

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

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## Dedication

“Hello, world.”

36

## Acknowledgment

37

“Hello, world.”

## Abstract

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

55 Suggested keywords based on ACM Computing Classification system can be found  
56 at [https://dl.acm.org/ccs/ccs\\_flat.cfm](https://dl.acm.org/ccs/ccs_flat.cfm)

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

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# <sup>171</sup> Chapter 1

## <sup>172</sup> Introduction

### <sup>173</sup> 1.1 Overview

<sup>174</sup> The tuna supply chain faces critical issues that affect both the industry and its  
<sup>175</sup> consumers. Illegal fishing, overfishing, and poor traceability threaten the sustain-  
<sup>176</sup> ability and ethical trade. A lack of transparency compromises product quality  
<sup>177</sup> and misleads consumers. Blockchain technology can address these challenges by  
<sup>178</sup> tracking the tuna's journey from ocean to plate through a secure, tamper-proof  
<sup>179</sup> ledger. This system also holds stakeholders to comply to legal standards.

<sup>180</sup> Although blockchain integration in the tuna sector is underway, gaps remain in its  
<sup>181</sup> implementation. This study helps to address the industry's need for transparent  
<sup>182</sup> and secure tracking of tuna products from ocean to consumer, while assessing the  
<sup>183</sup> feasibility of implementing blockchain at scale in the seafood sector.

## <sup>184</sup> 1.2 Problem Statement

<sup>185</sup> Fish is one of the most consumed protein products in the Philippines. Before the  
<sup>186</sup> COVID-19 pandemic, fish was the most consumed animal protein in the Philip-  
<sup>187</sup> pines with annual per capita consumption of 40 kg (Agriculture and Agri-Food  
<sup>188</sup> Canada, 2022). Among the wide variety of fish, tuna stands out as a particularly  
<sup>189</sup> significant commodity due to its high demand and economic value. Although the  
<sup>190</sup> nation is gifted with an abundance of aquatic resources, the methods of dispersal  
<sup>191</sup> of the product usually leads to inefficiency in terms of sales, pricing, and overall  
<sup>192</sup> product quality for the consumers. The problem arises with the introduction of  
<sup>193</sup> a supply chain from several middlemen between the fish farmer or producer and  
<sup>194</sup> wholesaler in the coastal and aquatic regions towards the consumers with less ac-  
<sup>195</sup> cess to fresh fish. Consequently, both consumers and suppliers struggle to ensure  
<sup>196</sup> transparent and fair pricing, accurately track tuna products, and maintain consis-  
<sup>197</sup> tent quality. These challenges stem from inefficient methods of product dispersal  
<sup>198</sup> and the presence of multiple intermediaries between fisherfolks in coastal munici-  
<sup>199</sup> palities and consumers. This fragmented supply chain introduces delays, obscures  
<sup>200</sup> product origin, and opens opportunities for mishandling or mislabeling. To ad-  
<sup>201</sup> dress this, the study focuses on the absence of a reliable, real-time traceability  
<sup>202</sup> system that allows stakeholders to verify the origin, novelty, handling processes,  
<sup>203</sup> and adherence to ethical sourcing practices of tuna at every stage. Without such  
<sup>204</sup> a system, the tuna supply chain and industry lack the transparency and account-  
<sup>205</sup> ability necessary to build consumer trust and improve supply chain efficiency. By  
<sup>206</sup> introducing a blockchain-driven solution, this study aims to streamline the trace-  
<sup>207</sup> ability process and reduce the negative impact of intermediary-heavy distribution.

<sup>208</sup> **1.3 Research Objectives**

<sup>209</sup> **1.3.1 General Objective**

<sup>210</sup> The general objective of the study is to design and develop a blockchain-driven  
<sup>211</sup> application that improves the traceability of the tuna supply chain. Given the  
<sup>212</sup> timely issues regarding illegal, unreported and unregulated (IUU) fishing and lack  
<sup>213</sup> of product traceability and transparency, this study addresses these challenges  
<sup>214</sup> through an application that has the capability to provide an immutable ledger  
<sup>215</sup> and tamper-proof records. The result of this study serves as a framework for  
<sup>216</sup> integrating blockchain technology in the fish supply chain, specifically for tuna.  
<sup>217</sup> This also supports future researchers and developers facing similar challenges in  
<sup>218</sup> the industry.

<sup>219</sup> **1.3.2 Specific Objectives**

<sup>220</sup> To further specify the research objectives, the study focuses to:

- <sup>221</sup> 1. develop a smart contract framework using blockchain technology for data  
<sup>222</sup> verification and transaction recording, ensuring secure and tamper-proof  
<sup>223</sup> data for the stakeholders,
- <sup>224</sup> 2. design and develop a blockchain-driven application with a user-friendly in-  
<sup>225</sup> terface that allows stakeholders to access and input data while enhancing  
<sup>226</sup> traceability in the tuna supply chain through a tuna asset record for the  
<sup>227</sup> supply chain participants, and

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

## 232        1.4 Scope and Limitations of the Research

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

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

## 245        1.5 Significance of the Research

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

248 supply chain, particularly with regards to product traceability.

249 • The Stakeholders

250 – This study enhances transparency and accountability, allowing stake-  
251 holders such as fishers, suppliers, and retailers to access tamper-proof  
252 and accurate information, thereby promoting a more ethical and au-  
253 thentic supply chain. By providing a digital record of the product's  
254 history, this study helps ensure compliance with environmental and  
255 legal standards. In cases of anomalies such as oil spills, red tide oc-  
256 currences, and illegal fishing activities, stakeholders can be involved  
257 in identifying and addressing these issues, fostering a collaborative ap-  
258 proach to sustainability. Similarly, the record of a tuna asset can be  
259 utilized for accountability purposes when problems such as damaged  
260 products, mislabeling, or contamination arise, allowing stakeholders to  
261 trace and resolve them efficiently.

262 • The Consumers

263 – This study helps consumers verify the history of the tuna product from  
264 its origin up until its journey to the consumers, therefore increasing  
265 trust and transparency. By promoting traceability, it offers a more de-  
266 tailed and verifiable record of the supply chain, enabling consumers to  
267 assess sustainability practices and identify stakeholders responsible for  
268 any potential issues affecting the tuna product. This, in turn, encour-  
269 ages critical evaluation of the tuna supply chain, driving improvements  
270 in accountability, resource management, and ethical sourcing.

271      • For Future Researchers

272            – As blockchain technology continues to grow, this study contributes to  
273                the application of blockchain in the supply chain management and the  
274                insights regarding its benefits and limitations. This research can be  
275                helpful in the growing knowledge on digital solutions for traceability  
276                and transparency for future research.

277      • The Policy Makers

278            – This study provides policy makers a reliable and data-driven founda-  
279                tion in monitoring and regulating the tuna supply chain. By lever-  
280                aging tamper-proof and transparent records, policymakers can more  
281                effectively enforce compliance with fishing quotas and environmental  
282                protections. This research also aids in lessening the illegal, unreported  
283                and unregulated (IUU) fishing practices, contributing to the national  
284                sustainability goals.

# <sup>285</sup> Chapter 2

## <sup>286</sup> Review of Related Literature

<sup>287</sup> This chapter reviews existing literature related to the traceability of the tuna sup-  
<sup>288</sup> ply chain and the potential application of blockchain technology. In purchasing  
<sup>289</sup> goods, one important consideration is the product quality. An important factor  
<sup>290</sup> of determining the quality is to know the traceability of the supply chain. Trace-  
<sup>291</sup> ability refers to the ability of tracking the journey of the product from its source  
<sup>292</sup> until its destination. The term “traceability” is now more utilized in both the  
<sup>293</sup> food and production industry (Islam & Cullen, 2021). In the context of the tuna  
<sup>294</sup> supply chain, it can be used not only to promote transparency to consumers but to  
<sup>295</sup> also ensure compliance with environmental and legal standards. With blockchain  
<sup>296</sup> technology, the status of tuna at each stage could be recorded in the blockchain  
<sup>297</sup> which could be used for traceability. This paper aims to address the following  
<sup>298</sup> research question: How can blockchain technology improve the traceability of the  
<sup>299</sup> tuna supply chain management? To explore this, the chapter reviews literature  
<sup>300</sup> on the state of the tuna industry in the Philippines, fishing regulations, and the

301 structure of the tuna supply chain, including its stages and the roles of key actors.  
302 It also examines factors that affect the efficiency and transparency of the supply  
303 chain. The discussion then turns to blockchain technology and its potential ap-  
304 plications in supply chain management, with examples from the Philippines and  
305 Indonesia. Finally, the chapter reviews existing traceability technologies and sys-  
306 tems and concludes with key insights that inform the development of this study's  
307 proposed solution.

308 In purchasing goods, one thing to consider is the quality of it. An important part  
309 of determining the quality is to know the traceability of the supply chain. Trace-  
310 ability refers to the ability of tracking the journey of the product from its source  
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313 supply chain, it can be used not only to promote transparency to consumers but to  
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315 technology, the status of tuna at each stage could be recorded in the blockchain  
316 which could be used for traceability. This paper aims to address the following  
317 research question: *How can blockchain technology improve the traceability of the*  
318 *tuna supply chain management?*

## 319 2.1 State of Tuna Industry in the Philippines

320 In 2014, the Philippines became the top global producer of tuna according to  
321 Llanto, et. al. (2018) . The tuna is caught in domestic and international fishing  
322 grounds near the country through various fishing methods such as purse seines,

323 gill nets, handline (hook and line) and ring net. Among the tuna species, the  
324 skipjack tuna accounted for the largest portion of the catch by 40%. The study of  
325 PCMARD (1993 as cited in Nepomuceno et al., 2020 ) stated that skipjack tuna  
326 are often caught out in open waters or in offshore areas. In addition, Nepomuceno  
327 et al. (2020) mentioned in their study that the dominant production of skipjack  
328 tuna, together with yellowfin tuna, was recorded in South Cotabato. The tuna  
329 supply has declined since 2000 due to various factors including overfishing, climate  
330 change, and the laws and regulations imposed by different governing bodies for  
331 the tuna fishing ground such as the Regulation No. 56, released by the Indone-  
332 sian Maritime Affairs and Fisheries Ministry in November 2014. The regulation  
333 imposed a moratorium on issuance of fishing licenses from 3 November 2014 to 30  
334 April 2015 to eliminate illegal, unreported, and unregulated fishing in Indonesian  
335 waters near Mindanao where tuna are known to thrive (Llanto et al, 2018) . The  
336 regulation imposed for the protection of tuna fishing grounds in the western and  
337 central pacific ocean also lead to the decline of local tuna production which re-  
338 quires the fishing operators of the Philippines to invest in the manufacturing and  
339 processing of fish particularly tuna in Indonesia which includes hiring Indonesian  
340 crew to be deployed in the Philippine fishing vessels (Llanto et al, 2018) .

## 341 2.2 Fishing Regulations in the Philippines

342 A study of Asche et al. (2018) divided the fishing management strategies that  
343 include right-based fishery management like territorial use of rights, access rights  
344 and harvest rights. It discussed that a rights-based system could support the sus-  
345 tainability of global fisheries by taking in account the three pillars of sustainability

346 (economic development, social development, and environmental protection) rather  
347 than focusing on their trade-offs. A restriction on the fisherman's behavior by har-  
348 vest rights and catch shares could be a profit problem for them in the short-run  
349 but in the long-run, this could help both in the fish stock and the fishermen's  
350 profit. Lack of restriction could lead to overfishing. Access rights limit the en-  
351 try to fishery through permits which can also reduce the effect of high harvest  
352 levels. A sustainable fishing management system in the Philippines is important  
353 in order to preserve marine resources. To preserve these resources and protect  
354 the livelihood of local communities, various fishing management strategies should  
355 be implemented. A collaboration between the fishermen, local government and  
356 other stakeholders often happens to manage marine resources (Pomeroy & Court-  
357 ney, 2018) . The study of Pomeroy and Courtney discussed that marine tenure  
358 refers to the rights and responsibilities in terms of who can access the marine and  
359 coastal resources. The 1998 Fisheries Code paved the way for local government  
360 units (LGUs) to be involved in the management of municipal waters. LGUs are  
361 given the responsibility to overlook and regulate fisheries and establish marine  
362 tenure rights for fishers within 15 km from shore and these rights are applicable  
363 for municipal fishers and their respective organizations that are listed in the reg-  
364 istry (Pomeroy & Courtney, 2018) . In this way, it resolved problems in terms of  
365 fishing rights between small-scale and commercial fishing.

366 According to the study conducted by Mullon et al. (2017) , the five major species  
367 of tuna: yellowfin *Thunnus albacares*, bigeye *Thunnus obesus*, bluefin *Thunnus*  
368 *thynnus* or *Thunus orientalis*, albacore *Thunnus alalunga*, and skipjack *Katsu-*  
369 *wonus pelamis* are harvested to meet the global supply chain demand which causes  
370 those group of tuna fishes to be heavily exploited and threatened. The study con-

371 ducted by Paillin et al. (2022) states that there are multiple risk agents in the  
372 supply chain assessment of tuna, these include the lack of standard environmental  
373 management system, lack of maintenance management, and lack of quality control  
374 from suppliers. The usage of efficient boats and good quality catching technology  
375 can also lead to fisheries depletion which causes various agency such as BFAR  
376 (Bureau of Fisheries and Aquatic Resources), the local government units, and the  
377 Philippine Coast Guard to enable policies for upholding closed fishing season to  
378 restrict large scale fishing vessel to minimize the fishing activities in the iden-  
379 tified areas (Macusi et al, 2023) . The implementation of closed fishing season  
380 caused delay or lack of fish supply, which led to higher fish prices. The growing  
381 demands and depleting population of tuna fishes coupled with the rapid increase  
382 in fuel costs can have a negative impact on the future of the supply chain in tuna  
383 fisheries (Mullon et al., 2017) . With factors concerning the slow decline of tuna  
384 catches in the Philippines and surrounding nations, the future of the global supply  
385 chain of tuna must be addressed.

