

1      SEAXCHANGE: A BLOCKCHAIN DRIVEN APP FOR  
2      TUNA SUPPLY CHAIN MANAGEMENT

3                                  A Special Problem  
4                                  Presented to  
5                                  the Faculty of the Division of Physical Sciences and Mathematics  
6                                  College of Arts and Sciences  
7                                  University of the Philippines Visayas  
8                                  Miag-ao, Iloilo

9                                  In Partial Fulfillment  
10                                of the Requirements for the Degree of  
11                                Bachelor of Science in Computer Science by

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17                                May 25, 2025

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21

**SEAXCHANGE: A BLOCKCHAIN DRIVEN APP FOR  
TUNA SUPPLY CHAIN MANAGEMENT**

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29                          **Declaration**

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

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## Dedication

36        This Special Problem, SeaXChange: A Blockchain-Driven App for Tuna Sup-  
37        ply Chain Management, is dedicated to those who were instrumental in its creation  
38        and purpose:

39        To our esteemed adviser and mentor, **Francis D. Dimzon, Ph.D.**, for his  
40        invaluable guidance, expertise, and unwavering support throughout our research  
41        journey.

42        To the members of the **Miagao community**, particularly the fishermen, sup-  
43        pliers, and retailers from **Barangay Sapa**, and the consumers from **Barangay**  
44        **Mat-y**, your participation and insights were crucial in assessing product trace-  
45        ability for our project.

46        To **Engr. Noel Lucero**, whose valuable perspectives during interviews pro-  
47        vided essential context for understanding current trends and issues in the tuna  
48        supply chain and the fishing industry as a whole.

49        To our fellow Special Problem classmates and colleagues—for the collabora-  
50        tion, shared challenges, and mutual support that made this academic endeavor  
51        more enriching.

52        And most importantly, to our beloved families—for their constant love, encour-  
53        agement, understanding, and sacrifices that enabled us to pursue and complete  
54        this work.

55        This Special Problem paper stands as a testament to your support and as a  
56        contribution toward addressing the challenges faced within the tuna supply chain.

57

## Acknowledgment

58 Our deepest appreciation goes to our thesis adviser, **Francis D. Dimzon**,  
59 **Ph.D.**, for his expertise, patient guidance, and unwavering support. We are also  
60 grateful to **Christi Florence C. Cala-or**, panelist, for her insightful feedback  
61 and suggestions that enriched this study.

62 We thank the **University of the Philippines Visayas**, particularly the **Di-**  
63 **sion of Physical Sciences and Mathematics**, College of Arts and Sciences,  
64 for providing the academic foundation and resources. We also acknowledge the  
65 **Computer Science Faculty** for equipping us with essential skills in software  
66 engineering.

67 Special thanks are extended to the **Institute of Marine Fisheries and**  
68 **Oceanology**. We particularly recognize **Ricardo P. Babaran Ph.D.**, for his  
69 valuable insights into the state of the tuna supply chain, existing technologies,  
70 and the importance of supporting marginalized groups within it. We also thank  
71 **Carmelo Del Castillo, Ph.D.**, for sharing related insights from prior thesis  
72 work on the tuna supply chain.

73 To our fellow Special Problem classmates and colleagues—thank you for the  
74 shared learning experiences, collaboration, and mutual support that made this  
75 academic journey more fulfilling.

76 The successful implementation of SeaXChange was made possible through the  
77 use of several tools and platforms. We acknowledge **Google Cloud Platform**  
78 for hosting our backend services and blockchain network, and the **Hyperledger**  
79 **Fabric** open-source framework, along with its documentation and community, for

80 providing a robust foundation for our blockchain system.

81 We extend our gratitude to the community participants and organizations in  
82 **Miagao** who generously shared their time and perspectives. Our sincere thanks  
83 go to the respondents—fisherfolk, suppliers, retailers, and consumers—whose real-  
84 world experiences were vital to this study. We especially thank **Jerome F. Ca-**  
85 **batuan** and **Veronica Jeruta** for facilitating access and participation within  
86 their respective communities. We also acknowledge **Jagnee Fishing Corpora-**  
87 **tion** and **Engr. Noel Lucero** for sharing their knowledge of the fish industry,  
88 fishing vessels, and the tuna supply chain.

89 Finally, and most importantly, we extend our heartfelt thanks to our families  
90 for their unwavering love, encouragement, sacrifices, and patience throughout the  
91 duration of this study.

92 This thesis is a culmination of the support and collaboration of all those men-  
93 tioned. We hope that this work contributes meaningfully to improving trans-  
94 parency and efficiency in the tuna supply chain.

95

## Abstract

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

112 **Keywords:** Blockchain, Traceability, Smart Contract, Supply Chain



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# <sup>236</sup> Chapter 1

## <sup>237</sup> Introduction

### <sup>238</sup> 1.1 Overview

- <sup>239</sup> The tuna supply chain faces critical issues that affect both the industry and its  
<sup>240</sup> consumers. Illegal fishing, overfishing, and poor traceability threaten the sustain-  
<sup>241</sup> ability and ethical trade (Ambarsari et al., 2023; Nurhayati & Purnomo, 2021).  
<sup>242</sup> A lack of transparency compromises product quality and misleads consumers.  
<sup>243</sup> Blockchain technology can address these challenges by tracking the tuna's jour-  
<sup>244</sup> ney from ocean to plate through a secure, tamper-proof ledger (Zheng et al., 2017).  
<sup>245</sup> This system also holds stakeholders to comply to legal standards.
- <sup>246</sup> Although blockchain integration in the tuna sector is underway, gaps remain in its  
<sup>247</sup> implementation. This study helps to address the industry's need for transparent  
<sup>248</sup> and secure tracking of tuna products from ocean to consumer, while assessing the  
<sup>249</sup> feasibility of implementing blockchain at scale in the seafood sector.

250 **1.2 Problem Statement**

251 Fish is one of the most consumed protein products in the Philippines. Before the  
252 COVID-19 pandemic, fish was the most consumed animal protein in the Philip-  
253 pines with annual per capita consumption of 40 kg (Agriculture and Agri-Food  
254 Canada, 2022). Among the wide variety of fish, tuna stands out as a particularly  
255 significant commodity due to its high demand and economic value (Kong et. al.,  
256 2023). Although the nation is gifted with an abundance of aquatic resources, the  
257 methods of dispersal of the product usually leads to inefficiency in terms of sales,  
258 pricing, and overall product quality for the consumers. The complexity arises with  
259 the introduction of a supply chain from several middlemen between the fish farmer  
260 or producer and wholesaler in the coastal and aquatic regions towards the con-  
261 sumers with less access to fresh fish. Consequently, both consumers and suppliers  
262 struggle to ensure transparent and fair pricing, accurately track tuna products,  
263 and maintain consistent quality (Adhikary et al., 2018; Stocco et al., 2022; Hoque  
264 et al., 2021). These challenges stem from inefficient methods of product dispersal  
265 and the presence of multiple intermediaries between fisherfolks in coastal munici-  
266 palities and consumers. This fragmented supply chain introduces delays, obscures  
267 product origin, and opens opportunities for mishandling or mislabeling. To ad-  
268 dress this, the study focuses on the absence of a reliable, real-time traceability  
269 system that allows stakeholders to verify the origin, novelty, handling processes,  
270 and adherence to ethical sourcing practices of tuna at every stage. Without such  
271 a system, the tuna supply chain and industry lack the transparency and account-  
272 ability necessary to build consumer trust and improve supply chain efficiency. By  
273 introducing a blockchain-driven solution, this study aims to streamline the trace-  
274 ability process and reduce the negative impact of intermediary-heavy distribution.

<sup>275</sup> **1.3 Research Objectives**

<sup>276</sup> **1.3.1 General Objective**

<sup>277</sup> The general objective of the study is to design and develop a blockchain-driven  
<sup>278</sup> application that improves the traceability of the tuna supply chain. Given the  
<sup>279</sup> timely issues regarding illegal, unreported and unregulated (IUU) fishing and lack  
<sup>280</sup> of product traceability and transparency, this study addresses these challenges  
<sup>281</sup> through an application that has the capability to provide an immutable ledger  
<sup>282</sup> and tamper-proof records. The result of this study serves as a framework for  
<sup>283</sup> integrating blockchain technology in the fish supply chain, specifically for tuna.  
<sup>284</sup> This also supports future researchers and developers facing similar challenges in  
<sup>285</sup> the industry.

<sup>286</sup> **1.3.2 Specific Objectives**

<sup>287</sup> To further specify the research objectives, the study focuses to:

- <sup>288</sup> 1. develop a smart contract framework using blockchain technology for data  
<sup>289</sup> verification and transaction recording, ensuring secure and tamper-proof  
<sup>290</sup> data for the stakeholders,
- <sup>291</sup> 2. design and develop a blockchain-driven application with a user-friendly in-  
<sup>292</sup> terface that allows stakeholders to access and input data while enhancing  
<sup>293</sup> traceability in the tuna supply chain through a tuna asset record for the  
<sup>294</sup> supply chain participants, and

295        3. deploy the application after completing all necessary preparations for soft-  
296        ware development and to evaluate its overall results and effectiveness in en-  
297        hancing the tuna supply chain, as discussed in the fourth and fifth chapters  
298        of the study.

## 299      **1.4 Scope and Limitations of the Research**

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

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

## 312      **1.5 Significance of the Research**

313     This study serves a significant purpose for several stakeholders in the tuna supply  
314     chain. This study aims to solve the problems related to the management of tuna

<sup>315</sup> supply chain, particularly with regards to product traceability.

<sup>316</sup> • The Stakeholders

<sup>317</sup> – This study enhances transparency and accountability, allowing stakeholders such as fishers, suppliers, and retailers to access tamper-proof  
<sup>318</sup> and accurate information, thereby promoting a more ethical and authentic supply chain. By providing a digital record of the product's  
<sup>319</sup> history, this study helps ensure compliance with environmental and  
<sup>320</sup> legal standards. In cases of anomalies such as oil spills, red tide occurrences,  
<sup>321</sup> 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  
<sup>322</sup> utilized for accountability purposes when problems such as damaged  
<sup>323</sup> products, mislabeling, or contamination arise, allowing stakeholders to  
<sup>324</sup> trace and resolve them efficiently.

<sup>329</sup> • The Consumers

<sup>330</sup> – This study helps consumers verify the history of the tuna product from its origin up until its journey to the consumers, therefore increasing  
<sup>331</sup> trust and transparency. By promoting traceability, it offers a more detailed and verifiable record of the supply chain, enabling consumers to  
<sup>332</sup> assess sustainability practices and identify stakeholders responsible for  
<sup>333</sup> any potential issues affecting the tuna product. This, in turn, encourages critical evaluation of the tuna supply chain, driving improvements  
<sup>334</sup> in accountability, resource management, and ethical sourcing.

- 338        • For Future Researchers
- 339            – As blockchain technology continues to grow, this study contributes to  
340                the application of blockchain in the supply chain management and the  
341                insights regarding its benefits and limitations. This research can be  
342                helpful in the growing knowledge on digital solutions for traceability  
343                and transparency for future research.
- 344        • The Policy Makers
- 345            – This study provides policy makers a reliable and data-driven founda-  
346                tion in monitoring and regulating the tuna supply chain. By lever-  
347                aging tamper-proof and transparent records, policymakers can more  
348                effectively enforce compliance with fishing quotas and environmental  
349                protections. This research also aids in lessening the illegal, unreported  
350                and unregulated (IUU) fishing practices, contributing to the national  
351                sustainability goals.

# <sup>352</sup> Chapter 2

## <sup>353</sup> Review of Related Literature

<sup>354</sup> This chapter reviews existing literature related to the traceability of the tuna sup-  
<sup>355</sup> ply chain and the potential application of blockchain technology. In purchasing  
<sup>356</sup> goods, one important consideration is the product quality. An important factor  
<sup>357</sup> of determining the quality is to know the traceability of the supply chain. Trace-  
<sup>358</sup> ability refers to the ability of tracking the journey of the product from its source  
<sup>359</sup> until its destination. The term “traceability” is now more utilized in both the  
<sup>360</sup> food and production industry (Islam & Cullen, 2021). In the context of the tuna  
<sup>361</sup> supply chain, it can be used not only to promote transparency to consumers but to  
<sup>362</sup> also ensure compliance with environmental and legal standards. With blockchain  
<sup>363</sup> technology, the status of tuna at each stage could be recorded in the blockchain  
<sup>364</sup> which could be used for traceability. This paper aims to address the following  
<sup>365</sup> research question: How can blockchain technology improve the traceability of the  
<sup>366</sup> tuna supply chain management? To explore this, the chapter reviews literature  
<sup>367</sup> on the state of the tuna industry in the Philippines, fishing regulations, and the  
<sup>368</sup> structure of the tuna supply chain, including its stages and the roles of key actors.  
<sup>369</sup> It also examines factors that affect the efficiency and transparency of the supply

370 chain. The discussion then turns to blockchain technology and its potential ap-  
371 plications in supply chain management, with examples from the Philippines and  
372 Indonesia. Finally, the chapter reviews existing traceability technologies and sys-  
373 tems and concludes with key insights that inform the development of this study’s  
374 proposed solution.

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

## 386 2.1 State of Tuna Industry in the Philippines

387 In 2014, the Philippines became the top global producer of tuna according to  
388 Llanto, et. al. (2018). The tuna is caught in domestic and international fishing  
389 grounds near the country through various fishing methods such as purse seines,  
390 gill nets, handline (hook and line) and ring net. Among the tuna species, the  
391 skipjack tuna accounted for the largest portion of the catch by 40%. The study of

392 PCMARD (1993 as cited in Nepomuceno et al., 2020 ) stated that skipjack tuna  
393 are often caught out in open waters or in offshore areas. In addition, Nepomuceno  
394 et al. (2020) mentioned in their study that the dominant production of skipjack  
395 tuna, together with yellowfin tuna, was recorded in South Cotabato. The tuna  
396 supply has declined since 2000 due to various factors including overfishing, climate  
397 change, and the laws and regulations imposed by different governing bodies for  
398 the tuna fishing ground such as the Regulation No. 56, released by the Indone-  
399 sian Maritime Affairs and Fisheries Ministry in November 2014. The regulation  
400 imposed a moratorium on issuance of fishing licenses from 3 November 2014 to 30  
401 April 2015 to eliminate illegal, unreported, and unregulated fishing in Indonesian  
402 waters near Mindanao where tuna are known to thrive (Llanto et al, 2018). The  
403 regulation imposed for the protection of tuna fishing grounds in the western and  
404 central pacific ocean also lead to the decline of local tuna production which re-  
405 quires the fishing operators of the Philippines to invest in the manufacturing and  
406 processing of fish particularly tuna in Indonesia which includes hiring Indonesian  
407 crew to be deployed in the Philippine fishing vessels (Llanto et al, 2018).

## 408 2.2 Fishing Regulations in the Philippines

409 A study of Asche et al. (2018) divided the fishing management strategies that  
410 include right-based fishery management like territorial use of rights, access rights  
411 and harvest rights. It discussed that a rights-based system could support the sus-  
412 tainability of global fisheries by taking in account the three pillars of sustainability  
413 (economic development, social development, and environmental protection) rather  
414 than focusing on their trade-offs. A restriction on the fisherman's behavior by har-

vest 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 man-

agement 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

<sup>463</sup> a global crisis affecting the biological, ecological, and socio-economics factors re-  
<sup>464</sup> volving around marine livelihood in Southeast Asia (Malinee et al, 2020). IUU  
<sup>465</sup> fishing is known to cause short- and long-term problems in the socio-economic  
<sup>466</sup> opportunities which affects food security and results in the possible collapse of  
<sup>467</sup> the fish industry and stocks due to overfishing (Malinee et al, 2020).

