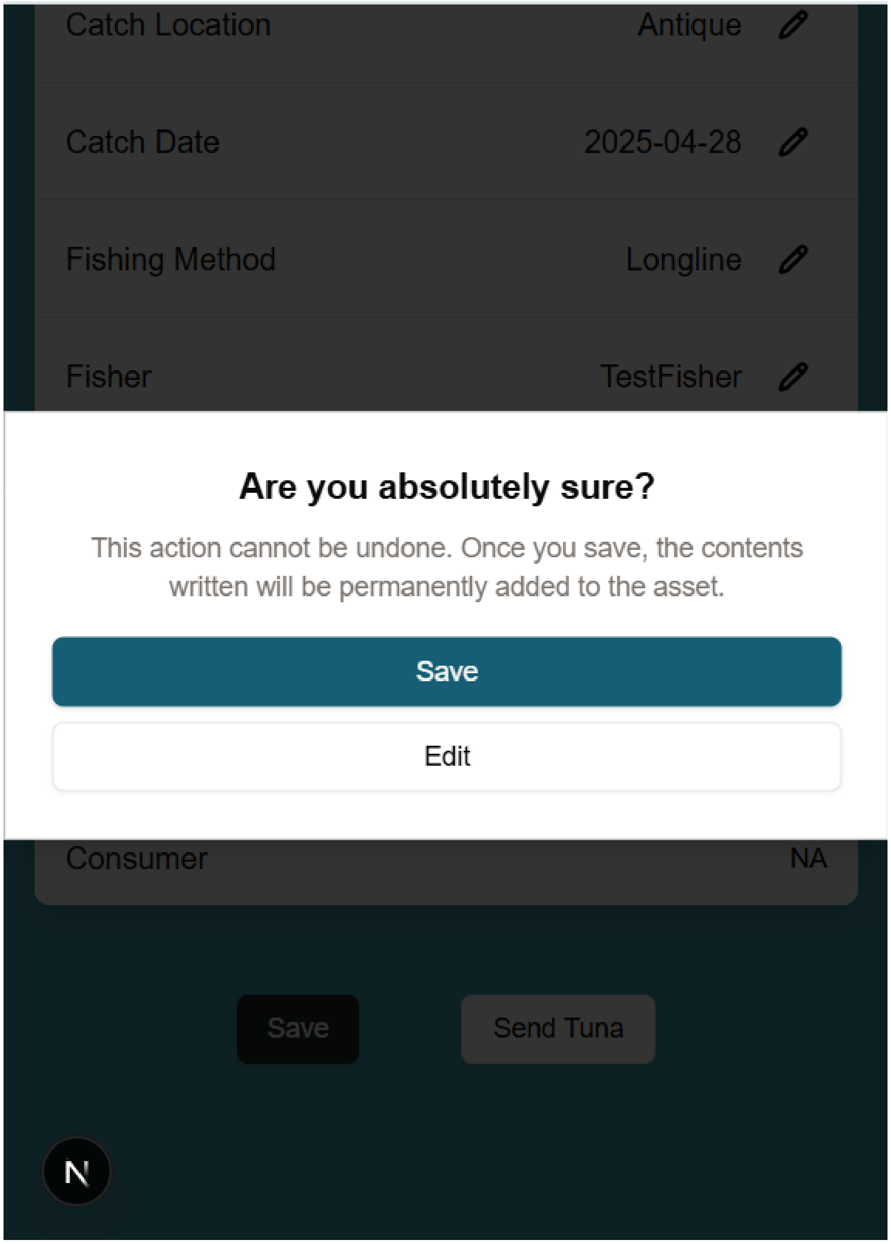


Figure 4.23: Save Details

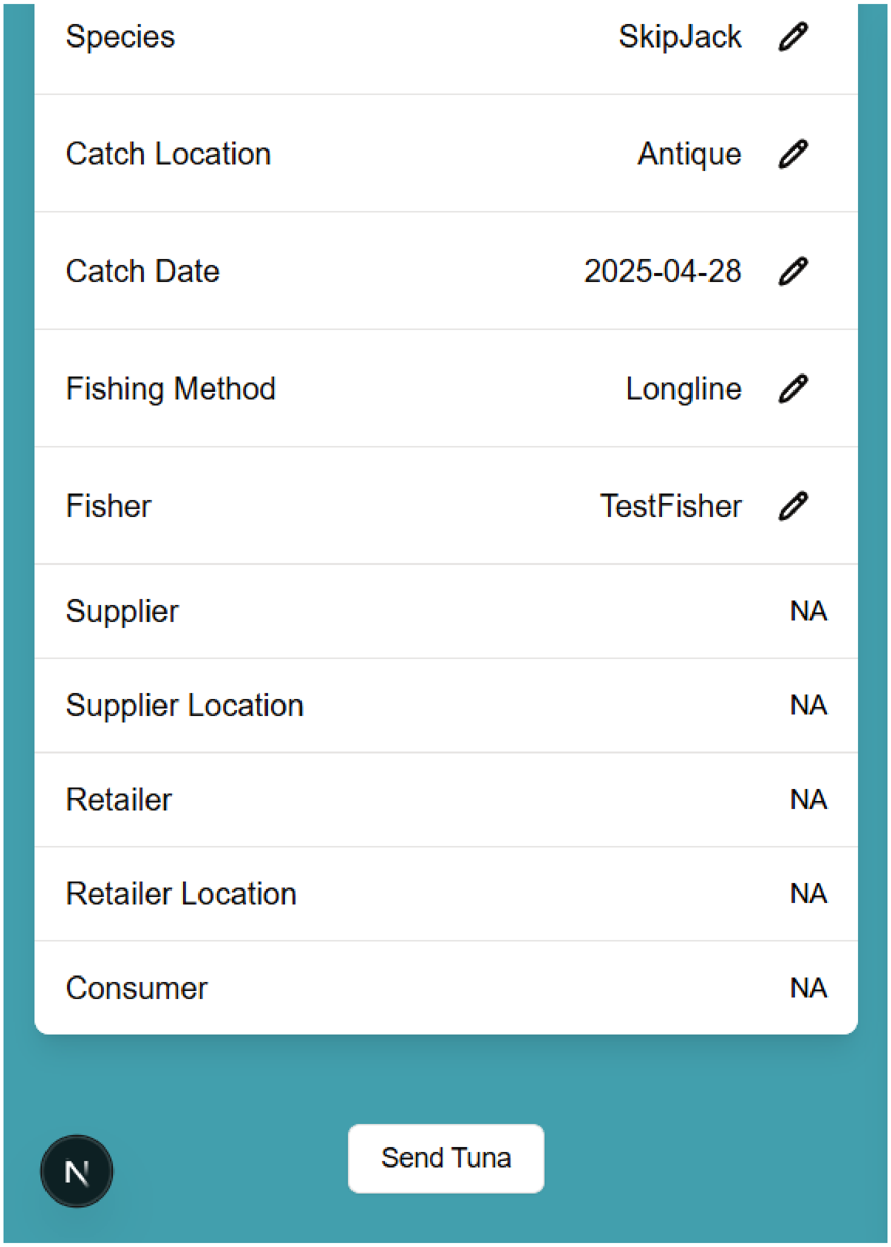


Figure 4.24: After Save Details

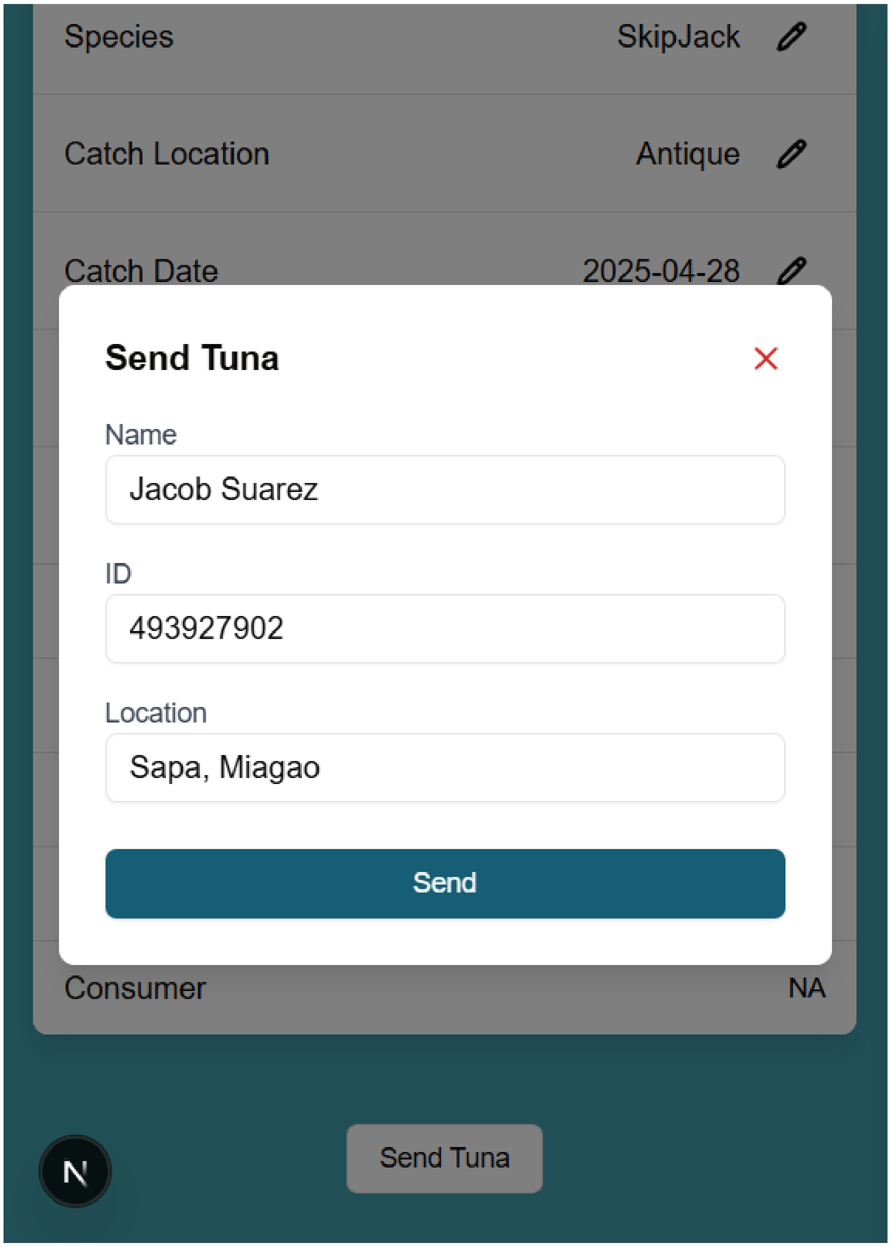


Figure 4.25: Send Asset

4.7.2 Feedback Collection Method

The feedback was collected through a combination of structured interviews and assessment forms. Participants were asked to complete an assessment rubric evaluating the SeaXChange app across key criteria such as functionality, end-user needs, performance, usability, ease of use and feasibility. Moreover, follow-up interviews were conducted to gather deeper qualitative insights and obtain suggestions for system improvement.

The feedback gathered from fishermen, suppliers and retailers, and consumers was analyzed based on the SeaXChange assessment rubric, which evaluated six major categories: Functionality, End-user Needs, Performance, Usability, Ease of Use and Feasibility. The collected data were analyzed using