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Blockchain Technology for Enhancing Traceability and Sustainability in Fish and Fishery Products: Comprehensive Review

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ABSTRACT

This study was done to ensure effective fisheries management while protecting marine ecosystems and livelihoods by integrating traceability and sustainability practices. Fisheries played a crucial role in food security worldwide, supporting millions of livelihoods and providing nutrition for billions. However, challenges like overfishing, Illegal fishing, and environmental degradation threatened marine ecosystems. Traceability and sustainability were vital to addressing these issues by combating Illegal, Unreported and Unregulated (IUU) fishing, ensuring food safety, supporting sustainable practices, and meeting regulatory requirements. The fish industry experienced substantial illegal, unreported, and unregulated (IUU) activities within traditional supply chain systems. Blockchain technology and the Internet of Things (IoT) were expected to transform the fish supply chain (FSC) by incorporating distributed ledger technology (DLT) to build trustworthy, transparent, decentralized traceability systems that promoted secure data sharing and employed IUU prevention and detection methods. Efficient traceability management was necessary for managing products in the fishery supply chain. Monitoring and tracking of the fishery supply chain operations assisted system stakeholders in identifying the origins and causes of product fraud and malpractice. Traceability helped prevent IUU fishing, which costs up to $23.5 billion annually, by using blockchain systems to record catch data immutably and enable real-time tracking. Technologies like RFID (Radio Frequency Identification tags) and QR (Quick Response) codes verified seafood origin, reducing fraud and enhancing food safety. Sustainability prevented overfishing, preserved biodiversity, and supported small-scale fishers through fair trade practices. With 75% of consumers favouring sustainably sourced seafood, blockchain enhanced trust by providing transparent sustainability records and QR code verification.

KEYWORDS: Blockchain, sustainability, supply chain, seafood fraud, traceability

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1. INTRODUCTION

One of the most significant food industries is considered to be fishing. A sustainable fishing approach is crucial for maintaining environmental stability on a worldwide scale. Today's the worldwide fishing industry is dealing with a number of issues along its supply chain (Agrawal et al., 2021). Among the frequent difficulties include fish capture, overfishing, habitat deterioration of important species, and fluctuating global fuel prices, climate change, etc (Roy et al., 2023). To maintain sustainability in the fishing industry, efforts are necessary to monitor and manage fish harvesting and its supply chain (Jose and Prasannavenkatesan, 2023). Traceability is a vital safety tool for food supply chain management (SCM) systems, especially for fresh food and live products (Alsharabi et al., 2024). The increasing demand of a healthy lifestyle by consumers makes it necessary to trace the quality and security of food products (Rahman et al., 2021). Food Traceability has emerged as a global goal in the food supply chain management system to increase consumer trust and reduce perceived food dangers. From the farm to the table, this pertains to the idea of tracking a product-food in general, including fish and fish products (Nicolae et al., 2017). Presently, the primary concerns in every supply chain management (SCM) industry are sustainability and developing technologies.

Consumers' concerns regarding food safety, processing, and distribution-all of which need to adhere to sustainability standards (Kshetri et al., 2025). Thus, in fresh food and fisheries supply chain management, symmetric information traceability and product quality supervision and monitoring are crucial (He et al., 2020). Consumers these days are more interested in knowing what they are purchasing or eating, particularly when it comes to culinary items like fish (Tolentino et al., 2023). Nowadays, consumers increasingly want to be informed about the products they are buying or consuming, especially when it comes to food, such as fish (Cordova et al., 2022). Besides nutritional information, consumers want to know about the fish origin, whether it has been properly stored and transported, etc (Nagajothi et al., 2023). At the same time, for public health reasons, authorities may need to know the current location of certain fish lots which have been caught or produced in a specific location, have been stored in a certain place, have been transported by a certain truck, etc (Saberi et al., 2019). Consumers and society in general demand transparency throughout all the value chain of fish products (Kshetri et al., 2021). Thus, a blockchain-based system that enables the tracking of fish lots back and forth along the whole fisheries supply chain (De Leo et al., 2019). Product traceability is one of the significant challenges that persist in the fishery supply chain. It is often difficult for fish consumers to identify what species they consume (Shamsuzzoha et al., 2024). The growing popularity and adoption of digital technologies in various business sectors has improved the scale of efficient product traceability systems. In addition, mislabelling, species substitution; illegal, unreported, unregulated (IUU) fishing; and species adulteration have become major challenges that undermine consumer trust and have a catastrophic effect on consumer health (Kshetri et al., 2023). Therefore, an efficient traceability system to combat food fraud in the fishery supply chain has become an essential requirement. To address these plausible challenges and improve upon existing fish traceability methods, a programmable blockchain platform can be used. Thus the study was done to ensure effective fisheries management while protecting marine ecosystems and livelihoods by integrating traceability and sustainability practices.