### 386 2.3 Tuna and Fish Supply Chain

387 According to Macusi et al (2023) , the implementation of traceability programs in  
388 the agricultural product commodities and value chain in the Philippines is slower  
389 than its competing nation for tuna production. The Philippines has been steadily  
390 responding to the market innovation and integration of cost-effective and smart  
391 technologies for the traceability of various commodities. Accurate catch data is  
392 crucial for determining the attributes of the fish health, size, volumes, and matu-  
393 rity (Grantham et al, 2022) which can be used as a basis for the transparency of

394 the traceability of the fish product. Illegal, unreported, and unregulated (IUU)  
395 is another concern for the fish industry. In the 2000s, the persistent IUU became  
396 a global crisis affecting the biological, ecological, and socio-economics factors re-  
397 volving around marine livelihood in Southeast Asia (Malinee et al, 2020) . IUU  
398 fishing is known to cause short- and long-term problems in the socio-economic  
399 opportunities which affects food security and results in the possible collapse of  
400 the fish industry and stocks due to overfishing (Malinee et al, 2020) .

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

## 411 2.4 Tuna Supply Chain Stages and Roles

412 The study conducted by Delfino (2023) highlights the roles of different actors  
413 involved in the supply, production, distribution, and marketing of skipjack tuna  
414 in Lagonoy Gulf in the Philippines. The study showcased a total of eleven inter-  
415 connected value chains but are generalized into four major stages or roles - fishers,

416 wholesalers, retailers, and processors. The fishers are the initial players responsible  
417 for catching fish using boats or fishing vessels equipped with purse seines, gillnets,  
418 and handlines(hook and line). Wholesalers are the actors for selling freshly caught  
419 fish locally and regionally, they receive the fish supply directly from the fishers.  
420 The next stage after wholesalers are the retailers, these intermediaries sell the fish  
421 product to local markets, house-to-house (*libod*" in Visayan languages), and other  
422 local medium such as *talipapa* or fish stands. Another intermediary is the proces-  
423 sors, they convert fresh skipjack tuna into products like smoked tuna. The given  
424 stages also overlapped in some cases as there are fisher-wholesalers who catch and  
425 sell the fishes directly to retailers and there are also retailer-processors that both  
426 sell whole and processed products. Despite having a firm system to transport fish  
427 from sea to table, all the actors face problems during seasonal challenges involving  
428 the availability of the tuna product. The fishers also need to consider strict local  
429 regulations such as RA 10654 and RA 8550. The strict implementation of RA  
430 10654 and RA 8850 at the local level or the Fisheries Code of the Local Philip-  
431 pines aims to curb the problem encountered during season of deficit tuna supply  
432 by limiting fishing activities and implementation of 15-km boundary lines in the  
433 municipal waters of each municipality (Delfino, 2023) . The study suggests that  
434 improving conditions for value chain actors, particularly through support services  
435 and government involvement could lead to a stable and sustainable exchange of  
436 skipjack tuna and other seafood products from sea to table.

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

441 2017) . This type of catching often targets dense fishes like tuna. Skipjack fishes  
442 that weigh 300 grams and above are often sold to canneries, while the smaller ones  
443 are sold at local markets, often used for consumption by Filipinos. Purse seiners  
444 are usually employees of a fishing company and they have a fixed salary. They  
445 could reach international waters so they need to bring their passports with them.  
446 Jamboleros, who act as distributors, often buy from different fishing companies  
447 per *banyera* or tub. They will then pack the fish and sell it to traders/truckers  
448 who go to General Santos fishport. These traders will deliver it to the retailers  
449 across Kidapawan who contacted them. There is no formal contract between the  
450 jambolero and traders/truckers. One of the issues of the retailer is for everyday  
451 that a fish is not sold, they would have a ₱10.00 less per kilogram.

## 452 2.5 Factors Affecting the Tuna Supply Chain

453 The tuna supply chain faced several factors and challenges for the safety and  
454 quality of the product (Mercogliano & Santonicola, 2019) . Without the proper  
455 handling of the tuna after catching it can lead to various food-borne diseases and  
456 outbreaks. The most frequent and mitigated food-borne causing compound is  
457 Histamine(HIS) which causes Scombrotoxin fish poisoning (SPF) outbreaks re-  
458 lated to food allergies when consumed (EFSA, 2017; Peruzy et al., 2017). Tuna  
459 species are known for having high presence of amino acid histidine concentrations  
460 which are converted to HIS by bacterial enzyme histidine-decarboxylase or HDS  
461 (Aponte et al., 2018; Verkhivker & Altman, 2018) . To combat the risk of SPF  
462 and other food-borne diseases caused by tuna consumption, several safety hazards  
463 and protocols were imposed to the tuna supply chain management. The term cold

464 chain refers to the storing of fish in temperatures less than 5°C after it was caught  
465 (Yang & Lin, 2017). According to the article published by Mercogliano and San-  
466 tonicola (2019), implementing a cold chain from the time the fish is caught until it  
467 is consumed is crucial for mitigating the outbreak of HIS poisoning. Additionally,  
468 the article also states that using high-quality raw tuna, cold chain maintenance,  
469 pre-cooking, and cooking can also reduce HIS development.

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

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

## <sup>487</sup> 2.6 Technology of Blockchain

<sup>488</sup> According to Zheng et al. (2017) , the idea of blockchain was first introduced in  
<sup>489</sup> 2008 and was first implemented in the Bitcoin business which deals with cryp-  
<sup>490</sup> tocurrencies. This kind of technology tracks transactions and stores it in a list of  
<sup>491</sup> blocks. According to Sarmah (2018) , it acts as a database of transactions which  
<sup>492</sup> is overseen and verified by distributed nodes. Blockchain works by linking blocks  
<sup>493</sup> (where data is stored). When a transaction is initiated, it is then broadcasted to  
<sup>494</sup> a network of computers that verifies the transaction and if the verification is suc-  
<sup>495</sup> cessful, it will then be grouped and linked with the previous transactions that will  
<sup>496</sup> be added to the blockchain (Zheng et al., 2017) . It does not require a middleman  
<sup>497</sup> because it operates on a peer-to-peer transaction. This eliminates the traditional  
<sup>498</sup> way of a central authority like the bank (Sarmah, 2018) .

<sup>499</sup> Automated process of transactions is also one of the salient features of blockchain  
<sup>500</sup> which is executed automatically based on predefined rules involving no third par-  
<sup>501</sup> ties. These predefined rules are conditions that need to be met in order for the  
<sup>502</sup> transaction to proceed. Given this, blockchain is described to be a “trust-free  
<sup>503</sup> technology” since it reduces the number of trusted individuals instead they trust  
<sup>504</sup> the machine itself which is difficult to manipulate given its cryptographic security  
<sup>505</sup> (Ali et al., 2023). Blockchain also ensures immutability with its data. Once the  
<sup>506</sup> data has been added to the blockchain, it is difficult to change since each block has  
<sup>507</sup> a cryptographic link to other blocks, which guarantees that the data is tamper-  
<sup>508</sup> proof and permanent (Ali et al., 2023). This also brings back to the essence  
<sup>509</sup> of blockchain being trustworthy. Immutability and tamper-proof enhances data  
<sup>510</sup> management. It also helps prevent fraudulent activities especially with finances.

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

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

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

## 529 **2.7 Opportunities of Blockchain Technology for** 530 **Supply Chain Management**

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

533 2024) . Companies and various industries are heavily relying on supply chains to  
534 achieve their business objectives. The purpose of supply chain began to be more  
535 significant in the last century as firms discovered that supply chain can be used for  
536 competitive advantage instead of just a cost driver as believed in the bygone days  
537 (Snyder & Shen, 2019) . Following the supply chain paradigm can demonstrate  
538 the delivery of a product or service while strongly emphasizing the customer's  
539 specifications. With the increasing studies conducted and published for supply  
540 chain, many companies adopted this practice for the benefit of their longevity,  
541 as such the term supply chain management has come into place. The Council of  
542 Supply Management Professionals or CSCMP (2024) defines supply chain man-  
543 agement as the planning and management of all activities involved in sourcing  
544 and procurement, conversion, and all logistics management activities; essentially,  
545 supply chain management integrates supply and demand management within and  
546 across the company. Supply chain management is also involved with the relation-  
547 ship with collaborators and channel partners such as suppliers, intermediaries,  
548 third party providers, and customers (CSCMP, 2024) .

549 In the article of Cordova et. al (Cordova et. al, 2021) , the role of supply chain  
550 management and the growing opportunities for blockchain technology in supply  
551 chain management was discussed. According to Cordova (2021) , the recent in-  
552 novation and globalization has given rise to the idea of using a data innovation  
553 framework for supply chain management. Technologies such as blockchains and  
554 enterprise resource planning (ERP) are among the highly contested platforms for  
555 supply chain management to operate in a seamless interaction and distribution  
556 with the product while heavily relying on modern technology and innovations.  
557 The logistic business of the supply chain market is wide and complex, the distri-

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

558 button and flow of products is not a simple job, and it heavily relies on paperwork  
559 (Georgiou, 2019; Cordova et. al, 2021) . The usage of paperwork for logistic  
560 business can be at higher risk for lack of transparency, complex or unreliable  
561 tracking, deficiency of information, and possible dispute due to the tendency of  
562 paper to disappear or tear down, this can in turn delay the process and delivery  
563 of the item/product. With the issues encountered in the supply chain market,  
564 businesses, people and enterprises are eyeing toward the application of blockchain  
565 technology on supply chain management (Cordova et. al, 2021) .

566 Implementing blockchain innovation in ERP systems and companies that use digi-  
567 tal platforms can provide opportunities and contribute greatly for business pro-  
568 cesses (EOS Costa Rica, 2019 as cited by Cordova et al, 2021) . The ability of  
569 blockchain technology to append new transactions to an existing block containing  
570 data can be thought of as a decentralized ledger (Cole et al, 2019) . The method  
571 of blockchain to behave like a decentralized ledger can serve as a single unified  
572 source of data which in turns create a clear and consistent audit trail involved  
573 in the manufacturing, assembly, supply, and maintenance processes. According  
574 to Cole et al (2019) , blockchains provide data to the movement and relation  
575 of products from its origin, inventory, shipment, and purchase. One potential of  
576 blockchain for supply chain management (Hackius & Petersen, 2017) is the ease of  
577 paperwork processing, specifically in ocean freight. When IBM and Maersk settled  
578 for a permissioned blockchain solution, they were able to connect a global network  
579 of shippers, carriers, ports, and customs. Another potential of blockchain in SCM  
580 is to identify counterfeit products. In the pharmaceutical industry and healthcare  
581 setting, blockchain could improve patient safety and hazard through establishing  
582 supply chain transparency from manufacturers through wholesale and pharmacies

583 to the individual patients (Hackius & Petersen, 2017) . Using blockchain can  
584 make it harder to tamper or alter the products chain of origin with illegal and  
585 counterfeit products. Blockchain have the potential to facilitate origin tracking.  
586 According to Cordova et al (2021) , blockchain allows organizations to input rel-  
587 evant data inside a chain which would have constant updates and tracking, this  
588 supports visibility and traceability of the origin of the product. Smart contracts,  
589 an executable code and a feature of blockchain, serves as a computer protocol  
590 made between participants to digitally facilitate, execute, verify, and enforce an  
591 agreement or terms of contract which is then stored in the blockchain (Khan et  
592 al, 2021) .

