







# Traceable Distribution of Fish Products: State of the Art of Blockchain Technology Applications to Fish Supply Chains

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**Abstract.** Fish products traceability is a sensitive issue for supply chains (SCs) involved in the capturing processes and successful distribution of these commodities. Full transparency and traceability of fish products' locomotion has a potential to stop the flow of illegally or unethically caught/processed fish. Blockchain technology (BCT) is considered to become a crucial part of the fish traceability solution, providing an end-to-end visibility, thus creating value for all stakeholders, including final consumers. In this study, we are aiming to explore the current state of the BCT implementations to the fish distribution SCs. This study applies a systematic literature review (SLR) approach of academic literature to reveal the status quo of BCT adoption in the fish and seafood SC cases, revealing the opportunities it holds in improving the levels of traceability, as well as the challenges that were identified in extant literature that need to be addressed throughout the development of the fish industry applications.

**Keywords:** blockchain · supply chain management · fish distribution

## 1 Introduction

Fish and seafood industry is one of the biggest worldwide, representing 12% of livelihoods across the globe, generating wealth to 1 out of every 10 people in the world [1]. In the last 50 years worldwide fish consumption grew almost in double – full market size figures surmounted \$500 billion USD [2]. Marine ecosystems are facing with high levels of pressure, where illegal, unreported, or unregulated (IUU) fishing activities are posing threat to the overall sustainability of ecosystems, thus seriously affecting the global economies and creating risks of consumer contamination cases. [3] estimated that, on a global scale, IUU fishing holds around 30% of the total global fisheries catch, resulting

into around 10 to 23.5 billion US\$ annual losses worldwide (around 11 to 26 million tons of fish products).

Seafood and fish products traceability is becoming critical for supply chains (SCs) involved in these commodities. Therefore, experts see full traceability and transparency of SCs as the only way to stop the flow of illegally or unethically caught/processed fish. Blockchain technology (BCT) has potential to become a significant part of the solution, providing end-to-end transparency and traceability, thus creating value for all stakeholders, including final consumers. In order to understand why BCT has a potential to address IUU fishing problem, it is essential to understand the features of the technology itself. Blockchain technology is based on a decentralized peer-to-peer architecture and is also defined as an encrypted digital ledger [4]. It is able to create a continuous, visible and unalterable sharable record of transactions and movements around SC in an immutable manner [5]. Like this, BCT is a set of chain blocks, that altogether represent a tamper-proof, permanent sequence of data and transactions that can be verified anytime in the future. This network is built based on the consensus algorithm, achieved by various voting mechanisms, where the chain can be extended with a next block, only when the majority of participants agree with it [6].

In this study, we are aiming to explore the current state of the BCT implications to the fish SCs and the existing scholar investigations in the field. This study will shed light on the traceability and transparency achievement with BCT implementation, other significant advantages and improvements that BCT can bring to fish and seafood SCs, as well as the current challenges in the field. The next sections are built as following: Sect. 2 will bring a general understanding of BCT and its potential in SC practices, Sect. 3 will disclose the methodology selected for the study, Sect. 4 will generate a discussion of extant literature systematization and Sect. 5 will provide conclusions of the study and future paths for the research.

## **2 Blockchain Technology Features and Implications to Supply Chain Management**

The global supply chain is an industry that is running the global economy and brings to consumers everything that is needed: food, transportation means, clothing and generally anything that might be needed for everyday life activities. Like this, one of the most emergent, promising technologies that holds the potential to transform and improve SC activities is Blockchain [7].

The distributed nature of BCT, the immutability of its records, and the ability to operate in a decentralized logic through smart contracts use make BCT-based networks significantly different from those previously developed and based on the Internet (e.g. Industry 4.0 sectors and supply chains) [8]. Smart contracts are essentially pre-defined self-executing codes, that are preventing risk of corruptions or tampers within the execution of a given contract [9]. Smart contract feature is one of the main novelties of BCT-based networks, and it is expected to play a crucial role in managing partnership efficiency – due to the information immutability, and automation it may result in transparency and improvement of SC collaboration [10]. BCT is assumed to become a “next holy grail for the enterprise”, as it holds huge potential for SC improvement in all of its aspects, such as manufacturing, production, orders placing, transportation, delivery and consumption [11].