<sup>468</sup> The establishment of marine protected areas in the Davao Gulf (MPAs) affected  
<sup>469</sup> the management of small-scale fisheries due to the growing population and de-  
<sup>470</sup> mands for seafood products. The closure of a wide range of fishing areas hosting  
<sup>471</sup> diverse and marine organisms has affected the socio-economics and livelihood of  
<sup>472</sup> the local and small-scale fishermen (Macusi et al, 2023), this in turn resulted  
<sup>473</sup> in IUU fishing. To ensure that fish stocks in the gulf are sustainably managed,  
<sup>474</sup> the implementation of GPS for tracking the movement and activities of fishers  
<sup>475</sup> through logbook and habitat monitoring can provide data and insights for track-  
<sup>476</sup> ing, monitoring, and understanding the condition of the marine resources (Obura  
<sup>477</sup> et al, 2019; Macusi et al, 2023).

## <sup>478</sup> 2.4 Tuna Supply Chain Stages and Roles

<sup>479</sup> The study conducted by Delfino (2023) highlights the roles of different actors in-  
<sup>480</sup> volved in the supply, production, distribution, and marketing of skipjack tuna in  
<sup>481</sup> Lagonoy Gulf in the Philippines. The study showcased a total of eleven intercon-  
<sup>482</sup> nected value chains but are generalized into four major stages or roles - fishers,  
<sup>483</sup> wholesalers, retailers, and processors. The fishers are the initial players responsible  
<sup>484</sup> for catching fish using boats or fishing vessels equipped with purse seines, gillnets,

485 and handlines(hook and line). Wholesalers are the actors for selling freshly caught  
486 fish locally and regionally, they receive the fish supply directly from the fishers.  
487 The next stage after wholesalers are the retailers, these intermediaries sell the fish  
488 product to local markets, house-to-house (*libod*" in Visayan languages), and other  
489 local medium such as *talipapa* or fish stands. Another intermediary is the proces-  
490 sors, they convert fresh skipjack tuna into products like smoked tuna. The given  
491 stages also overlapped in some cases as there are fisher-wholesalers who catch and  
492 sell the fishes directly to retailers and there are also retailer-processors that both  
493 sell whole and processed products. Despite having a firm system to transport fish  
494 from sea to table, all the actors face problems during seasonal challenges involving  
495 the availability of the tuna product. The fishers also need to consider strict local  
496 regulations such as RA 10654 and RA 8550. The strict implementation of RA  
497 10654 and RA 8850 at the local level or the Fisheries Code of the Local Philip-  
498 pines aims to curb the problem encountered during season of deficit tuna supply  
499 by limiting fishing activities and implementation of 15-km boundary lines in the  
500 municipal waters of each municipality (Delfino, 2023). The study suggests that  
501 improving conditions for value chain actors, particularly through support services  
502 and government involvement could lead to a stable and sustainable exchange of  
503 skipjack tuna and other seafood products from sea to table.

504 A study of Digal et al. (2017) discussed one of the value chains which was the  
505 purse seine or the skipjack tuna value chain in the Philippines. Purse seining  
506 is the method of catching a school of fish wherein it uses a large net around it,  
507 trapping them and pulling the bottom of the net like a purse-like (Digal et al.,  
508 2017) . This type of catching often targets dense fishes like tuna. Skipjack fishes  
509 that weigh 300 grams and above are often sold to canneries, while the smaller ones

510 are sold at local markets, often used for consumption by Filipinos. Purse seiners  
511 are usually employees of a fishing company and they have a fixed salary. They  
512 could reach international waters so they need to bring their passports with them.  
513 Jamboleros, who act as distributors, often buy from different fishing companies  
514 per *banyera* or tub. They will then pack the fish and sell it to traders/truckers  
515 who go to General Santos fishport. These traders will deliver it to the retailers  
516 across Kidapawan who contacted them. There is no formal contract between the  
517 jambolero and traders/truckers. One of the issues of the retailer is for everyday  
518 that a fish is not sold, they would have a ₱10.00 less per kilogram.

## 519 2.5 Factors Affecting the Tuna Supply Chain

520 The tuna supply chain faced several factors and challenges for the safety and  
521 quality of the product (Mercogliano & Santonicola, 2019). Without the proper  
522 handling of the tuna after catching it can lead to various food-borne diseases and  
523 outbreaks. The most frequent and mitigated food-borne causing compound is  
524 Histamine(HIS) which causes Scombrotoxin fish poisoning (SPF) outbreaks re-  
525 lated to food allergies when consumed (EFSA, 2017; Peruzy et al., 2017). Tuna  
526 species are known for having high presence of amino acid histidine concentrations  
527 which are converted to HIS by bacterial enzyme histidine-decarboxylase or HDS  
528 (Aponte et al., 2018; Verkhivker & Altman, 2018). To combat the risk of SPF  
529 and other food-borne diseases caused by tuna consumption, several safety hazards  
530 and protocols were imposed to the tuna supply chain management. The term cold  
531 chain refers to the storing of fish in temperatures less than 5°C after it was caught  
532 (Yang & Lin, 2017). According to the article published by Mercogliano and San-

533 tonicola (2019), implementing a cold chain from the time the fish is caught until it  
534 is consumed is crucial for mitigating the outbreak of HIS poisoning. Additionally,  
535 the article also states that using high-quality raw tuna, cold chain maintenance,  
536 pre-cooking, and cooking can also reduce HIS development.

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

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

## 554 2.6 Technology of Blockchain

555 According to Zheng et al. (2017), the idea of blockchain was first introduced in  
556 2008 and was first implemented in the Bitcoin business which deals with cryp-  
557 tocurrencies. This kind of technology tracks transactions and stores it in a list of  
558 blocks. According to Sarmah (2018) , it acts as a database of transactions which  
559 is overseen and verified by distributed nodes. Blockchain works by linking blocks  
560 (where data is stored). When a transaction is initiated, it is then broadcasted to  
561 a network of computers that verifies the transaction and if the verification is suc-  
562 cessful, it will then be grouped and linked with the previous transactions that will  
563 be added to the blockchain (Zheng et al., 2017). It does not require a middleman  
564 because it operates on a peer-to-peer transaction. This eliminates the traditional  
565 way of a central authority like the bank (Sarmah, 2018).

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

## 2.7. OPPORTUNITIES OF BLOCKCHAIN TECHNOLOGY FOR SUPPLY CHAIN MANAGEMENT

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

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

## 596 **2.7 Opportunities of Blockchain Technology for 597 Supply Chain Management**

598 Supply chain is the term used for understanding the business activities for design-  
599 ing, developing, delivering, purchasing, and using a product or service (Hugos,

600 2024). Companies and various industries are heavily relying on supply chains to  
601 achieve their business objectives. The purpose of supply chain began to be more  
602 significant in the last century as firms discovered that supply chain can be used for  
603 competitive advantage instead of just a cost driver as believed in the bygone days  
604 (Snyder & Shen, 2019). Following the supply chain paradigm can demonstrate the  
605 delivery of a product or service while strongly emphasizing the customer's speci-  
606 fications. With the increasing studies conducted and published for supply chain,  
607 many companies adopted this practice for the benefit of their longevity, as such  
608 the term supply chain management has come into place. The Council of Supply  
609 Management Professionals or CSCMP (2024) defines supply chain management  
610 as the planning and management of all activities involved in sourcing and pro-  
611 curement, conversion, and all logistics management activities; essentially, supply  
612 chain management integrates supply and demand management within and across  
613 the company. Supply chain management is also involved with the relationship  
614 with collaborators and channel partners such as suppliers, intermediaries, third  
615 party providers, and customers (CSCMP, 2024) .

616 In the article of Cordova et. al (Cordova et. al, 2021), the role of supply chain man-  
617 agement and the growing opportunities for blockchain technology in supply chain  
618 management was discussed. According to Cordova (2021), the recent innovation  
619 and globalization has given rise to the idea of using a data innovation framework  
620 for supply chain management. Technologies such as blockchains and enterprise  
621 resource planning (ERP) are among the highly contested platforms for supply  
622 chain management to operate in a seamless interaction and distribution with the  
623 product while heavily relying on modern technology and innovations. The logistic  
624 business of the supply chain market is wide and complex, the distribution and

## 2.7. OPPORTUNITIES OF BLOCKCHAIN TECHNOLOGY FOR SUPPLY CHAIN MANAGEMENT

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 pharma-

650 cies to the individual patients (Hackius & Petersen, 2017). Using blockchain can  
651 make it harder to tamper or alter the products chain of origin with illegal and  
652 counterfeit products. Blockchain have the potential to facilitate origin tracking.  
653 According to Cordova et al (2021) , blockchain allows organizations to input rel-  
654 evant data inside a chain which would have constant updates and tracking, this  
655 supports visibility and traceability of the origin of the product. Smart contracts,  
656 an executable code and a feature of blockchain, serves as a computer protocol  
657 made between participants to digitally facilitate, execute, verify, and enforce an  
658 agreement or terms of contract which is then stored in the blockchain (Khan et  
659 al, 2021).

## 660 **2.8 Supply Chain Model with Blockchain Tech- 661 nology of Fishing Industry in Indonesia**

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

669    **2.9 Existing Technology Intended for Traceabil-**

670                 **ity and Supply Chain**

671    A study of Shamsuzzoha et al. (2023) discussed the feasibility of implementing  
672    a blockchain driven application called ‘Tracey’ for monitoring the fish traceabil-  
673    ity in supply chain management. The study utilized the theoretical framework  
674    developed by Islam & Cullen (2021) for improving the understanding and effec-  
675    tiveness of implementing a food traceability system. The framework consists of  
676    four principles as a basis for the supply chain management: identification, data  
677    recording, data integration, and accessibility (Islam & Cullen, 2021). The Tracey  
678    application utilized a public-private hybrid blockchain-based conceptual frame-  
679    work by Mantravadi and Srai (2023) to uphold the transparency, traceability, and  
680    certification of the sea food produce, specifically shrimp. The prototype being  
681    studied by Shamsuzzoha et al. (2023) called Tracey focuses on the mobile-based  
682    solution approach, the study found that the most widely used smartphone type  
683    in the Philippines is the android phone which is where the Tracey prototype is  
684    intended to be used. The Tracey app allows fishermen to log their catch details  
685    and buyers to verify and update transaction history (Shamsuzzoha et al., 2023).  
686    The Tracey app uses a central database for storing fish trading data and a decen-  
687    tralized ledger or blockchain for traceability purposes. The decentralized ledger  
688    acts as a tamper-proof copy of the data recorded by fishermen and buyers. The  
689    result of the study finds that fishermen are open to using digital methods for  
690    payments and confidentiality which is required for exporting the fish product to  
691    maintain high standards for traceability, catch certification, and product quality.  
692    The usage of blockchain as exemplified by the Tracey project can be used for

693 upholding the restriction for IUU due to its ability to ensure transparent trade,  
694 consistent records, and accessibility. The result and discussion of the study of  
695 Shamsuzzoha et al. (2023) provides a solution for improving the sustainability of  
696 tuna fishery and ensures that Filipino fishermen receive fair compensation. For  
697 the study limitation of the Tracey project, although there is a high acceptabil-  
698 ity of potentially using the app for fishermen, there are still constraints in terms  
699 of proper incentives, connectivity issues, technology usability, and education for  
700 using the app.

701 A study of Cocco and Mannaro (2021) proposed a blockchain-based technology  
702 in the traceability of the supply chain management of a traditional Italian food  
703 product, Carasau bread, which is made from durum wheat flour, salt, yeast and  
704 water. Since the production of this product is traditional, consumers would de-  
705 mand for transparency on the methods used in the Carasau bread production to  
706 ensure authenticity. The proposed model involves the combination of the appli-  
707 cation of Internet of Things (IoT), specifically the Radio Frequency Identification  
708 (RFID) sensors and Interplanetary File System (IPFS) with Blockchain (Cocco  
709 & Mannaro, 2021). RFID is a technology that uses radio frequencies to identify  
710 and track a tagged object while IPFS allows files to be stored and tracked over a  
711 decentralized and distributed file system. Cocco and Mannaro (2021) also stated  
712 that using RFID tags that will be integrated with different sensors to monitor  
713 food quality will be useful in their study. These sensors include freshness indica-  
714 tors to monitor the food quality when packaged, biosensors to detect degradation  
715 molecules, time temperature indicator to measure and record temperature and  
716 humidity sensors to detect the amount of water vapor in the atmosphere. The  
717 integration of IoT and blockchain technology can have a huge impact in increasing

718 traceability in agri-food supply chain. Moreover, this study proposed to have a  
719 generic agri-food traceability system which will be based on Ethereum blockchain,  
720 Radio-frequency identification (RFID), Near Field Communication (NFC), and  
721 Interplanetary File System (IPFS) technology. Moreover, the model proposal also  
722 includes sensor network devices, smart contacts, optical cameras and an external  
723 database. Each IoT device will be connected to Raspberry Pi and interfaces with  
724 blockchain implementing smart contracts and IPFS which authorities can inspect  
725 every node and batch online through the uploaded files in IFPS; hashes of the  
726 uploaded files on IFPS are also stored on blockchain (Cocco & Mannaro, 2021) .  
727 In this way, users along the chain supply can view and trace each batch using the  
728 NFC tags promoting transparency and traceability. Overall, the proposed model  
729 is a combination of two subsystems. The first one is an on-chain system which is  
730 the blockchain implementing smart contracts and will be developed using Solidity,  
731 an object-oriented language. The second one is an off-chain system that will be  
732 implemented in Javascript using Node.js (to interact with the smart contracts)  
733 and Web3.js packages (to interact with blockchain) and these packages should be  
734 installed on the Raspberry Pi. However, the purpose of this study is to exam-  
735 ine the traceability systems of the agri-food industry and further provide possible  
736 solutions.

## 737 2.10 Developing a Traceability System for Tuna

### 738 Supply Chains

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

751 The journal article of Tiwari (2020) called Application of Blockchain in Agri-  
752 Food Supply Chain conducted two case studies for a blockchain driven app built  
753 for supply chain related to food, fishing, and agriculture. The first case-study is  
754 the usage and effectiveness of the Provenance system for tuna tracking certifica-  
755 tion. The objective of the Provenance system is to enhance transparency in the  
756 tuna supply chain by ensuring certification and standard compliance across all  
757 roles(e.g. supplier, retailer) in the chain. The system is built using six modular  
758 programs: registering, standards, production, manufacturing, tagging, and user-  
759 interface. The usage of blockchain in the Provenance system allows transactions to  
760 be recorded to allow shared ledger for transparency and smart contracts for secure

761 exchanges of money or information. The usage of the Provenance system is to  
762 solve the issues encountered in the tuna fishing industry affected by various factors  
763 such as illegal, unregulated, unauthorized (IUU) fishing, fraud, and human rights  
764 abuses. The solution of the Provenance system is to allow tracking, tracing, and  
765 certification of tuna using blockchain. The Provenance system has a smart tag-  
766 ging feature that allows fishermen to use SMS for digital assets on the blockchain  
767 to track where the fish, in return, all supply chain stakeholders can access the  
768 data that was sourced from the SMS. The second case-study is the usage of the  
769 IBM Food Trust for transparency in the food supply chain. The IBM Food Trust  
770 aims to solve the problems in the food supply chain, specifically in product safety.  
771 Locating supply chain items in real-time using identifiers like GTIN or UPC is  
772 the primary feature of the IBM Food Trust. The app also provides end-to-end  
773 product provenance, real-time location and status, and facilitates rapid product  
774 recalls. The IBM Food Trust also provides insights and visibility for the freshness  
775 of the product to reduce losses and spoilage. Lastly, the IBM Food Trust provides  
776 certifications from the information taken when handling and managing the prod-  
777 ucts in the supply chain. The case studies conducted by Tiwari (2020) illustrates  
778 the potential of blockchain technology in improving transparency, efficiency, and  
779 ethical practices within supply chains.

