Innovative blockchain traceability technology and Stakeholders' Engagement strategy for boosting Sustainable seafood visibility, social acceptance and consumption in Europe

D1.2- REPORT ON THE MAIN IMPEDIMENTS AND POTENTIAL INCENTIVES FOR SEAFOOD BLOCKCHAIN DEPLOYMENT

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

Document Information

Settings	Value
Deliverable Title	Report on the main impediments and potential incentives for seafood blockchain deployment
Work Package Title	WP1. From bottlenecks to strategy building
Deliverable number	D1.2
Description	Report identifying the main barriers to the introduction of seafood blockchain, based on a review of the literature.
Lead Beneficiary	UAVR
Lead Authors	Cristina Pita /Gisela Costa (UAVR)
Contributors	Sofia Alexandre/João Pontes/Mafalda Rangel (CCMAR)
Submitted by	Carlos Mazorra

Review History

Version	Date	Reviewer	Short Description of Changes
1	20.06.2023	Nuno Leite	Overall errors' review and clarifications.
2	22.06.2023	Carlos Mazorra	Details regarding the Sea2See blockchain tool.

Document Approval

Name	Role	Action	Date
Carlos Mazorra	Project Coordinator	*Approved*	27.06.2023

Nature of the deliverable

R	Document, report (excluding the periodic and final reports)	**X**
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press and media actions, videos, etc.	
DATA	Data sets, microdata, etc.	
DMP	Data management plan	
Ethics	Deliverables related to ethics issues.	
SECURITY	Deliverables related to security issues	
Other	Software, technical diagram, algorithms, models, etc.	

Dissemination level

PU	Public — fully open (automatically posted online on the Project Results platforms)	**X**
SEN	Sensitive — limited under the conditions of the Grant Agreement	

ACKNOWLEDGEMENT

This report is a deliverable from the Sea2See project which has received funding from the European Union's Horizon Europe Research and Innovation Programme under grant agreement No. 101060564.

Current seafood traceability tools and services have the potential to take advantage of novel blockchain technologies to obtain a wide range of data, making sustainable seafood practices more visible to consumers. The Sea2See project aims at filling existing seafood traceability gaps through the development of an innovative end-to-end blockchain model and professional and consumer applications to increase trust and social acceptance of sustainably fished and farmed seafood. The project will provide technological solutions to answer the need of a valuable source of data collected throughout the whole seafood value chain, verified, and covering inputs from diverse stakeholders. For that purpose, a specific focus will be put on active commitment of stakeholders and real empowerment of consumers through the implementation of societal and sectoral strategies for co-creation, communication and awareness raising.

More information on the project can be found at: http://www.sea2see.eu/

COPYRIGHT

EXECUTIVE SUMMARY

The current report presents the results of a systematic review of the literature aimed at identifying the challenges and incentives of implementing blockchain traceability in seafood value chains, both for the fisheries and aquaculture sectors.

Blockchain technology allows for the creation of ledgers of transactions by forming blocks of information. When using this decentralized technology, transaction details are shared in real-time and cannot be tampered with, which allows data to be exchanged in a secure way.

Seafood traceability has become increasingly important in the globalized seafood market. The use of blockchain technology in seafood value chains improves their transparency, promoting trust amongst seafood actors and consumers, and providing seafood actors with better access to reliable information regarding a products' origin, production method, processing and/or transformation method (if applied), at any point in the value chain.

Almost 60% of the seafood consumed in the European Union (EU) is imported and concerns about food safety, illegal unreported and unregulated (IUU) fishing, healthy fish stocks and sustainable fisheries have led to increasing seafood traceability regulations. In the EU, import documents and labeling information for consumers are mandatory for seafood products. Recently, in order to strengthen transparency, safety, accountability and safeguard consumers interests, the EU Parliament and the European Council Presidency agreed on new rules regarding seafood traceability, including digital traceability, which will certainly change seafood trade into the EU in the near future.

For this report a literature review was carried out by searching all databases in Scopus and ISI Web of Science (WoS). In total, after a thorough selection, 15 manuscripts were selected discussing opportunities and/or challenges related to blockchain traceability systems in fisheries and/or aquaculture.

A total of 17 incentives to using blockchain traceability systems in seafood value chains were identified, namely: improves efficiency (e.g., time of transactions); improves traceability; allows for the identification of origin/source of seafood products; increases value chain trust; increases public acceptance and trust; allows to demonstrate compliance; allows for real-time access to information; allows to apply for certification/labeling; improves food safety (food quality); helps minimize IUU fishing; improves market opportunities; improves data security and decentralization; enhances reputation, accountability and ethics; leads to environmental sustainability; empowers communities and improves relationships; contributes to improve human rights and social sustainability; and reduces the cost of information exchange.

On the other hands, a total of 12 challenges related with the use of this technology in seafood were identified, such as: the cost/price of implementation; the size of the supply chains; the complexity and amount of information needed; confidentiality/trust issues; the lack of interest by actors in the

value chain/lack of buy-in; the complexity of use of this technology; the lack of interest by the public/consumers; the lack of interoperability of the information systems; the adulteration of seafood products during processing; the lack of access to technologies and lack of incentives (for the actors) to join the system.

The report also presents six examples, from around the world, of seafood supply chains where blockchain was implemented, describing in detail the opportunities and challenges to implementing this technology. Since different sectors face different challenges and incentives, we present two examples of blockchain in small-scale fisheries (Provenance, FLAGCHAIN), two in large-scale fisheries (Fiji Tuna Supply Chain Solution, Fishcoin), and two in aquaculture (Sustainable Shrimp Partnership, IBM Blockchain Transparent in Norway).

We concluded that most incentives and challenges to the implementation of blockchain are common to the fisheries and aquaculture sectors. However, some incentives are specific to the fisheries sector (reducing/stopping IUU fishing, enhancing reputation, improving accountability and ethics, enhancing community empowerment and relationships, and improving human rights and social sustainability), and some are specific to the aquaculture sector (improving market opportunities, and reducing costs of information exchange). The same was observed in terms of barriers, with some being specific to the fisheries sector, such as the size of the supply chain, the lack of access to technologies, and the lack of incentives for the actors to join blockchain traceability systems.

The type of blockchain technology put in place should be adapted to the specific fishery or aquaculture value chain and level of traceability aimed to achieve, so that a fair, trustful and transparent value chain can be efficiently implemented.

ABBREVIATIONS

Abbreviation	Description
AI	Artificial Intelligence
ASC	Aquaculture Stewardship Council
CFP	Common Fisheries Policy
CMO	Common organization of the markets in fishery and aquaculture products
DApps	Decentralized Applications
EC	European Commission
EP	European Parliament
EU	European Union
FAO	Food and Agriculture Organization
FLAGs	Fisheries Local Action Groups
IBM	International Business Machine Corporation
IoT	Internet of Things
ISO	International Organization for Standardization
IUU	Illegal, Unreported and Unregulated
LCA	Life Cycle Analysis
NFC	Near Field Communication
NGO	Non-governmental Organization
P2P	Peer-to-peer
QR	Quick Response
RFID	Radio Frequency Identification
SDG	Sustainable Development Goals
SDKs	Software Development Kits
SSF	Small-scale fisheries
SSP	Sustainable Shrimp Partnership
TRL	Technology Readiness Levels
USA	United States of America
UN	United Nations
WoS	Web of Science
WWF	World Wide Fund for Nature

TABLE OF CONTENTS

TABLES

FIGURES

1. INTRODUCTION

1.1. TRADE IN SEAFOOD

International trade of aquatic products has grown significantly during recent decades. Seafood is currently the world's most traded food commodity, with 225 states and territories reporting trading activity of seafood products in 2020 (FAO, 2022). According to Gadhok and Avesani (2021), in 2019, 37% of seafood entered international trade. Recent data shows that, since the 1960s, seafood destined for human consumption more than doubled (now being 20.2 kg per capita) and is expected to continue increasing with population growth (FAO, 2022). The largest seafood markets in the world are the European Union (EU), the United States of America (USA), China and Japan, which together were recipients of 68% of all traded seafood in 2020 (FAO, 2022).

The EU has a big demand for seafood (importing 60% of the seafood it consumes) and traceability systems in place are crucial to ensure some accountability of practices along the supply chains (the UE's and its seafood supply countries) (Poulsen and Leroy, 2021). Traceability and catch documentation are considered essential to ensure compliance with food safety regulations and combat Illegal, Unreported and Unregulated (IUU) fishing. As such, information about a product's value chain and journey is expanding to be increasingly technological, ensuring transparency, data security and easy access to information (FAO, 2022).

There are currently increasing concerns about seafood's fair and safe trade, such originating from IUU fishing, ethical issues, human rights violations, and food security issues (both in terms of health and supply access), most of which would benefit from an increase in transparency and traceability in seafood supply chains (Du et al., 2020; Tsolakis et al., 2021; Zhang et al., 2021).

1.2. SEAFOOD TRACEABILITY

There are several available definitions of traceability, such as the one by the International Organization for Standardization (ISO) 9000:2005 which describes it as "*the ability to trace the history, application or location of that which is under consideration*", or the definition by the European Union's (EU) General Food Law that defines it as "*the ability to trace and follow food, feed, and ingredients through all stages of production, processing and distribution*". In simple words, traceability is the collection and verification of information on the product's origin and movements. However, there are global gaps (in terms of commitment, technology, implementation standards and awareness) on what information should be included in the breadth of traceability and what its applicability should be. This can result in a lack of interoperability and, therefore, act as a barrier to the strategic cooperation between different entities, with possible loss of key data regarding a seafood product (Borit and Olsen, 2016). Therefore, traceability could benefit from political and strategic cooperation and unification of what it encompasses (Blaha and Katafono, 2020).

Seafood traceability has gained increasing prominence. Making seafood products traceable from the point-of-catch to the point-of-sale is a necessary precondition to prevent IUU products and illicit fish trade from reaching markets, improve safety and security of products, as well as improve sustainability and governance, reduce adverse human rights impacts and safeguard the livelihoods of fisheries-dependent communities (Borit and Olsen, 2016; Lewis and Boyle, 2017; Longo et al., 2021; Teh et al., 2019). Traceability is also key to monitoring and accounting for the environmental and social credentials of seafood products (Lewis and Boyle, 2017).

Traceability systems can either be paper- or computer-based. Considering the international seafood trade and the increasing digitalization of all kinds of industries, the use of technological data-sharing solutions is expected to enhance seafood traceability and to be increasingly used in the future. The use of digital tools such as the ones based on Blockchain, Internet of Things (IoT), Radio Frequency Identification (RFID), and other technologies, has the potential to facilitate tracking the movement and origin of seafood within its supply chain.

1.2.1. Traceability requirement for seafood products in the European Union

The EU imports almost 60% of its seafood (CFP, 2022) and these products originate mostly from developing countries. Concerns with food safety, IUU fishing, sustainable fisheries and healthy fish stocks have resulted in EU regulation to improve the traceability of seafood products sold in the EU market, and also improved consumer information.

The EU regulation to prevent, deter and eliminate IUU fishing (Council Regulation (EC) No 1005/2008 of 29 September 2008) has established a Catch Certificate Scheme, with the aim to ensure that products originating from IUU fishing activities were prevented from entering the EU market. Under this Scheme, all fisheries imports entering the EU need to be accompanied by import documents (i.e., catch certificates). The large volume of catch certificates received annually, most of which were paper-based or scanned copies of paper certificates, has resulted in the EU launching, in 2019, a EU-wide digital database of catch certificates (known as CATCH).

The EU seafood traceability requirements, for fisheries control purposes, are outlined in Council Regulation (EC) No 1224/2009 of 20 November 2009, establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy (CFP). This regulation dictates the requirements needed for seafood trade (of both wild caught and aquaculture products), from catching or harvesting to the retail stage.

Regulation (EU) No. 1379/2013 of 11 December 2013, establishes the common organization of the markets in fishery and aquaculture products (CMO), and defines the needs in terms of labeling for consumer information.

Regulations (EC) No. 1224/2009 and (EU) No. 1379/2013 set the rules on the mandatory and voluntary information to be provided for prepackaged and non-prepacked fishery and aquaculture products. The mandatory information required on the label of all fisheries and aquaculture products includes:

- the commercial and scientific name of the species,
- the fishing gear used or the production method,
- the production method ("…caught…" or "…caught in freshwater…" or "…farmed…"),
- the area where the product was caught or farmed,
- the category of fishing gear used,
- whether the product has been defrosted (with limited exceptions),
- date of minimum durability ('best-before' date) – where appropriate.