By its nature, BCT is bringing transparency throughout the whole supply network, in this way providing reliability in information about products’ origins and confidence in its provenance [12]. BCT-based distributed ledgers provide a single version of truth through consensus protocols [13], therefore enhancing the performance of SC, and eliminating the need in establishing trust relationships among players, since every participant will be a holder of all information flow existing around the network [9]. Transparency of records and transactions about products and processes empowers suppliers to be engaged with further activities and decisions, like strategies development, joint knowledge creation and innovation support [14].

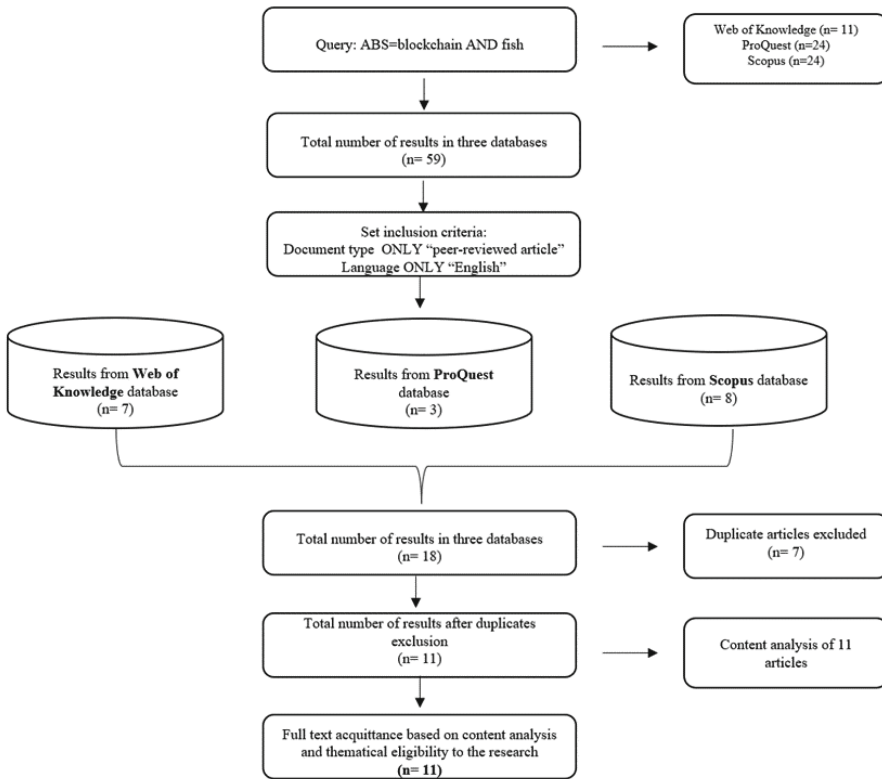
Scholars were already proposing BCT applications to various sections and fields that would improve life and experiences of populations, including smart cities applications to parking spaces gamifications [15], construction engineering [9], agriculture [16], automobile trade [17], wine counterfeiting reduction [18] and many other fields. BCT applications are actively discussed to bring improvements to the SCs related to perishable commodities, as all data regarding movement, storage conditions and temperature can be successfully traced and assured for safety purposes. In this light, fish SCs were used as a potential field of application of BCT [19, 20], as the sensitivity and potential food risk for consumers make fish SCs justified for transparent technology integration. In the next sections, BCT-based academic solutions for fish and seafood SCs will be discussed closely, exploring important scholarly articles in the field.

### 3 Methodology

In order to address the aims of this study, a systematic literature review (SLR) was chosen as a suitable methodology, which enables clarity and academic integrity to follow a pre-defined route for choosing and analyzing the most relevant extant literature in the field. For the SLR, this study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) checklist, that allows a structured and transparent process of literature selection, that can be reproduced by other scholars. The graphical representation of the literature selection process can be found in a flow diagram (Fig. 1).