## 780 2.11 Chapter Summary

### 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

### 781 2.11.2 Research Gaps and Problem

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

<sup>787</sup> tion, digital literacy, and connectivity.

<sup>788</sup> Furthermore, existing technologies have primarily focused on large-scale imple-  
<sup>789</sup> mentations and theoretical frameworks without adequately considering the prac-  
<sup>790</sup> tical implications and user experience needed for effective system integration. This  
<sup>791</sup> study aims to address these gaps by exploring real-world challenges faced by users,  
<sup>792</sup> especially fishermen, in adopting blockchain technology for traceability.

### <sup>793</sup> 2.11.3 Summary

<sup>794</sup> The literature reviewed highlighted the critical challenges and opportunities re-  
<sup>795</sup> garding the tuna supply chain, particularly in the areas of traceability and sustain-  
<sup>796</sup> ability. Existing supply chain technologies, especially those utilizing blockchain,  
<sup>797</sup> present solutions but also come with limitations in terms of blockchain adoption.  
<sup>798</sup> The application of blockchain technology in the tuna supply chain has shown po-  
<sup>799</sup> tential for enhancing traceability from ocean to consumer.

<sup>800</sup> Through this paper, a blockchain-driven solution could contribute to providing a  
<sup>801</sup> more efficient and transparent supply chain. However, further studies are neces-  
<sup>802</sup> sary to assess the long-term sustainability of blockchain in such systems.



<sup>803</sup> **Chapter 3**

<sup>804</sup> **Research Methodology**

<sup>805</sup> This chapter outlines a clear and detailed description of the research methods and  
<sup>806</sup> processes used in the development and evaluation of SeaXChange: A Blockchain  
<sup>807</sup> Driven App for Tuna Supply Chain Management. The algorithms, systems, theo-  
<sup>808</sup> ries, framework and models are described in detail in which this chapter establishes  
<sup>809</sup> the foundation of this study .This chapter also explains the data collection method  
<sup>810</sup> used ensuring the validity and reliability of the results.In addition, the chapter  
<sup>811</sup> discusses the considerations and potential limitations of this study. Overall, this  
<sup>812</sup> will serve as a guide for the readers in understanding the structured process of  
<sup>813</sup> developing the SeaXChange.

<sup>814</sup> **3.1 Software Development**

<sup>815</sup> Scrum is a framework within the Agile development that prioritizes flexibility.  
<sup>816</sup> It is an iterative software development approach that lets a project be broken  
<sup>817</sup> down into phases and emphasizes continuous improvements. For this study, the

818 researchers opted to use Scrum because it involved many stakeholders and it  
819 operated in a ever-changing environment. Scrum allowed the team to adapt to  
820 new requirements through structured sprint planning, weekly reports, and sprint  
821 reviews, ensuring continuous alignment with project goals.

## 822 **3.2 Research Activities**

823 For this study, the researchers opted for interviews because it enabled in-depth  
824 exploration of stakeholder perspectives and experiences. The identified fisher and  
825 supplier client interface was tested within the perimeters of Barangay Sapa, Mi-  
826 agao, Iloilo, Philippines. The identified retailer testers were the vendors who  
827 reside in Barangay Mat-y and Barangay Sapa in Miagao. The identified con-  
828 sumer testers were situated in Miagao. The specific choice of these stakeholders  
829 and locations within Miagao was made to align with the study's defined scope,  
830 which concentrates on applying blockchain technology to enhance traceability and  
831 transparency within the small-scale tuna supply chain and localized market in the  
832 specified barangay of Miagao, Iloilo. This focus includes examining the trace-  
833 ability of whole, small-sized caught tuna products from capture through the local  
834 supply chain to consumers within this area. This localized approach facilitated a  
835 practical assessment of the SeaXChange application's potential effectiveness and  
836 user experience within a specific operational context.

**837 3.2.1 Feedback Collection Method**

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

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

**852 3.2.2 Data Gathering****853 • Primary Data:**

- 854 – Stakeholder(Fishermen, Supplier, Retailers, and Consumers) interviews  
855 were conducted to identify the use-case and user requirements, interface  
856 usability, and adoption challenges.
- 857 – Observations were made of existing tuna supply chain processes in local  
858 settings.

859      • **Secondary Data:**

- 860            – Literature review was conducted on blockchain applications in supply  
861                chain management and product traceability.
- 862            – Industry reports and regulatory documents related to tuna fishing and  
863                supply chain operations.

864    **3.2.3 Designing and Developing the System**

865    **1. Software Development Methodology:** The project followed a Scrum  
866            framework to ensure continuous iteration, stakeholder involvement, and flex-  
867            ibility in adapting to feedback.

868    **2. Technology Stack:**

869            • **Front-end Development:** Used React for creating a secure and user-  
870                friendly interface for stakeholders, prioritizing simple and responsive  
871                user-interface.

872            • **Back-end Development:** Used Node.js along with Express for managing  
873                back-end processes and API integration. Express is a flexible we applic-  
874                ation framework for Node.js used to build APIs for web applications.  
875                Docker for containerization of the project and Window Subsystem for  
876                Linux (Ubuntu as the Linux distribution) for setting up the network.

877            • **Cloud Infrastructure:** Used Google Cloud to host backend services and  
878                manage the databases, where the app could be accessed globally. It  
879                also ensured the app could scale smoothly as more data and users were  
880                added.

- 881           • Blockchain Framework: Used Go language for developing smart con-  
882           tracts and providing an immutable ledger for transaction data.
- 883           • Database for Accounts: Used Firebase managing user accounts and  
884           authentication.

885       **3. Blockchain Development Platform:**

- 886           • Used Hyperledger Fabric for its permissioned nature and scalable ar-  
887           chitecture.
- 888           • The open-sourced resources and timely updates of Hyperledger Fabric  
889           components is ideal for creating a distributed ledger for tuna supply  
890           chain.

891       **3.2.4 Implementing Algorithms and Services**

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

896       **1. Consensus Algorithm**

897       The project followed Raft(Leader-based consensus) for handling organiza-  
898       tions or nodes. Raft is intended for managing a replicated log in a blockchain  
899       network. Raft is a Crash Fault Tolerant (CFT) protocol, is designed to han-  
900       dle non-malicious node failures (e.g., hardware crashes, network issues) In  
901       Raft, one node is elected as the leader, and it coordinates the ordering of

902 transactions (Xu et al, 2022) . The leader replicates log entries (transactions)  
903 to follower nodes, ensuring consistency across the network.

904 **2. Cryptographic Algorithm**

905 The project employed several cryptographic algorithms to ensure security  
906 and privacy. These cryptographic data served as digital signatures and iden-  
907 tity verification for the project. ECDSA (Elliptic Curve Digital Signature  
908 Algorithm) was used for generating digital signatures while X.509 certifi-  
909 cates are intended for identity management and authentication of partic-  
910 ipants (Anitha & Sankarasubramanian, n.d.) . For the encryption, AES  
911 (Advanced Encryption Standard) was used for encrypting data at rest and  
912 in transit. TLS (Transport Layer Security) secured communication between  
913 network nodes. SHA-256 (Secure Hash Algorithm-256) ensured data in-  
914 tegrity by generating unique hashes for blocks and transactions.

915 **3. Membership Service**

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

926 **4. Ordering Service**

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

936        **5. Endorsement Policy**

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

941        **6. Chaincode (Smart Contract)**

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

### 951 3.2.5 Modeling the System Architecture

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

956 • **Blockchain Architecture**

957 The project involved peer, ordering services, ledger, and client application  
958 to perform various transaction such as tracing the origin and the stop points  
959 of a tuna asset. Peers are nodes in the blockchain network that maintained  
960 a copy of the distributed ledger and execute chaincode (smart contracts).  
961 The ordering service is the central component of the blockchain for ordering  
962 transactions and creating blocks to distribute to peers through consensus  
963 mechanism. The ledger is the immutable record of all transaction in the tuna  
964 supply chain network, stored across all peers. The client application is the  
965 interface through which users or tuna supply chain participants interact with  
966 the blockchain network. Figure 3.1 below shows the blockchain architecture  
967 of SeaXChange.

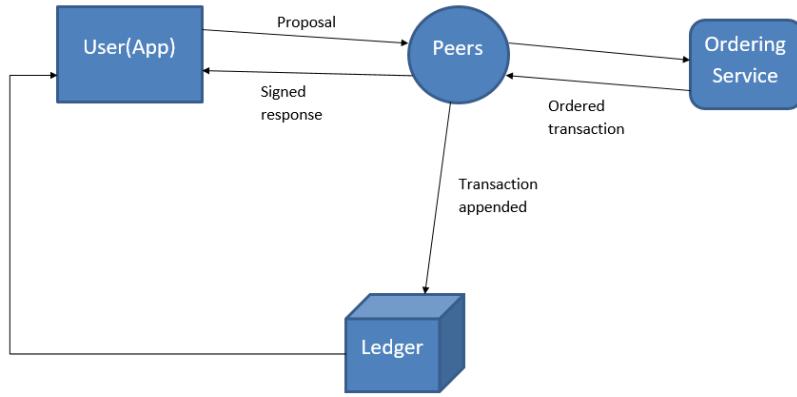


Figure 3.1: Blockchain Architecture of SeaXChange

### • 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. As shown in Figure 3.2, 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.

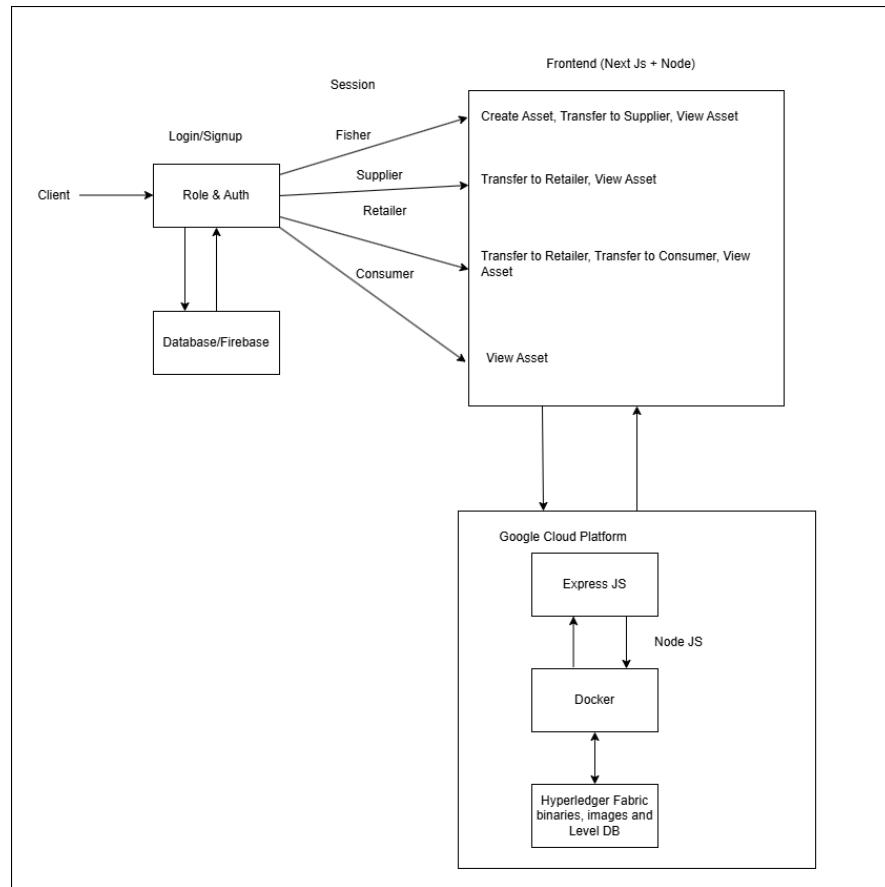


Figure 3.2: Overall System Architecture of SeaXChange

981      • **Use Case**

982      The use case shows the outline on how the user will interact with the SeaX-  
 983      Change App. It followed the major stages or participants in the tuna supply  
 984      chain. Figure 3.3 shows the use case diagram for SeaXChange.

985      1. **Fisher**

- 986      - Encodes tuna I.D. of fish.
- 987      - Encodes the date when the fish was captured.
- 988      - Encodes the location where the fish was captured.
- 989      - Encodes the fishing method used.

990 - Query the origin and exchange of the tuna asset.

991 **2. Supplier**

992 - Encodes when the product was transferred from fisher to supplier.

993 - Query the origin and exchange of the tuna asset.

994 - Generate supplier's location during retrieval of tuna asset.

995 **3. Retailer**

996 - Encodes when the product was retrieved from the supplier or another  
997 retailer.

998 - Query the origin and exchange of the tuna asset.

999 - Generate retailer's location during retrieval of tuna asset.

1000 **4. Consumer**

1001 - Retrieve data from retailer.

1002 - Query the origin and exchange of the tuna asset.

1003 There are four (4) types of users that will use the app. The first user  
1004 type is the Fisher, which will be the starting point of the blockchain.

1005 It will encode the catch details of a tuna product such as the date of  
1006 capture, location, and fishing method. The second user type is the  
1007 Supplier, which will encode when the product was transferred from  
1008 the fisher to the supplier, as well as generate their location during  
1009 the retrieval of the tuna asset. The third type is the Retailer, which  
1010 will encode when the product was transferred from the supplier to the  
1011 retailer or in the case of multiple retailers, from the previous retailer to  
1012 the current retailer, their location is also generated during the retrieval  
1013 of the tuna asset. Lastly, the Consumers, which can only query the  
1014 origin and exchange of tuna assets.

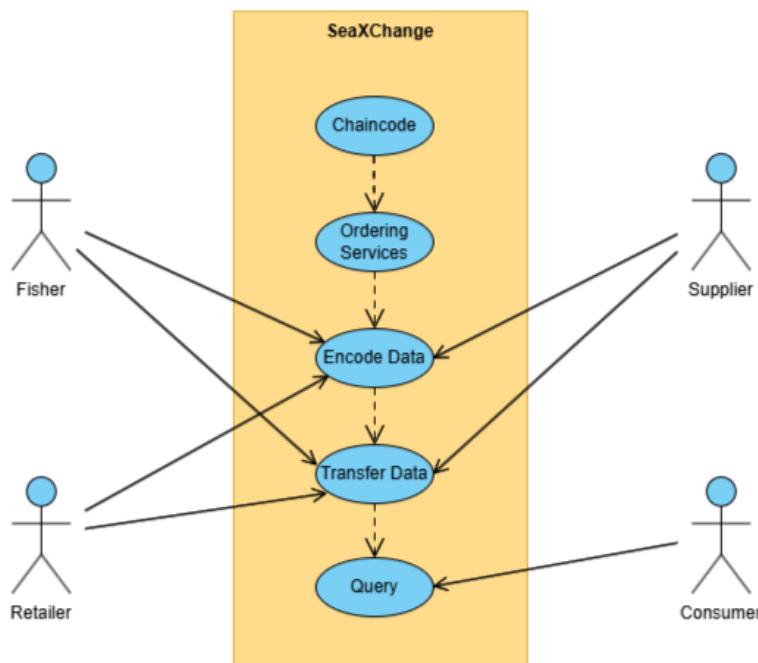


Figure 3.3: Use case diagram for SeaXChange.