descriptive statistics, through the computation of mean scores for each assessment criterion. These mean values were used to summarize stakeholder perceptions of the system. Mean ratings were calculated based on the 1-5 Likert Scale where 1 = Poor and 5 = Very Good.

4.7.3 Summarized Feedback

Functionality	**Stakeholder**	**Mean**	**Description**
Track assets	Entire Group	3.67	Average
	Fishermen	4.0	Good
	Supplier and Retailers	3.0	Average
	Consumers	4.0	Good
Verify tuna assets	Entire Group	3.67	Average
	Fishermen	3.33	Average
	Supplier and Retailers	4.0	Good
	Consumers	3.67	Average
Support real-time updates	Entire Group	3.56	Average
	Fishermen	3.78	Average
	Supplier and Retailers	4.0	Good
	Consumers	4.0	Good
Enable smart contract execution	Entire Group	3.42	Average
	Fishermen	2.33	Fair
	Supplier and Retailers	3.25	Average
	Consumers	4.67	Good

Table 4.2: Mean ratings and descriptions for functionality-related features per stakeholder group.

When taken as a whole, the respondents have average feedback in asset tracking but when classified by stakeholder, the fishermen (M = 4.0) and consumers (M = 4.0) had good feedback in tracking , while the supplier and retailers have an average rating (M = 3.0). For verifying tuna assets, the entire group has an average feedback. When classified by stakeholder, the fishermen (M = 3.33) and consumers (M = 3.67) have average ratings. For real-time updates, the respondents, when taken as a whole, have an average feedback. When classified by stakeholder, the fishermen (M = 3.78) have an average rating, while both supplier and retailers (M = 4.0) and consumers (M = 4.0) have good ratings. For smart contract execution, the respondents, when taken as a whole, also have an average feedback. When classified according to stakeholder, the fishermen have a fair rating (M = 2.33), the supplier and retailers have average ratings (M = 3.25) and the consumers have good ratings (M = 4.67).