## 593 **2.8 Supply Chain Model with Blockchain Tech- 594 nology of Fishing Industry in Indonesia**

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

602 **2.9 Existing Technology Intended for Traceabil-**

603 **ity and Supply Chain**

604 A study of Shamsuzzoha et al. (2023) discussed the feasibility of implementing a  
605 blockchain driven application called ‘Tracey’ for monitoring the fish traceability  
606 in supply chain management. The study utilized the theoretical framework devel-  
607 oped by Islam & Cullen (2021) for improving the understanding and effectiveness  
608 of implementing a food traceability system. The framework consists of four prin-  
609 ciples as a basis for the supply chain management: identification, data recording,  
610 data integration, and accessibility (Islam & Cullen, 2021) . The Tracey applica-  
611 tion utilized a public-private hybrid blockchain-based conceptual framework by  
612 Mantravadi and Srai (2023) to uphold the transparency, traceability, and certifi-  
613 cation of the sea food produce, specifically shrimp. The prototype being studied  
614 by Shamsuzzoha et al. (2023) called Tracey focuses on the mobile-based solution  
615 approach, the study found that the most widely used smartphone type in the  
616 Philippines is the android phone which is where the Tracey prototype is intended  
617 to be used. The Tracey app allows fishermen to log their catch details and buyers  
618 to verify and update transaction history (Shamsuzzoha et al., 2023) . The Tracey  
619 app uses a central database for storing fish trading data and a decentralized ledger  
620 or blockchain for traceability purposes. The decentralized ledger acts as a tamper-  
621 proof copy of the data recorded by fishermen and buyers. The result of the study  
622 finds that fishermen are open to using digital methods for payments and confiden-  
623 tiality which is required for exporting the fish product to maintain high standards  
624 for traceability, catch certification, and product quality. The usage of blockchain  
625 as exemplified by the Tracey project can be used for upholding the restriction

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

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

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

## 2.10 Developing a Traceability System for Tuna Supply Chains

The study of Kresna et al. (2017) , proposed an IT-based traceability system for tuna supply chain as opposed to the traditional paper based traceability sys-

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

The journal article of Tiwari (2020) called Application of Blockchain in Agri-Food Supply Chain conducted two case studies for a blockchain driven app built for supply chain related to food, fishing, and agriculture. The first case-study is the usage and effectiveness of the Provenance system for tuna tracking certification. The objective of the Provenance system is to enhance transparency in the tuna supply chain by ensuring certification and standard compliance across all roles(e.g. supplier, retailer) in the chain. The system is built using six modular programs: registering, standards, production, manufacturing, tagging, and user-interface. The usage of blockchain in the Provenance system allows transactions to be recorded to allow shared ledger for transparency and smart contracts for secure exchanges of money or information. The usage of the Provenance system is to solve the issues encountered in the tuna fishing industry affected by various factors such as illegal, unregulated, unauthorized (IUU) fishing, fraud, and human rights abuses. The solution of the Provenance system is to allow tracking, tracing, and certification of tuna using blockchain. The Provenance system has a smart tag-

698 ging feature that allows fishermen to use SMS for digital assets on the blockchain  
699 to track where the fish, in return, all supply chain stakeholders can access the  
700 data that was sourced from the SMS. The second case-study is the usage of the  
701 IBM Food Trust for transparency in the food supply chain. The IBM Food Trust  
702 aims to solve the problems in the food supply chain, specifically in product safety.  
703 Locating supply chain items in real-time using identifiers like GTIN or UPC is  
704 the primary feature of the IBM Food Trust. The app also provides end-to-end  
705 product provenance, real-time location and status, and facilitates rapid product  
706 recalls. The IBM Food Trust also provides insights and visibility for the freshness  
707 of the product to reduce losses and spoilage. Lastly, the IBM Food Trust provides  
708 certifications from the information taken when handling and managing the prod-  
709 ucts in the supply chain. The case studies conducted by Tiwari (2020) illustrates  
710 the potential of blockchain technology in improving transparency, efficiency, and  
711 ethical practices within supply chains.

## 712 2.11 Chapter Summary

### 713 2.11.2 Research Gaps and Problem

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

### 2.11.1 Comparison Table of Related Studies

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

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

719 tion, digital literacy, and connectivity.

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

**725 2.11.3 Summary**

726 The literature reviewed highlighted the critical challenges and opportunities re-  
727 garding the tuna supply chain, particularly in the areas of traceability and sustain-  
728 ability. Existing supply chain technologies, especially those utilizing blockchain,  
729 present solutions but also come with limitations in terms of blockchain adoption.

730 The application of blockchain technology in the tuna supply chain has shown po-  
731 tential for enhancing traceability from ocean to consumer.

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



# <sup>735</sup> Chapter 3

## <sup>736</sup> Research Methodology

<sup>737</sup> This chapter outlines a clear and detailed description of the research methods and  
<sup>738</sup> processes used in the development and evaluation of SeaXChange: A Blockchain  
<sup>739</sup> Driven App for Tuna Supply Chain Management. The algorithms, systems, theo-  
<sup>740</sup> ries, framework and models are described in detail in which this chapter establishes  
<sup>741</sup> the foundation of this study .This chapter also explains the data collection method  
<sup>742</sup> used ensuring the validity and reliability of the results.In addition, the chapter  
<sup>743</sup> discusses the considerations and potential limitations of this study. Overall, this  
<sup>744</sup> will serve as a guide for the readers in understanding the structured process of  
<sup>745</sup> developing the SeaXChange.

### <sup>746</sup> 3.1 Software Development

<sup>747</sup> Scrum is a framework within the Agile development that prioritizes flexibility.  
<sup>748</sup> It is an iterative software development approach that lets a project be broken

749 down into phases and emphasizes continuous improvements. For this study, the  
750 researchers opted to use Scrum because it involved many stakeholders and it  
751 operated in a ever-changing environment. Scrum allowed the team to adapt to  
752 new requirements through structured sprint planning, weekly reports, and sprint  
753 reviews, ensuring continuous alignment with project goals.

## 754 3.2 Research Activities

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

### 762 3.2.1 Feedback Collection Method

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

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

### 777 3.2.2 Data Gathering

#### 778 • Primary Data:

- 779 – Stakeholder(Fishermen, Supplier, Retailers, and Consumers) interviews  
780 were conducted to identify the use-case and user requirements, interface  
781 usability, and adoption challenges.
- 782 – Observations were made of existing tuna supply chain processes in local  
783 settings.

#### 784 • Secondary Data:

- 785 – Literature review was conducted on blockchain applications in supply  
786 chain management and product traceability.
- 787 – Industry reports and regulatory documents related to tuna fishing and  
788 supply chain operations.

### 789 3.2.3 Designing and Developing the System

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

793 2. **Technology Stack:**

794 • Front-end Development: Used React for creating a secure and user-  
795 friendly interface for stakeholders, prioritizing simple and responsive  
796 user-interface.

797 • Back-end Development: Used Node.js along with Express for managing  
798 back-end processes and API integration. Express is a flexible web applica-  
799 tion framework for Node.js used to build APIs for web applications.  
800 Docker for containerization of the project and Windows Subsystem for  
801 Linux (Ubuntu as the Linux distribution) for setting up the network.

802 • Cloud Infrastructure: Used Google Cloud to host backend services and  
803 manage the databases, where the app could be accessed globally. It  
804 also ensured the app could scale smoothly as more data and users were  
805 added.

806 • Blockchain Framework: Used Go language for developing smart con-  
807 tracts and providing an immutable ledger for transaction data.

808 • Database for Accounts: Used Firebase managing user accounts and  
809 authentication.

810 3. **Blockchain Development Platform:**

- 811           • Used Hyperledger Fabric for its permissioned nature and scalable ar-  
812           chitecture.
- 813           • The open-sourced resources and timely updates of Hyperledger Fabric  
814           components is ideal for creating a distributed ledger for tuna supply  
815           chain.

### 816       **3.2.4 Implementing Algorithms and Services**

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

#### 821       **1. Consensus Algorithm**

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

#### 829       **2. Cryptographic Algorithm**

830       The project employed several cryptographic algorithms to ensure security  
831       and privacy. These cryptographic data served as digital signatures and iden-  
832       tity verification for the project. ECDSA (Elliptic Curve Digital Signature

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

### 3. Membership Service

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

### 4. Ordering Service

The ordering service in this study played a crucial role in maintaining the integrity and functionality of the blockchain network. Its primary responsibilities included ensuring that transactions are processed in the correct sequence (transaction ordering), grouping transactions into blocks based on configurable parameters like size or timeout (block creation), and distributing these ordered blocks to peers for validation and commitment (block

858 distribution) (Nassar et al, 2024). Additionally, the ordering service pro-  
859 vided fault tolerance to ensure the network remains operational even in the  
860 presence of node failures through Raft.

861 **5. Endorsement Policy**

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

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

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

876 **3.2.5 Modeling the System Architecture**

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

881      • **Blockchain Architecture**

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

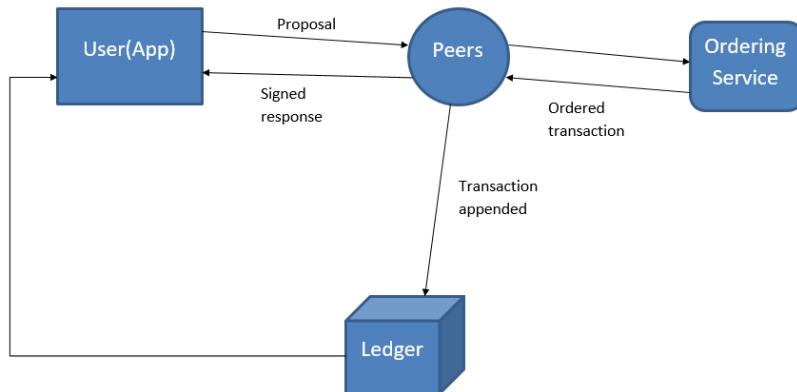


Figure 3.1: Blockchain Architecture of SeaXChange

892      • **Overall System Architecture**

893      The overall system architecture contains a web application built with Next.js  
 894      for the frontend, utilizing Firebase for user authentication and account man-  
 895      agement. The application follows a role-based access model (Fisher, Sup-  
 896      plier, Retailer, Consumer) where each role has specific permissions for inter-

897       acting with tuna assets in the supply chain. The backend runs on Google  
 898       Cloud Platform, consisting of an Express.js API that interfaces with a Hyperledger Fabric blockchain network (containerized in Docker) which stores  
 899       and manages the immutable record of tuna assets and their transfers between supply chain participants. This architecture enables secure tracking  
 900       of tuna from creation by fishers through the supply chain to consumers, with appropriate viewing and transfer capabilities assigned to each role in  
 901       the process.  
 902  
 903  
 904

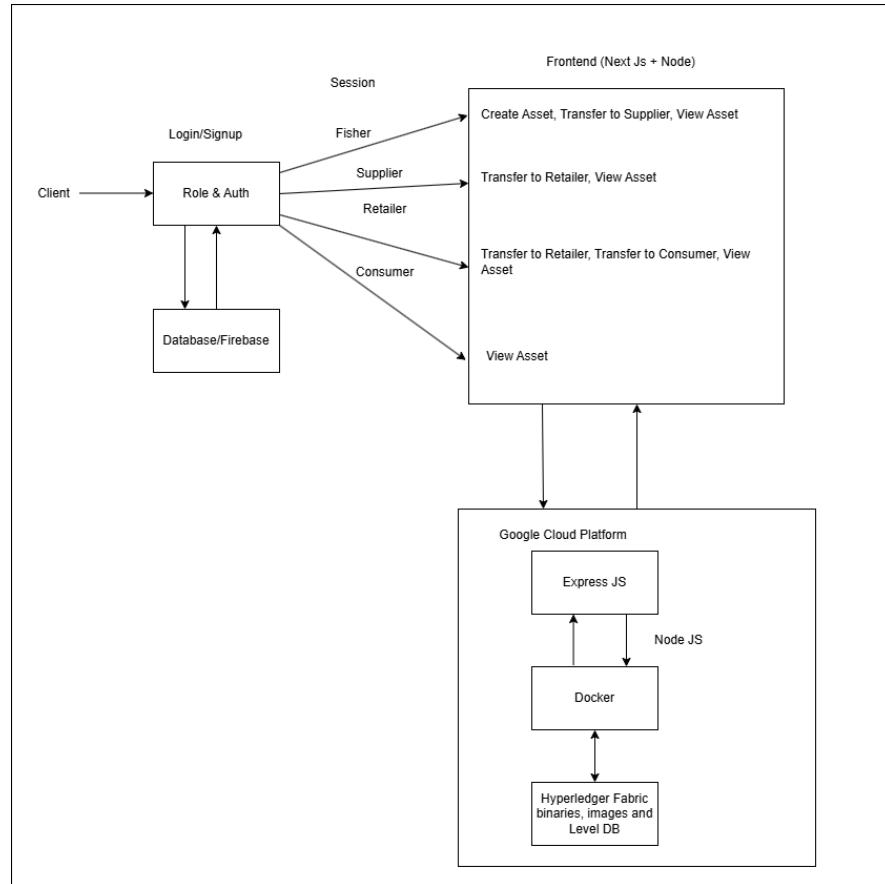


Figure 3.2: Overall System Architecture of SeaXChange

905       • Use Case

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

909       **1. Fisher**

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

915       **2. Supplier**

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

919       **3. Retailer**

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

924       **4. Consumer**

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

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

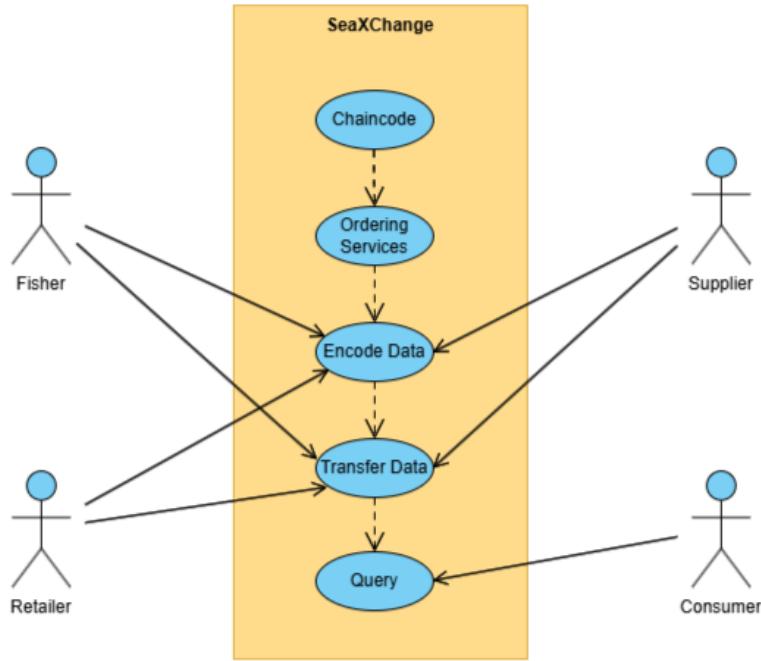


Figure 3.3: Use case diagram for SeaXChange.