1015 **Chapter 4**

1016 **Results and Discussions**

1017 **4.1 Overview**

1018 This chapter presents the results of the system. Included in this chapter are  
1019 screenshots and the discussion of results. The tuna supply chain management  
1020 smart contract on Hyperledger Fabric has been initiated and tested within a con-  
1021 trolled blockchain environment. Results indicated that the system was function-  
1022 ally robust and reliable, having managed assets, transaction integrity, and the  
1023 ability to query and update the ledger in the blockchain. This chapter presents  
1024 the details of the major steps executed during the process, results for those steps,  
1025 and the current status of the system's operations.

1026 **4.2 Smart Contract Deployment and Installa-**

1027 **tion**

1028 **4.2.1 Hyperledger Fabric Prerequisites**

1029 Before executing a smart contract framework and blockchain system, it is cru-  
1030 cial to first install and set up the necessary tools and technologies. This includes  
1031 setting up Hyperledger Fabric, which involves installing the Fabric binaries, con-  
1032 figuring the network, and ensuring all necessary dependencies like Docker, Docker  
1033 Compose, and Node.js are installed and properly configured. Additionally, setting  
1034 up the required certificates, defining the channel configurations, and ensuring that  
1035 peer nodes and orderers are correctly connected and synchronized are all essential  
1036 steps in preparing the environment for blockchain and smart contract operations.

1037 • **Software Requirements:**

- 1038 – **Docker and Docker Compose:** Hyperledger Fabric needs to have  
1039 Docker installed and running on the system. Docker is required to run  
1040 the peer and ordering services of the blockchain system.
- 1041 – **Node.js:** Required for the Fabric SDK for client application integra-  
1042 tion with JavaScript libraries such as react.
- 1043 – **Go:** Ensure Go is installed, and the GOPATH environment variable  
1044 is set up. This is essential for building and running chaincode(smart  
1045 contract) written in Go.
- 1046 – **Fabric Samples:** Clone the official Hyperledger Fabric's fabric-samples  
1047 repository from GitHub:

```
1048     git clone -b release-2.4 --single-branch  
1049     https://github.com/hyperledger/fabric-samples  
1050     cd fabric-samples/test-network
```

1051

1052 – **Binaries and Docker Images:**

```
1053 curl -sSL https://bit.ly/2ysbOFE | bash -s
```

1054

1055 • **Network Setup:**

- 1056 – Run the `test-network` script to start the Hyperledger Fabric test net-  
1057 work:

```
1058 ./network.sh up
```

1059

1060 This script starts a peer, an ordering service, and a CA (Certificate  
1061 Authority) on the local machine.

- 1062 – After starting the network to docker in the same directory (`test-network`),  
1063 a channel must be created:

```
1064 ./network.sh createChannel
```

1065

1066 • **Deploying Chaincode (Smart Contract):**

- 1067 – Step 1:

```
1068 export PATH=${PWD}/../bin:$PATH
```

1069

1070 — Step 2:

```
1071         export FABRIC_CFG_PATH=$PWD/../../config/
```

1072

1073 — Step 3:

```
1074         export CORE_PEER_TLS_ENABLED=true
```

```
1075         export CORE_PEER_LOCALMSPID="Org1MSP"
```

```
1076     export CORE_PEER_TLS_ROOTCERT_FILE=${PWD}/organizations
```

1077 /peerOrganizations/org1.example.com/peers/peer0.org1.example.com

1078 /tls/ca.crt

```
1079     export CORE_PEER_MSPCONFIGPATH=${PWD}/organizations
```

1080 /peerOrganizations/org1.example.com/users

1081 /Admin@org1.example.com/msp

```
1082     export CORE_PEER_ADDRESS=localhost:7051
```

1083

### **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.

```
zyyx100@BLAPTOR-09JUN00:~$ /mnt/c/SpecialProblems/hyperledger-fabric/c#fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args":["GetAllAssets"]}'  
{"Assets": [{"ID": "tuna", "Species": "Tuna", "Weight": 5.5, "CatchLocation": "Pacific", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Beefs"}, {"ID": "salmon", "Species": "Salmon", "Weight": 8.5, "CatchLocation": "Pacific", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Santos"}, {"ID": "tuna", "Species": "Tuna", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Jagmees"}, {"ID": "salmon", "Species": "Salmon", "Weight": 8.5, "CatchLocation": "Antique", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Beefs"}, {"ID": "salmon", "Species": "Salmon", "Weight": 8.5, "CatchLocation": "Antique", "CatchDate": "2024-12-04", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Davood"}, {"ID": "tuna", "Species": "Tuna", "Weight": 5.5, "CatchLocation": "Albacore", "CatchDate": "2024-12-05", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Jagmees"}, {"ID": "salmon", "Species": "Salmon", "Weight": 8.5, "CatchLocation": "Albacore", "CatchDate": "2024-12-05", "FishingMethod": "Longline", "Vessel": "Supplier", "Retailer": "Beefs"}]}  
zyyx200@BLAPTOR-09JUN00:~$ /mnt/c/SpecialProblems/hyperledger-fabric/c#fabric-samples/test-network$
```

Figure 4.1: Query Smart Contract: Check assets

1089     ● **Adding new tuna assets:**

1090     Here, a new tuna asset is created and registered on the blockchain. This in-  
 1091     volves invoking the smart contract to add a new entry, which includes details  
 1092     such as the type of tuna, quantity, and any other relevant information. This  
 1093     step ensures that newly caught or acquired tuna can be tracked throughout  
 1094     the supply chain.

```
ryxx2082@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblems/hyperledger-fabric-samples/test-network$ peer chaincode invoke -o localhost:7050 --ordererTLSHostnameOverride orderer.example.com --tlsRootCertFiles $PWD/organizations/ordererOrganizations/example.com/tlsca/tlsca.example.com-cert.pem -C mychannel -n mychannel -c '{"function": "CreateAsset", "args": ["tunaA","Skipjack","6.0","2024-12-05","Antique","Longline","Jaunesse","NA","NA"]}'
```

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

1095     ● **Check all assets after adding a new tuna asset:**

1096     After adding a new tuna asset, the smart contract is queried again to verify  
 1097     that the asset has been successfully added. This step confirms that the new  
 1098     asset is part of the current inventory and that no discrepancies exist in the  
 1099     recorded data.

```
ryxx2082@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblems/hyperledger-fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args": ["GetAllAssets"]}'
```

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

1100     ● **Transfer tuna asset to Supplier:**

1101     This step involves transferring ownership of a tuna asset from the current  
 1102     holder (e.g., a fisherman or a trader) to a supplier. The smart contract is  
 1103     invoked to facilitate the transfer, ensuring that the transaction is securely  
 1104     recorded on the blockchain and that the asset's new owner is updated ac-  
     cordingly.

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.

```
[xyz@xyz-DELL-APTOR-QQ-UWQ:~/mnt/c/SpecialProblems/hyperledger-fabric3/fabric-samples/xyz20200814APTOR-QQ-UWQ]# ./mnt/c/SpecialProblems/hyperledger-fabric3/fabric-samples/test-network.sh peer chaincode invoke -c "{'function': 'transferset', 'args': ['tunaua', 'SupplierA']}"
```

- 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.

```
[{"ID": "tuna6", "Species": "Skipjack", "Weight": 6, "CatchLocation": "2024-12-05", "CatchDate": "Antique", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retazzyre2002@ARTOP_09U2009: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/zapryre2002@ARTOP_09U2009: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-net-world_worm_chicken_ipv6_no_localhost: 7859...wonderful! Shortened overdrive endpoint example for url...mcfile.tifmml/encapsulatedips/overdrive/bioinzipation/examples/codes/rxdy
```

• Check the updated type 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

### 4.3. BACKEND SECURITY ANALYSIS (HYPERLEDGER FABRIC ON GCP)47

1120       the retailer now has ownership of the tuna asset. It confirms that the asset  
1121       has moved through the supply chain correctly.

```
laptop-Q93UQUB:~/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args":["ReadAsset","tuna0"]}'  
{"ID":"tuna0","Species":"Skipjack","Weight":6,"CatchDate":"2024-12-05","CatchLocation":"Antique","FishingMethod":"Longline","Vessel":"Jagnee","Supplier":"SupplierA","Retailer":"RetailerA"}  
laptop-Q93UQUB:~/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network$
```

Figure 4.7: Query Smart Contract: Check asset after transfer

#### 1122 • **Query Smart Contract and check updated assets:**

1123       The final step involves querying the smart contract to get a complete overview  
1124       of all the assets in the supply chain. This includes all tuna assets from fishing  
1125       to retail, allowing stakeholders to monitor and manage inventory effectively.  
1126       It provides traceability in the supply chain, helping to maintain freshness  
1127       and authenticity of the tuna as it moves through the market.

```
laptop-Q93UQUB:~/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args":["DetailAssets"]}'  
[{"ID":"tuna0","Species":"Skipjack","Weight":6.5,"CatchDate":"2024-12-01","FishingMethod":"Longline","Vessel":"Jagnee","Supplier":"SupplierX","Retailer":"RetailerX"}, {"ID":"tuna1","Species":"Yellowfin","Weight":8.5,"CatchDate":"2024-12-02","FishingMethod":"Longline","Vessel":"Palawan","Supplier":"SupplierY","Retailer":"RetailerY"}, {"ID":"tuna2","Species":"Bluefin","Weight":9.5,"CatchDate":"2024-12-03","FishingMethod":"Longline","Vessel":"Ariane","Supplier":"SupplierZ","Retailer":"RetailerZ"}, {"ID":"tuna3","Species":"Chubachi","Weight":5.5,"CatchDate":"2024-12-04","FishingMethod":"Longline","Vessel":"Jagnee","Supplier":"SupplierA","Retailer":"RetailerA"}, {"ID":"tuna4","Species":"Skipjack","Weight":5,"CatchDate":"2024-12-05","FishingMethod":"Longline","Vessel":"Davao","Supplier":"SupplierB","Retailer":"RetailerB"}, {"ID":"tuna5","Species":"Atbacore","Weight":6,"CatchDate":"2024-12-05","FishingMethod":"Longline","Vessel":"Jagnee","Supplier":"SupplierX","Retailer":"RetailerX"}, {"ID":"tuna6","Species":"Skipjack","Weight":6,"CatchDate":"2024-12-05","FishingMethod":"Antique","Vessel":"Jagnee","Supplier":"SupplierA","Retailer":"RetailerA"}]
```

Figure 4.8: Query Smart Contract: Check updated assets

## 1128     4.3 Backend Security Analysis (Hyperledger Fab- 1129       ric on GCP)

### 1130     4.3.1 System Architecture and Deployment Overview

1131       The backend of the system's tuna assets was developed using a containerized  
1132       Hyperledger Fabric deployed on Google Cloud Platform (GCP). The network of

<sub>1133</sub> Hyperledger Fabric consists of a peer node, an ordering node, and Certificate  
<sub>1134</sub> Authorities (CAs).

<sub>1135</sub> **4.3.2 Blockchain Network Security**

<sub>1136</sub> The blockchain network leverages Hyperledger Fabric's security model to ensure  
<sub>1137</sub> authenticated transactions and controlled access. A Membership Service Provider  
<sub>1138</sub> (MSP) manages identities and issues certificates based on a Public Key Infrastruc-  
<sub>1139</sub> ture (PKI) model, ensuring that only verified participants can interact with the  
<sub>1140</sub> network.

<sub>1141</sub> Key security features include:

<sub>1142</sub> **Channel Privacy**

<sub>1143</sub> Channels act as private communication subnets, isolating transaction data so that  
<sub>1144</sub> only authorized organizations can access and process specific transactions.

<sub>1145</sub> **Policies and Access Control**

<sub>1146</sub> Policies, including endorsement policies and access control lists (ACLs), govern  
<sub>1147</sub> how transactions are validated, how channel resources are accessed, and how  
<sub>1148</sub> changes to the network are approved. Endorsement policies specifically define  
<sub>1149</sub> which peer nodes must approve a transaction before it is committed to the ledger.

**1150 Secure Communication**

1151 Transport Layer Security (TLS) is enforced across node communications to protect  
1152 data in transit. Mutual TLS is used for operational endpoints like monitoring  
1153 services.

**1154 Identity and Role Management**

1155 Every network participant—peer nodes, orderer nodes, client applications (SeaX-  
1156 Change Web Application)—has a cryptographically verifiable identity, with roles  
1157 defined within the framework to control access and permissions within channels.

**1158 Hardware Security Modules (HSMs)**

1159 Critical cryptographic operations, such as signing transactions under the blockchain  
1160 assets invocation, can optionally be handled by HSMs to secure private keys out-  
1161 side of the software environment.

1162 These layered mechanisms collectively ensure the confidentiality, integrity, and  
1163 authenticity of transactions in the blockchain network.

**1164 4.3.3 Smart Contract Automated Test Result**

1165 To validate the security and functionality of the deployed smart contracts on the  
1166 Hyperledger Fabric network, an automated testing script (app.js) under asset-  
1167 transfer-basic directory was executed. The script interacted with the blockchain

1168 network through the gateway application, utilizing the defined channel (mychan-  
 1169 nel) and chaincode (basic). The automated tests performed the following opera-  
 1170 tions:

### 1171 **InitLedger Transaction**

1172 The ledger was initialized by creating a predefined set of tuna asset entries. The  
 1173 transaction was successfully committed, confirming the proper initialization of  
 1174 asset data. (See Figure 4.9 for initialization confirmation.)

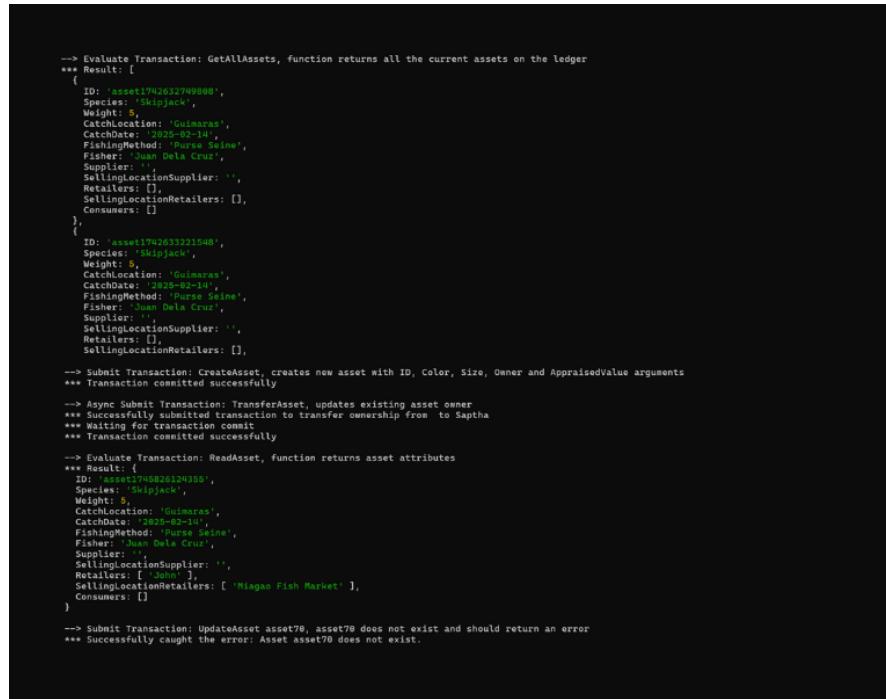
```
x-www-jp2e-AP10-03:~/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/asset-transfer-basic/application-gateway-javascript/src$ node app.js
channelName: mychannel
chaincodeName: basic
rootCertPath: /opt/certs
cryptoPath: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network/organizations/peerOrganizations/org1.example.com
keyDirectoryPath: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/users/User1@org1.example.com/msp
keyPath: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/users/User1@org1.example.com/msp/cert.pem
certDirectoryPath: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/users/User1@org1.example.com/msp/certs
signcerts
signcertPath: /mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/users/User1@org1.example.com/msp/certs
/tls/cert.pem
peerEndpoint: localhost:7981
peerHostAlias: peer0.org1.example.com
--> Submit Transaction InitLedger, function creates the initial set of assets on the ledger
*** Transaction committed successfully
```

Figure 4.9: Initialization Confirmation of the Ledger

### 1175 **GetAllAssets Query**

1176 A query operation retrieved all existing assets recorded on the ledger. The results  
 1177 displayed multiple tuna asset entries with details such as species, weight, catch  
 1178 location, catch date, fishing method, fisher, supplier, retailers, selling locations,  
 1179 and consumers. (See Figure 4.10 for the asset retrieval output.)