The voluntary basis information recommended on the label of all fisheries and aquaculture products includes:

- date of catch of fishery products or date of harvest of aquaculture products,
- date of landing of fishery products or information on the port at which the products were landed,
- more detailed information on the type of fishing gear,
- in the case of fishery products caught at sea, details of the flag State of the vessel that caught those products,
- environmental information,
- information of an ethical or social nature,
- information on production techniques and practices,
- information on the nutritional content of the product.

In addition to the mandatory information set by Regulation (EU) No. 1379/2013, prepacked products must also display all the relevant information specified in Articles 9 and 10 of Regulation (EU) No. 1169/2011 of 25 October 2011 on the provision of food information to consumers.

Figure 1 provides a schematic representation of the information required in seafood labels by the European Union.

The EU is in the process of reviewing its rules on seafood traceability as part of the revision of its fisheries control system. There are calls for a EU-mandated traceability system. Such a system would encourage transparency and accountability in the EU, but also beyond the EU in international seafood supply. In March 2021, the European Parliament (EP) voted for seafood products in the EU market to be digitally traceable from the point of catch to the point of retail. On the 30th of May

2023, an agreement was reached between the EP and the European Council Presidency on an update of CFP rules regarding, amongst other, the traceability of fish products. According to the agreed text, information on fresh and frozen fish will be fully accessible, including digitally, to safeguard food safety and consumer interests. This system of digitalized traceability will also be extended to cover processed fish in five years[1].

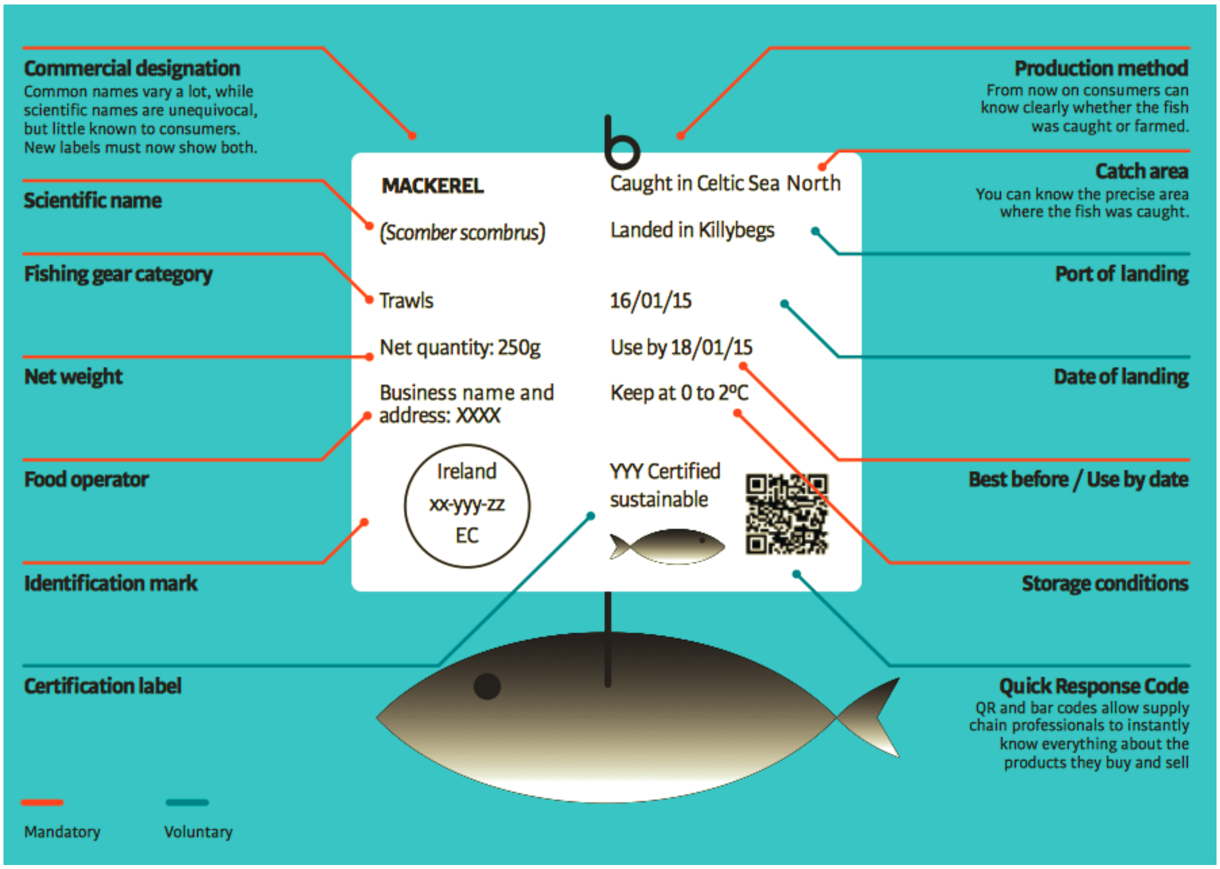

Figure 1. Information required in seafood labels by the European Union (Source: European Union, 2015).

1.3. OBJECTIVES AND STRUCTURE OF THE DELIVERABLE

Technologies are expected to bring more transparency, trust, efficiency, market opportunities and other benefits to seafood industries. However, several challenges encompass traceability implementation and its digitalization.

1 https://www.europarl.europa.eu/news/en/press-room/20230526IPR92701/fisheries-deal-reached-on-new-rules-to-improve-compliance-and-traceability

The present document aims at identifying the main incentives and barriers to the implementation of seafood blockchain, based on a review of the literature. The report is organized in 5 sections:

- Section 1 presents an introduction to traceability and the purpose of this deliverable,
- Section 2 describes blockchain, its history, and the use of blockchain as a seafood traceability tool,
- Section 3 describe the incentives and barriers to seafood blockchain in fisheries and aquaculture,
- Section 4 provides examples of several initiatives using blockchain technology to trace seafood from catch to consumer,
- Section 5 presents the conclusions of this report.

2. BLOCKCHAIN

In this section we describe what is blockchain, how it first came to be, its utility, and briefly discuss the different types of existing blockchain (section 2.1), we also discuss the reasons why blockchain should be used as a form of traceability in the seafood sector (section 2.2).

2.1. WHAT IS BLOCKCHAIN

According to Ruoti et al. (2019), blockchain's core concepts emerged in the late 1980's, early 1990's. One of the most recognized descriptions of blockchain is in the work of researchers Haber and Stornetta (1991), where they discuss timestamps that could not be tampered with. In 2008, an anonymous person or group of people (under the name "Satoshi Nakamoto") conceptualized the decentralized blockchain in a paper entitled "Bitcoin: A Peer-to-Peer Electronic Cash System" (Nakamoto, 2008). The following year, Nakamoto used this technology to design the bitcoin cryptocurrency, which today is one of the most well-known forms of application of the blockchain technology.

Blockchain technology builds a digital ledger of transactions. As the name implies, this ledger is formed by a chain of blocks of information (Figure 2). Each block contains a digital impression that identifies the particular block (the current transaction), called hash or label. The first block of information (the genesis block) only has one hash. Every other block in the chain has the hash from the previous block (data) containing transaction details and timestamps (Di Pierro, 2017; Lin et al., 2021).

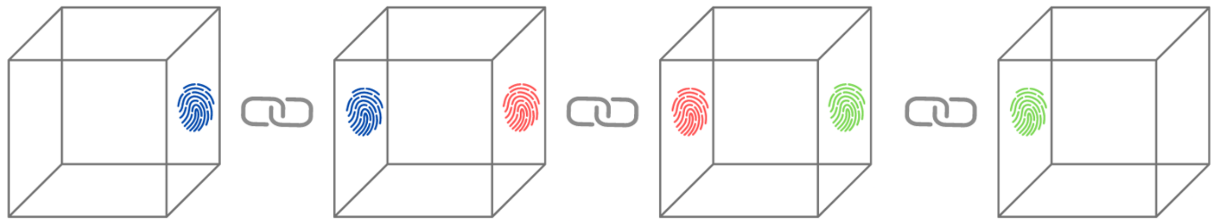

Figure 2. Schematic representation of how blockchain traceability connects blocks of information, each with specific hashes. Adapted from Seafood Alliance Legality and Traceability (SALT, 2021).

This is a decentralized ledger, which means there is no authority managing the whole database (Blaha and Katafono, 2020). Instead, the data is distributed peer-to-peer (P2P), between all the different participants of the blockchain ledger. This way, data is verified when there is a consensus of its validity between all participants, meaning a synchronization of the transaction ledger is in place (powered by consensus algorithms) (Lin et al., 2021). When new information is added to the blockchain, it is sent to everyone on the network and each node verifies it.

These characteristics make it a secure and tamper proofing technology, because:

1. If a block is changed, for example, if it is tampered with, its hash changes, which means the hash in the next block changes too and an error is detected, making the chain invalid and not allowing transactions,
2. When a transaction happens, there is no way to delete that information. The data becomes immutable, unless the majority of the participants in the blockchain agree to change some information within it.

Blockchains can be public, private or a consortium. Public blockchains are open, so anyone can join to either view information or help verify it. This makes the database free to access and completely transparent, but, in some cases, there can be issues regarding the energy requirements to validate the transactions and, with this, concerns arise regarding blockchain sustainability. On the other hand, private blockchains are restricted to only include certain participants and restrict who can see the transactions. This way, the public is only allowed to see selected information which is disclosed. Finally, consortium blockchains are a hybrid between private and public, since the network is managed by a group of entities and not just by a single entity (which is what happens in private blockchains). Consortium blockchains allow information sharing that can enhance transparency across several businesses, including the seafood sector.

There are multiple blockchain platforms (as can be seen in Section 4 regarding "Examples of Seafood Blockchain Initiatives"), each with different characteristics. According to Blaha and Katafono (2020), the two most common blockchain platforms applied in seafood value chains are:

- Ethereum: decentralized applications (DApps) can be built from it, with a big community of active developers surrounding it and a native cryptocurrency associated,

- Hyperledger: mostly used in the International Business Machine Corporation's (IBM) blockchain solutions, hosted by the Linux Foundation; it is a solution made possible by the collaborative effort of cross-industry blockchain technologies.

Besides these, there are other solutions and tools that can be found in Section 4, such as:

- Quadrans: open source, public and decentralized blockchain, this platform seems to be particularly environmentally oriented, as it is being developed to ensure there is minimal energy consumption in creating new blocks of information and sharing data (Quadrans Blockchain, 2023),
- Viant: a tool to improve Ethereum's efficiency in supply chain traceability systems. It uses the Proof of Authority consensus mechanism, a type of algorithm to achieve consensus within the blockchain system that achieves greater performance and energy efficiency (Cook, 2018).

Potential blockchain applications include digital payments and cryptocurrencies, smart contracts (self-executing contracts), asset trading, database management and market transactions (Ruoti et al., 2019). Blockchain can be used for recording and allowing transactions within value chains of different products, including seafood.

2.2. BLOCKCHAIN IN FISHERIES AND AQUACULTURE

As described before, blockchain is a decentralized system that allows for tamper-proof data to be exchanged between stakeholders in a transparent way. The use of this technology in seafood value chains can enhance traceability and transparency regarding products and its transactions.

Blockchain can be used to connect different stakeholders along the value chain, from producers to final consumers (Figure 3). This technology allows data to be exchanged in a secure way, with each stakeholder having access to selected information. For instance, when choosing to buy a seafood product, the blockchain technology solution might be programmed to allow the consumer to have access to who produced, processed and transported it, when and where. This allows actors to make conscious decisions regarding what they consume and might add value to products that are produced in a more transparent way.