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



<sup>939</sup> **Chapter 4**

<sup>940</sup> **Results and Discussions**

<sup>941</sup> **4.1 Overview**

<sup>942</sup> This chapter presents the results of the system. Included in this chapter are  
<sup>943</sup> screenshots and the discussion of results. The tuna supply chain management  
<sup>944</sup> smart contract on Hyperledger Fabric has been initiated and tested within a con-  
<sup>945</sup> trolled blockchain environment. Results indicated that the system was function-  
<sup>946</sup> ally robust and reliable, having managed assets, transaction integrity, and the  
<sup>947</sup> ability to query and update the ledger in the blockchain. This chapter presents  
<sup>948</sup> the details of the major steps executed during the process, results for those steps,  
<sup>949</sup> and the current status of the system's operations.

950 **4.2 Smart Contract Deployment and Installation**

951

952 **4.2.1 Hyperledger Fabric Prerequisites**

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

961 • **Software Requirements:**

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

```
972     git clone -b release-2.4 --single-branch  
973     https://github.com/hyperledger/fabric-samples  
974     cd fabric-samples/test-network  
975
```

976 – **Binaries and Docker Images:**

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

```
978
```

979 • **Network Setup:**

- ```
980 – Run the test-network script to start the Hyperledger Fabric test net-  
981 work:
```

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

```
983
```

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

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

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

```
989
```

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

- ```
991 – Step 1:
```

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

```
993
```

994 – Step 2:

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

```
996
```

997 – Step 3:

```
998     export CORE_PEER_TLS_ENABLED=true
999     export CORE_PEER_LOCALMSPID="Org1MSP"
1000    export CORE_PEER_TLS_ROOTCERT_FILE=${PWD}/organizations
1001    /peerOrganizations/org1.example.com/peers/peer0.org1.example.com
1002    /tls/ca.crt
1003    export CORE_PEER_MSPCONFIGPATH=${PWD}/organizations
1004    /peerOrganizations/org1.example.com/users
1005    /Admin@org1.example.com/msp
1006    export CORE_PEER_ADDRESS=localhost:7051
1007
1008
```

### 1009 4.2.2 Invoking the Blockchain System

1010 After setting up the prerequisites, including Docker containers, the test network,  
 1011 and chaincode, the tuna supply chain system can now be invoked for creating,  
 1012 transferring, and querying tuna assets. The figures provided below demonstrate  
 1013 the processes involved in invoking the blockchain system.

## 4.2. SMART CONTRACT DEPLOYMENT AND INSTALLATION

45

```
[root@ryrex2002@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network]# peer chaincode query -C mychannel -n basic_cc -f "QueryAllAssets"
[{"ID": "tuna1", "Species": "Skipjack", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-01", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierX", "Retailer": "Reyes"}, {"ID": "tuna2", "Species": "Yellowfin", "Weight": 8.5, "CatchLocation": "Palawan", "CatchDate": "2024-12-02", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierY", "Retailer": "Cruz"}, {"ID": "tuna3", "Species": "Bluefin", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierZ", "Retailer": "Cruz"}, {"ID": "tuna4", "Species": "Albacore", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-04", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierA", "Retailer": "MA"}, {"ID": "tuna5", "Species": "Albacore", "Weight": 6, "CatchLocation": "Davao", "CatchDate": "2024-12-05", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierB", "Retailer": "MA"}, {"ID": "tuna6", "Species": "Albacore", "Weight": 6, "CatchLocation": "Davao", "CatchDate": "2024-12-06", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierC", "Retailer": "MA"}]
[ryrex2002@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network]
```

Figure 4.1: Query Smart Contract: Check assets

1014     • Adding new tuna assets:

1015       Here, a new tuna asset is created and registered on the blockchain. This in-  
 1016       volves invoking the smart contract to add a new entry, which includes details  
 1017       such as the type of tuna, quantity, and any other relevant information. This  
 1018       step ensures that newly caught or acquired tuna can be tracked throughout  
 1019       the supply chain.

```
[root@ryrex2002@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network]# peer chaincode invoke -o localhost:7050 --ordererTLSHostnameOverride orderer.example.com --tlsRootCertFile $PWD/organizations/ordererOrganizations/example.com/msp/tlscacerts/tlscacert.pem -C mychannel -n basic_cc -peersAddresses localhost:9051 --tlsRootCertFiles "$PWD/organizations/peerOrganizations/org1.example.com/peers/peer0.org1.example.com/tls/ca.crt" --peerAddresses localhost:9051 --tlsRootCertFiles "$PWD/organizations/peerOrganizations/org2.example.com/peers/peer0.org2.example.com/tls/ca.crt" -c '{"function": "CreateAsset", "Args": ["tuna7", "Skipjack", "6.5", "2024-12-07", "Antique", "Longline", "Jagnew", "SupplierA", "Retailer"]}'
ChaincodeCmd: chaincodeInvokeOrQuery >> Chaincode invoke successful, result: status:200
[ryrex2002@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network]
```

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

1020     • Check all assets after adding a new tuna asset:

1021       After adding a new tuna asset, the smart contract is queried again to verify  
 1022       that the asset has been successfully added. This step confirms that the new  
 1023       asset is part of the current inventory and that no discrepancies exist in the  
 1024       recorded data.

```
[root@ryrex2002@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network]# peer chaincode query -C mychannel -n basic_cc -f "QueryAllAssets"
[{"ID": "tuna1", "Species": "Skipjack", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-01", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierX", "Retailer": "Reyes"}, {"ID": "tuna2", "Species": "Yellowfin", "Weight": 8.5, "CatchLocation": "Palawan", "CatchDate": "2024-12-02", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierY", "Retailer": "Cruz"}, {"ID": "tuna3", "Species": "Bluefin", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierZ", "Retailer": "Cruz"}, {"ID": "tuna4", "Species": "Albacore", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-04", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierA", "Retailer": "MA"}, {"ID": "tuna5", "Species": "Albacore", "Weight": 6, "CatchLocation": "Davao", "CatchDate": "2024-12-05", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierB", "Retailer": "MA"}, {"ID": "tuna6", "Species": "Albacore", "Weight": 6, "CatchLocation": "Davao", "CatchDate": "2024-12-06", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierC", "Retailer": "MA"}, {"ID": "tuna7", "Species": "Skipjack", "Weight": 6.5, "CatchLocation": "Antique", "CatchDate": "2024-12-07", "FishingMethod": "Longline", "Vessel": "Jagnew", "Supplier": "SupplierA", "Retailer": "MA"}]
[ryrex2002@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/fabric-samples/test-network]
```

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

1025     • Transfer tuna asset to Supplier:

1026       This step involves transferring ownership of a tuna asset from the current

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

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

- Check the updated tuna asset:

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

#### • 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.

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

1042     • **Check the updated tuna asset:**

1043       After the transfer to the retailer, another query is made to verify the updated  
1044       asset details. This step ensures that the transaction was successful and that  
1045       the retailer now has ownership of the tuna asset. It confirms that the asset  
1046       has moved through the supply chain correctly.

```
zyrex2082@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args":["ReadAsset","tuna6"]}'  
[{"ID": "tuna6", "Species": "Skipjack", "Weight": 6.5, "CatchLocation": "Antique", "CatchRate": "200-12-01", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Jose"}]  
zyrex2082@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network$
```

Figure 4.7: Query Smart Contract: Check asset after transfer

1047     • **Query Smart Contract and check updated assets:**

1048       The final step involves querying the smart contract to get a complete overview  
1049       of all the assets in the supply chain. This includes all tuna assets from fishing  
1050       to retail, allowing stakeholders to monitor and manage inventory effectively.  
1051       It provides traceability in the supply chain, helping to maintain freshness  
1052       and authenticity of the tuna as it moves through the market.

```
zyrex2082@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network$ peer chaincode query -C mychannel -n basic -c '{"Args":["GetAllAssets"]}'  
[{"ID": "tuna1", "Species": "Skipjack", "Weight": 6.5, "CatchLocation": "Antique", "CatchRate": "200-12-01", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Reyes"}, {"ID": "tuna2", "Species": "Yellowfin", "Weight": 8.5, "CatchLocation": "Palawan", "CatchDate": "2024-12-02", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Reyes"}, {"ID": "tuna3", "Species": "Bluefin", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Santos"}, {"ID": "tuna4", "Species": "Bull", "Weight": 5.5, "CatchLocation": "Antique", "CatchDate": "2024-12-03", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Santos"}, {"ID": "tuna5", "Species": "Albacore", "Weight": 6, "CatchLocation": "2024-12-05", "CatchDate": "2024-12-05", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Mia"}, {"ID": "tuna6", "Species": "Skipjack", "Weight": 6, "CatchLocation": "2024-12-05", "CatchDate": "2024-12-05", "FishingMethod": "Longline", "Vessel": "Jagnee", "Supplier": "SupplierA", "Retailer": "Mia"}]  
zyrex2082@LAPTOP-Q93UQUB8:/mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network$
```

Figure 4.8: Query Smart Contract: Check updated assets

1053 **4.3 Backend Security Analysis (Hyperledger Fab-**

1054 **ric on GCP)**

1055 **4.3.1 System Architecture and Deployment Overview**

1056 The backend of the system's tuna assets was developed using a containerized  
1057 Hyperledger Fabric deployed on Google Cloud Platform (GCP). The network of  
1058 Hyperledger Fabric consists of a peer node, an ordering node, and Certificate  
1059 Authorities (CAs).

1060 **4.3.2 Blockchain Network Security**

1061 The blockchain network leverages Hyperledger Fabric's security model to ensure  
1062 authenticated transactions and controlled access. A Membership Service Provider  
1063 (MSP) manages identities and issues certificates based on a Public Key Infrastruc-  
1064 ture (PKI) model, ensuring that only verified participants can interact with the  
1065 network.

1066 Key security features include:

1067 **Channel Privacy**

1068 Channels act as private communication subnets, isolating transaction data so that  
1069 only authorized organizations can access and process specific transactions.

### *4.3. BACKEND SECURITY ANALYSIS (HYPERLEDGER FABRIC ON GCP)49*

#### **1070 Policies and Access Control**

1071 Policies, including endorsement policies and access control lists (ACLs), govern  
1072 how transactions are validated, how channel resources are accessed, and how  
1073 changes to the network are approved. Endorsement policies specifically define  
1074 which peer nodes must approve a transaction before it is committed to the ledger.

#### **1075 Secure Communication**

1076 Transport Layer Security (TLS) is enforced across node communications to protect  
1077 data in transit. Mutual TLS is used for operational endpoints like monitoring  
1078 services.

#### **1079 Identity and Role Management**

1080 Every network participant—peer nodes, orderer nodes, client applications (SeaX-  
1081 Change Web Application)—has a cryptographically verifiable identity, with roles  
1082 defined within the framework to control access and permissions within channels.

#### **1083 Hardware Security Modules (HSMs)**

1084 Critical cryptographic operations, such as signing transactions under the blockchain  
1085 assets invocation, can optionally be handled by HSMs to secure private keys out-  
1086 side of the software environment.

1087 These layered mechanisms collectively ensure the confidentiality, integrity, and

1088 authenticity of transactions in the blockchain network.

### 1089 4.3.3 Smart Contract Automated Test Result

1090 To validate the security and functionality of the deployed smart contracts on the  
 1091 Hyperledger Fabric network, an automated testing script (app.js) under asset-  
 1092 transfer-basic directory was executed. The script interacted with the blockchain  
 1093 network through the gateway application, utilizing the defined channel (mychan-  
 1094 nel) and chaincode (basic). The automated tests performed the following opera-  
 1095 tions:

#### 1096 InitLedger Transaction

1097 The ledger was initialized by creating a predefined set of tuna asset entries. The  
 1098 transaction was successfully committed, confirming the proper initialization of  
 1099 asset data. (See Figure 4.9 for initialization confirmation.)

```
cd /opt/gopath/src/github.com/SpecialProblem/hyperledger-fabric-samples/asset-transfer-basic/application-gateway/javascript/src; node app.js
channelName: mychannel
chaincodeName: basic
msp: Org1MSP
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
certDirectoryPath: /mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/users/User1@org1.example.com/msp
signcerts
tlsCertPath: /mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/peers/peer0.org1.example.com/tls
caCertPath: /mnt/c/SpecialProblem/hyperledger-fabric3/Fabric-samples/test-network/organizations/peerOrganizations/org1.example.com/ca/tls
peerEndpoint: localhost:7051
peerHostAlias: peer0.org1.example.com
--> Submit Transaction: InitLedger, function creates the initial set of assets on the ledger
*** Transaction committed successfully
```