### 4.3. BACKEND SECURITY ANALYSIS (HYPERLEDGER FABRIC ON GCP)51



```
--> Evaluate Transaction: GetAllAssets, function returns all the current assets on the ledger
*** Result: [
  {
    ID: 'asset1742632749908',
    Species: 'Skipjack',
    Weight: 5,
    CatchLocation: 'Guimaraes',
    CatchDate: '2025-02-14',
    FishingMethod: 'Purse Seine',
    Fisher: 'Juan Della Cruz',
    Supplier: '',
    SellinglocationSupplier: '',
    Retailers: [],
    SellinglocationRetailers: [],
    Consumers: []
  },
  {
    ID: 'asset1742631221548',
    Species: 'Skipjack',
    Weight: 5,
    CatchLocation: 'Guimaraes',
    CatchDate: '2025-02-14',
    FishingMethod: 'Purse Seine',
    Fisher: 'Juan Della Cruz',
    Supplier: '',
    SellinglocationSupplier: '',
    Retailers: [],
    SellinglocationRetailers: []
  }
]
--> Submit Transaction: CreateAsset, creates new asset with ID, Color, Size, Owner and AppraisedValue arguments
*** Transaction committed successfully
--> Async Submit Transaction: TransferAsset, updates existing asset owner
*** Successfully submitted transaction to transfer ownership from to Captha
*** Waiting for transaction commit
*** Transaction committed successfully
--> Evaluate Transaction: ReadAsset, function returns asset attributes
*** Result: {
  ID: 'asset174263124388',
  Species: 'Skipjack',
  Weight: 5,
  CatchLocation: 'Guimaraes',
  CatchDate: '2025-02-14',
  FishingMethod: 'Purse Seine',
  Fisher: 'Juan Della Cruz',
  Supplier: '',
  SellinglocationSupplier: '',
  Retailers: ['John'],
  SellinglocationRetailers: ['Miaoga Fish Market'],
  Consumers: []
}

--> Submit Transaction: UpdateAsset asset70, asset70 does not exist and should return an error
*** Successfully caught the error: Asset asset70 does not exist.
```

Figure 4.10: Initialization Confirmation of the Ledger

#### 1180 CreateAsset Transaction

1181 A new asset was successfully created and appended to the blockchain. The trans-  
1182 action was committed without errors, validating the chaincode's ability to handle  
1183 new data insertion.

#### 1184 TransferAsset Transaction

1185 Ownership transfer of an existing asset was simulated. The transaction was suc-  
1186 cessfully submitted and committed, demonstrating the correct application of asset  
1187 updates in the blockchain ledger.

**1188 ReadAsset Query**

1189 The updated asset was retrieved and verified to ensure the correctness of the  
1190 transfer. The retrieved asset data reflected the changes made through the previous  
1191 transaction, confirming data consistency.

**1192 UpdateAsset Error Handling**

1193 An attempt to update a non-existent asset (asset70) was performed to test the  
1194 smart contract's error-handling mechanism. The application correctly caught and  
1195 reported the error, verifying that improper transactions are adequately handled  
1196 and rejected.

**1197 Summary of Results**

1198 All positive transactions (initialization, creation, transfer, and reading) were suc-  
1199 cessfully executed and committed. The smart contract exhibited robust error  
1200 handling during invalid operations. Endorsement policies and Membership Ser-  
1201 vice Provider (MSP) enforcement ensured transaction authenticity and integrity  
1202 during the process. These tests confirm the functional reliability and transac-  
1203 tion security of the smart contracts used within the tuna supply chain blockchain  
1204 network.

1205 **4.3.4 GCP Infrastructure Security**

1206 The Hyperledger Fabric network deployment on Google Cloud Platform (GCP)  
1207 was secured by leveraging multiple layers of Google's infrastructure security model,  
1208 following best practices in network, identity, and data protection.

1209 **Firewall Rules and Network Control**

1210 Only essential ports (e.g., 7051 for peer communication and 7050 for the ordering  
1211 service) were opened to minimize network exposure. GCP's VPC firewall rules,  
1212 ingress and egress controls, and options like VPC Service Controls help further  
1213 isolate services and prevent unauthorized access. Traffic between virtual machines  
1214 and Google APIs is securely routed through Google's internal network infrastruc-  
1215 ture using Private Google Access when available.

1216 **IAM Roles and Access Management**

1217 The principle of least privilege was enforced by assigning minimal permissions to  
1218 users and services through GCP Identity and Access Management (IAM). Access  
1219 decisions involve authentication, authorization checks, and enforcement of policies  
1220 through centralized services, helping reduce the risk of unauthorized actions or  
1221 privilege escalation.

**1222 Encryption**

1223 GCP ensures that data is encrypted both at rest and in transit by default. Storage  
1224 systems use multiple layers of encryption, with cryptographic keys managed by  
1225 Google. For additional control, Cloud Key Management Service (KMS) enables  
1226 customers to manage their own encryption keys. Data in transit between services  
1227 is protected using Application Layer Transport Security (ALTS), and all external  
1228 communication with Google services is encrypted via TLS.

**1229 Access Control**

1230 Access to virtual machines and services was restricted using secure access methods.  
1231 Identity-Aware Proxy (IAP) or VPN connections were employed to safeguard SSH  
1232 and administrative access. GCP's zero-trust model emphasizes verifying identity  
1233 and device security rather than relying solely on network location, aligning with  
1234 best practices for modern infrastructure protection.

**1235 Infrastructure and Operational Security**

1236 GCP's underlying infrastructure benefits from Google's proprietary hardware de-  
1237 signs, including the Titan security chip, secure boot mechanisms, and service iden-  
1238 tity enforcement. Google's physical data centers use multi-layered defenses such  
1239 as biometrics and intrusion detection systems. Operational security practices, in-  
1240 cluding binary authorization and extensive monitoring, reduce insider risks and  
1241 enforce software integrity throughout the lifecycle.

<sub>1242</sub> By deploying the blockchain network on GCP, the project leveraged a highly se-  
<sub>1243</sub> cure environment, benefiting from Google's layered security architecture across  
<sub>1244</sub> networking, identity management, encryption, access control, and operational  
<sub>1245</sub> practices.

### <sub>1246</sub> 4.3.5 Threat Model and Mitigations

<sub>1247</sub> 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

<sub>1248</sub>

## <sub>1249</sub> 4.4 Mockups

<sub>1250</sub> The mockups represent the preliminary design for the SeaXChange web appli-  
<sub>1251</sub> cation, created using Figma to facilitate collaboration and incorporate feedback  
<sub>1252</sub> efficiently (see Figures showing initial mockup designs). The visual design features  
<sub>1253</sub> a teal-based color scheme to evoke an oceanic theme, aligning with the app's focus  
<sub>1254</sub> on tuna products supply chain. This aesthetic choice reinforces the app's identity  
<sub>1255</sub> and enhances user engagement.

<sub>1256</sub> Upon launching the app, users are first directed to the Login or Sign-Up page,

1257 where authentication is required to access any data. This ensures security and  
1258 role-specific access within the blockchain system.

1259 Once authenticated, users are redirected to their personalized homepages, which  
1260 include their profile information and a dashboard showing relevant tuna product  
1261 assets. The user experience is role-dependent:

- 1262 • All users can view available assets on the blockchain.
- 1263 • Fishermen are the only users who can create new assets, representing newly  
1264 caught tuna.
- 1265 • Suppliers and Retailers have the ability to pass on assets down the supply  
1266 chain, updating the product's status, location, or freshness.

1267 This role-based structure ensures traceability, accountability, and clarity across  
1268 the supply chain, while maintaining a clean and intuitive interface tailored to  
1269 each user type.

#### 4.4. MOCKUPS

57

**Login Page**

SeaXChange

Email: \_\_\_\_\_  
Password: \_\_\_\_\_  
**Log In**

Don't have an account? Sign up

**Fisher Homepage**

SeaXChange

Logout Tuna ID Profile Sign Out

+ ADD CATCH

Picture

TUNA1 Dec 1, 2024 Available

Picture

TUNA1 Dec 1, 2024 Available

Picture

TUNA1 Dec 1, 2024 Sold

Picture

TUNA1 Dec 1, 2024 Available

Picture

TUNA1 Dec 1, 2024 Available

Picture

TUNA1 Dec 1, 2024 Available

**Fisher Add Catch Page**

SeaXChange

TUNA1

Species: Skipjack ✓  
Weight (kg): 5.5 ✓  
Catch Location: Africa ✓  
Catch Date: 2024-12-01 ✓  
Fishing Method: Longline ✓  
Vessel: Japene ✓  
Supplier: NA  
Retailer: NA  
Consumer: NA

**Fisher Add Catch Page 2**

SeaXChange

TUNA1

Species: Skipjack ✓  
Weight (kg): 5.5 ✓  
Catch Location: Africa ✓  
Catch Date: 2024-12-01 ✓  
Fishing Method: Longline ✓  
Vessel: Japene ✓  
Supplier: NA  
Retailer: John Doe ✓  
Consumer: NA

You won't be able to sell the tuna selected for it later.

**Supplier Homepage**

SeaXChange

Logout Tuna ID Profile Sign Out

Enter Tuna ID

Picture

TUNA1 Dec 1, 2024 Available

**Supplier Search/Click Result Page**

SeaXChange

TUNA1

Species: Skipjack  
Weight (kg): 5.5  
Catch Location: Africa  
Catch Date: 2024-12-01  
Fishing Method: Longline  
Vessel: Japene  
Supplier: John Doe ✓  
Retailer: NA  
Consumer: NA

**Retailer Search/Sell Page**

SeaXChange

TUNA1

Species: Skipjack  
Weight (kg): 5.5  
Catch Location: Africa  
Catch Date: 2024-12-01  
Fishing Method: Longline  
Vessel: Japene  
Supplier: Uncle Bob  
Retailer: NA  
Consumer: NA

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

## <sup>1270</sup> 4.5 Operational Flow of the Web Application

<sup>1271</sup> This section will discuss the flow in using the SeaXChange Web Application. It  
<sup>1272</sup> will show the respective interface for every page and how the users can interact  
<sup>1273</sup> with it.

### <sup>1274</sup> 4.5.1 Landing Page

<sup>1275</sup> Users are be greeted with the landing page (Figure 4.12), where it shows a ocean  
<sup>1276</sup> visuals and a tagline “Discover the Journey your tuna made from the ocean to  
<sup>1277</sup> your dinner plate”. Users are given the option to Login, where they are redirected  
<sup>1278</sup> 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

1279 **4.5.2 Sign Up Page**

1280 First time users will be required to create an account (Figure 4.14). They are to  
1281 provide their name, email and password. For their user type, there are four roles  
1282 to choose from: Fisher, Supplier, Retailer and Consumer.

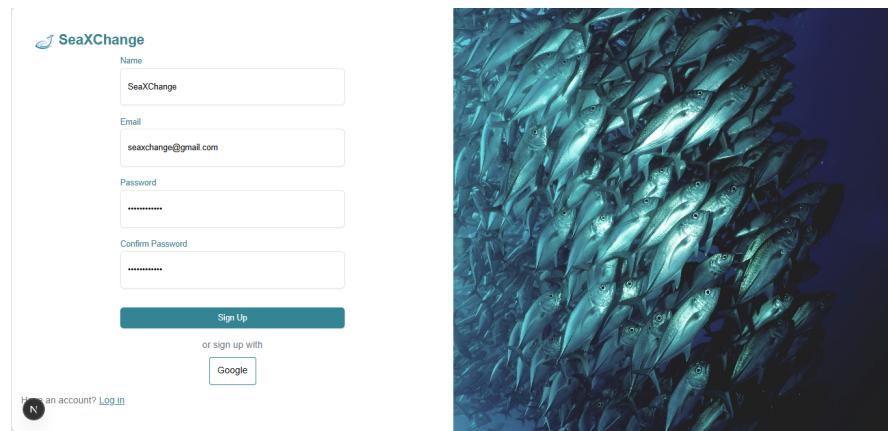


Figure 4.14: SignUp Page

1283 **4.5.3 Login Page**

1284 Returning users are required to login with their email and password (Figure 4.15).

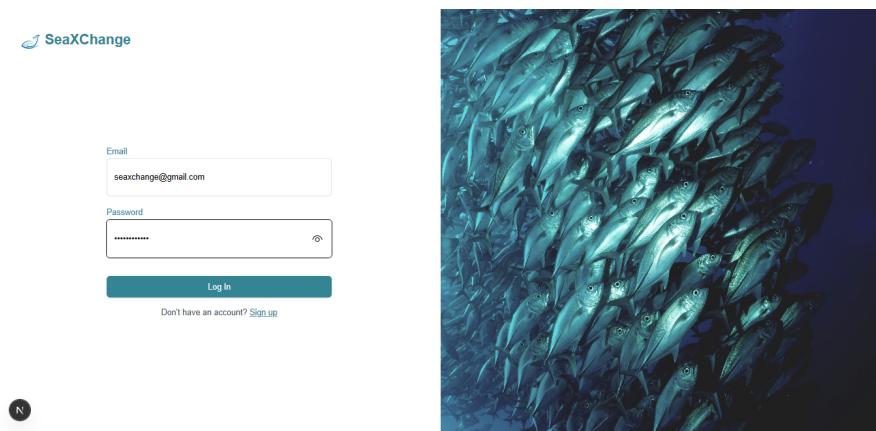


Figure 4.15: LogIn Page

#### 1285 4.5.4 Homepage

1286 Each user type has their own respective homepages and features, as shown in the  
1287 following interface designs.

1288 • **Fisher** Fishers can add a fish catch using the "Add catch" button (Figure  
1289 4.16), where they are to input the species of the fish, weight in kg, catch  
1290 location, catch date, fishing method used and vessel name. The remaining  
1291 text fields like the Supplier name, Retailer name and Consumer name are  
1292 left null and cannot be edited because they will be filled out by the other  
1293 users receiving the tuna asset. Users can send a tuna asset to the Supplier.  
1294 Users can also browse existing tuna assets.