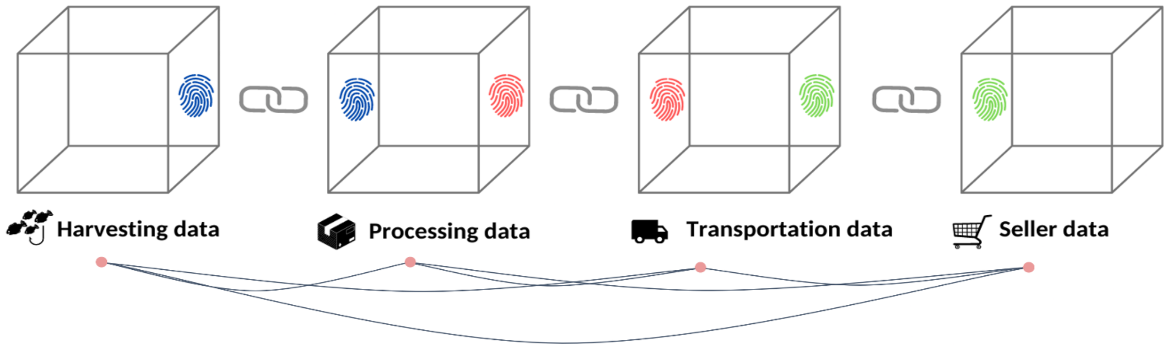

Figure 3. Schematic example of a seafood blockchain with possible connections between value chain actors. Adapted from Seafood Alliance Legality and Traceability (SALT, 2021).

Transparent interactions between value chain actors leads to increased trust-based relationships and to a fairer and sustainable seafood trading system (Lin et al., 2021; Zhang et al., 2021). Avoiding seafood fraud also avoids quality and health concerns for consumers and helps combat IUU fishing (Senguptaet al., 2021; Tsolakis et al., 2021; Zhang et al., 2021).

There are several technological solutions for seafood traceability such as RFID, Near Field Communication (NFC) and Quick Response (QR) codes but, according to Patro et al. (2022), these do not work as well as blockchain since they are not tamper-proof nor decentralized, leaving space for more vulnerabilities. Additionally, these tools do not work as well for fragmented data, which is common in seafood value chains. Some RFID tags, for example, are very prone to damage during transportation; meanwhile, by using blockchain it is possible to create a digital profile and add a QR-code to the product. DNA barcoding methods, the identification of geographic origin and other morphological identification are also used for enhancing seafood traceability, but they are susceptible to data tampering since they involve manual activities.

2.2.1. Sea2See blockchain

Sea2See blockchain innovative platform will be built upon the existing prototype of blockchain model (Tilkal blockchain tool, currently live or in deployment (Technology Readiness Levels (TRL) 6 to 9) in food, cosmetics and textile sectors). Additionally, a prototype has been developed as a result of one small-scale project for a blockchain platform with TRL 7 in the seafood industry on a short value chain, which will serve as a basis for Sea2See.

The Tilkal platform is based on a permissioned blockchain that uses the Multichain technology. A permissioned blockchain is a decentralized ledger that requires permission to access and use. Only a specific group of participants who have been granted access by the network administrators can join and use the network. Tilkal's permissioned blockchain uses a PBFT algorithm (Practical Bizantine

Fault Tolerant), a "round robin" type, where there is a random validation of each block. It does not require a significant amount of energy.

In contrast, public blockchain is a decentralized ledger that is open to anyone who wants to participate, typically used for cryptocurrencies, such as Bitcoin. They use a proof-of-work (PoW) consensus algorithm, which requires nodes to solve complex mathematical problems to validate transactions and add new blocks to the blockchain. This process is computationally intensive and requires a significant amount of energy, as nodes compete to be the first to solve the problem and earn a reward.

The Sea2See blockchain network creates a distributed database based on a protocol which ensures that no one can modify the data posteriori. The system includes encryption and complete auditability for each member. The system allows sharing data through a specific format with predefined content to extract entities from the notarized message.

Main advancements of the Sea2See blockchain: Adding new predefined content such as Life Cycle Analysis (LCA) analysis of the value chain, more advanced industry specific data. Add data quality assessment to verify coherence and completeness. Existing small-scale platform will be extended with new industry specific algorithms powered by AI and additional platforms to be fully functional for the European seafood industry. Sea2See blockchain technology consolidates and analyzes data from these value chains, in a system that is flexible enough to adapt to the changes of the value chain. At the end of the value chain, it provides transparency to end consumers. On the one hand, data collection has to adapt to the physical reality of each working conditions in the field as well as to what is measured: from automated measures through Internet of Things (IoT), to manual entries through a mobile app, to passive or active tags, etc., from bulk measures to individual tracking, from volume measures to practice evaluation. On the other hand, all of the above stated data shall be collected and aggregated to build a “360° traceability view”. As some data collected on the field might be wrong (mistake, broken sensor, fraud, etc.) the collection of data from field sources shall be fully traced and immutable, with multiple verifications after the data notarization to track any data incoherence. The system will be opened enough to be enriched by new measures over time, to be enriched by new actors in the supply chain, to provide its traceability data in more or less “open data” for various usage (marketing, optimization, product control or even recall, regulation and customs, etc.).

3. INCENTIVES AND BARRIERS TO SEAFOOD BLOCKCHAIN

Blockchain traceability can be used for both fisheries and aquaculture products, and it is to be expected that the challenges and opportunities faced by each industry may be different. In this section we describe the incentives and barriers to seafood blockchain in fisheries and aquaculture. The identification of incentives and barriers to seafood blockchain is based on a systematic review of the literature and, in section 3.1, we describe the methodology used for the review. Section 3.2 describes and discusses incentives to seafood blockchain for fisheries and aquaculture, and section 3.3 describes and discusses barriers to seafood blockchain for fisheries and aquaculture.

3.1. SYSTEMATIC REVIEW OF THE LITERATURE

A systematic review of the literature was undertaken in order to identify challenges and opportunities for the implementation of blockchain traceability systems in the seafood sector.

3.1.1. Search strategy and inclusion criteria

The literature search was carried out by searching all databases in Scopus and ISI Web of Science (WoS). A sensitive systematic search strategy combining the terms ‘blockchain’, with ‘seafood’, ‘fisheries’, ‘fishery’, ‘aquaculture’, ‘aquatic food’, ‘aquatic supply chain’, ‘aquatic value chain’, ‘aquaculture value chain’, ‘seafood value chain’, ‘seafood supply chain’, ‘aquaculture supply chain’ or ‘aquatic supply chain’, and ‘barrier’, ‘problem’, ‘challenge’, ‘difficulty’, ‘impediment’, ‘obstacle’, ‘struggle’, adversity’, ‘hindrance’, opportunity’, ‘incentive’, ‘benefits’, ‘motivation’ or ‘advantage’ and their synonyms, and using the truncation features of the databases. Titles and abstracts were scanned by all authors to identify studies potentially eligible for inclusion. No major disagreements arose regarding the studies selected for inclusion. The full text of the initially selected studies was then retrieved, and a further selection process undertaken. References in all relevant papers were screened for additional papers.

Criteria for inclusion in the rapid review were restricted to the following:

(1) the study focused on blockchain in seafood,
(2) the studies identified challenges or opportunities regarding the use of blockchain,
(3) the study was published in a peer-reviewed journal indexed in the databases up to December 2022.

The review question was intentionally left broad with the aim of identifying all articles. To the best of our knowledge, no previous attempt has been made to systematically review any of the work published in this topic. Also, and although systematic reviews often benefit from spatial restrictions as country and cultural context may severely impact outcomes (Egan et al., 2009), no geographic, sectoral (we included both the fisheries and aquaculture sectors) or language restrictions were included in the search in order to collect all available data (i.e., although the search terms were in English, due to all the databases searched being indexed and having titles and abstracts available in English, no studies were excluded on the basis of being published in another language). Overall, a total of 65 papers were identified through Scopus (n=36) and WoS (n=29). Of those, 50 were excluded due to being a duplicate or not fulfilling the inclusion criteria. In total, 15 full text documents were selected and included in the review (Figure 4).

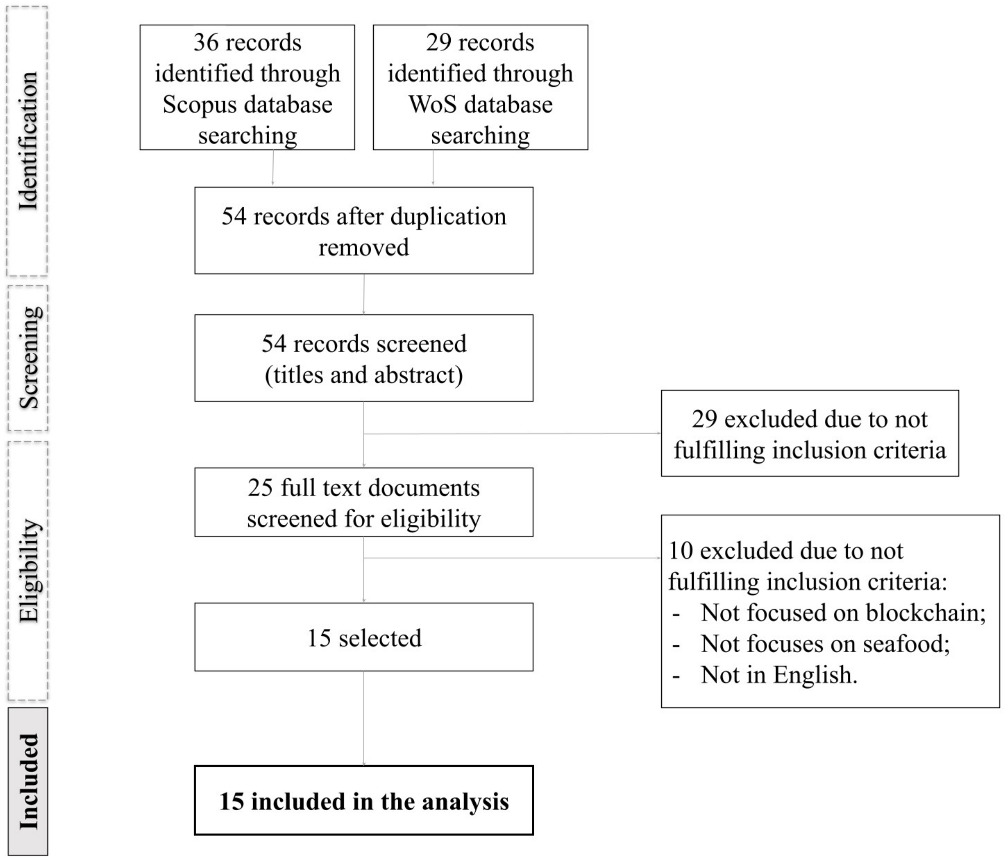

Figure 4. Flowchart showing the stages of identification of the studies in the systematic review.

3.1.2 Data extraction and analysis

A database was created with the essential information extracted from the papers, this included:

- Topics covered,
- Sector (fisheries, aquaculture or both),
- Governance aspects,
- Supply chain identified,
- Challenges to using blockchain,
- Incentives to using blockchain.

The articles were analyzed descriptively. The literature review provided an overview on the use of blockchain in different seafood value chains around the world, mapping motivations and/or barriers to its implementation in fisheries and aquaculture, and providing important insights to the potential use of blockchain by different segments of the seafood value chain.

3.2. INCENTIVES TO BLOCKCHAIN IN SEAFOOD SUPPLY CHAINS

Table 1 shows the incentives to using blockchain in fisheries and aquaculture as identified in the literature. A total of 17 incentives to the implementation of blockchain were identified in the literature.

Table 1. Result from the systematic review of the literature on incentives to the implementation of blockchain in fisheries and aquaculture value chains.

Incentives to blockchain in fisheries and aquaculture			
	Fisheries	Aquaculture	Reference
Improve efficiency (e.g., time, transactions)	✓	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Improve traceability	✓	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Identification of origin/source	✓	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Tsolakis et al. (2021); Zhang et al. (2021).
Increase value chain trust	✓	✓	Afrianto et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jiang and Ræder (2022); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Increase public acceptance and trust	✓	✓	Afrianto et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Hang et al. (2020); Jiang and Ræder (2022); Lin et al. (2021); Patro et al. (2022);

			Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Demonstration of compliance (with rules and regulations, with certification schemes)	✓	✓	Gopi et al. (2019); Hang et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Rahman et al. (2021); Tsolakis et al. (2021); Zhang et al. (2021).
Real-time access to information	✓	✓	Garrard and Fielke (2020); Gopi et al. (2019); Jiang and Ræder (2022); Lin et al. (2021); Mondragon et al (2020); Patro et al. (2022); Tsolakis et al. (2021); Zhang et al. (2021).
Ability to apply for certification/labeling	✓	✓	Garrard and Fielke (2020); Korneyko and Podvolotskaya (2019); Zhang et al. (2021).
Food safety (food quality)	✓	✓	Patro et al. (2022); Tsolakis et al. (2021); Zhang et al. (2021).
Stop IUU fishing	✓	✗	Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Patro et al. (2022); Tsolakis et al. (2021).
Improve market opportunities	✗	✓	Afrianto et al. (2020); Du et al. (2020); Garrard and Fielke (2020); Zhang et al. (2021).
Data security and decentralization	✓	✓	Afrianto et al. (2020); Patro et al. (2022); Zhang et al. (2021).
Enhance reputation, accountability and ethics	✓	✗	Lin et al. (2021); Tsolakis et al. (2021)
Environmental sustainability	✓	✓	Hang et al. (2020); Tsolakis et al. (2021).
Community empowerment and relationship improvement	✓	✗	Lin et al. (2021).
Human rights and social sustainability	✓	✗	Tsolakis et al. (2021).
Reduce costs of information exchange	✗	✓	Zhang et al. (2021).