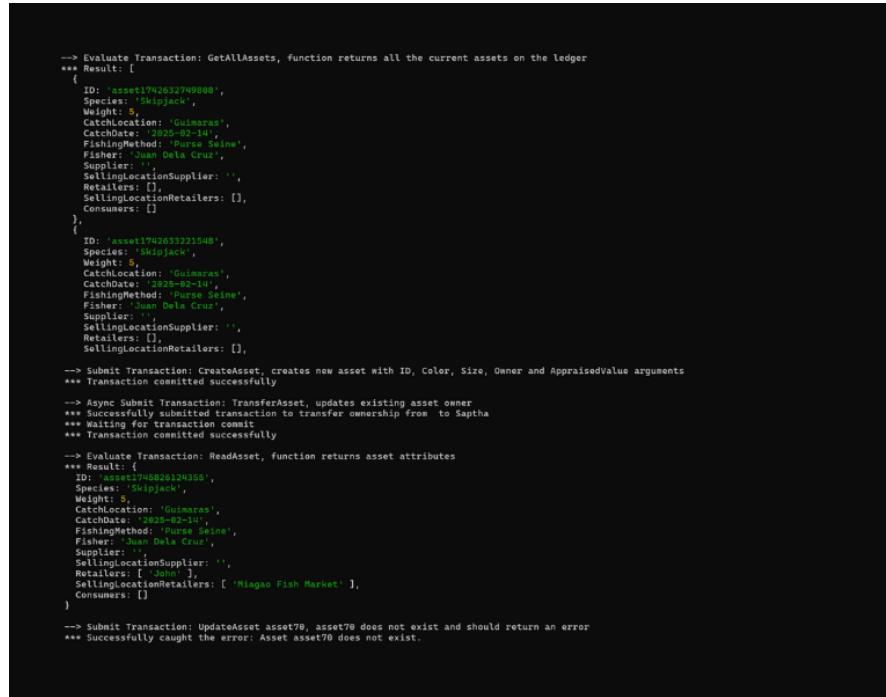
Figure 4.9: Initialization Confirmation of the Ledger

#### 1100 GetAllAssets Query

1101 A query operation retrieved all existing assets recorded on the ledger. The results  
 1102 displayed multiple tuna asset entries with details such as species, weight, catch