Three academic databases were used for the query: Web of Knowledge (WoS), ProQuest, and Scopus. These databases were chosen as being trusted global databases for academic queries and for the capacity to provide publications from top international

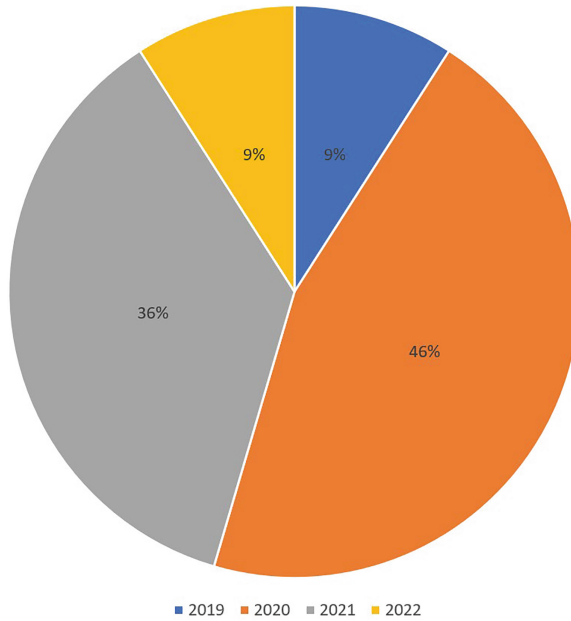
multidisciplinary journals. The keywords for the search were ‘blockchain’ and ‘fish’, with an advanced search function to extract studies with both keywords found in the abstract. The search was further limited only to peer-reviewed articles written in English. All publications available up to beginning of April 2022 were included, without any limitations per year.



**Fig. 1.** Literature selection process

As can be seen in Fig. 1, the initial number of studies identified in three databases upon abstract keyword inclusion criteria was 59. It is important to note, that among these documents, the types include conference proceedings, newspaper articles, erratum etc. This highlights the interest in the topic not only in the scientific field, but a general public interest in fish traceability solutions. In order to focus more on academic studies, we further used the filter to exclude it to peer-reviewed articles only. Total number of peer-reviewed articles resulted in 18 studies, after excluding the duplicates, final result revealed 11 unique articles. All of the 11 articles were thoroughly screened through full-text for their suitability and soundness to the purpose of this study. As a result, all 11 articles were kept for final inclusion to this SLR, as they serve the aim of the study and bring different aspects to further discussion.

Figure 2 represents the ratio of the 11 selected articles based on the year of publication, which reveals that the highest level of academic interest in fish traceability solutions was witnessed in 2020. It can be further assumed, that the worldwide pandemic situation awakens an increased interest to the provenance and safety assurance of products, including perishable commodities, such as fish products.



**Fig. 2.** Publications ratio per year based on the 11 articles included in SLR

Table 1 shows the full list of articles, that were selected for this SLR. Table 1 reflects the multidisciplinary nature of the topic – the journals, where articles were published include different spectrum of fields: technological, business, and environmental studies. The primary focus of the selected articles, as can be seen from Table 1 is the development and proposition of traceability and monitoring solutions for fish products supply chains. This focus signifies the interest of consumers in fish products processing and transportation transparency, that will ensure food safety. In the next section, the discussion of issues addressed by selected studies will be performed, including views on transparency solutions, other improvements that BCT is able to bring to fish supply chains, and the current challenges in the field.

**Table 1.** Full list of 11 articles included in systematic literature review

Author(s)	Year	Journal	Title	Issues discussed
Korneyko and Podvolotskaya	2019	Journal of Engineering and Applied Sciences	Assessment of the Blockchain Capabilities to Combat the Global Trade in “Falsified” and “Illegal” Fish Products	Review of literature on blockchain-based solutions to combat illegal and falsified fish products in markets
Altoukhov, A	2020	Earth and Environmental Science	Industrial product platforms and blockchain in aquaculture	Modern automation systems integration for fishes and crustaceans farming
Grecuccio et al	2020	Energies	Combining blockchain and IoT: Food-chain traceability and beyond	Design and development of a software framework for food supply chains traceability under Industry 4.0 context
Hang et al	2020	Computers and Electronics in Agriculture	A secure fish farm platform based on blockchain for agriculture data integrity	Blockchain-based fish farm platform for agricultural data integrity assurance
Petri et al	2020	Computers in Industry	Blockchain for energy sharing and trading in distributed prosumer communities	Blockchain-based energy framework proposition based on real fish processing industrial site
Probst, W	2020	ICES Journal of Marine Science	How emerging data technologies can increase trust and transparency in fisheries	Digital data technologies impact on commercial fisheries
Low et al	2021	Chemical Engineering Transactions	Development of Traceability System for Seafood Supply Chains in Malaysia	Food management tool development for seafood supply chains traceability