From the total of 17 incentives to the implementation of blockchain identified in the literature, the most popular were enhancing traceability and improving efficiency, followed by identifying the origin/source of the products, increasing value chain actors and consumers trust, amongst others (Figure 5).

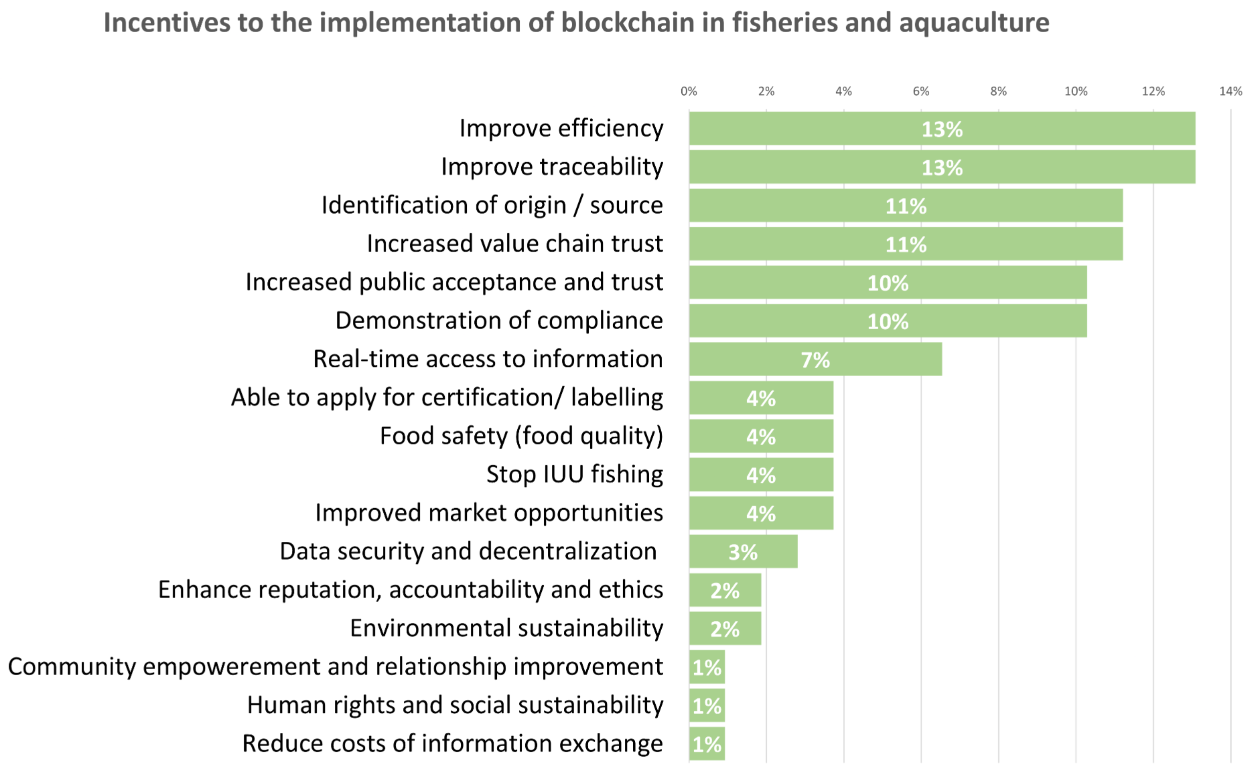

Figure 5. Incentives to the implementation of blockchain in seafood value chains (fisheries and aquaculture) as identified in the systematic review of the literature.

Most incentives, but not all, were common to the aquaculture and fisheries sectors. In this section, we discuss in detail the incentives identified in the literature and, in case of differences between sectors, we provide information on how they apply to the aquaculture and fisheries sectors (Figure 6).

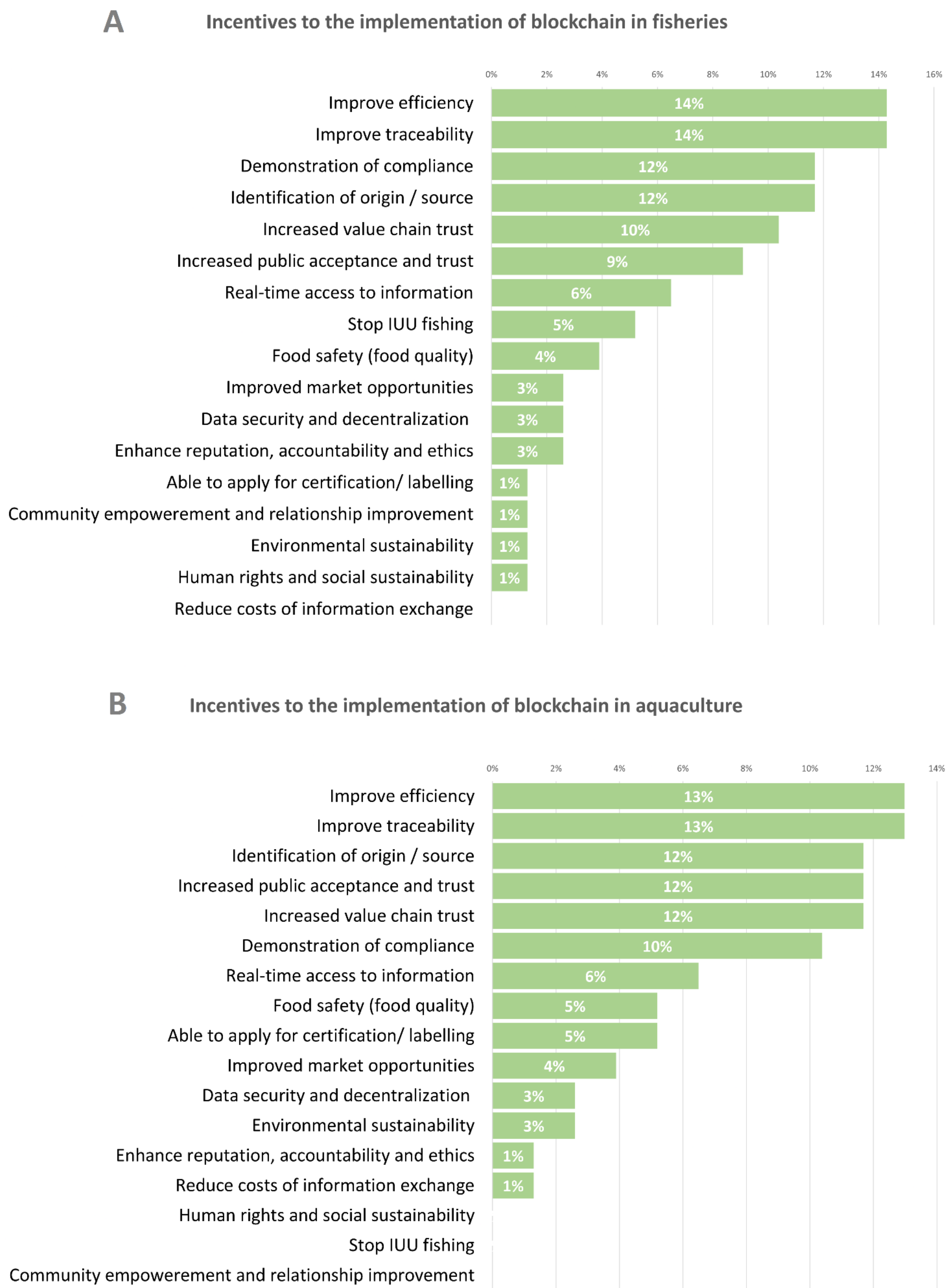

Figure 6. Incentives to the implementation of blockchain in (a) fisheries and (b) aquaculture value chains as identified in the systematic review of the literature.

Improve efficiency

Seafood value chains can be complex systems that deal with a significant amount of information and actors. Blockchain technologies can improve efficiency by connecting information and actors in an easy real-time accessible network that has a good response time of operation and prevents data manipulation (Jaya et al., 2021; Zhang et al., 2021). There are reports that show that real-time data availability and transparency improve the efficiency of transactions, in particular, within aquaculture value-chains (Jiang and Ræder, 2022). To add to this, according to Korneyko and Podvolotskaya (2019), the use of digital tools substitutes a large number of papers/physical documents, decreasing the time taken to ensure traceability.

Improve traceability

All the blockchain characteristics (already described), including the fact that it cannot be tampered with and the amount of information it can store and transmit in real-time, enhance traceability in seafood in general. Lin et al. (2021) refer that blockchain enhances efficient traceability of seafood and, in the case of the fisheries sector, blockchain could trace seafood to the individual fisher who caught it. In the case of aquaculture, Sengupta et al. (2021) refer that blockchain might also address issues related with food-fraud, food waste and food safety.

Allow for the identification of origin/source

With blockchain, it is possible to easily trace the source of a seafood product, which can be very helpful for consumers to be more aware of their choices, to prevent a food safety outbreak, to identify the origin of the product, and to guarantee a product's authenticity (Lin et al., 2021). Information on the origin of the seafood (as well as identifying the several steps from catch/production to sale, such as processing and transportation) improves the product's reliability not only for consumers, but also for producers, retailers, and all other value chain actors. According to Jiang and Ræder (2022) this proof of authenticity might add value to seafood products.

Increase value chain trust

Blockchain tools contribute to increasing trust in and acceptance of seafood and also of traceability itself amongst all actors in the value chain (including consumers). The increase in data sharing, security and accountability, improves mutual trust amongst value chain actors (Zhang et al., 2021), including producers, processors, retailers and governments/regulator entities. Lin et al. (2021) refers that the blockchain decentralized system (which means there is not a particular entity that owns the data) and immutable data allows to build trust among value chain actors, since the database is secure and the data cannot be tampered with. Besides these characteristics, smart contracts also enhance compliance with value chain processes and, therefore, increase the confidence of actors (Mondragon et al., 2020). The automatization and digitalization of the value chain processes makes it easier to avoid data mistakes or non-compliances within the seafood sectors, improving trust in the technology used and in the seafood produced, and improving transparency between the actors that operate it (Lin et al., 2021).

Increase public acceptance and trust

The use of blockchain technology in seafood traceability has been reportedly increasing consumers' trust in seafood products. Consumers are increasingly interested in knowing where their seafood comes from, if it is environmentally friendly and if it involves ethical working conditions (Tsolakis et al., 2021). Therefore, these digital tools resonate in general with consumers. With blockchain technology, consumers are able to access information that allows them to make more conscious purchase decisions and, as such, it increases their trust in the product (Gopi et al., 2019; Lin et al., 2021).

Reports of improvement on consumers trust usually come together with reports of increases of accuracy of data reporting and aquatic food quality information - such as in Tsolakis et al. (2021) or Zhang et al. (2021) - which, consequently, improves transparency, safety and reliability within the seafood sector. In particular, this has been allowing consumers to gain confidence in blockchain and aquaculture (Hang et al., 2020).

Demonstration of compliance

Since aquaculture industries have to comply with specific chemical and physical parameters in their production, those that use blockchain traceability technologies have an easier way to prove their legal status and responsibility with regards to the quality of their seafood. In aquaculture, this demonstration of compliance is related with seafood safety and animal welfare and can contribute to increasing consumer trustworthiness in the sector (Zhang et al., 2021).

In the fishery sector, blockchain traceability is seen as a way to ensure regulatory compliance with legal and ethical sourcing and allows for efficient regulatory audits (Lin et al., 2021). Tsolakis et al. (2021) further describe blockchain traceability as a way to ensure seafood quality and safety and, at the same time, ensure that fisheries are performing in a responsible way and not misleading consumers about the origin of the product.