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

1103 location, catch date, fishing method, fisher, supplier, retailers, selling locations,  
1104 and consumers. (See Figure 4.10 for the asset retrieval output.)



```
--> Evaluate Transaction: GetAllAssets, function returns all the current assets on the ledger
*** Result: [
  {
    ID: 'asset174632749008',
    Species: 'Skipjack',
    Weight: 5,
    CatchLocation: 'Guimaras',
    CatchDate: '2025-02-14',
    FishingMethod: 'Purse Seine',
    Fisher: 'Juan Dela Cruz',
    Supplier: '',
    SellinglocationSupplier: '',
    Retailers: [],
    SellinglocationRetailers: [],
    Consumers: []
  },
  {
    ID: 'asset174633221548',
    Species: 'Skipjack',
    Weight: 5,
    CatchLocation: 'Guimaras',
    CatchDate: '2025-02-14',
    FishingMethod: 'Purse Seine',
    Fisher: 'Juan Dela Cruz',
    Supplier: '',
    SellinglocationSupplier: '',
    Retailers: [],
    SellinglocationRetailers: []
  }
]
--> Submit Transaction: CreateAsset, creates new asset with ID, Color, Size, Owner and AppraisedValue arguments
*** Transaction committed successfully
--> Asynchronous Submit Transaction: TransferAsset, updates existing asset owner
*** Successfully submitted transaction to transfer ownership from to Saptha
*** Waiting for transaction commit
*** Transaction committed successfully
--> Evaluate Transaction: ReadAsset, function returns asset attributes
*** Result: [
  {
    ID: 'asset174636124555',
    Species: 'Skipjack',
    Weight: 5,
    CatchLocation: 'Guimaras',
    CatchDate: '2025-02-14',
    FishingMethod: 'Purse Seine',
    Fisher: 'Juan Dela Cruz',
    Supplier: '',
    SellinglocationSupplier: '',
    Retailers: [ 'John' ],
    SellinglocationRetailers: [ 'Miagao 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

#### 1105 CreateAsset Transaction

1106 A new asset was successfully created and appended to the blockchain. The trans-  
1107 action was committed without errors, validating the chaincode's ability to handle  
1108 new data insertion.

#### 1109 TransferAsset Transaction

1110 Ownership transfer of an existing asset was simulated. The transaction was suc-  
1111 cessfully submitted and committed, demonstrating the correct application of asset

1112 updates in the blockchain ledger.

### 1113 **ReadAsset Query**

1114 The updated asset was retrieved and verified to ensure the correctness of the  
1115 transfer. The retrieved asset data reflected the changes made through the previous  
1116 transaction, confirming data consistency.

### 1117 **UpdateAsset Error Handling**

1118 An attempt to update a non-existent asset (asset70) was performed to test the  
1119 smart contract’s error-handling mechanism. The application correctly caught and  
1120 reported the error, verifying that improper transactions are adequately handled  
1121 and rejected.

### 1122 **Summary of Results**

1123 All positive transactions (initialization, creation, transfer, and reading) were suc-  
1124 cessfully executed and committed. The smart contract exhibited robust error  
1125 handling during invalid operations. Endorsement policies and Membership Ser-  
1126 vice Provider (MSP) enforcement ensured transaction authenticity and integrity  
1127 during the process. These tests confirm the functional reliability and transac-  
1128 tion security of the smart contracts used within the tuna supply chain blockchain  
1129 network.

<sup>1130</sup> **4.3.4 GCP Infrastructure Security**

<sup>1131</sup> The Hyperledger Fabric network deployment on Google Cloud Platform (GCP)  
<sup>1132</sup> was secured by leveraging multiple layers of Google's infrastructure security model,  
<sup>1133</sup> following best practices in network, identity, and data protection.

<sup>1134</sup> **Firewall Rules and Network Control**

<sup>1135</sup> Only essential ports (e.g., 7051 for peer communication and 7050 for the ordering  
<sup>1136</sup> service) were opened to minimize network exposure. GCP's VPC firewall rules,  
<sup>1137</sup> ingress and egress controls, and options like VPC Service Controls help further  
<sup>1138</sup> isolate services and prevent unauthorized access. Traffic between virtual machines  
<sup>1139</sup> and Google APIs is securely routed through Google's internal network infrastruc-  
<sup>1140</sup> ture using Private Google Access when available.

<sup>1141</sup> **IAM Roles and Access Management**

<sup>1142</sup> The principle of least privilege was enforced by assigning minimal permissions to  
<sup>1143</sup> users and services through GCP Identity and Access Management (IAM). Access  
<sup>1144</sup> decisions involve authentication, authorization checks, and enforcement of policies  
<sup>1145</sup> through centralized services, helping reduce the risk of unauthorized actions or  
<sup>1146</sup> privilege escalation.

**1147 Encryption**

1148 GCP ensures that data is encrypted both at rest and in transit by default. Storage  
1149 systems use multiple layers of encryption, with cryptographic keys managed by  
1150 Google. For additional control, Cloud Key Management Service (KMS) enables  
1151 customers to manage their own encryption keys. Data in transit between services  
1152 is protected using Application Layer Transport Security (ALTS), and all external  
1153 communication with Google services is encrypted via TLS.

**1154 Access Control**

1155 Access to virtual machines and services was restricted using secure access methods.  
1156 Identity-Aware Proxy (IAP) or VPN connections were employed to safeguard SSH  
1157 and administrative access. GCP's zero-trust model emphasizes verifying identity  
1158 and device security rather than relying solely on network location, aligning with  
1159 best practices for modern infrastructure protection.

**1160 Infrastructure and Operational Security**

1161 GCP's underlying infrastructure benefits from Google's proprietary hardware de-  
1162 signs, including the Titan security chip, secure boot mechanisms, and service iden-  
1163 tity enforcement. Google's physical data centers use multi-layered defenses such  
1164 as biometrics and intrusion detection systems. Operational security practices, in-  
1165 cluding binary authorization and extensive monitoring, reduce insider risks and  
1166 enforce software integrity throughout the lifecycle.

<sub>1167</sub> By deploying the blockchain network on GCP, the project leveraged a highly se-  
<sub>1168</sub> cure environment, benefiting from Google's layered security architecture across  
<sub>1169</sub> networking, identity management, encryption, access control, and operational  
<sub>1170</sub> practices.

#### <sub>1171</sub> 4.3.5 Threat Model and Mitigations

<sub>1172</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>1173</sub>

## <sub>1174</sub> 4.4 Mockups

<sub>1175</sub> The mockups represent the preliminary design for the SeaXChange web applica-  
<sub>1176</sub> tion, created using Figma to facilitate collaboration and incorporate feedback  
<sub>1177</sub> efficiently. The visual design features a teal-based color scheme to evoke an oceanic  
<sub>1178</sub> theme, aligning with the app's focus on tuna products supply chain. This aesthetic  
<sub>1179</sub> choice reinforces the app's identity and enhances user engagement.

<sub>1180</sub> Upon launching the app, users are first directed to the Login or Sign-Up page,  
<sub>1181</sub> where authentication is required to access any data. This ensures security and

<sub>1182</sub> role-specific access within the blockchain system.

<sub>1183</sub> Once authenticated, users are redirected to their personalized homepages, which  
<sub>1184</sub> include their profile information and a dashboard showing relevant tuna product  
<sub>1185</sub> assets. The user experience is role-dependent:

<sub>1186</sub> • All users can view available assets on the blockchain.

<sub>1187</sub> • Fishermen are the only users who can create new assets, representing newly  
<sub>1188</sub> caught tuna.

<sub>1189</sub> • Suppliers and Retailers have the ability to pass on assets down the supply  
<sub>1190</sub> chain, updating the product's status, location, or freshness.

<sub>1191</sub> This role-based structure ensures traceability, accountability, and clarity across  
<sub>1192</sub> the supply chain, while maintaining a clean and intuitive interface tailored to  
<sub>1193</sub> each user type.

#### 4.4. MOCKUPS

57

**Login Page**

SeaXChange

Email:

Password:

**Log In**

Don't have an account? [Sign up](#)

**Fisher Homepage**

SeaXChange

Order Tuna 32

+ ADD CATCH

Picture Picture Picture

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Sold

Picture Picture Picture

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Available

**Fisher Add Catch Page**

SeaXChange

TUNA1

Species: Skipjack

Weight (kg): 5.5

Catch Location: Antipe

Catch Date: 2024-10-01

Fishing Method: Longline

Vessel: Japone

Supplier: NA

Retailer: NA

Consumer: NA

**SAVE** **SEND TUNA**

**Fisher Add Catch Page 2**

SeaXChange

TUNA1

Species: Skipjack

Weight (kg): 5.5

Catch Location: Antipe

Catch Date: 2024-10-01

Fishing Method: Longline

Vessel: Japone

Supplier: NA

Retailer: NA

Consumer: NA

**SEND** **EDIT**

**SAVE** **SEND TUNA**

**Supplier Homepage**

SeaXChange

Order Tuna 32

Picture Picture Picture

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Sold

Picture Picture Picture

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Available

TUNA1 Dec 1, 2024 Available

**Supplier Search/Click Result Page**

SeaXChange

TUNA1

Species: Skipjack

Weight (kg): 5.5

Catch Location: Antipe

Catch Date: 2024-10-01

Fishing Method: Longline

Vessel: Japone

Supplier: John Doe

Retailer: NA

Consumer: NA

**SEND TUNA**

**Retailer Search/Sell Page**

SeaXChange

TUNA1

Species: Skipjack

Weight (kg): 5.5