*(continued)*

**Table 1.** (continued)

Author(s)	Year	Journal	Title	Issues discussed
Rahman et al	2021	Foods	Traceability of Sustainability and Safety in Fishery Supply Chain Management Systems Using Radio Frequency Identification Technology	Traceability systems for food safety, sustainability and product quality assurance of fish supply chains
Sengupta et al	2021	Information Systems Frontiers	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	Fish supply chain challenges in developing countries and disruptive technologies integrating solutions
Tsolakis et al	2021	Journal of Business Research	Supply network design to address United Nations Sustainable Development Goals: A case study of blockchain implementation in Thai fish industry	Design of a blockchain-based fish supply chain for Sustainable Development Goal achievement
Feng et al	2022	Computers and Electronics in Agriculture	Modeling and evaluation of quality monitoring based on wireless sensor and blockchain technology for live fish waterless transportation	Waterless fish transportation and intelligent monitoring solutions

## 4 Discussion

Some of the brightest innovative features of BCT are: improved transparency and further traceability of information, as well as increased trust between stakeholders [21]. Fast-moving SCs, such as those dealing with perishable items, that require a cold chain

storage were named among the most crucial industries for BCT penetration [5]. In this context, fish product SCs represent a perfect example of disruptive technology integration for the traceability and trust improvement purposes. In the following subsections the transparency solutions, further advantages and challenges of BCT-based networks for fish SCs will be discussed; the discussion is based upon the set of studies selected for the SLR.

#### 4.1 Traceability and Transparency of Blockchain-Based Fish Supply Chains

At this stage of globalization and international long SCs, global traceability systems are required to bring together all the processes and shared data across seafood industry stakeholders; and BCT is specifically interesting for seafood trade applications, as such networks can guarantee unaltered and veridical real-time data [22]. Like this, [22] believe that final consumers would not question the accuracy of data, as the immutability feature of BCT allows to rely on authenticity of available data. However, not only final consumers might value high transparency of data, such controlling agents as non-governmental organizations (NGOs) and management authorities are generally interested in traceable information availability for sensitive commodities [23]. In his study, [23] highlights the application of various disruptive technologies for different levels of fish SCs. Like this, he claims, that data mining and artificial intelligence (AI) seem to be useful for stages of monitoring and controlling fishing vessels, as they help accumulating knowledge on catches and following compliance to rules and standards at the sea; BCT and smart contracts, on their turn, are useful for information transparency assurance across the given supply chain.

A motivation for BCT-based application architecture for [24] was the detection of trust absence towards fish quality from consumers, as upstream activities information, such as catchment source, storage conditions and packaging processes are generally not available for the final consumer. The proposition is to build a BCT-based app, which can scan the QR code on fish and seafood products and bring transparency to information such as satellite-based fish zone data, hyper local weather data, and GPS and IoT based vessel communication; like this, quality and safety measures in the fresh fish and seafood SCs can be improved [24]. Among other applications of BCT-technologies to fish SCs, an innovative waterless transportation monitoring system based on flexible wireless sensor for live sea bass was suggested [25]. This application showed the ability to reach dynamic and continuous monitoring and tracing of transportation parameters, and with the use of BCT ensure security and reliability of shared data.

A seafood traceability system for inputting data was proposed by [22], which is designed to deal with complex SCs, bringing to a unified network all players, starting from aquafarms, all the way to final consumers. As complex SCs have a higher risk of food contamination and poisoning, the proposed system simplifies the tracking and tracing information kept on blockchain all the way back to the potential affected batch of products [22]. An interoperable solution, involving a combination of blockchain with multiple technologies, such as Internet of Things (IoT), wireless sensor networks (WSN), and radio frequency identification (RFID) also enables building a traceability system for sustainable and safe fisheries SCs [26]. Besides having a potential to improve aquaculture and seafood traceability, such technologically advanced SCs may resolve potential issues

of managing customer requests and responding quickly to unexpected changes in orders [26, 27] explain BCT-based networks by drawing analogy with Enterprise Resource Planning (ERP) software, where registered batches of products, and any information related to the product's lifecycle can be stored in an immutable manner, being available to all network players simultaneously. The potential of BCT-based solutions in bringing transparency and traceability to products SCs is obvious, and fish SCs are identified as a suitable application case, due to perishability and short lifecycle of the product. Transparent information and traceability possibilities can bring value-added aspect not only to final consumers, but to every stakeholder of such SC, as it assures the safe concerns and decreases the risk of fish and seafood contamination cases.