Real-time access to information

Blockchain technologies allow for the real-time access to information at any point in the seafood value chain, which reinforces its transparency and efficiency (Jiang and Ræder, 2022; Zhang et al., 2021). Real-time access to information and historical data about seafood products is a motivation to use blockchain technologies in seafood traceability. With value chains having complex transactions, real-time information is a relevant feature for different parties to be able to check all records being made (Zhang et al., 2021).

Ability to apply for certification/labeling

Most literature points to the fact that with blockchain technologies in place (to ensure a transparent data sharing system and information tracking) mislabeling is reduced and chances of getting a certification/label can be improved as well. For instance, Lin et al. (2021), presented the case of a traceable solution for a tuna value chain called TraceTales, which allowed for automated print of labels, giving actors more trust in the product and in the accuracy of information.

Food safety (food quality)

Food safety is an important topic in seafood, and in particular for aquaculture products. The transparency promoted by blockchain traceability tools ensures that the production, storage and transportation of seafood is done in accordance with quality parameters and ensures food safety, which potentiates consumers trust to acquire these products (Du et al., 2020; Tsolakis et al., 2021; Zhang et al., 2021). According to Tsolakis et al. (2021), seafood quality can also be ensured in fisheries by using blockchain technologies. This relates with the elimination of IUU fishing and with the possibility of having a mechanism that easily verifies food quality and traces seafood back to its origin if any concerns arise.

Stop IUU fishing (specific to the fisheries sector)

Studies indicate that blockchain traceability helps eliminate IUU fishing by improving the visibility of exploitation practices and supporting regulatory entities to identify responsible actors (Tsolakis et al., 2021).

Improve market opportunities (specific to the aquaculture sector)

The aquaculture sector has reportedly had market advantages with the implementation of blockchain traceability. Zhang et al. (2021) refers that the increase in consumers' trust in aquaculture products makes the use of these tools a competitive advantage and might lead to improved market opportunities. There are no studies about the real costs of implementing and maintaining this technology in seafood value chains, so it is difficult to evaluate the costs and economic return. The fact that this opportunity was not reported for fisheries might relate to the lack of knowledge about it, but can also be due to smaller businesses, such as SSF value chains, lacking economic capital to risk the investment in blockchain (Lin et al., 2021).

Data security and decentralization

The blockchain decentralized system and database management is by itself considered to be an opportunity to record business transactions in a secure way for both the fisheries and aquaculture sectors. These characteristics have been mentioned by Patro et al. (2022) and Zhang et al. (2021) as motivations for implementing blockchain. The cryptography used in this tool improves the security of transactions, and the reliability and decentralization of this technology allows for a solid distributed system that is access free and fair.

Enhanced reputation, accountability and ethics **(specific to the fisheries sector)**

The transparency promoted by blockchain technology allows all involved parties to confirm ethical work conditions and seafood production, and holds everyone accountable (Lin et al. 2021). These incentives of blockchain have only been referred to in fishery studies, but it is to be expected that blockchain has the potential to enhance any entity's reputation for ethics and sustainability.

Environmental sustainability

Blockchain traceability contributes to the prevention of food waste, the equal distribution of surplus food, and allows seafood industries and consumers to be aware of their ecological footprint (Hang et al., 2020; Tsolakis et al., 2021).

Tsolakis et al. (2021) also refers to the United Nations' (UN) Sustainable Development Goal (SDG) 14 "Life Below Water", stating that blockchain technologies can monitor and inform consumers about the fisheries activities and how their exploitation is affecting ocean life. This study highlights several blockchain advantages from a sustainability perspective, such as increasing the visibility of the environmental impact of food, enabling the identification of foodborne illnesses, and helping promote a circular economy. This way, it potentially helps to conserve marine ecosystems and create adequate regulations.

Community empowerment and relationship improvement **(specific to the fisheries sector)**

According to Lin et al. (2021), blockchain can enhance the fishing communities' empowerment by giving them access to information and promoting more transparent, responsible and efficient practices. It can also promote accountability of decision-making (Tsolakis et al., 2021).

Human rights and social sustainability **(specific to the fisheries sector)**

Enhancing the transparency of seafood value chains means it is easier to understand if workers and communities are engaged in an equitable system. Tsolakis et al. (2021) pointed out different UN SDGs, which can be addressed when using traceability tools like blockchain. Even though these are addressed in regard to the fisheries sector, blockchain can also potentially enhance social aspects in aquaculture industries. Tsolakis et al. (2021) mention in their study that blockchain can address SDG 1 "No Poverty" (it allows for an increase in the visibility of fish captured by traditional fishers and, with this, allows for more exports and enhancement of household incomes), SDG 5 "Gender Equality" (it can help increase the visibility of women's role in the seafood industry and enhance gender equity), SDG 8 "Decent Work and Economic Growth" (migrant workers living in poor conditions are increasingly employed in the fishing industry, where illegal labor conditions are prevalent, blockchain can help increase their visibility and promote the fight for human rights). It also can contribute to limiting the eviction of local populations and safeguarding personal identity (especially in case of refugees) (Tsolakis et al., 2021).

<u>Reduce costs of information exchange</u> (specific to the aquaculture sector)

Blockchain traceability is seen as providing an opportunity to reduce the costs of information exchange in the aquaculture sector. Zhang et al. (2021) refer that blockchain is a way to cut costs related with data storage and exchange and, at the same time, ensure high safety and quality of large amounts of information content. This contributes to cutting the costs of aquaculture food production.

3.3. BARRIERS TO BLOCKCHAIN IN SEAFOOD SUPPLY CHAINS

A total of 12 barriers to the implementation of blockchain in fisheries and/or aquaculture were identified in the 15 papers reviewed. Table 2 shows the barriers to the implementation of blockchain as identified by the literature and to which sector (fisheries and/or aquaculture) these barriers applied.

Table 2. Result from the systematic review of the literature on barriers to the implementation of blockchain in fisheries and aquaculture value chains.

Barriers to blockchain in fisheries and aquaculture			
	Fisheries	Aquaculture	Reference
Cost/price	✓	✓	Du et al. (2020); Hang, et al. (2020); Jaya et al. (2021); Jiang and Ræder (2022); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Rahman et al., 2021; Sengupta et al. (2022); Tsolakiset al. (2021).
Size of supply chain	✓	✗	Du et al. (2020); Gopi et al. (2019); Jaya et al. (2021); Jiang and Ræder (2022); Rahman et al. (2021); Tsolakis et al. (2021).
Complexity of information needed	✓	✓	Gopi et al. (2019); Jiang and Ræder (2022); Patro et al. (2022); Rahman et al. (2021); Sengupta et al. (2021); Tsolakis et al. (2021).
Confidentiality/trust issues	✓	✓	Du et al. (2020); Garrard and Fielke (2020); Jaya et al. (2021); Mondragon et al. (2020); Patro et al. (2022); Tsolakis et al. (2021).
Amount of information needed	✓	✓	Du et al. (2020); Garrard and Fielke (2020); Gopi et al. (2019); Jiang and Ræder (2022); Rahman et al. (2021).

Lack of interest by actors in the value chain/lack of buy-in	✓	✓	Hang et al. (2020); Korneyko and Podvolotskaya (2019); Lin et al. (2021); Rahman et al. (2021); Tsolakis et al. (2021).
Complexity of use	✓	✓	Lin et al. (2021); Patro et al. (2022); Rahman et al. (2021); Tsolakis et al. (2021).
Lack of interest by the public/consumers	✓	✓	Lin et al. (2021); Rahman et al. (2021).
Lack of interoperability of information systems	✓	✓	Patro et al. (2022), Tsolakis et al. (2021).
Adulteration of seafood products during processing	✓	✓	Patro et al. (2022).
Lack of access to technologies	✓	✗	Lin et al. (2021).
Lack of incentives for the actors to join	✓	✗	Lin et al. (2021).

From the 12 barriers identified, the one most commonly mentioned in the literature, for both the fisheries and aquaculture sectors, was the cost/price of implementation of this kind of traceability technology (Figure 7).

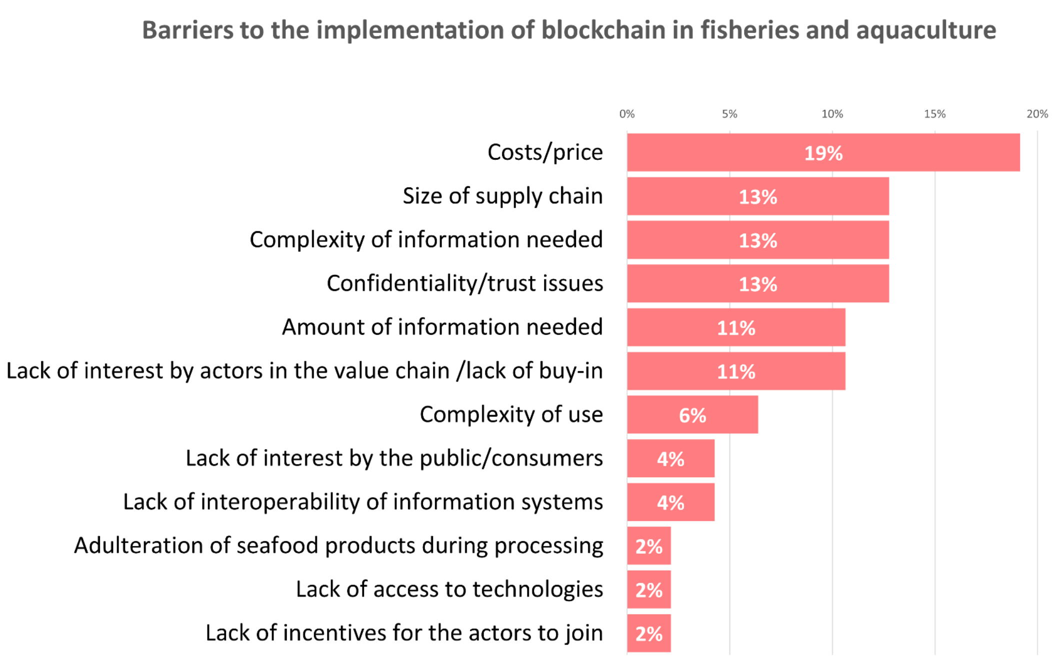

Figure 7. Barriers to the implementation of blockchain in seafood value chains(fisheries and aquaculture) as identified in the systematic review of the literature.

Most barriers to the implementation of blockchain in seafood identified in the literature were common to the fisheries and aquaculture sectors, except for three: the size of the supply chain, the lack of incentives for the actors to join blockchain, and the lack of access to technologies. These were only mentioned as a problem for the fisheries sector. Also, in the case of the fisheries sector, besides costs, the size of the supply chain was commonly identified as an important barrier to the implementation of blockchain. While in the case of the aquaculture sector, the complexity of information needed seems to be the second most mentioned barrier, after costs, that makes the implementation of this technology difficult (Figure 8).

Figure 8. Barriers to the implementation of blockchain in (a) fisheries and (b) aquaculture value chains as identified in the systematic review of the literature.

Cost/price of implementation

Although it is hard to estimate the costs of implementing the blockchain technology (Lin et al., 2021), the initial costs of implementing IoT equipment are very large and cannot be ignored (Korneyko and Podvolotskaya, 2019; Tsolakis et al., 2021). It is important to notice that in order to implement blockchain well any enterprise/value chain needs to invest in infrastructure, skills and training (Jiang and Ræder, 2022). The application of blockchain in both fisheries and aquaculture is similar to a major software development project that will store large amounts of data. This requires everything from a software backbone to a hardware sensor, processing power, etc. (Jaya et al., 2021; Sengupta et al., 2021). Hang et al. (2020) refer that small and medium-sized businesses might not even have the means to invest in blockchain platforms by themselves.

Size of the supply chain (specific to the fisheries sector)

Fisheries supply chains are usually very long and complex, involving a great number of actors and covering a wide geographical area (Rahman et al., 2021). According to Jaya et al. (2021), a long value chain means more users and, consequently, fewer "*throughput*" (a measure of how many actions are completed within a given time frame). This represents a challenge for maintaining food quality and performing an efficient food recall when necessary. Therefore, the ideal condition is to keep the value chain length as short as possible. Perhaps the fact that, in general, the aquaculture sector has shorter value chains, with less actors, could justify this being less of a challenge for the sector.