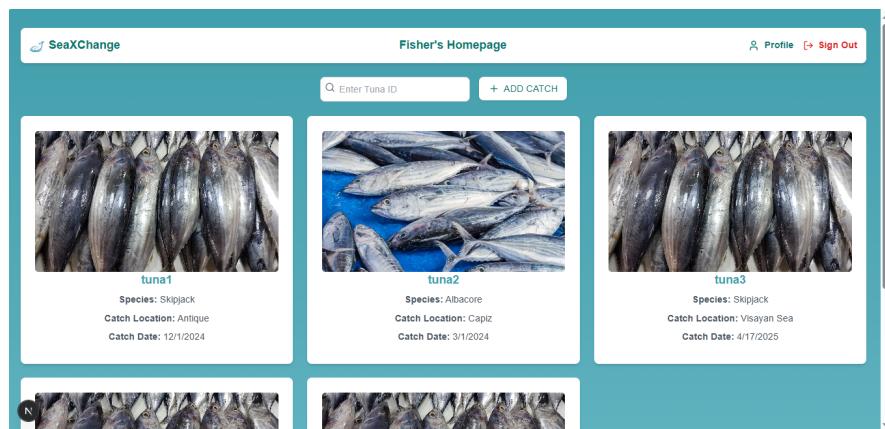


Figure 4.16: Fisher Homepage

1295 • **Supplier** Suppliers can browse existing tuna assets (Figure 4.17). Upon  
1296 clicking a tuna asset, the user can only edit the Supplier text field. They  
1297 can send the tuna asset to the Retailer.

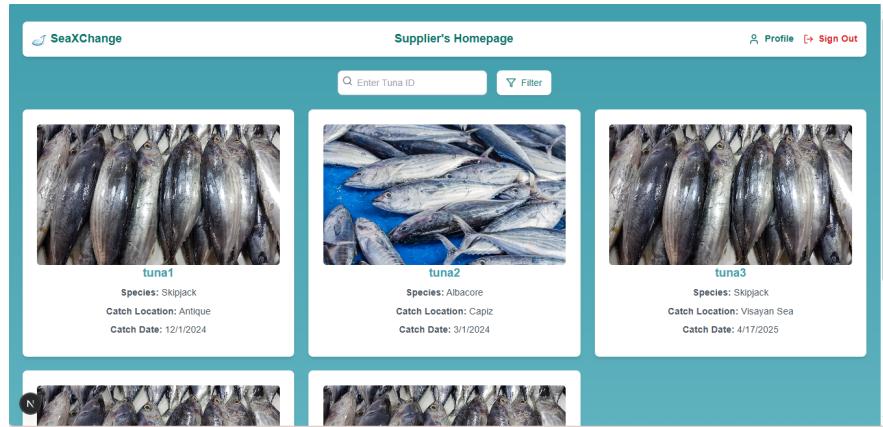


Figure 4.17: Supplier Homepage

- 1298 • **Retailer** Retailers can browse existing tuna assets and can send it to the  
1299 Consumer (Figure 4.18).

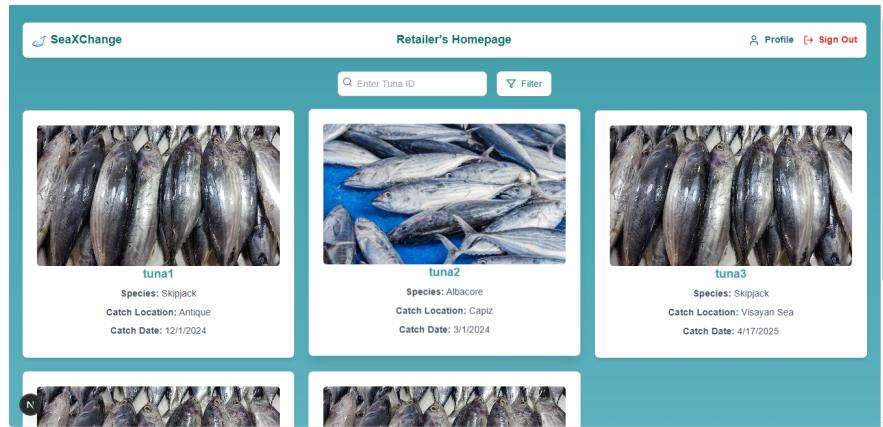


Figure 4.18: Retailer Homepage

- 1300 • **Consumer** Consumers can only view the tuna asset and cannot edit anything else (Figure 4.19).  
1301

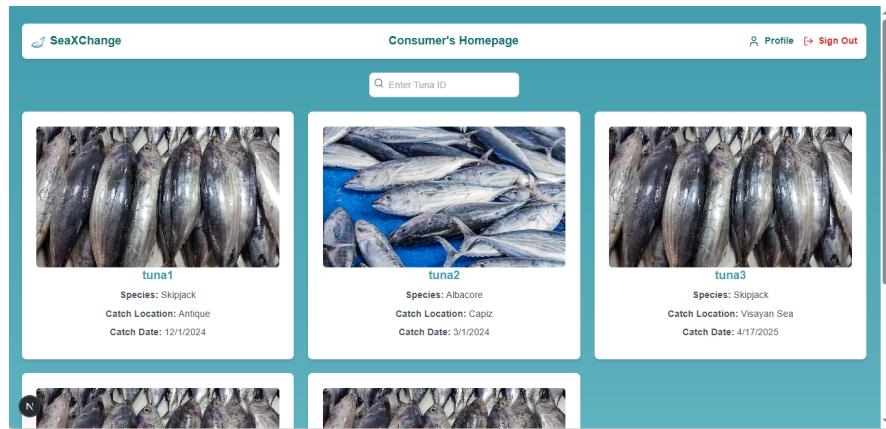


Figure 4.19: Consumer Homepage

### 1302 4.5.5 Profile

- 1303 The user's profile information is shown on the homepage through a pop-up (Figure  
 1304 4.20). It shows the user's name and role.

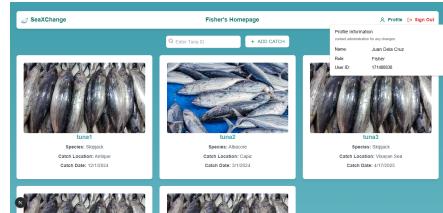


Figure 4.20: View Profile

### 1305 4.5.6 Logout

- 1306 Users can logout of their accounts and is redirected to the Signup Page (Figure  
 1307 4.21).

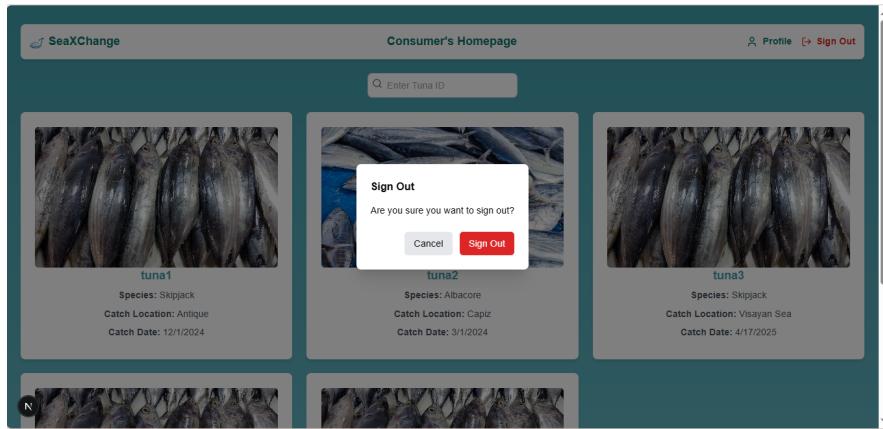


Figure 4.21: Log Out

## 1308 4.6 System Discussion

1309 After modifying the Hyperledger Fabric smart contract to assess necessary pro-  
1310 cesses involved in the tuna supply chain, the blockchain is ready to be invoked  
1311 wherein the smart contract can be activated. To start, a new tuna asset is added  
1312 and registered to the blockchain. Each tuna asset has its attributes or details.  
1313 Before proceeding to the transfer of tuna asset, the smart contract is queried to  
1314 verify if the creation of the asset is successful and if it is part of the current in-  
1315 ventory. After that, the tuna asset can be transferred from fisher to supplier and  
1316 the asset's owner is updated. The smart contract is queried again to verify if the  
1317 asset details have been updated successfully. With the same process, the tuna as-  
1318 set is transferred from supplier to retailer using the smart contract and the owner  
1319 is updated again. To ensure that the asset details are successfully updated, the  
1320 smart contract is queried again. The final step is to query the smart contract to  
1321 show the overview of all the assets in the supply chain. With this, it can be seen  
1322 all the tuna assets from fishing to retail. Overall, the steps and process provides

<sub>1323</sub> transparency and traceability in the tuna supply chain.

## <sub>1324</sub> 4.7 User Demonstration and Feedback Results

### <sub>1325</sub> 4.7.1 Demo Setup and Scenario

<sub>1326</sub> During the demonstration of the system, the participants had a brief introduction  
<sub>1327</sub> of the key functionalities of the SeaXChange app. They were shown how to  
<sub>1328</sub> create an account, input and send tuna assets from one stakeholder to another.

<sub>1329</sub> The demonstration included the asset creation process (Figure 4.22), saving asset  
<sub>1330</sub> details (Figure 4.23), and transferring assets between stakeholders (Figure 4.24).

<sub>1331</sub> Participants were also shown how real-time updates were reflected on the app.

<sub>1332</sub> Finally, they were introduced on how to view transaction histories and traceability  
<sub>1333</sub> information on each tuna asset. Throughout the demonstration, participants

<sub>1334</sub> were encouraged to ask questions and provide feedback on the usability and functionality  
<sub>1335</sub> of the system. After the demonstration, they were given feedback forms

<sub>1336</sub> in order to assess the SeaXChange app.

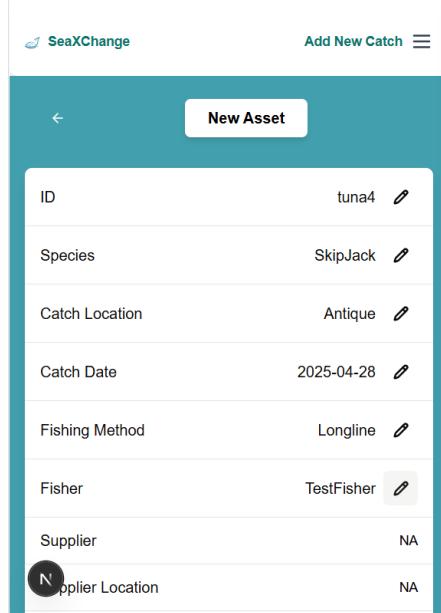


Figure 4.22: Add Catch (Asset)

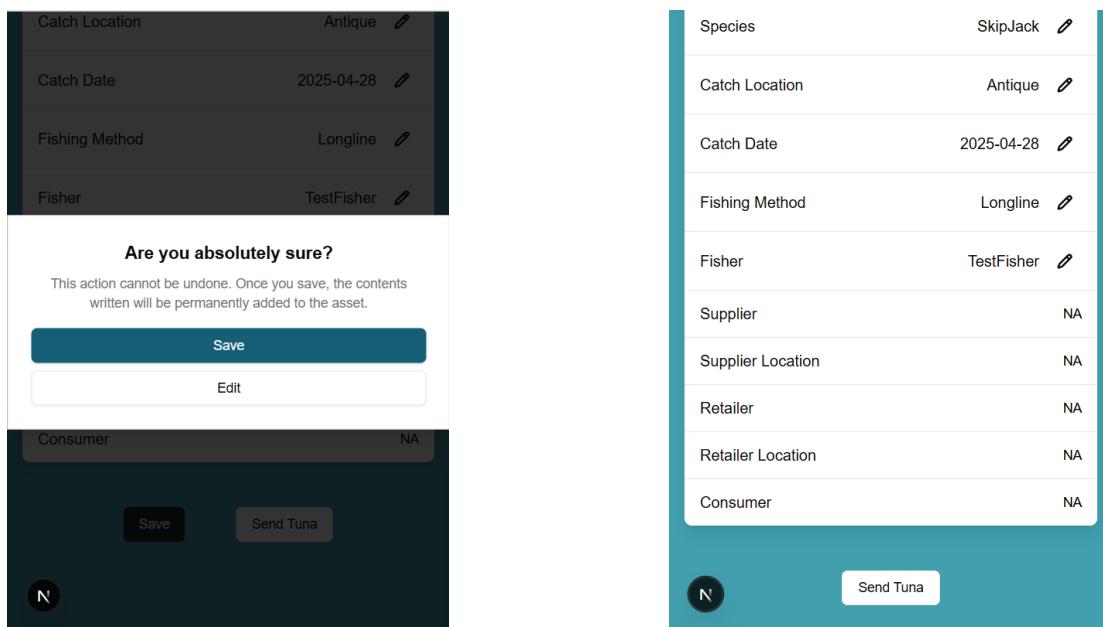


Figure 4.23: Save Details

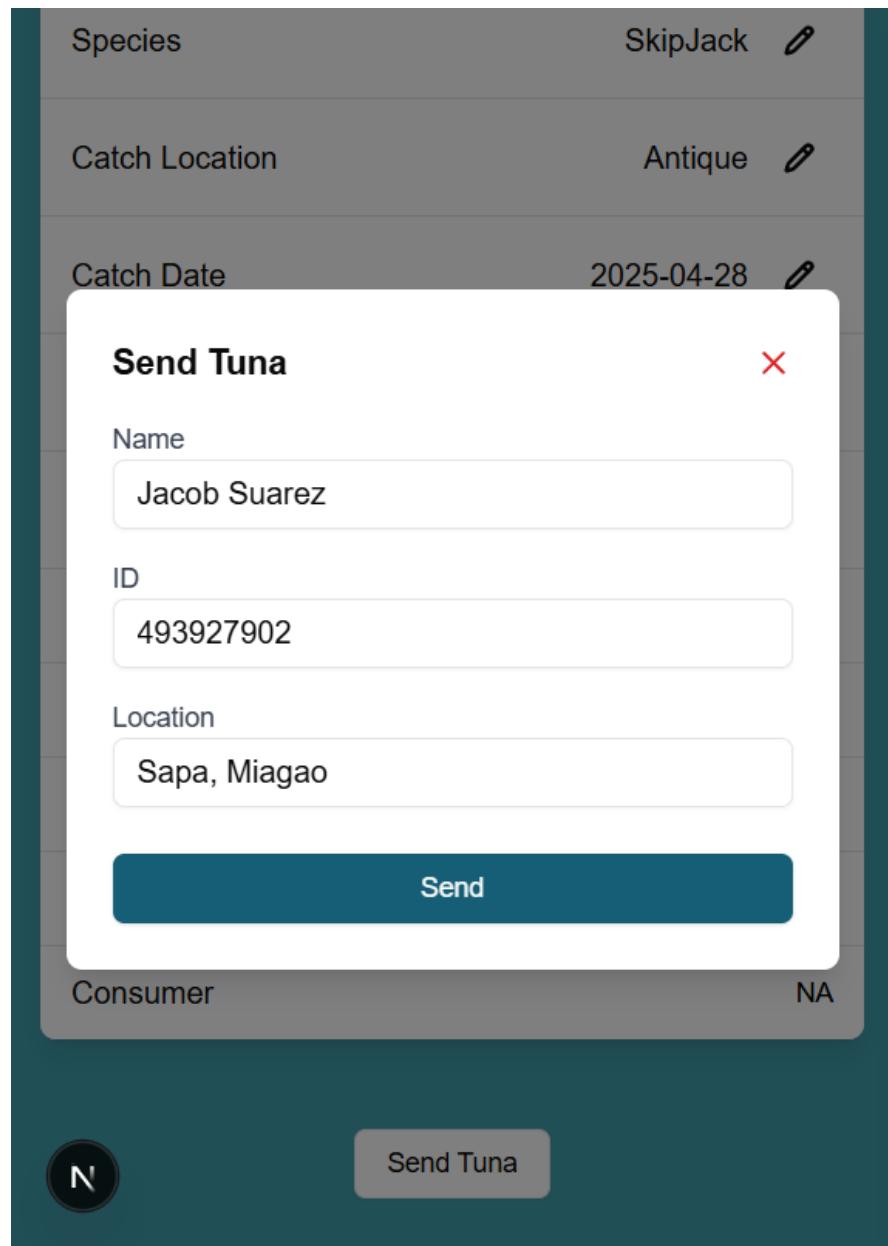


Figure 4.24: Send Asset

<sup>1337</sup> **4.7.2 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.