End-user Needs	Stakeholder	Mean	Description
Provide transparency in tracking	Entire Group	3.56	Average
	Fishermen	2.67	Fair
	Supplier and Retailers	4.0	Good
	Consumers	4.0	Good
Provide seamless interaction	Entire Group	3.77	Average
	Fishermen	1.33	Poor
	Supplier and Retailers	3.0	Average
	Consumers	4.0	Good

Table 4.3: Mean ratings and descriptions for end-user needs-related features per stakeholder group.

The respondents, when taken as a whole, had an average feedback in transparency. When classified by stakeholder, The fishermen have fair ratings (M = 2.67), while both supplier and retailers (M = 4.0) and consumers (M = 4.0) have good ratings. In evaluating the seamless interaction of the app, the entire group has an average feedback (M = 3.77). When classified by stakeholder, the fishermen (M = 1.33) have poor feedback, the supplier and retailers have average feedback (M = 3.0) and the consumers have good feedback (M = 4.0) in seamless interaction.

Performance	Stakeholder	Mean	Description
Processes transactions efficiently	Entire Group	3.81	Average
	Fishermen	3.67	Average
	Supplier and Retailers	3.75	Average
	Consumers	4.0	Good
Ensures data integrity and security	Entire Group	3.31	Average
	Fishermen	2.67	Fair
	Supplier and Retailers	3.25	Average
	Consumers	4.0	Good

Table 4.4: Mean ratings and descriptions for performance-related features per stakeholder group.

As a whole, the respondents have an average feedback on efficient transactions (M = 3.81). If evaluated per stakeholder, both fishermen (M = 3.67), supplier and retailers (M = 3.75) evaluated average while consumers had good feedback (M = 4.0). For data security, the entire group has an average feedback (M = 3.31). The fishermen have fair evaluation (M = 2.67), supplier and retailers (M = 3.25) have an average and consumers have solid scores (M = 4.0).

Usability	**Stakeholder**	**Mean**	**Description**
Provides intuitive interface	Entire Group	3.83	Average
	Fishermen	4.0	Good
	Supplier and Retailers	3.5	Average
	Consumers	4.0	Good
Allows cross-platform accessibility	Entire Group	4.14	Good
	Fishermen	4.0	Good
	Supplier and Retailers	3.75	Average
	Consumers	4.67	Good
Clear, structured, and visually appealing info	Entire Group	3.80	Average
	Fishermen	3.33	Average
	Supplier and Retailers	3.75	Average
	Consumers	4.33	Good

Table 4.5: Mean ratings and descriptions for usability-related features per stakeholder group.

It shows the frequency of intuitive interface among the respondents when taken as a whole is average (M = 3.83). When classified according to stakeholder, both fishermen (M = 4.0) and consumers (M = 4.0) have good ratings, while the supplier and retailers (M = 3.5) have average ratings. For cross-platform usage, the entire group rated good (M = 4.14). When classified according to stakeholder, both fishermen (M = 4.0) and consumers (M = 4.1) also have good ratings, while supplier and retailers (M = 3.75) have average. For visual clarity, the entire group rated average (M = 3.80). When classified by each stakeholder, both fishermen (M = 3.33) and supplier and retailers (M = 3.75) have average ratings, while consumers (M = 4.33) have good ratings.

Ease of Use	**Stakeholder**	**Mean**	**Description**
Clear instructions for new users	Entire Group	3.89	Average
	Fishermen	4.0	Good
	Supplier and Retailers	4.0	Good
	Consumers	3.67	Average
Uses clear and simple language	Entire Group	3.31	Average
	Fishermen	4.03	Good
	Supplier and Retailers	3.75	Average
	Consumers	4.33	Good

Table 4.6: Mean ratings and descriptions for ease of use-related features per stakeholder group.

When taken as a whole, the respondents (M = 3.89) rated instruction clarity as average. When classified by stakeholder, both fishermen (M = 4.0) and supplier and retailers (M = 4.0) have good feedback regarding instruction clarity, while the consumers (M = 3.67) have average feedback. The entire group rated language clarity as average (M = 3.31). When evaluated by each stakeholder, both fishermen (M = 4.03) and consumers (M = 4.33) have good feedback, while supplier and retailers (M = 3.75) have average feedback.

Feasibility	**Stakeholder**	**Mean**	**Description**
Integration with tuna industry	Entire Group	4.06	Good
	Fishermen	4.0	Good
	Supplier and Retailers	4.5	Good
	Consumers	3.67	Average
Consumer use to track tuna products	Entire Group	4.03	Good
	Fishermen	4.0	Good
	Supplier and Retailers	3.75	Average
	Consumers	4.33	Good

Table 4.7: Mean ratings and descriptions for feasibility-related features per stakeholder group.