Complexity of information needed

Blockchain technology is used mainly to combat fraud, document long and complex production cycles and track critical chains of custody (Senguptaet al., 2021). Value chains can be long and complex, and the initial product can be processed multiple times before reaching consumers, therefore it can be difficult to manage and trace its multiple components and the probability of losing some information is high (Gopi et al., 2019; Rahman et al., 2021). For instance, a processing company might get the same species of fish from multiple sources, a box of filets might get filled with fish from different sources and that information might not be stored in the blockchain platform since the filets are indistinguishable (Gopi et al., 2019). All actors need to collaborate to ensure an unbroken traceability chain despite the asymmetries in information caused by the domination of middlemen in the value chains (Jiang and Ræder, 2022; Tsolakis et al, 2021). The required digitalisation of the supply chain and the implementation and maintenance of digital tools used in a blockchain platform (e.g., RFID equipment, tags and sensors) can be challenging and complex (Tsolakis, et al., 2021).

This point seems to be a bigger problem for the fisheries sector than for the aquaculture sector (the only paper reviewed focusing on this problem in aquaculture is Sengupta et al. (2019)), and this might be linked to the fact that value chains tend to be smaller in the aquaculture sector and, therefore, there is less data to collect.

Confidentiality/trust issues

Although confidentiality and trust issues are mentioned by some authors, this seems to be more of a barrier in public value chains, since these are open to everyone (Jaya et al., 2021). To combat this barrier, the data being collected must itself be trustworthy (Garrard and Fielke, 2020; Tsolakis et al., 2021). For Jaya et al. (2021), these issues are minimized by only accepting organizations approved by the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia. In private blockchains systems, actors share transaction and contract records, therefore trust no longer needs to be verified. This also lowers expenses since there is no need for auditors or third-party intermediaries to verify the information (Du et al., 2020; Mondragon et al., 2020).

Amount of information needed

The amount of information needed in a blockchain traceability system depends on the size of the value chain and the type of blockchain used (Garrard and Fielke, 2020; Rahman et al., 2021). Public blockchains are fully decentralized, immutable and vulnerable to a variety of failures, meanwhile private blockchains are easy to query, and can have large amounts of data being inserted quickly (Garrard and Fielke, 2020). Jiang and Ræder (2022) suggest that not all data should be stored on the blockchain system, rather only essential data, and their hash should be stored on-chain, while detailed information for traceability should be stored on an off-chain database. Although this might cause entropy when collecting data (Jiang and Ræder, 2022).

Lack of interest by the actors in the value chain/lack of buy-in

There is a lack of literature aiming at identifying digital solutions to combat counterfeit goods in specific markets, especially seafood products, limited by the lack of existing databases and disinterest of fishery companies and the government of some countries in such studies for commercial and political reasons (Korneyko and Podvolotskaya, 2019). The reluctance shown towards this technology by consumers, distributors and sellers is also caused by the lack of full-scale successful implementation (Rahman, 2021; Tsolakis et al., 2021). Hang et al. (2020) point out that one of the most common arguments against blockchain technologies is the fact that there is no significant adoption of this methodology outside of cryptocurrencies.

Complexity of use

Working with a blockchain platform can be complex and its implementation can be challenging. Not only because of the range of products that can derive from a single seafood product, but also because of the limited organizational level of education and skills (Tsolakis et al., 2021), the maintenance of the system itself, and the architecture of the network and data management (Rahman et al., 2021). The complexity of the platform is usually linked to the length of the value chain and collected data.

Lack of interest by the public/consumers

The lack of interest by the public/consumers is mentioned only by Lin et al. (2021) and Rahman et al. (2021). The former authors mention mainly the fact that consumers are very "price sensitive" and question if the change in price aggravated by the implementation of blockchain technology would be worth it, as it would probably result in a lack of interest by consumers. Rahman et al. (2021) approach the problem from a different perspective and mention the lack of interest by consumers and other actors in the value chain in using the technology available to know more information about the seafood products.

Lack of interoperability of information systems

The use of different data recording mechanisms among supply chain actors and, consequently, a lack of interoperability (the ability of different systems, devices or applications used by different actors to connect and communicate in a coordinated way) of information systems represents a barrier to the implementation of an efficient blockchain system. The lack of a standard data collecting system will lead to longer transaction times that will limit blockchain feasibility (Du et al., 2020), for this reason it is essential that all actors use compatible systems.

Adulteration of seafood products during processing

As mentioned previously value chains tend to be long and complex and, normally, have a processing step. It is often difficult for seafood consumers to identify the species they consume, and this becomes even harder if the product they consume has been through a processing step. Processing companies might get seafood products from various sources or even get two different species in which one is cheaper than the other, and process it the same way, if this is the case it is quite difficult to differentiate the products (Gopi et al., 2019). Furthermore, mislabelling, species substitution, and IUU fishing have become major barriers that undermine consumers' trust and represent a big challenge for traceability systems (Patro et al., 2022).

Lack of and/or difficulties in the access to technologies (specific to the fisheries sector)

The lack of access to technologies and/or the lack of know-how to work with said technologies is a problem, especially when talking about small-scale fisheries, where fishers are most of the time older with low levels of formal education. Lin et al. (2021), for example, focused on fishery in a remote island in Indonesia and point to the fact that although children had access to tablets and knew how to work with them, adults seemed to have a lot of problems having access and working with any type of technology, and opted to collect data manually.

Lack of incentives for the actors in the value chain (specific to the fisheries sector)

The lack of incentives for actors in the value chain to join blockchain is mentioned by Lin et al. (2021) when trying to engage fishers to join the blockchain platform and use it effectively. The authors defend that, in remote communities, where there is a lack of knowledge regarding this kind of technology, incentives are one way to convince actors to collect data and share it with the value chain.

4. EXAMPLES OF SEAFOOD BLOCKCHAIN INITIATIVES

In this section we provide examples of several initiatives using blockchain technology to trace seafood from catch to consumer around the globe (Figure 9). We divided the initiatives into three categories, according to the sector: small-scale fisheries (4.1), large-scale fisheries (4.2) and aquaculture (4.3), and analyzed two initiatives from each sector.

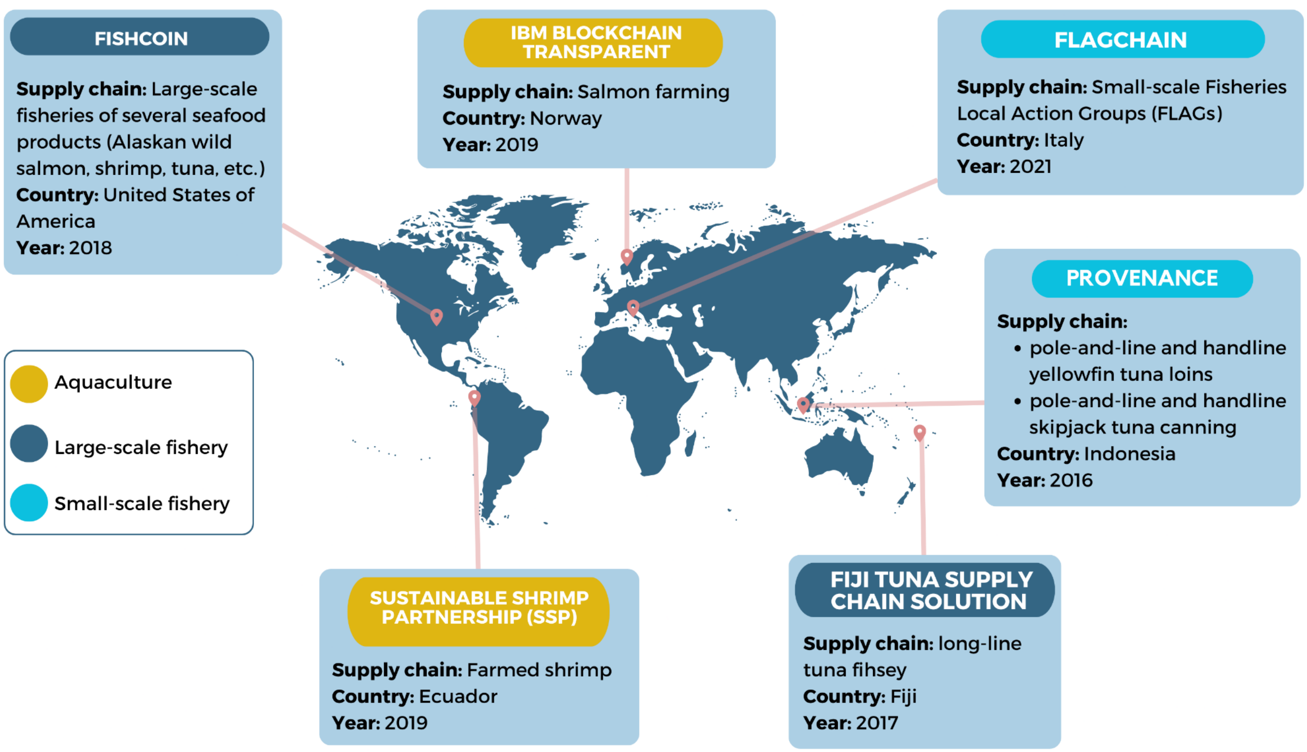

Figure 9. Blockchain initiatives applied to the large- and small-scale fisheries and aquaculture sectors around the globe.

4.1. SMALL-SCALE FISHERIES

In this section we identify and analyze the implementation of blockchain in two small-scale fisheries initiatives: provenance pilot blockchain, in Indonesia (4.1.1), and FLAGCHAIN, in Italy (4.1.2).

4.1.1. Provenance

In 2016, Provenance used the peer-to-peer (P2P) payment system technology used by bitcoin to track tuna from landing to the factory and beyond, in Maluku, Indonesia. To the best of our knowledge, this was the first blockchain documented initiative applied to the fisheries sector. Table 3 sums up the Provenance pilot, the way of operating and the technicalities of their platform.

Table 3. Summary of the Provenance pilot project.

Provenance pilot blockchain
Type of fishery: Small-scale
Supply chain: pole-and-line and handline yellowfin tuna loins, pole-and-line and handline skipjack tuna canning
Country/region: Indonesia
Year started: 2016 (6 months pilot)
Way of operating
Actors involved: local Non-governmental Organizations (NGO), fishers, suppliers.
How it works: mobile phone and smart tags.
Challenges: connecting the physical asset (tuna) to the digital asset; amount of time spent.
Technicalities
Blockchain platform: Ethereum
Blockchain type: NA

Sources of information: Blaha and Katafono (2020), Provenance (2016).

The Provenance project was a six-month pilot study to demonstrate how blockchain technology could be used to track fish from sea to consumer, ensuring transparent, traceable and sustainable fishing practices. This pilot focused on the pole-and-line and handline tuna fishery, tracking the supply chains of yellowfin tuna loins and skipjack tuna for canning. The primary objectives included assisting local fishers in recording their catches, tracing the catch data to the suppliers, and evaluating how the technology could be used to: (i) aid robust proof of compliance with standards; (ii) prevent the "double-spend" of certificates; and (iii) explore how the technology could form the basis for an open system for traceability (Blaha and Katafono, 2020).

The pilot tracked tuna from catch to landing on to the factory and into retail using the Ethereum blockchain, mobile phones, and smart tags. According to the pilot report, a significant challenge encountered was establishing a connection between the physical asset (tuna) and the digital asset. Various methods such as two-dimensional QR codes, RFID and NFC were implemented for identification purposes. Nevertheless, the process of digitizing each stage consumed considerable time. To ensure interoperability, fairness, and consensus, the report recommended the utilization of public blockchains (Provenance, 2016).

Certain aspects of the process remained unclear. It was uncertain whether each tuna was individually tagged and recorded on the blockchain, or if the entire catch was tagged and recorded as a collective unit. Additionally, the tracking of the catch from the supplier to the factory, as well as within the factory itself, lacked clarity in terms of how the catch was monitored and differentiated in various products (Provenance, 2016).

4.1.2. FLAGCHAIN

The FLAGCHAIN project was started by three Fisheries Local Action Groups (FLAGs) from Campania, southern Italy. The project uses blockchain to deliver the "history" of the product (origin, capture techniques, processes undergone, transport, and conservation) to consumers. It aims at providing complete transparency and traceability of the catches from small-scale fisheries (SSF) boats in their areas of operation. In table 4 we present, in a very concise way, the FLAGCHAIN project, the way of operating and the technicalities of their platform.