Catch Location: Antipe

Catch Date: 2024-10-01

Fishing Method: Longline

Vessel: Japone

Supplier: NA

Retailer: Oscar Gomes

**SEND TUNA** **MARK AS SOLD**

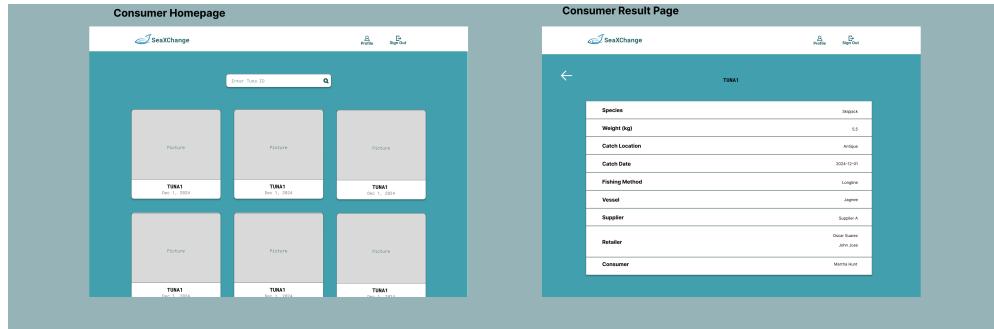


Figure 4.11: SeaXChange Mockups showing the Authentication Page, Role-Based Homepage, Asset Transfer Interfaces for Fishermen, Suppliers, and Retailers, and Asset Viewing page for the Consumers

## <sup>1194</sup> 4.5 Operational Flow of the Web Application

<sup>1195</sup> This section will discuss the flow in using the SeaXChange Web Application. It  
<sup>1196</sup> will show the respective interface for every page and how the users can interact  
<sup>1197</sup> with it.

### <sup>1198</sup> 4.5.1 Landing Page

<sup>1199</sup> Users are be greeted with the landing page, where it shows a ocean visuals and  
<sup>1200</sup> a tagline “Discover the Journey your tuna made from the ocean to your dinner  
<sup>1201</sup> plate”. Users are given the option to Login, where they are redirected to the login  
<sup>1202</sup> page or Get Started, where they are redirected to the sign up page.



Figure 4.12: Landing Page

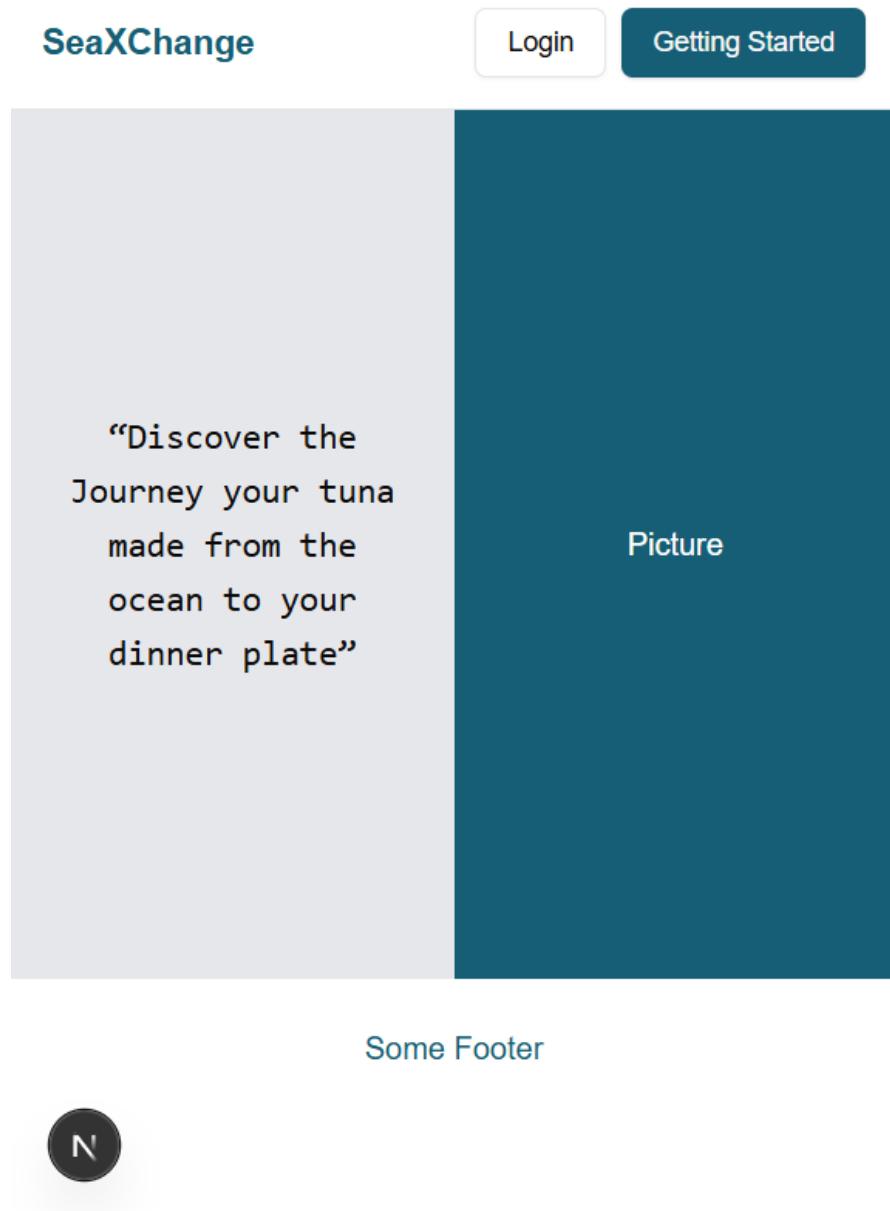


Figure 4.13: Mobile View: Landing Page

1203 **4.5.2 Sign Up Page**

1204 First time users will be required to create an account. They are to provide their  
1205 name, email and password. For their user type, there are four roles to choose  
1206 from: Fisher, Supplier, Retailer and Consumer.

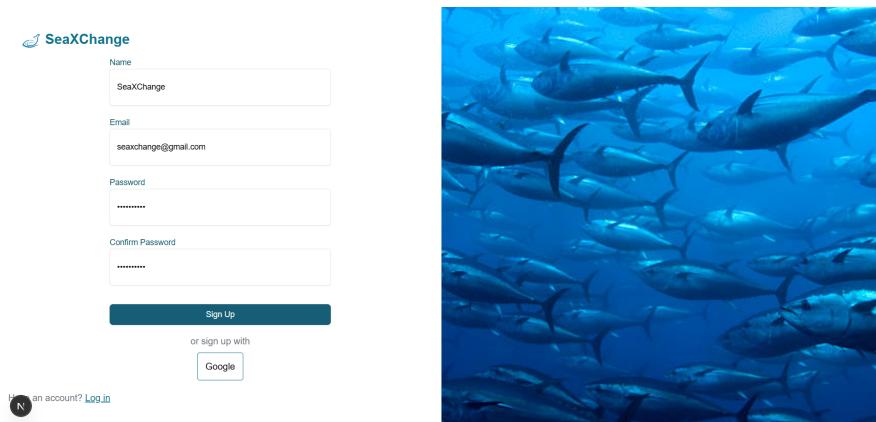


Figure 4.14: SignUp Page

1207 **4.5.3 Login Page**

1208 Returning user are required to login with their email and password.

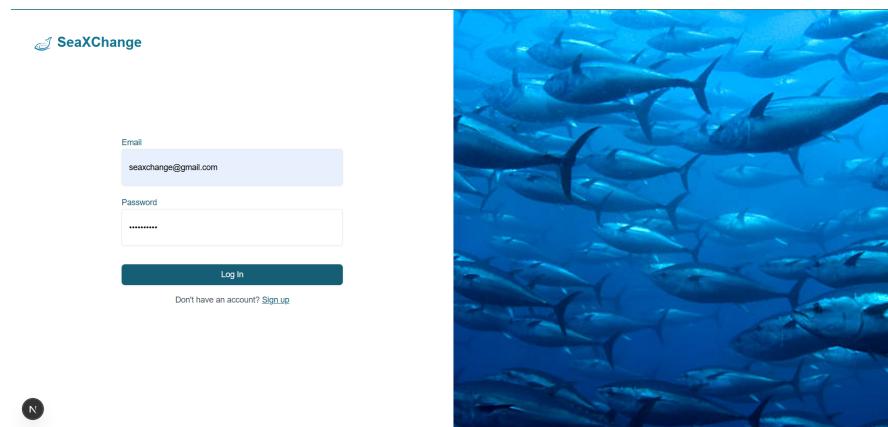


Figure 4.15: LogIn Page

<sub>1209</sub> **4.5.4 Homepage**

<sub>1210</sub> Each user type has their own respective homepages and features.

- <sub>1211</sub> • **Fisher** Fishers can add a fish catch using the "Add catch" button, where
- <sub>1212</sub> they are to input the species of the fish, weight in kg, catch location, catch
- <sub>1213</sub> date, fishing method used and vessel name. The remaining text fields like
- <sub>1214</sub> the Supplier name, Retailer name and Consumer name are left null and
- <sub>1215</sub> cannot be edited because they will be filled out by the other users receiving
- <sub>1216</sub> the tuna asset. Users can send a tuna asset to the Supplier. Users can also
- <sub>1217</sub> browse existing tuna assets.

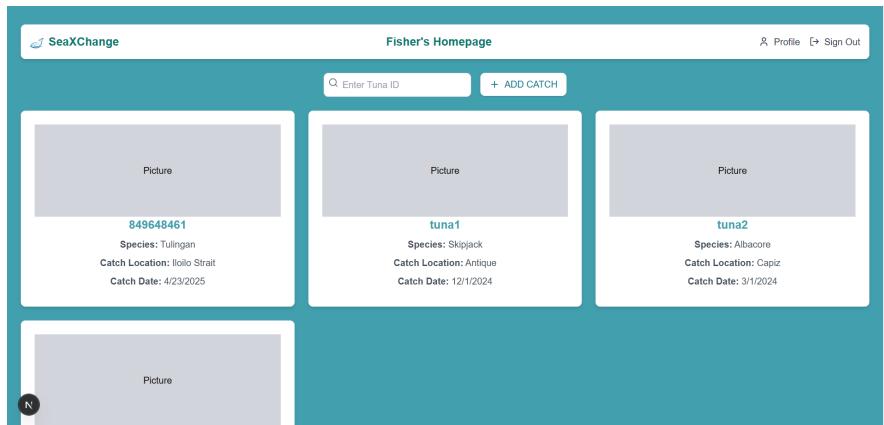


Figure 4.16: Fisher Homepage

- <sub>1218</sub> • **Supplier** Suppliers can browse existing tuna assets. Upon clicking a tuna
- <sub>1219</sub> asset, the user can only edit the Supplier text field. They can send the tuna
- <sub>1220</sub> asset to the Retailer.

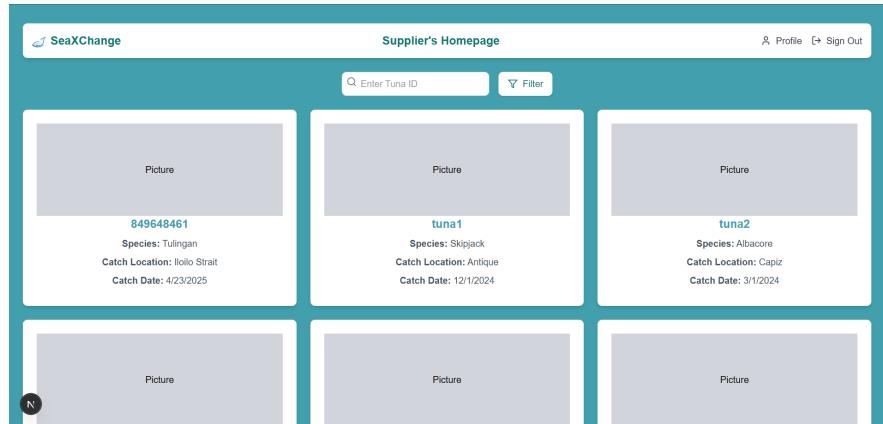


Figure 4.17: Supplier Homepage

- 1221 • **Retailer** Retailers can browse existing tuna assets and can send it to the Consumer.
- 1222

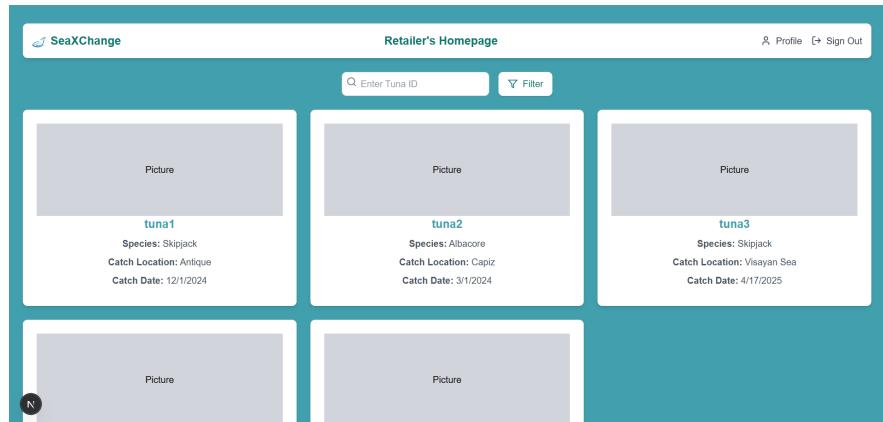


Figure 4.18: Retailer Homepage

- 1223 • **Consumer** Consumers can only view the tuna asset and cannot edit anything else
- 1224

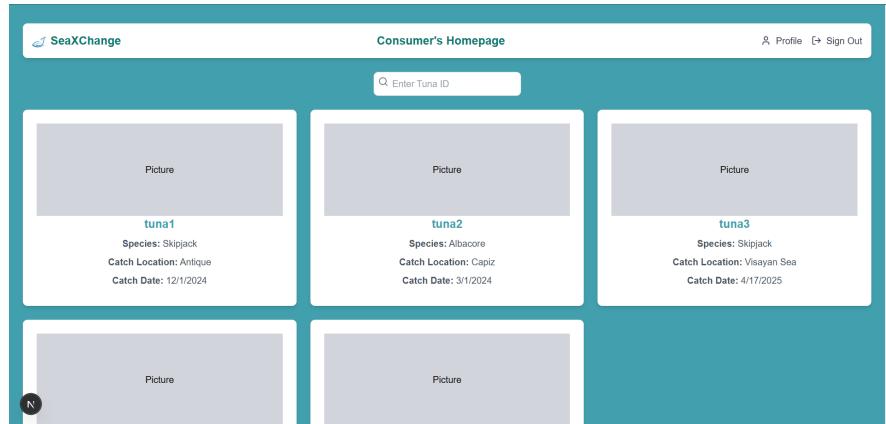


Figure 4.19: Consumer Homepage

### 1225 4.5.5 Profile

1226 The user's profile information is shown on the homepage through a pop-up. It  
1227 shows the user's name and role.

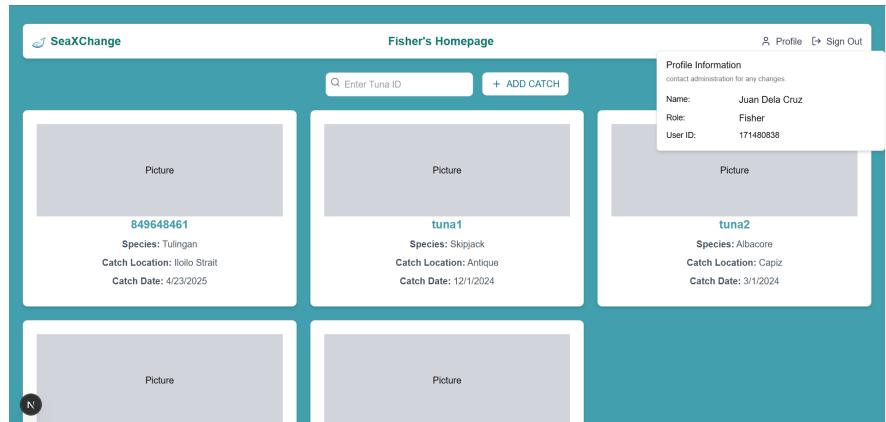


Figure 4.20: View Profile

### 1228 4.5.6 Logout

1229 Users can logout of their accounts and is redirected to the Signup Page.

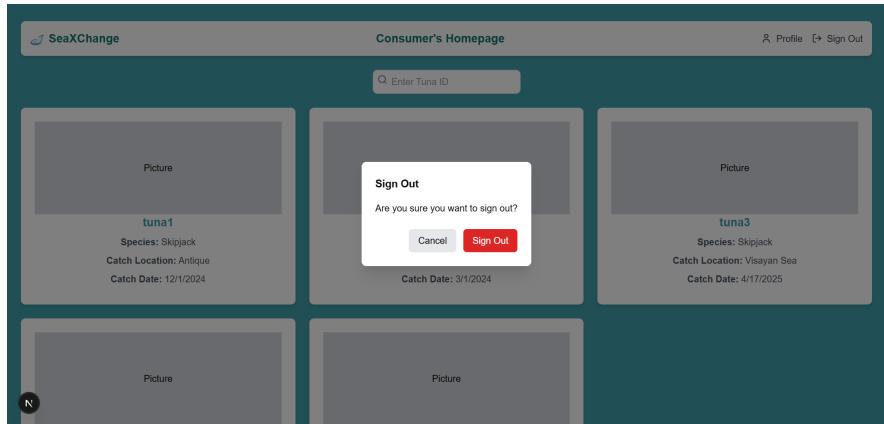


Figure 4.21: Log Out

## 1230 4.6 System Discussion

1231 After modifying the Hyperledger Fabric smart contract to assess necessary pro-  
1232 cesses involved in the tuna supply chain, the blockchain is ready to be invoked  
1233 wherein the smart contract can be activated. To start, a new tuna asset is added  
1234 and registered to the blockchain. Each tuna asset has its attributes or details.  
1235 Before proceeding to the transfer of tuna asset, the smart contract is queried to  
1236 verify if the creation of the asset is successful and if it is part of the current in-  
1237 ventory. After that, the tuna asset can be transferred from fisher to supplier and  
1238 the asset's owner is updated. The smart contract is queried again to verify if the  
1239 asset details have been updated successfully. With the same process, the tuna as-  
1240 set is transferred from supplier to retailer using the smart contract and the owner  
1241 is updated again. To ensure that the asset details are successfully updated, the  
1242 smart contract is queried again. The final step is to query the smart contract to  
1243 show the overview of all the assets in the supply chain. With this, it can be seen  
1244 all the tuna assets from fishing to retail. Overall, the steps and process provides

<sup>1245</sup> transparency and traceability in the tuna supply chain.

## <sup>1246</sup> 4.7 User Demonstration and Feedback Results

### <sup>1247</sup> 4.7.1 Demo Setup and Scenario

<sup>1248</sup> During the demonstration of the system, the participants had a brief introduction  
<sup>1249</sup> of the key functionalities of the SeaXChange app. They were shown how to  
<sup>1250</sup> create an account, input and send tuna assets from one stakeholder to another.

<sup>1251</sup> Participants were also shown how real-time updates were reflected on the app.

<sup>1252</sup> Finally, they were introduced on how to view transaction histories and traceability information on each tuna asset. Throughout the demonstration, participants  
<sup>1253</sup> were encouraged to ask questions and provide feedback on the usability and functionality  
<sup>1254</sup> of the system. After the demonstration, they were given feedback forms  
<sup>1255</sup> in order to assess the SeaXChange app.  
<sup>1256</sup>

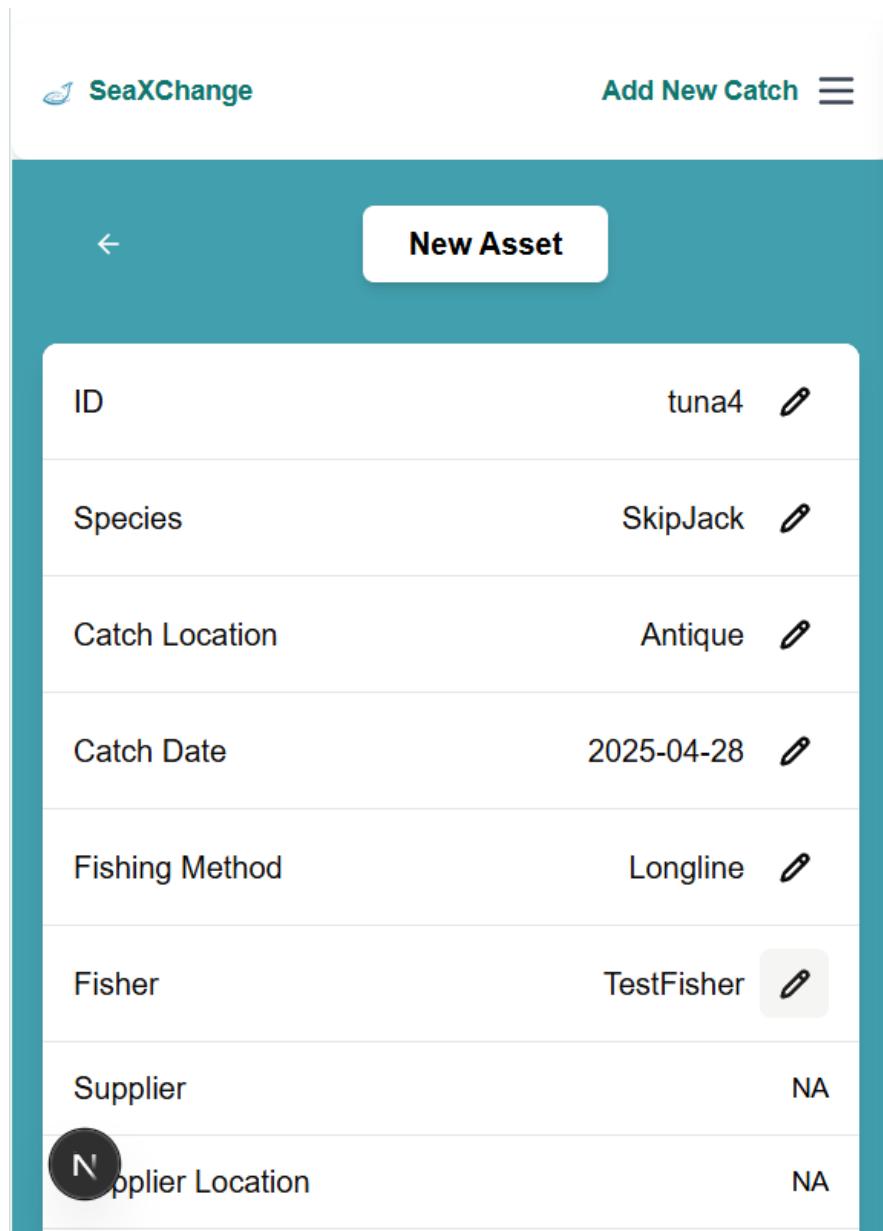


Figure 4.22: Add Catch (Asset)

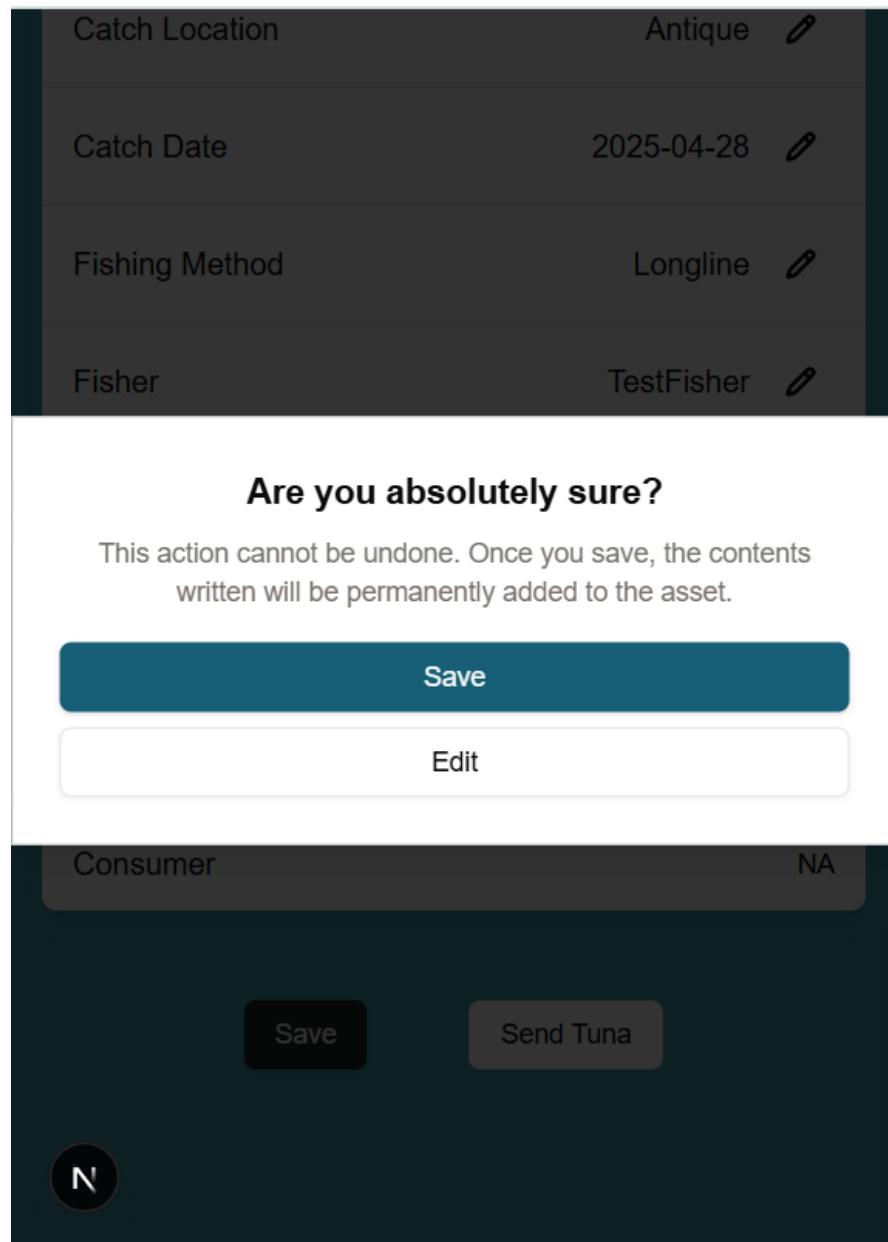


Figure 4.23: Save Details

|                   |                                                                                                |
|-------------------|------------------------------------------------------------------------------------------------|
| Species           | SkipJack    |
| Catch Location    | Antique     |
| Catch Date        | 2025-04-28  |
| Fishing Method    | Longline    |
| Fisher            | TestFisher  |
| Supplier          | NA                                                                                             |
| Supplier Location | NA                                                                                             |
| Retailer          | NA                                                                                             |
| Retailer Location | NA                                                                                             |
| Consumer          | NA                                                                                             |

 Send Tuna

Figure 4.24: After Save Details

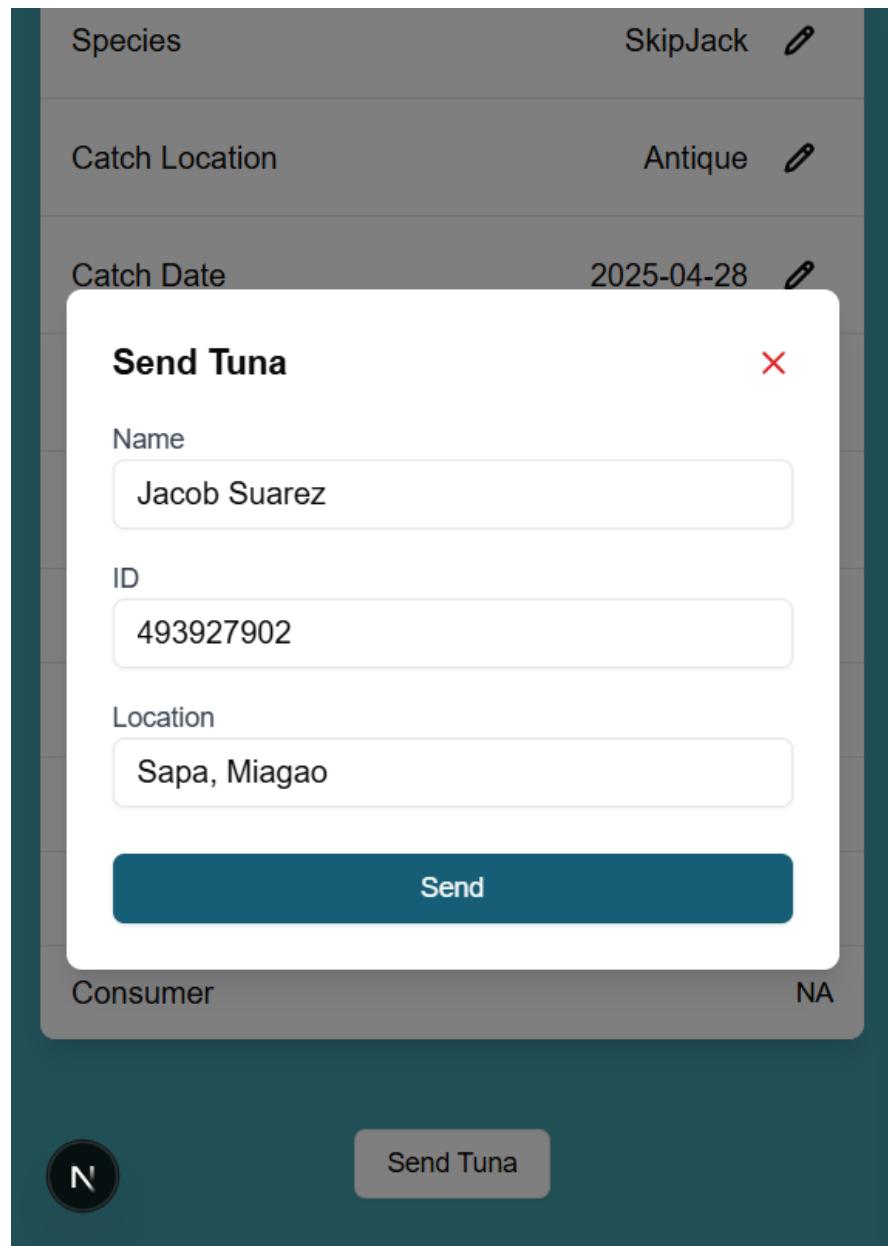


Figure 4.25: Send Asset

<sup>1257</sup> **4.7.2 Feedback Collection Method**

<sup>1258</sup> The feedback was collected through a combination of structured interviews and  
<sup>1259</sup> assessment forms. Participants were asked to complete an assessment rubric evalu-  
<sup>1260</sup> ating the SeaXChange app across key criteria such as functionality, end-user needs,  
<sup>1261</sup> performance, usability, ease of use and feasibility. Moreover, follow-up interviews  
<sup>1262</sup> were conducted to gather deeper qualitative insights and obtain suggestions for  
<sup>1263</sup> system improvement.

<sup>1264</sup> The feedback gathered from fishermen, suppliers and retailers, and consumers  
<sup>1265</sup> was analyzed based on the SeaXChange assessment rubric, which evaluated six  
<sup>1266</sup> major categories: Functionality, End-user Needs, Performance, Usability, Ease of  
<sup>1267</sup> Use and Feasibility. The collected data were analyzed using descriptive statistics,  
<sup>1268</sup> through the computation of mean scores for each assessment criterion. These  
<sup>1269</sup> mean values were used to summarize stakeholder perceptions of the system. Mean  
<sup>1270</sup> ratings were calculated based on the 1-5 Likert Scale where 1 = Poor and 5 =  
<sup>1271</sup> Very Good.

<sup>1272</sup> **4.7.3 Summarized Feedback**

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

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

<sup>1273</sup> When taken as a whole, the respondents have average feedback in asset tracking  
<sup>1274</sup> but when classified by stakeholder, the fishermen ( $M = 4.0$ ) and consumers ( $M$   
<sup>1275</sup>  $= 4.0$ ) had good feedback in tracking , while the supplier and retailers have an  
<sup>1276</sup> average rating ( $M = 3.0$ ). For verifying tuna assets, the entire group has an average  
<sup>1277</sup> feedback. When classified by stakeholder, the fishermen ( $M = 3.33$ ) and consumers  
<sup>1278</sup> ( $M = 3.67$ ) have average ratings. For real-time updates, the respondents, when  
<sup>1279</sup> taken as a whole, have an average feedback. When classified by stakeholder, the  
<sup>1280</sup> fishermen ( $M = 3.78$ ) have an average rating, while both supplier and retailers ( $M$   
<sup>1281</sup>  $= 4.0$ ) and consumers ( $M = 4.0$ ) have good ratings. For smart contract execution,  
<sup>1282</sup> the respondents, when taken as a whole, also have an average feedback. When  
<sup>1283</sup> classified according to stakeholder, the fishermen have a fair rating ( $M = 2.33$ ),

- <sub>1284</sub> the supplier and retailers have average ratings ( $M = 3.25$ ) and the consumers have  
<sub>1285</sub> 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.