<sup>1338</sup> When taken as a whole, the respondents have average feedback in asset tracking  
<sup>1339</sup> but when classified by stakeholder, the fishermen ( $M = 4.0$ ) and consumers ( $M$   
<sup>1340</sup>  $= 4.0$ ) had good feedback in tracking , while the supplier and retailers have an  
<sup>1341</sup> average rating ( $M = 3.0$ ). For verifying tuna assets, the entire group has an average  
<sup>1342</sup> feedback. When classified by stakeholder, the fishermen ( $M = 3.33$ ) and consumers  
<sup>1343</sup> ( $M = 3.67$ ) have average ratings. For real-time updates, the respondents, when  
<sup>1344</sup> taken as a whole, have an average feedback. When classified by stakeholder, the  
<sup>1345</sup> fishermen ( $M = 3.78$ ) have an average rating, while both supplier and retailers ( $M$   
<sup>1346</sup>  $= 4.0$ ) and consumers ( $M = 4.0$ ) have good ratings. For smart contract execution,  
<sup>1347</sup> the respondents, when taken as a whole, also have an average feedback. When  
<sup>1348</sup> classified according to stakeholder, the fishermen have a fair rating ( $M = 2.33$ ),

- <sup>1349</sup> the supplier and retailers have average ratings ( $M = 3.25$ ) and the consumers have  
<sup>1350</sup> 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.

- <sup>1351</sup> The respondents, when taken as a whole, had an average feedback in transparency.  
<sup>1352</sup> When classified by stakeholder, The fishermen have fair ratings ( $M = 2.67$ ), while  
<sup>1353</sup> both supplier and retailers ( $M = 4.0$ ) and consumers ( $M = 4.0$ ) have good ratings.  
<sup>1354</sup> In evaluating the seamless interaction of the app, the entire group has an average  
<sup>1355</sup> feedback ( $M = 3.77$ ). When classified by stakeholder, the fishermen ( $M = 1.33$ )  
<sup>1356</sup> have poor feedback, the supplier and retailers have average feedback ( $M = 3.0$ )  
<sup>1357</sup> 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.

1358 As a whole, the respondents have an average feedback on efficient transactions ( $M$   
 1359 = 3.81). If evaluated per stakeholder, both fishermen ( $M = 3.67$ ), supplier and  
 1360 retailers ( $M = 3.75$ ) evaluated average while consumers had good feedback ( $M =$   
 1361 4.0). For data security, the entire group has an average feedback ( $M = 3.31$ ). The  
 1362 fishermen have fair evaluation ( $M = 2.67$ ), supplier and retailers ( $M = 3.25$ ) have  
 1363 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.

1364 It shows the frequency of intuitive interface among the respondents when taken  
 1365 as a whole is average ( $M = 3.83$ ). When classified according to stakeholder,  
 1366 both fishermen ( $M = 4.0$ ) and consumers ( $M = 4.0$ ) have good ratings, while the  
 1367 supplier and retailers ( $M = 3.5$ ) have average ratings. For cross-platform usage,  
 1368 the entire group rated good ( $M = 4.14$ ). When classified according to stakeholder,  
 1369 both fishermen ( $M = 4.0$ ) and consumers ( $M = 4.1$ ) also have good ratings, while  
 1370 supplier and retailers ( $M = 3.75$ ) have average. For visual clarity, the entire group  
 1371 rated average ( $M = 3.80$ ). When classified by each stakeholder, both fishermen  
 1372 ( $M = 3.33$ ) and supplier and retailers ( $M = 3.75$ ) have average ratings, while

<sup>1373</sup> 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.

<sup>1374</sup> When taken as a whole, the respondents ( $M = 3.89$ ) rated instruction clarity as  
<sup>1375</sup> average. When classified by stakeholder, both fishermen ( $M = 4.0$ ) and supplier  
<sup>1376</sup> and retailers ( $M = 4.0$ ) have good feedback regarding instruction clarity, while the  
<sup>1377</sup> consumers ( $M = 3.67$ ) have average feedback. The entire group rated language  
<sup>1378</sup> clarity as average ( $M = 3.31$ ). When evaluated by each stakeholder, both fisher-  
<sup>1379</sup> men ( $M = 4.03$ ) and consumers ( $M = 4.33$ ) have good feedback, while supplier  
<sup>1380</sup> 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.

<sup>1381</sup> When taken as a whole, it shows that the respondents have good feedback in the

1382 system integration. When classified by each stakeholder, both the fishermen ( $M =$   
1383 4.0) and supplier and retailers ( $M = 4.5$ ) have good feedback in system integration,  
1384 while the consumers( $M = 3.67$ ) have an average rating. The frequency of consumer  
1385 use among stakeholders, when taken as a whole, have good feedback ( $M = 4.03$ ).  
1386 When analyzed individually, both the fishermen ( $M = 4.0$ ) and consumers ( $M =$   
1387 4.33) have a good rating, while an average rating for the supplier and retailers ( $M$   
1388 = 3.75).

### 1389 4.7.3 Results and Analysis

1390 For functionality, fishermen rated asset tracking positively but identified chal-  
1391 lenges in real-time updates and smart contract execution. Suppliers and retail-  
1392 ers similarly found strengths in verification and real-time updates, although as-  
1393 set tracking averaged slightly lower. Consumers consistently rated functionality  
1394 highly, particularly appreciating the system's ability to support smart contracts.

1395 Regarding end-user needs, fishermen provided the lowest ratings, highlighting  
1396 difficulties with seamless interaction, considering the digital barrier that they ex-  
1397 perience while interacting with the app. Suppliers, retailers, and consumers gave  
1398 higher scores, suggesting that while transparency was generally achieved, the sys-  
1399 tem's ease of interaction required further improvement for all users.

1400 In terms of performance, fishermen and suppliers reported average transaction  
1401 efficiency but noted concerns regarding data integrity and security. Consumers,  
1402 on the other hand, expressed confidence in both areas.

1403 For usability, consumers provided the highest ratings, emphasizing the intuitive

<sup>1404</sup> design and accessibility of the interface. Fishermen and suppliers also rated us-  
<sup>1405</sup> ability positively but suggested improvements, such as better visual appeal and  
<sup>1406</sup> language localization. Feedbacks suggested incorporating the Karay-a language  
<sup>1407</sup> since most of the potential users uses that language in their everyday lives. An-  
<sup>1408</sup> other suggestion was to use capitalization (UI/UX) for the name of the tuna to  
<sup>1409</sup> give more emphasis to it.

<sup>1410</sup> Ease of use was generally rated positively across all groups. However, feedback  
<sup>1411</sup> highlighted the need for additional user guidance features, including clearer button  
<sup>1412</sup> descriptions and localized instructions for broader accessibility.

<sup>1413</sup> Finally, feasibility was strongly affirmed by all groups. Stakeholders believed the  
<sup>1414</sup> system could be effectively integrated into the existing tuna supply chain and  
<sup>1415</sup> accessed by consumers as a means to monitor tuna products.

# <sup>1416</sup> Chapter 5

## <sup>1417</sup> Conclusion

### <sup>1418</sup> 5.1 Overview

<sup>1419</sup> This chapter presents the key findings and conclusion of the study. It also discusses  
<sup>1420</sup> how the system addresses the challenges of traceability within the tuna supply  
<sup>1421</sup> chain. This chapter also provides recommendations in enhancing the system's  
<sup>1422</sup> functionality and usability, ensuring that the SeaXChange app continues to meet  
<sup>1423</sup> evolving needs of its users.

### <sup>1424</sup> 5.2 Conclusion

<sup>1425</sup> This study aimed to develop and evaluate SeaXChange, which is a blockchain-  
<sup>1426</sup> driven app designed to enhance transparency, traceability and accountability  
<sup>1427</sup> within the tuna supply chain. Through the adaption of Scrum, the team was  
<sup>1428</sup> able to develop a functional prototype that was based on iterative development

<sup>1429</sup> to achieve goals.

<sup>1430</sup> The results from the gathered data suggests that the app has effectively addressed  
<sup>1431</sup> key challenges in traceability and accountability, especially among suppliers and  
<sup>1432</sup> consumers. The stakeholders consistently rated the system as good. However,  
<sup>1433</sup> some areas need improvement, especially in ensuring seamless interaction and  
<sup>1434</sup> data security for fishermen.

<sup>1435</sup> Overall, SeaXChange demonstrates strong potential as a technological solution for  
<sup>1436</sup> promoting transparency, combating illegal, unreported, and unregulated (IUU)  
<sup>1437</sup> fishing, and empowering stakeholders across the tuna supply chain.

### <sup>1438</sup> 5.3 Recommendations

<sup>1439</sup> After analyzing and interpreting the gathered data, the researchers had identi-  
<sup>1440</sup> fied some improvements and recommendations for the further development and  
<sup>1441</sup> implementation of the SeaXChange app.

#### <sup>1442</sup> 1. Incorporation of Local Language

<sup>1443</sup> Since most of the target users are within Miagao, the system could provide  
<sup>1444</sup> multi-language support, including the Karay-a language. This will improve  
<sup>1445</sup> guidance through clearer button descriptions.

#### <sup>1446</sup> 2. Utilization of IoT

<sup>1447</sup> The system could use Internet of Things (IoT) in verifying the fisherman's lo-  
<sup>1448</sup> cation. This will add more accountability in tracing the fisherman's current  
<sup>1449</sup> location. Suitable IoT devices include temperature sensors (like DS18B20,

1450 DS1922L) to monitor the fish's temperature during transportation and stor-  
1451 age and GPS chips to track the location of fishing boats and transport  
1452 vehicles.

1453 **3. Inclusion of User Manual**

1454 To further enhance the experience of its users, the researcher could provide  
1455 printed or digital copies on the system's functionalities. This will help users  
1456 navigate through the system without being lost.

1457 **5.4 Summary**

1458 In conclusion, the development of the SeaXChange app highlights the critical role  
1459 of emerging technologies in providing solution regarding the traceability, trans-  
1460 parency and accountability within the tuna supply chain. While the system has  
1461 demonstrated strong potential, continuous improvements are still needed to en-  
1462 sure its effectiveness. Moreover, further development and usability enhancements  
1463 will be essential in attaining SeaXChange's goal of creating a more traceable,  
1464 transparent and accountable tuna industry.



<sup>1465</sup> **Chapter 6**

<sup>1466</sup> **References**

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1604 [1&isAllowed=y](https://himolde.brage.unit.no/himolde-xmlui/bitstream/handle/11250/3052893/Cristin-id_1318891_engelseth.pdf?sequence=1&isAllowed=y).
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1647 **Appendix A**

1648 **Code Snippets**

```
1649
1650     const checkAssetAccess = (
1651         asset, userIdentifier, role
1652     ) => {
1653
1654         switch (role.toLowerCase()) {
1655             case 'fisher':
1656                 if (asset.Fisher === userIdentifier)
1657                     return { hasAccess: true, accessType
1658                         : 'full' };
1659
1660             case 'supplier':
1661                 if (asset.Supplier ===
1662                     userIdentifier)
1663                     return { hasAccess: true, accessType
1664                         : 'full' };
1665
1666             case 'retailer':
```

```

1666i           if (asset.Retailers?.includes(
1667               userIdentifier))
1668i             return { hasAccess: true, accessType
1669                 : 'full' };
1670i             break;
1671i             case 'consumer':
1672i               if (asset.Consumers?.includes(
1673                   userIdentifier))
1674i                 return { hasAccess: true, accessType
1675                     : 'full' };
1676i                     break;
1677i     }
1678i
1679i     if (role.toLowerCase() === 'consumer') {
1680i       return { hasAccess: true, accessType
1681                     : 'readonly' };
1682i     }
1683i
1684i     return { hasAccess: false, accessType: 'none'
1685                     };
1686i   };
1687i }
```

Listing A.1: Role-based access logic for tuna asset visibility

```

1688
1689i   const grpc = require('@grpc/grpc-js');
1690i   const { connect, hash, signers } = require(
1691               '@hyperledger/fabric-gateway');
1692i   const crypto = require('node:crypto');
```

```
1693:     const fs = require('node:fs/promises');
1694:     const path = require('node:path');
1695:     const { TextDecoder } = require('node:util');
1696:
1697:     const channelName = envOrDefault('CHANNEL_NAME', 'mychannel');
1698:
1699:     const chaincodeName = envOrDefault('CHAINCODE_NAME', 'basic');
1700:
1701:     const mspId = envOrDefault('MSP_ID', 'Org1MSP');
1702:
1703:     // Path to crypto materials.
1704:     const cryptoPath = envOrDefault(
1705:       'CRYPTO_PATH',
1706:       path.resolve(
1707:         __dirname,
1708:         '..',
1709:         '..',
1710:         '..',
1711:         'test-network',
1712:         'organizations',
1713:         'peerOrganizations',
1714:         'org1.example.com'
1715:       )
1716:     );
1717:
1718:     const keyDirectoryPath = envOrDefault(
1719:       'KEY_DIRECTORY_PATH',
```

```
1720)     path.resolve(
1721)       cryptoPath,
1722)       'users',
1723)       'User1@org1.example.com',
1724)       'msp',
1725)       'keystore'
1726)   )
1727)
1728)
1729)   const certDirectoryPath = envOrDefault(
1730)     'CERT_DIRECTORY_PATH',
1731)     path.resolve(
1732)       cryptoPath,
1733)       'users',
1734)       'User1@org1.example.com',
1735)       'msp',
1736)       'signcerts'
1737)
1738)
1739)
1740)   const tlsCertPath = envOrDefault(
1741)     'TLS_CERT_PATH',
1742)     path.resolve(cryptoPath, 'peers', 'peer0.org1.
1743)           example.com', 'tls', 'ca.crt')
1744)
1745)
1746)   const peerEndpoint = envOrDefault('PEER_ENDPOINT', '
```

```

1747           localhost:7051');
1748
1749   const peerHostAlias = envOrDefault('PEER_HOST_ALIAS',
1750                                         'peer0.org1.example.com');
1751
1752   const utf8Decoder = new TextDecoder();
1753
1754   const assetId = asset${String(Date.now())};

```

Listing A.2: Node.js configuration for Hyperledger Fabric Gateway

```

1754
1755   type Asset struct {
1756
1757     ID
1758     Species
1759     Weight
1760     float64 Weight
1761
1762     CatchLocation
1763     string CatchLocation
1764     CatchDate
1765     string CatchDate
1766     FishingMethod
1767     string FishingMethod
1768     Fisher
1769     string Fisher
1770     Supplier
1771     string Supplier
1772     SellingLocationSupplier
1773     string SellingLocationSupplier

```

```

1774:             Retailers
1775:                 [] string `json:"Retailers"
1776:                     "
1777:             SellingLocationRetailers []
1778:                 string `json:"SellingLocationRetailers"
1779:             Consumers
1780:                 [] string `json:"Consumers"
1781:                     "
1782:     }
1783:
```