When taken as a whole, it shows that the respondents have good feedback in the system integration. When classified by each stakeholder, both the fishermen (M =

4.0) and supplier and retailers (M = 4.5) have good feedback in system integration, while the consumers(M = 3.67) have an average rating. The frequency of consumer use among stakeholders, when taken as a whole, have good feedback (M = 4.03). When analyzed individually, both the fishermen (M = 4.0) and consumers (M = 4.33) have a good rating, while an average rating for the supplier and retailers (M = 3.75).

4.7.4 Results and Analysis

For functionality, fishermen rated asset tracking positively but identified challenges in real-time updates and smart contract execution. Suppliers and retailers similarly found strengths in verification and real-time updates, although asset tracking averaged slightly lower. Consumers consistently rated functionality highly, particularly appreciating the system's ability to support smart contracts.

Regarding end-user needs, fishermen provided the lowest ratings, highlighting difficulties with seamless interaction, considering the digital barrier that they experience while interacting with the app. Suppliers, retailers, and consumers gave higher scores, suggesting that while transparency was generally achieved, the system's ease of interaction required further improvement for all users.

In terms of performance, fishermen and suppliers reported average transaction efficiency but noted concerns regarding data integrity and security. Consumers, on the other hand, expressed confidence in both areas.

For usability, consumers provided the highest ratings, emphasizing the intuitive design and accessibility of the interface. Fishermen and suppliers also rated usability positively but suggested improvements, such as better visual appeal and language localization. Feedbacks suggested incorporating the Karay-a language since most of the potential users uses that language in their everyday lives. Another suggestion was to use capitalization (UI/UX) for the name of the tuna to give more emphasis to it.

Ease of use was generally rated positively across all groups. However, feedback highlighted the need for additional user guidance features, including clearer button descriptions and localized instructions for broader accessibility.

Finally, feasibility was strongly affirmed by all groups. Stakeholders believed the system could be effectively integrated into the existing tuna supply chain and accessed by consumers as a means to monitor tuna products.

Chapter 5

Conclusion

5.1 Overview

This chapter presents the key findings and conclusion of the study. It also discusses how the system addresses the challenges of traceability within the tuna supply chain. This chapter also provides recommendations in enhancing the system's functionality and usability, ensuring that the SeaXChange app continues to meet evolving needs of its users.

5.2 Conclusion

This study aimed to develop and evaluate SeaXChange, which is a blockchain-driven app designed to enhance transparency, traceability and accountability within the tuna supply chain. Through the adaption of Scrum, the team was able to develop a functional prototype that was based on iterative development to achieve goals.

The results from the gathered data suggests that the app has effectively addressed key challenges in traceability and accountability, especially among suppliers and consumers. The stakeholders consistently rated the system as good. However, some areas need improvement, especially in ensuring seamless interaction and data security for fishermen.

Overall, SeaXChange demonstrates strong potential as a technological solution for promoting transparency, combating illegal, unreported, and unregulated (IUU) fishing, and empowering stakeholders across the tuna supply chain.

5.3 Recommendations

After analyzing and interpreting the gathered data, the researchers had identified some improvements and recommendations for the further development and implementation of the SeaXChange app.

1. **Incorporation of Local Language**
   Since most of the target users are within Miagao, the system could provide multi-language support, including the Karay-a language. This will improve guidance through clearer button descriptions.

2. **Utilization of IoT**
   The system could use Internet of Things (IoT) in verifying the fisherman's location. This will add more accountability in tracing the fisherman's cur-

rent location.

3. **Inclusion of User Manual**

   To further enhance the experience of its users, the researcher could provide printed or digital copies on the system's functionalities. This will help users navigate through the system without being lost.

In conclusion, the development of the SeaXChange app highlights the critical role of emerging technologies in providing solution regarding the traceability, transparency and accountability within the tuna supply chain. While the system has demonstrated strong potential, continuous improvements are still needed to ensure its effectiveness. Moreover, further development and usability enhancements will be essential in attaining SeaXChange's goal of creating a more traceable, transparent and accountable tuna industry.

Chapter 6

References

Appendix A

Code Snippets

Appendix B

Resource Persons

Dr. Firstname1 Lastname1

Role1

Affiliation1

`emailaddr@domain.com`

Mr. Firstname2 Lastname2

Role2

Affiliation2

`emailaddr2@domain.com`

Ms. Firstname3 Lastname3

Role3

Affiliation3

`emailaddr3@domain.net`