- <sub>1286</sub> The respondents, when taken as a whole, had an average feedback in transparency.  
<sub>1287</sub> When classified by stakeholder, The fishermen have fair ratings ( $M = 2.67$ ), while  
<sub>1288</sub> both supplier and retailers ( $M = 4.0$ ) and consumers ( $M = 4.0$ ) have good ratings.  
<sub>1289</sub> In evaluating the seamless interaction of the app, the entire group has an average  
<sub>1290</sub> feedback ( $M = 3.77$ ). When classified by stakeholder, the fishermen ( $M = 1.33$ )  
<sub>1291</sub> have poor feedback, the supplier and retailers have average feedback ( $M = 3.0$ )  
<sub>1292</sub> 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.

1293 As a whole, the respondents have an average feedback on efficient transactions ( $M$   
 1294 = 3.81). If evaluated per stakeholder, both fishermen ( $M = 3.67$ ), supplier and  
 1295 retailers ( $M = 3.75$ ) evaluated average while consumers had good feedback ( $M =$   
 1296 4.0). For data security, the entire group has an average feedback ( $M = 3.31$ ). The  
 1297 fishermen have fair evaluation ( $M = 2.67$ ), supplier and retailers ( $M = 3.25$ ) have  
 1298 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.

1299 It shows the frequency of intuitive interface among the respondents when taken  
 1300 as a whole is average ( $M = 3.83$ ). When classified according to stakeholder,  
 1301 both fishermen ( $M = 4.0$ ) and consumers ( $M = 4.0$ ) have good ratings, while the  
 1302 supplier and retailers ( $M = 3.5$ ) have average ratings. For cross-platform usage,  
 1303 the entire group rated good ( $M = 4.14$ ). When classified according to stakeholder,  
 1304 both fishermen ( $M = 4.0$ ) and consumers ( $M = 4.1$ ) also have good ratings, while  
 1305 supplier and retailers ( $M = 3.75$ ) have average. For visual clarity, the entire group  
 1306 rated average ( $M = 3.80$ ). When classified by each stakeholder, both fishermen  
 1307 ( $M = 3.33$ ) and supplier and retailers ( $M = 3.75$ ) have average ratings, while

<sub>1308</sub> consumers ( $M = 4.33$ ) have good ratings.

| <b>Ease of Use</b>               | <b>Stakeholder</b>     | <b>Mean</b> | <b>Description</b> |
|----------------------------------|------------------------|-------------|--------------------|
| 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.

<sub>1309</sub> When taken as a whole, the respondents ( $M = 3.89$ ) rated instruction clarity as  
<sub>1310</sub> average. When classified by stakeholder, both fishermen ( $M = 4.0$ ) and supplier  
<sub>1311</sub> and retailers ( $M = 4.0$ ) have good feedback regarding instruction clarity, while the  
<sub>1312</sub> consumers ( $M = 3.67$ ) have average feedback. The entire group rated language  
<sub>1313</sub> clarity as average ( $M = 3.31$ ). When evaluated by each stakeholder, both fisher-  
<sub>1314</sub> men ( $M = 4.03$ ) and consumers ( $M = 4.33$ ) have good feedback, while supplier  
<sub>1315</sub> and retailers ( $M = 3.75$ ) have average feedback.

| <b>Feasibility</b>                  | <b>Stakeholder</b>     | <b>Mean</b> | <b>Description</b> |
|-------------------------------------|------------------------|-------------|--------------------|
| 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.

<sub>1316</sub> When taken as a whole, it shows that the respondents have good feedback in the  
<sub>1317</sub> system integration. When classified by each stakeholder, both the fishermen ( $M =$

1318 4.0) and supplier and retailers ( $M = 4.5$ ) have good feedback in system integration,  
1319 while the consumers( $M = 3.67$ ) have an average rating. The frequency of consumer  
1320 use among stakeholders, when taken as a whole, have good feedback ( $M = 4.03$ ).  
1321 When analyzed individually, both the fishermen ( $M = 4.0$ ) and consumers ( $M =$   
1322 4.33) have a good rating, while an average rating for the supplier and retailers ( $M$   
1323 = 3.75).

#### 1324 4.7.4 Results and Analysis

1325 For functionality, fishermen rated asset tracking positively but identified chal-  
1326 lenges in real-time updates and smart contract execution. Suppliers and retail-  
1327 ers similarly found strengths in verification and real-time updates, although as-  
1328 set tracking averaged slightly lower. Consumers consistently rated functionality  
1329 highly, particularly appreciating the system's ability to support smart contracts.

1330 Regarding end-user needs, fishermen provided the lowest ratings, highlighting  
1331 difficulties with seamless interaction, considering the digital barrier that they ex-  
1332 perience while interacting with the app. Suppliers, retailers, and consumers gave  
1333 higher scores, suggesting that while transparency was generally achieved, the sys-  
1334 tem's ease of interaction required further improvement for all users.

1335 In terms of performance, fishermen and suppliers reported average transaction  
1336 efficiency but noted concerns regarding data integrity and security. Consumers,  
1337 on the other hand, expressed confidence in both areas.

1338 For usability, consumers provided the highest ratings, emphasizing the intuitive  
1339 design and accessibility of the interface. Fishermen and suppliers also rated us-

ability positively but suggested improvements, such as better visual appeal and language localization. Feedbacks suggested incorporating the Karay-a language since most of the potential users use that language in their everyday lives. Another suggestion was to use capitalization (UI/UX) for the name of the tuna to give more emphasis to it.

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

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

# <sup>1351</sup> Chapter 5

## <sup>1352</sup> Conclusion

### <sup>1353</sup> 5.1 Overview

<sup>1354</sup> This chapter presents the key findings and conclusion of the study. It also discusses  
<sup>1355</sup> how the system addresses the challenges of traceability within the tuna supply  
<sup>1356</sup> chain. This chapter also provides recommendations in enhancing the system's  
<sup>1357</sup> functionality and usability, ensuring that the SeaXChange app continues to meet  
<sup>1358</sup> evolving needs of its users.

### <sup>1359</sup> 5.2 Conclusion

<sup>1360</sup> This study aimed to develop and evaluate SeaXChange, which is a blockchain-  
<sup>1361</sup> driven app designed to enhance transparency, traceability and accountability  
<sup>1362</sup> within the tuna supply chain. Through the adaption of Scrum, the team was

<sub>1363</sub> able to develop a functional prototype that was based on iterative development  
<sub>1364</sub> to achieve goals.

<sub>1365</sub> The results from the gathered data suggests that the app has effectively addressed  
<sub>1366</sub> key challenges in traceability and accountability, especially among suppliers and  
<sub>1367</sub> consumers. The stakeholders consistently rated the system as good. However,  
<sub>1368</sub> some areas need improvement, especially in ensuring seamless interaction and  
<sub>1369</sub> data security for fishermen.

<sub>1370</sub> Overall, SeaXChange demonstrates strong potential as a technological solution for  
<sub>1371</sub> promoting transparency, combating illegal, unreported, and unregulated (IUU)  
<sub>1372</sub> fishing, and empowering stakeholders across the tuna supply chain.

### <sub>1373</sub> 5.3 Recommendations

<sub>1374</sub> After analyzing and interpreting the gathered data, the researchers had identified  
<sub>1375</sub> some improvements and recommendations for the further development and  
<sub>1376</sub> implementation of the SeaXChange app.

#### <sub>1377</sub> 1. Incorporation of Local Language

<sub>1378</sub> Since most of the target users are within Miagao, the system could provide  
<sub>1379</sub> multi-language support, including the Karay-a language. This will improve  
<sub>1380</sub> guidance through clearer button descriptions.

#### <sub>1381</sub> 2. Utilization of IoT

<sub>1382</sub> The system could use Internet of Things (IoT) in verifying the fisherman's  
<sub>1383</sub> location. This will add more accountability in tracing the fisherman's cur-

<sup>1384</sup> rent location.

<sup>1385</sup> **3. Inclusion of User Manual**

<sup>1386</sup> To further enhance the experience of its users, the researcher could provide  
<sup>1387</sup> printed or digital copies on the system's functionalities. This will help users  
<sup>1388</sup> navigate through the system without being lost.

<sup>1389</sup> In conclusion, the development of the SeaXChange app highlights the critical role  
<sup>1390</sup> of emerging technologies in providing solution regarding the traceability, trans-  
<sup>1391</sup> parency and accountability within the tuna supply chain. While the system has  
<sup>1392</sup> demonstrated strong potential, continuous improvements are still needed to en-  
<sup>1393</sup> sure its effectiveness. Moreover, further development and usability enhancements  
<sup>1394</sup> will be essential in attaining SeaXChange's goal of creating a more traceable,  
<sup>1395</sup> transparent and accountable tuna industry.



<sup>1396</sup>

# Chapter 6

<sup>1397</sup>

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<sup>1546</sup> Appendix A

<sup>1547</sup> Code Snippets



<sup>1548</sup> **Appendix B**

<sup>1549</sup> **Resource Persons**

<sup>1550</sup> **Dr. Firstname1 Lastname1**

<sup>1551</sup> Role1

<sup>1552</sup> Affiliation1

<sup>1553</sup> emailaddr@domain.com

<sup>1554</sup> **Mr. Firstname2 Lastname2**

<sup>1555</sup> Role2

<sup>1556</sup> Affiliation2

<sup>1557</sup> emailaddr2@domain.com

<sup>1558</sup> **Ms. Firstname3 Lastname3**

<sup>1559</sup> Role3

<sup>1560</sup> Affiliation3

<sup>1561</sup> emailaddr3@domain.net

<sup>1562</sup>