Table 4. Summary of the FLAGCHAIN project.

Flagchain
Type of fishery: Small-scale **Supply chain:** Small-scale boats operating in the areas of operation of the Pesca Flegrea, Litorale Miglio D'Oro and Sviluppo Mare Isole di Ischia e Procida. **Country/region:** Campania, Italy **Year started:** 2021
Way of operating
Actors involved: Fishers, Port authorities, Cooperatives. **How it works:** mobile app.

Challenges: poor digitalization, onerous bureaucracy required to comply with marketing regulations, lack of traceability of the SSF catches, low public awareness of local catches and their season, loss of traditional habits of eating local fish.

Technicalities

Blockchain platform: Quadrans

Blockchain type: Private

Sources of information: FARNET (2021), FEAMP (2020).

The main goal of the three FLAGs was to have a common platform where all the information needed to ensure the traceability of fish originating from the local SSF sector was recorded. The FLAGCHAIN app was built using the blockchain platform Quadrans, which has low running costs and energy requirements. This platform can be customized to meet the needs of other FLAG areas, and the more fishers use the app, the more detailed the traceability will be. Using this technology modernizes the SSF value chain and moves the sector towards a digitalization process. It allows small-scale fishers to get ahead of their competitors, satisfy the pressing consumer demand for transparency, and emphasize the strengths of the sector, the quality of their product and the processes they use.

The project trained fishers who, due to their age, lacked digital skills. The fishers who entered their data into the system via their phones were involved from the start of the project in order to ensure the app was user-friendly. An awareness-raising campaign was carried out to stress the benefits of traceability to small-scale fishers, and thus promote the use of the app.

All three FLAGs identified weaknesses in the implementation of blockchain, mainly related to poor digitalization, the bureaucracy required to comply with marketing regulations, the lack of traceability of the SSF catches, the reduced public awareness regarding local catches and their seasons, and the loss of traditional habits of eating local fish.

This project shows that the involvement of all stakeholders (small-scale fishers, port authorities, cooperatives) from the start of the blockchain implementation process is vital to ensure transparency and traceability in the value chain of SSF products. It also shows that blockchain systems can be applied successfully in the SSF sector, even given the old age of fishers and low level of digitalization.

4.2. LARGE-SCALE FISHERIES

In section 4.2 we identify and analyze two large-scale fisheries initiatives: the Fiji Tuna supply chain solution (4.2.1) and Fishcoin, adopted in Alaska (4.2.2).

4.2.1. Fiji Tuna Supply Chain Solution

To the best of our knowledge, the first documented application of blockchain technology in a tuna longline fishery was implemented in 2017 when the World Wild Fund for Nature (WWF), ConsenSys, Sea Quest (Fiji) Ltd and TraSeable Solutions partnered to implement the project in Fiji. The goal was to create a completely transparent and traceable supply chain in this fishery, using an innovative blockchain technology, for the fresh and frozen tuna supply chain. In table 5 we present, in a very concise way, the Fiji Tuna Supply Chain Solution project, the way of operating and the technicalities of their platform.

Table 5. Summary of the Fiji Tuna Supply Chain Solution.

Fiji Tuna Supply Chain Solution
Type of Fishery: Large-scale **Supply chain:** longline tuna fishery **Country/region:** Fiji **Year started:** 2017
Way of operating
Actors involved: Fishers, regulators, processors, distributors/retailers and consumers. **How it works:** QR codes and RFID technology. **Challenges:** reliance on paper-based processes, availability of local suppliers and technicians, mapping the supply chain past the importer, cooperation of downstream supply chain actors, authenticity of data, transaction time limitations, basic costs.
Technicalities
Blockchain platform: Ethereum (Viant) **Blockchain type:** NA

Sources of information: TraSeable Solutions (2023), Blaha and Katafono (2020), Cook (2018).

The first step of the process consisted of mapping the supply chain into Viant and setting the needed roles and permissions. Onboard the vessels, each tuna was tagged with unique identifiers initially using RFID tags, and later with QR code tags. Key data about the capture event (e.g., catch zone, vessel, crew details) and tuna (e.g., weight, RFID number, species) were recorded into the app. Individual landed fish were given a tag, so it was possible to trace it through the value chain, from the moment it was caught to the final consumer. The QR code or RFID tags associated with each product could be scanned by any individual at any given time, and the entire journey of that asset (tuna) would pop up on their phone - no application download or sign was needed.

Various challenges related to the application of this blockchain solution where identified, such as:

- The reliance on paper-based processes,
- Lack of local suppliers and technicians,
- Difficulties mapping the supply chain past the importer,
- Lack of cooperation of downstream supply chain actors,
- Authenticity of data,
- Transaction time limitation,
- Basic costs.

Nevertheless, project participants also identified several advantages (such as the increase of detail of the fishing activities, increase value chain trust, decrease of theft of catch onboard fishing vessels, and the reduction of paperwork and payment processing time (Cook, 2018)) to this approach and expect that this will become the standard way to use the blockchain-based platform Viant for complex supply chains where digital traceability platforms already exist.

4.2.2. Fishcoin

Fishcoin was created in 2018 as a way to provide an affordable, accessible, transparent, secure and trusted interoperable traceability tool for seafood supply chains. It was designed to be a blockchain peer-to-peer traceability system, a decentralized tool, with the engagement of the seafood industry to develop the tool. In table 6 we present, in a very concise way, the Fishcoin project, the way of operating and the technicalities of their platform.

Table 6. Summary of the Fishcoin project.

Fishcoin
Type of fishery: Large-scale **Supply chain:** Different seafood products (Alaskan wild salmon, shrimp, tuna, etc.) **Country/region:** USA **Year started:** 2018
Way of operating
Actors involved: Eachmile Technologies, Fishcoin. **How it works:** the system uses a public blockchain system that rewards value chain stakeholders for providing information regarding seafood transactions. **Challenges:** understanding the company’s values and mission.

Technicalities
Blockchain platform: Ethereum
Blockchain type: Public

Sources of information: Douglas (2021), Fishcoin (2018), Fishcoin (n.d.).

This blockchain involves a token ecosystem mechanism, meaning that seafood producers and intermediaries are rewarded (with tokens, or digital vouchers) for providing data onto the platform. The Fishcoin team believes this will allow for more information to be available for consumers, improving the safety and quality of seafood, while shifting the economic burden of it to downstream actors such as hotels, restaurants and retailers. Its network works through a series of open-source tools and software development kits (SDKs) that can be used by stakeholders to integrate decentralized applications (DApps) to the Fishcoin Ecosystem (Fishcoin, 2018; Fishcoin, n.d).

Not many challenges were identified regarding this initiative. However, the Fishcoin Manifesto was not easy to achieve. The team described that there were some difficulties trying to appeal to investors, employees and society, all at once, and that brought difficulties when trying to write a truthful mission, vision and values regarding Fishcoin. Nevertheless, after this reflection, a Manifesto came to life to explain Fishcoin's beliefs, including the importance of working in partnerships, how the positive changes for achieving ocean sustainability should be industry-driven, and the need to ensure that fishers and farmers are not the ones to carry the costs of traceability (Douglas, 2021).

4.3. AQUACULTURE

Finally, we describe and analyze two examples from aquaculture, the Sustainable Shrimp Partnership case study in Ecuador (4.3.1) and IBM Blockchain Transparent in Norway (4.3.2).

4.3.1. Sustainable Shrimp Partnership (SSP)

The Ecuador-based SSP joined the IBM Food Trust blockchain platform in May 2019. This was the first shrimp organization to join the IBM Food Trust network and includes three Ecuador-based producers using the platform: Omarsa, Songa, and Promarisco-Grupo Nueva Pescanova (Ledger Insights, 2020). In table 7 we present, in a very concise way, the Sustainable Shrimp Partnership project, the way of operating and the technicalities of their platform.

Table 7. Summary of the Sustainable Shrimp Partnership project.

Sustainable Shrimp Partnership (SSP)
Sector: Aquaculture **Supply chain:** Ecuadorian farmed shrimp **Country/region:** Ecuador **Year started:** 2019
Way of operating
Actors involved: Sustainable Shrimp, Partnership (SSP), IBM Food, Trust, Ecuadorian shrimp farm processors, retailers. **How it works:** a Consortium/Private (IBM) blockchain and consumers have access to a traceability web-application. **Challenges:** price competitive market and the communication with stakeholders
Technicalities
Blockchain platform: HyperLedger **Blockchain type:** Consortium/Private

Sources of information: Tolentino-Zondervan et al. (2023), Sustainable Shrimp Partnership (2022), Blaha and Katafono (2020), Ledger Insights (2020).

The blockchain platform is used to provide transparency and traceability, which is something lacking in the farmed shrimp sector with the rise of food fraud (FishFocus, 2019). This platform helps retailers to remain informed about production and processing methods. Consumers are also able to access data about the value chain processes through an app. Additionally, IBM Food Trust also enhances food safety by making sure the shrimp is antibiotic-free, Aquaculture Stewardship Council (ASC) certified, and has a neutral impact on the environment (Blaha and Katafono, 2020; Ledger Insights, 2020).

Given the price competition in the industry (that often leads to seafood fraud), SSP's level of transparency appeared to be a challenge. However, SSP's traceability solution seemed to have changed the sector, since other companies started to embrace these practices and push for improvement in the Ecuador shrimp industry. Another challenge involved sharing information with consumers and customers in a meaningful way. This allowed them to make informed purchasing decisions by simply scanning a QR code (Sustainable Shrimp Partnership, 2022).

4.3.2. IBM Blockchain Transparent (Norwegian seafood)

In 2019, the IBM Food Trust, in collaboration with Atea (a technological partner), launched a blockchain tracking tool aimed for seafood traceability. Later, the Norwegian Seafood Association (or Sjømatbedriftene) joined the collaboration to develop this tool in the Norwegian seafood industry. In table 8 we present, in a very concise way, the IBM Blockchain Transparent (Norwegian Seafood) project, the way of operating and the technicalities of their platform.

Table 8. Summary of the IBM Blockchain Transparent (Norwegian Seafood) project.

IBM Blockchain Transparent (Norwegian seafood)
Aquaculture
Supply chain: Salmon farming **Country/region:** Norway **Year started:** 2019
Way of operating
Actors involved: Norwegian Seafood Association, IBM, Atea. **How it works:** the private (IBM Hyperledger) blockchain systems provide data to consumers about the salmon origin, processing processes and nutritional content. **Challenges:** employees initial mistrust of the traceability system and user difficulties to operate it.
Technicalities
Blockchain platform: Hyperledger **Blockchain type:** Private

Sources of information: Tolentino-Zondervan et al. (2023), IBM (2021), Norwegian Seafood Trust. (n.d.).

With this blockchain technology, the consumer can have information about the origin of the salmon, what it has been fed and how sustainable the production has been. The initiative defends that this enhances consumer trust in the product, by making it safer and more traceable. It appeared as a way to push the Norwegian seafood industry to be more sustainable while also giving it a competitive market advantage (IBM, 2021; Norwegian Seafood Trust, n.d.).

It is noticed that the older generation of farmers is a bit more skeptical about using this technology because there is a lack of user experience and worries about data security and privacy. Nevertheless, trust is being built with producers by explaining the system’s technicalities.

Additional features projected to the future are related to transportation details (which will be helpful for wholesalers and enhance further the traceability of salmon), calculation of carbon footprints and the use of AI (Artificial Intelligence) to increase production efficiency (IBM, 2021; Norwegian Seafood Trust, n.d.).

5. CONCLUSIONS

Seafood products are the most traded food commodity globally and the EU is one of its largest markets, importing 60% of all the seafood consumed. The current increasing concerns about IUU fishing, fair trade, ethical issues, human rights violations and food security has resulted in the need to improve transparency and traceability in seafood supply chains.

The use of blockchain in seafood value chains ensures better traceability from sea to plate in a secure and tamper proof way and is gathering a lot of interest recently. The development and implementation of blockchain technologies is inevitable and may bring many advantages to markets and actors of the seafood value chain, but there are also many challenges to its implementation.

The major barriers to implementing blockchain in fisheries and aquaculture include the cost of implementation, the difficulty of implementing this technology in large supply chains, the concerns regarding the complexity and amount of information needed, issues around confidentiality and trust by actors in the value chain, and even the lack of interest and buy-in by some actors of the seafood value chain and by the public/consumers.