Listing A.3: Asset Data Structure

```

1784
1785:     func (s *SmartContract) CreateAsset(ctx contractapi.
1786:                                         TransactionContextInterface, id string, species
1787:                                         string, weight float64, catchLocation string,
1788:                                         catchDate string, fishingMethod string, fisher
1789:                                         string) error {
1790:
1791:         exists, err := s.AssetExists(ctx, id)
1792:
1793:         if err != nil {
1794:
1795:             return err
1796:
1797:         }
1798:
1799:         asset := Asset{
2000:             ID:           id,
```

```

18012           Species:             species,
1802           Weight:              weight,
1803           CatchLocation:      catchLocation,
1804           CatchDate:           catchDate,
1805           FishingMethod:      fishingMethod,
1806           Fisher:              fisher,
1807           Retailers:           [] string{},
1808           SellingLocationRetailers: []
1809                         string{},
1810           Consumers:           [] string{},
1811       }
1812   assetJSON, err := json.Marshal(asset)
1813   if err != nil {
1814     return err
1815   }
1816
1817   return ctx.GetStub().PutState(id, assetJSON)
1818 }
1819

```

Listing A.4: CreateAsset Function

```

1820
1821   func (s *SmartContract) TransferAsset(ctx
1822     contractapi.TransactionContextInterface, id
1823     string, role string, newParticipant string,
1824     newLocation string) (string, error) {
1825     asset, err := s.ReadAsset(ctx, id)
1826     if err != nil {
1827       return "", fmt.Errorf("failed to

```

```
1828         fetch asset: %v", err)
1829     }
1830
1831     switch role{
1832         case "Supplier":
1833             oldSupplier := asset.Supplier
1834             asset.Supplier = newParticipant
1835             asset.SellingLocationSupplier =
1836                 newLocation
1837             return oldSupplier, s.SaveAsset(ctx,
1838                     id, asset)
1839         case "Retailer":
1840             if !contains(asset.Retailers,
1841                     newParticipant){
1842                 asset.Retailers = append(
1843                     asset.Retailers,
1844                     newParticipant)
1845                 asset.
1846                     SellingLocationRetailers
1847                     = append(asset.
1848                     SellingLocationRetailers,
1849                     newLocation)
1850     }
1851     return "", s.SaveAsset(ctx, id,
1852                     asset)
1853     case "Consumer":
1854         if !contains(asset.Consumers,
```

```

1855             newParticipant) {
1856                 asset.Consumers = append(
1857                     asset.Consumers,
1858                     newParticipant)
1859             }
1860             return "", s.SaveAsset(ctx, id,
1861                         asset)
1862         default:
1863             return "", fmt.Errorf("invalid role
1864                         specified: %s", role)
1865         }
1866     }
1867 }
```

Listing A.5: TransferAsset Function

```

1868
1869     func (s *SmartContract) ReadAsset(ctx contractapi.
1870                                         TransactionContextInterface, id string) (*Asset,
1871                                         error) {
1872         assetJSON, err := ctx.GetStub().GetState(id)
1873         if err != nil {
1874             return nil, fmt.Errorf("failed to
1875                         read from world state: %v", err)
1876         }
1877         if assetJSON == nil {
1878             return nil, fmt.Errorf("the asset %s
1879                         does not exist", id)
1880         }
1881         var asset Asset
```

```

1882)         err = json.Unmarshal(assetJSON, &asset)
1883)         if err != nil {
1884)             return nil, err
1885)         }
1886)         if asset.Consumers == nil {
1887)             asset.Consumers = []string{}
1888)         }
1889)
1890)         return &asset, nil
1891)
1892}

```

Listing A.6: ReadAsset Function

```

1893
1894)     func (s *SmartContract) GetAllAssets(ctx contractapi.
1895)                                         .TransactionContextInterface) ([]*Asset, error) {
1896)         resultsIterator, err := ctx.GetStub().
1897)             GetStateByRange("", "")
1898)         if err != nil {
1899)             return nil, err
1900)
1901)         defer resultsIterator.Close()
1902)
1903)         var assets []*Asset
1904)         for resultsIterator.HasNext() {
1905)             queryResponse, err :=
1906)                 resultsIterator.Next()
1907)             if err != nil {
1908)                 return nil, err

```

```

1909:         }
1910:
1911:         var asset Asset
1912:         err = json.Unmarshal(queryResponse.
1913:                               Value, &asset)
1914:         if err != nil {
1915:             return nil, err
1916:         }
1917:         if asset.Consumers == nil {
1918:             asset.Consumers = []string{}
1919:         }
1920:         assets = append(assets, &asset)
1921:     }
1922:
1923:     return assets, nil
1924: }
1925:
```

Listing A.7: GetAllAssets Function

```

1926
1927:     async function main() {
1928:         displayInputParameters();
1929:
1930:         const client = await newGrpcConnection();
1931:
1932:         const gateway = connect({
1933:             client,
1934:             identity: await newIdentity(),
1935:             signer: await newSigner(),
```

```
1936)         hash: hash.sha256 ,  
1937)         evaluateOptions: () => ({ deadline:  
1938)             Date.now() + 5000 }),  
1939)         endorseOptions: () => ({ deadline:  
1940)             Date.now() + 15000 }),  
1941)         submitOptions: () => ({ deadline:  
1942)             Date.now() + 5000 }),  
1943)         commitStatusOptions: () => ({  
1944)             deadline: Date.now() + 60000 }),  
1945)     } );  
1946)  
1947)     try {  
1948)         const network = gateway.getNetwork(  
1949)             channelId);  
1950)         const contract = network.getContract  
1951)             (chaincodeName);  
1952)  
1953)         await initLedger(contract);  
1954)         await getAllAssets(contract);  
1955)         await createAsset(contract);  
1956)         await transferAssetAsync(contract);  
1957)         await readAssetByID(contract);  
1958)         await updateNonExistentAsset(  
1959)             contract);  
1960)     } finally {  
1961)         gateway.close();  
1962)         client.close();
```

```

1963)         }
1964)     }
1965)
1966)     main().catch((error) => {
1967)       console.error('** FAILED to run the
1968)         application:', error);
1969)       process.exitCode = 1;
1970)     });
1971)

```

Listing A.8: `main()` Function and Gateway Logic

## 1972 A.1 Hyperledger Fabric Deployment Instructions

1973 The following steps outline the process for deploying and testing the fish supply  
 1974 chain smart contract on Hyperledger Fabric using Google Cloud Platform.

### 1975 A.1.1 Environment Setup

#### 1976 1. Open GCP and access the VM instance:

- 1977 • Navigate to Console → Compute Engine → VM instances → start →  
 1978 click SSH
- 1979 • Alternatively: Virtual Machine → start → instance → SSH

#### 1980 2. Connect to the instance:

Listing A.9: Connect to GCP VM via `gcloud`

```

1982      gcloud compute ssh instance
1983          -20250322-102900 --zone=us-central1-c
1984

```

1985     3. Navigate to the test network directory:

1986       Listing A.10: Navigate to Compose Directory

```

1987      cd ~/fabric-samples/test-network/
1988      compose
1989

```

1990     A.1.2 Network Startup and Smart Contract Deployment

1991     1. Start the Hyperledger Fabric network:

1992       Listing A.11: Start Fabric Network

```

1993      sudo docker-compose -f
1994          compose-test-net.yaml
1995      start
1996

```

1997     • Deploy the chaincode:

1998       Listing A.12: Deploy Chaincode

```

1999      cd ../
2000      ./network.sh deployCC -ccn
2001          basic -ccp ../asset-
2002              transfer-basic/chaincode-
2003                  go -ccl go
2004

```

2005     • Set environment path variables:

Listing A.13: Path Environment Variables

```

2006
2007           export PATH=${PWD}/../bin:
2008           $PATH
2009
2010           export FABRIC_CFG_PATH=$PWD
2011           /../config/

```

- **Configure organization environment variables:**

Listing A.14: Org1 Environment Configuration

```

2013
2014           # Environment variables for
2015           Org1
2016           export CORE_PEER_TLS_ENABLED
2017           =true
2018           export CORE_PEER_LOCALMSPID=
2019           "Org1MSP"
2020           export
2021           CORE_PEER_TLS_ROOTCERT_FILE
2022           =${PWD}/organizations/
2023           peerOrganizations/org1.
2024           example.com/peers/peer0.
2025           org1.example.com/tls/ca.
2026           crt
2027           export
2028           CORE_PEER_MSPCONFIGPATH=$
2029           ${PWD}/organizations/
2030           peerOrganizations/org1.
2031           example.com/users/
2032           Admin@org1.example.com/

```

```

2033           msp
2034           export CORE_PEER_ADDRESS=
2035           localhost:7051
2036

```

### **2037 A.1.3 Testing the Smart Contract**

#### **2038 1. Initialize the ledger:**

Listing A.15: Invoke InitLedger

```

2039
2040     peer chaincode invoke -o localhost:7050
2041         --ordererTLSHostnameOverride orderer
2042         .example.com --tls --cafile "${PWD}/
2043             organizations/ordererOrganizations/
2044             example.com/orderers/orderer.example.
2045             com/msp/tlscacerts/tlsca.example.com-
2046             cert.pem" -C mychannel -n basic --
2047             peerAddresses localhost:7051 --
2048             tlsRootCertFiles "${PWD}/
2049             organizations/peerOrganizations/org1.
2050             example.com/peers/peer0.org1.example.
2051             com/tls/ca.crt" --peerAddresses
2052             localhost:9051 --tlsRootCertFiles "${
2053             PWD}/organizations/peerOrganizations/
2054             org2.example.com/peers/peer0.org2.
2055             example.com/tls/ca.crt" -c '{"
2056             function":"InitLedger","Args":[]}'
2057

```

2058        2. Query assets:

2059                  Listing A.16: Query Fish Asset

```
2060                  # Query a specific fish asset  
2061                  peer chaincode query -C mychannel -n  
2062                  basic -c '{"Args":["ReadAsset","tuna1  
2063                  "]}]'  
2064  
2065                  # Query all assets in the ledger  
2066                  peer chaincode query -C mychannel -n  
2067                  basic -c '{"Args":["GetAllAssets"]}'  
2068
```

2069        3. Shut down the network:

2070                  Listing A.17: Stop Fabric Network

```
2071                  sudo docker-compose -f compose-test-net  
2072                  .yaml stop  
2073
```

#### 2074        A.1.4 Important Notes

- 2075        • Ensure proper network connectivity when working with Google Cloud Platform.
- 2076
- 2077        • The environment variables must be set correctly for the organization context.
- 2078        • TLS certificates are required for secure communication between nodes.
- 2079
- 2080        • The commands assume the blockchain network is already provisioned on GCP.



<sup>2081</sup> **Appendix B**

<sup>2082</sup> **Resource Persons**

<sup>2083</sup> **Dr. Ricardo P. Babaran**

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<sup>2085</sup> Institute of Marine Fisheries and Oceanology

<sup>2086</sup> University of the Philippines Visayas

<sup>2087</sup> rpbabaran@upv.edu.ph

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<sup>2089</sup> Engineer

<sup>2090</sup> Jagnee Fishing Corp.

<sup>2091</sup> JagneeFishingCorp@outlook.com

<sup>2092</sup> **Ms. Veronica Jeruta**

<sup>2093</sup> Barangay Kagawad

<sup>2094</sup> Sapa Barangay Hall

<sup>2095</sup> veronicanave9@gmail.com



<sup>2097</sup> **Appendix C**

<sup>2098</sup> **Interview Request Letter**

<sup>2099</sup> Here is the scanned copy of the letter sent to the interviewees (Figure C.1).

Division of Physical Science and Mathematics  
College of Arts and Sciences  
University of the Philippines Visayas  
Miag-ao, Iloilo

Dear Ma'am/Sir,

Maayong adlaw! We are a group of Computer Science students from the University of the Philippines currently working on our project entitled "SeaXChange: A Blockchain-Driven App for Tuna Supply Chain Management". As part of the development and testing phase, we would like to interview selected fishermen, suppliers, retailers and consumers here in Barangay Mat-Y to gather feedback and evaluate the usability and practicality of our application. The interview will be conducted from April 21-25, 2025.

The goal of our system is to help track tuna products from the ocean to the consumers and to improve the traceability of the tuna supply chain. We believe that the insights from the fishermen, suppliers, retailers and consumers will be extremely valuable in making it more effective and user-friendly.

We respectfully request your permission to lend us your precious time to participate in our short interviews or discussions. Rest assured that all information collected will remain confidential and will be used for academic and research purposes only.

We hope for your favorable response. Thank you for your time and support!

Sincerely,  
The student researchers

  
Jeff Rouzel Bat-og  
Student Researcher

  
Maxinne Gwen Cahilig  
Student Researcher

  
Zyrex Djewel Ganit  
Student Researcher

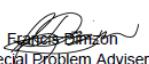
  
Francis Dimzon  
Special Problem Adviser

Figure C.1: Scanned Interview Request Letter

<sup>2100</sup> **Appendix D**

<sup>2101</sup> **App Demo Documentation**

<sup>2102</sup> As shown in Figure D.1, the respondents from Barangay Sapa, Miagao actively en-  
<sup>2103</sup> gaged in the app demonstration. Similarly, Figure D.2 illustrates the involvement  
<sup>2104</sup> of respondents from Barangay Mat-Y, Miagao during the same activity.

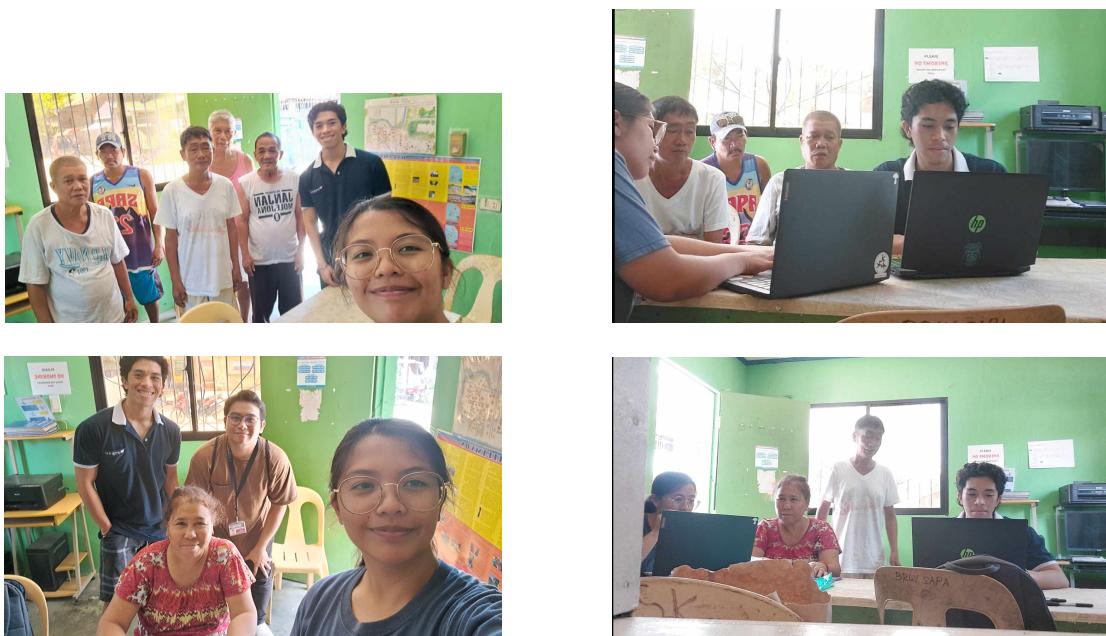


Figure D.1: Respondents (Fishermen, supplier, and retailer) from Barangay Sapa, Miagao



Figure D.2: Respondents (Retailer, and consumer) from Barangay Mat-Y, Miagao