## 4.2 Blockchain Driven Improvements for Fish Supply Chains

Apart from bringing a previously unattainable level of transparency to supply networks, BCT has other significant inherited features, that are able to improve SC processes. BCT-based solutions make it perfect to apply in use cases, where trust of network participants lacks due to lengthy and poor communication across network, e.g. SCs of imported seafood products that are flowing through multiple responsible controlling authorities when crossing borders [23]. The trust-improving factor will drive social and economic benefits to fishermen as well, as it will highlight consumer trust towards sellers, create a better management of fish SCs and develop more resilience across SCs to cope with emergency situations [24].

BCT is maintained to be as well the technology, that can help in identifying anomalies throughout the production and consumption processes, e.g. a frozen fish fillet can be traced back and checked for saturated water and chemicals additives, that could be illegally used to increase fillet's weight [28]. Another improvement, that BCT can bring to fish SCs is flexibility and the speed of information updating for players; it can as well result in reduction of costs by creating digital certification for products involved [29]. The BCT-based platform proposed in one of the selected studies, can provide fish farmers with benefits of secure, tamper-proof storage of big agriculture data, and automate transactions via smart contract usage; therefore, reducing levels of errors or data manipulation [30]. Moreover, when combined with other technologies, such as IoT, BCT is claimed to bring even more advantages to food SCs, by overall improvement of business processes and increasing customer satisfaction, e.g. when applied to cold-chain use cases [27].

## 4.3 Current Challenges of Blockchain-Based Solutions for Fish Supply Chains

When talking about advantages, that BCT-based networks are able to bring to the fish SCs, it is important to keep in mind the infancy of this technology applications to business practices. Hence, there are still some challenges and considerations that need to be kept in mind when developing an implementation plan to a real use case.

When designing BCT-based solutions, one thing that should be primarily evaluated and considered is the existing data structuring type and technology specifications in each given case; for instance, when applied to Thai government system, the challenge

remained in the data inaccuracy and initial incorrect number of registered vessels, making the traceability in this case incomplete [31]. Thus, each specific case of a specific country cannot be fully generalized, as there can be nuances that are only characteristic to that specific SC and existing regulations and flaws. [24] further support, that cultural differences and contextual conditions may result in a degree of complexities for different regions – depending on the existing infrastructure, it requires the willingness of stakeholders in the BCT adoption process.

The real-life implementation of anti-counterfeit BCT is still challenging due to general limitations such as the heterogeneity of participation in global SCs, the high cost of technology implementation and support, and the potential risk of software vulnerability, caused by uncertain legally recognized status in many countries across the globe [28]. As from the scientific side, there are already some propositions of models and systems that are existing, the practical implementation is still at a lower level of progress. For instance, the system proposed by [22] should be further implemented in a real use case to validate the system and check the food hazards sensitivity. Trustworthiness of smart meters, proposed by [32] should as well be further evaluated through usage of trust and reputation techniques to check the level of reliability of smart devices and their associated risks. Overall, in-depth research for the technical aspects of BCT deployment is required, such concerns as storage capability, speed of transactions, and its overall performance and behavior, when used in a combination with other technology, such as IoT [25].

## 5 Conclusions and Future Research

In general, the application of BCT to a specific SC of fish distribution opens many frontiers for industry improvement. Fish industry represents a network of stakeholders that are involved in a fast-moving SC, where the product under distribution is perishable and sensitive to storage conditions. Thus, BCT implementation would allow a real-time data visibility for upstream players to manage the fluctuations in demand, as well as would bring more trust for downstream players (final consumers), as information about the origins would be open and easily accessible. It would also serve a purpose of social and economic benefit creation for fishermen, as it would exclude data manipulation in further SC stages and would build trust for the product, potentially leading to a higher rates of consumption of fish products. However, it is important to keep in mind the introductory stages of BCT applications in businesses, so challenges like heterogeneity of participation in technology adoption and concerns regarding high costs of technology implementation and its further support may still arise at this stage.

The focus, therefore should be on both academic and practical exploration of BCT potential to bring improvements to fish SCs. We hope that this study helped gaining a status quo of BCT adoption in the fish and seafood SC cases, revealing the opportunities it holds in improving the levels of traceability and transparency to all network players, including the final consumers. The challenges identified in the selected set of articles were revealed, and need to be addressed by further scholar and industry applications.

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