Although there are a lot of challenges to the implementation of this traceability technology, there are also many incentives to the implementation of blockchain in fisheries and aquaculture. These incentives include enhancing traceability and improving efficiency, being able to identify the origin/source of seafood products, increasing value chain actors and consumers trust, acceptance and confidence in products, providing the ability to demonstrate compliance with certification and labeling schemes, rules and regulations and sustainable fishing, allowing for real-time access to information, putting the fishery/aquaculture production in a better position to apply for certification and labeling, improving food safety, combating IUU fishing and improving marketing opportunities.

Some examples of implementation and using blockchain technology demonstrate that it can be implemented both in the fisheries (small- and large-scale) and aquaculture sectors, but also attest to the complexity of implementing such traceability technology in these sectors. Examples also demonstrate that there is not a one-model-fits-all blockchain technology, and different types of technologies should be chosen and adapted, using different platforms and forms of data collection adjusted to the level of traceability aimed to achieve in different fisheries and aquaculture value chains.

6. REFERENCES

Afrianto, I., Djanta, T., Arkeman, Y., Hermadi, I. and Sitanggang, I. 2020. Block chain technology architecture for supply chain traceability of fisheries products in Indonesia: Future challenge. Journal of Engineering Science and Technology, Special Issue on INCITEST2020, 41-49.

Blaha, F. and Katafono, K. 2020. Blockchain application in seafood value chains. FAO Fisheries and Aquaculture Circular No. 1207. Rome, FAO. https://doi.org/10.4060/ca8751en.

Borit, M and Olsen, P., 2016. Seafood traceability systems: gap analysis of inconsistencies in standards and norms [online]. FAO, Fisheries and Aquaculture Circular No. 1123. Rome, Italy. Available from: https://www.fao.org/3/i5944e/i5944e.pdf [Accessed on 10 May 2023].

CFP. 2022. Facts and figures on the common fisheries policy – Basic statistical data. Publications Office of the European Union. https://doi.org/10.2771/737237

Cook, B. 2018. Blockchain: Transforming the seafood supply chain. World Wide Fund for Nature [online]. Available from: http://awsassets.wwfnz.panda.org/downloads/draft_blockchain_report_1_4_1.pdf [Accessed on 02 May 2023].

Di Pierro, M. 2017. What Is the Blockchain? Computing in Science and Engineering, 19 (5), 92-95. http://doi.org/10.1109/MCSE.2017.3421554.

Douglas, A. 2021. The Fishcoin Manifesto [online]. Available from: https://medium.com/fishcoin/the-fishcoin-manifesto-9cd155740f4c [Accessed on 08 May 2023].

Du, Z., Wu, K., Wen, B., Xiao, K. and Su, R. 2020. Traceability of animal products based on a blockchain consensus mechanism. IOP Conference Series: Earth and Environmental Science, 559 (1), 12032. https://doi.org/10.1088/1755-1315/559/1/012032.

Egan, M., Bambra, C., Petticrew, M. and Whitehead, M. 2009. Reviewing evidence on complex social interventions: appraising implementation in systematic reviews of the health effects of organisational-level workplace interventions. Journal of epidemiology and community health, 63, 4–11. https://doi.org/10.1136/jech.2007.071233.

European Union. 2015. EU: Sustainable Tools for the World's Largest Seafood Market. Available at: https://oceans-and-fisheries.ec.europa.eu/publications/sustainable-tools-worlds-largest-seafood-market_en [Accessed on 29 May 2023].

FAO. 2022. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en.

FARNET. 2021. Blockchain improves traceability for small-scale fishers [online]. Available from: https://webgate.ec.europa.eu/fpfis/cms/farnet2/blockchain-improves-traceability-small-scale-fishers_en.html [Accessed on 04 May 2023].

FEAMP. 2020. FLAGCHAIN | Garanzia e sicurezza sul pescato locale [online]. Available from: https://pofeamp.politicheagricole.it/it/notizie/flagchain-garanzia-e-sicurezza-sul-pescato-locale/?fbclid=IwAR29gyAxVjXNLFDEr3dXFDnHgWEwQOU-U80LaTSt-RMik_nGTQmzlXj5G6s [Accessed on 04 May 2023].

Fishcoin 2018. Whitepaper - A Blockchain Based Data Ecosystem For The Global Seafood Industry [online]. Available from: https://t1.daumcdn.net/cfile/tistory/99D35D395B06086C15?download [Accessed on 08 May 2023].

Fishcoin (n.d.). Fishcoin Project [online]. Available from: https://fishcoin.co/ [Accessed on 08 May 2023].

FishFocus (2019.). Shrimp tastes better with blockchain traceability [online]. Available from: https://fishfocus.co.uk/shrimp-tastes-sweeter-with-blockchain-traceability/ [Accessed on 20 June 2023].

Gadhok, I. and Avesani, C. 2021. Public food stockholding: objectives, experiences and main issues. Trade policy briefs, no. 46. Rome. https://doi.org/10.4060/cb7271en.

Garrard, R. and Fielke, S. 2020. Blockchain for trustworthy provenances: A case study in the Australian aquaculture industry. Technology in Society, 62, 101298. https://doi.org/10.1016/j.techsoc.2020.101298.

Gopi, K., Mazumder, D., Sammut, J. and Saintilan, N. 2019. Determining the provenance and authenticity of seafood: A review of current methodologies. Trends in Food Science and Technology, 91, 294-304. https://doi.org/10.1016/j.tifs.2019.07.010.

Haber, S. and Stornetta, W. S. 1991. How to time-stamp a digital document. Journal of Cryptology, 3, 99–111. https://doi.org/10.1007/BF00196791.

Hang, L., Ullah, I. and Kim, D. 2020. A secure fish farm platform based on blockchain for agriculture data integrity. Computers and Electronics in Agriculture, 170, 105251. https://doi.org/10.1016/j.compag.2020.105251.

IBM. 2021. Blockchain stories: Giving Norwegian seafood a competitive edge [online]. Available from: https://www.ibm.com/blog/blockchain-stories-giving-norwegian-seafood-a-competitive-edge/ [Accessed on 04 May 2023].

Jaya, E., Candra, M. and Ferindra, T. 2021. Development of Blockchain-Based Traceability System for Fishery Products. Proceedings of 2021 International Conference on Data and Software Engineering: Data and Software Engineering for Supporting Sustainable Development Goals, ICoDSE 2021. https://doi.org/10.1109/ICoDSE53690.2021.9648448.

Jiang, S. and Ræder, T. B. 2022. Experience on Using ArchiMate Models for Modelling Blockchain-Enhanced Value Chains. ACM International Conference Proceeding Series, 375-382. http://doi.org/10.1145/3530019.3531346.

Korneyko, O. and Podvolotskaya, A. 2019. Assessment of the Blockchain Capabilities to Combat the Global Trade in "Falsified" and "Illegal" Fish Products. ARPN Journal of Engineering and Applied Sciences, 14(10), 3310-3315. https://doi.org/10.36478/JEASCI.2019.3310.3315.

Ledger Insights. 2020. Sustainable Shrimp Partnership Launches Blockchain Traceability app using IBM Food Trust [online]. Available from: https://www.ledgerinsights.com/sustainable-shrimp-partnership-blockchain-traceability-ibm-food-trust/ [Accessed on 03 May 2023].

Lewis, S. and Boyle, M., 2017. The expanding role of traceability in seafood: Tools and key initiatives. Journal of Food Science, 82, A13–A21. https://doi.org/10.1111/1750-3841.13743.

Lin, Y., Pyke, D., Clarke, R. and Corporandy, A. 2021. Bumble Bee and Blockchain. Operations Management Education Review, 15, 33-58.

Longo, C., Buckley, L., Good, S., Gorham, T., Koerner, L., Lees, S., Liow, S., Oloruntuyi, O., Schley, D., Rice, J. and Currey, R. 2021. A Perspective on the Role of Eco-Certification in Eliminating Illegal, Unreported and Unregulated Fishing. Frontiers in Ecology and Evolution, 9: 637228. https://doi.org/10.3389/fevo.2021.637228.

Mondragon, A., Mondragon, C. and Coronado, E. 2020. Feasibility of Internet of Things and Agnostic Blockchain Technology Solutions: A Case in the Fisheries Supply Chain. 2020 IEEE 7th International Conference on Industrial Engineering and Applications, ICIEA 2020, 9102080, 504-508. https://doi.org/10.1109/ICIEA49774.2020.9102080.

Nakamoto, S. 2008. Bitcoin: A Peer-to-Peer Electronic Cash System [online]. Available from: www.bitcoin.org [Accessed on 10 May 2023].

Norwegian Seafood Trust. (n.d.) Tracking technology [online]. Available from: https://norwegianseafoodtrust.no/vart-arbeid/?lang=en [Accessed on 04 May 2023].

Patro, P., Jayaraman, R., Salah K. and Yaqoob, I. 2022. Blockchain-Based Traceability for the Fishery Supply Chain. IEEE Access, 10, 81134-81154. http://doi.org/10.1109/ACCESS.2022.3196162.

Poulsen, K. and Leroy, A. 2021. Seafood traceability: Exemptions risk fuelling illegal fishing. WWF European Policy Office [online]. https://wwfeu.awsassets.panda.org/downloads/wwf_seafood_treacability___exemptions_risk_fuelling_illegal_fishing_jan_2021.pdf [Accessed on 27 March 2023].

Provenance. 2016. From shore to plate: Tracking tuna on the blockchain [online]. Available from: https://www.provenance.org/tracking-tuna-on-the-blockchain#introduction [Accessed on 11 May 2023].

Quadrans Blockchain. 2023. Quadrans Blockchain [online]. Available from: https://quadrans.io/ [Accessed on 22 May 2023].

Rahman, L., Alam, L., Marufuzzaman, M. and Sumaila, U. 2021. Traceability of sustainability and safety in fishery supply chain management systems using radio frequency identification technology. Foods, 10(10), 2265. https://doi.org/10.3390/foods10102265.

Ruoti, S., Kaiser, B., Yerukhimovich, A., Clark, J. and Cunningham, R. 2019. Blockchain technology: what is it good for? Communications of the ACM, 63(1), 46-53. https://doi.org/10.1145/3369752.

SALT. 2021. Unpacking the Blockchain: A Seafood Perspective on Blockchain Technology [online]. Available from: https://www.salttraceability.org/story-hub/unpacking-the-blockchain-a-seafood-perspective-on-blockchain-technology/ [Accessed on 29 April 2023].

Sengupta, T., Narayanamurthy, G., Moser, R., Pereira, V. and Bhattacharjee, D. 2021. Disruptive Technologies for Achieving Supply Chain Resilience in COVID-19 Era: An Implementation Case Study of Satellite Imagery and Blockchain Technologies in Fish Supply Chain. Information Systems Frontiers, 24(4), 1107-1123. https://doi.org/10.1007/s10796-021-10228-3.

Sustainable Shrimp Partnership. 2022. 3 years in 3 words: challenge, innovation, trust [online]. Available from: https://www.sustainableshrimppartnership.org/3-years-in-3-words-challenge-innovation-trust/ [Accessed on 04 May 2023].

Teh, L., Caddell, R., Allison, E., Finkbeiner, E., Kittinger, J., Nakamura, K. and Ota, Y., 2019. The role of human rights in implementing socially responsible seafood. PLoS One, 14, 1–22. https://doi.org/10.1371/journal.pone.0210241.

Tolentino-Zondervan, F., Ngoc, P., and Roskam, J. 2023. Use cases and future prospects of blockchain applications in global fishery and aquaculture value chains. Aquaculture, 565, 739158. https://doi.org/10.1016/j.aquaculture.2022.739158.

TraSeable Solutions. 2023. Reimagine: Transforming Pacific Fisheries and Agriculture through Collaborative, Transparent, Traceability [online]. Available from: https://www.traseable.com/ [Accessed on 05 May 2023].

Tsolakis, N., Niedenzu, D., Simonetto, M., Dora, M. and Kumar, M. 2021. Supply network design to address United Nations Sustainable Development Goals: A case study of blockchain implementation in Thai fish industry. Journal of Business Research, 131, 495-519. https://doi.org/10.1016/j.jbusres.2020.08.00.

Zhang, Y., Liu, Y., Jiong, Z., Zhang, X., Li, B. and Chen E. 2021. Development and assessment of blockchain-IoT-based traceability system for frozen aquatic product. Journal of Food Process Engineering, 44(5), e13669. https://doi.org/10.1111/jfpe.13669.