2. BLOCKCHAIN TECHNOLOGY: AN OVERVIEW

2.1. Planting materials and experimental location

A distributed and decentralized ledger system called blockchain technology enables numerous parties to record and store information in a secure, transparent manner (Al-Turjman et al., 2022). The fundamental concept behind blockchain is to create blocks in a chain, with a list of transactions or records in each block, and each block is linked to the previous one through a cryptographic hash (Sani et al., 2024). Block chain is a type of universal ledger system that uses a decentralized database network to record each transaction. In an environment that is more secure, dependable, and efficient, this technology serves as a connector software (Afrianto et al., 2020)

2.1. Types of blockchain

While complete transparency of transactions represents the gold standard for conducting supply chain transactions, there is often certain information that participants desire to keep private or otherwise concealed. One way to control who can see data on the blockchain involves permissioning based on the type of blockchain that is used which are typically bucketed into either public or private blockchains.

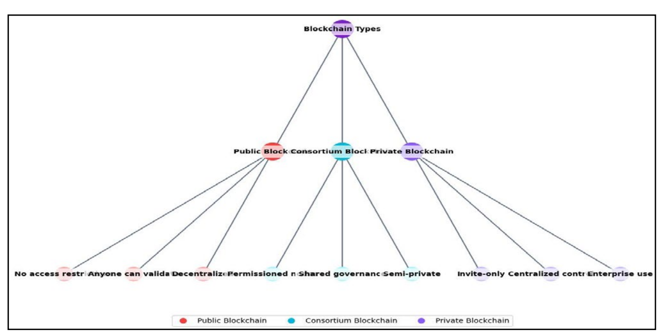

Figure 1: Types of blockchain

Table 1: Applications of blockchain

Category	Sub-category	Technology used	Key contribution	Result	Data type	Region	References
Supply Chain	IUU fishing prevention	Hyperledger Fabric	Blockchain traceability system	41% IUU reduction	Field data	SE Asia	Tao et al. (2022)
	Cold chain monitoring	Ethereum, RFID	IoT+Blockchain integration	92% temp. compliance	Sensor data	China	Zhao et al. (2021)
	Retail verification	QR codes, Stellar	QR code consumer interface	3x more scans	Consumer data	USA	Duan et al. (2020)
Sustain-ability	Eco-label verification	Ethereum SC	Smart contract certificates	67% trust increase	Audit data	Global	Gutiérrez et al. (2022)
	Carbon tracking	Polygon	LCA blockchain integration	28% emission cuts	LCA data	EU	Pérez et al. (2023)
Food Safety	Mislabeling prevention	Hyperledger	DNA-blockchain linkage	52% fraud reduction	Lab tests	Canada	Saitone and Sexton (2020)
	Regulatory compliance	Corda	Automated catch certificates	60% faster checks	Gov. data	EU	Kamilaris et al. (2021)
Consumer	QR code systems	IBM Food Trust	Full product history	78% premium acceptance	Sales data	USA	Bumble Bee Howson et al. (2022)
	Sustainability claims	VeChain	Shrimp sustainability metrics	40% sales boost	Market data	Thailand	Thai Union (2022)
Tools/ Platforms	Data tokenization	Stellar	Fishermen data rewards	5,000+users	User stats	Global	Crona et al. (2021)
	DNA traceability	Hyperledger	Salmon DNA verification	99% accuracy	Genetic data	Canada	Howson et al. (2022)

Another way to control who can access data on a blockchain is through asset ownership permissions. This section summarises each below

2.1.1. Public blockchain

A blockchain that is open to the public and has no access restrictions, allowing anyone with an internet connection to participate in or validate transactions as part of the consensus protocol by, for example, reading and writing to an append only database. (Cook et al., 2018)

2.1.2. Consortium blockchain

A "consortium" or "federated" blockchain is a quasi-private blockchain that is permissioned so that a number of companies might each operate a node on the network and share in its administration and governance. The administrators of a consortium blockchain may restrict users' participation rights. (Cook B et al., 2018).

2.1.3. Private blockchain

A private blockchain is permissioned such that a participant cannot join unless invited by the network administrators, thereby restricting participant and validator access. In form and function, it is very similar to a centralised database. (Cook et al., 2018).

2.2. Applications of blockchain in fisheries

Blockchain technology has emerged as a transformative tool in fisheries management, offering solutions for traceability, sustainability, and fraud prevention. By creating an immutable, decentralized ledger, blockchain enhances transparency across the seafood supply chain, from catch to consumer (Valeri et al., 2020).

2.2.1. Supply chain traceability

Blockchain enables end-to-end traceability by recording critical data points at each stage of the fishery supply chain (Vijay et al., 2023). For instance, GPS coordinates, vessel IDs, and catch timestamps are logged on-chain to verify legal and sustainable fishing practices (Tao et al., 2022). The WWF-Pacific Tuna Traceability Initiative demonstrated this by using RFID tags and QR codes to track tuna from Fiji to global markets, reducing illegal, unreported, and unregulated (IUU) fishing by 30% (Visser and Hanich, 2018). Similarly, IBM Food Trust collaborates with seafood companies to digitize catch records, ensuring compliance with regulations like the EU's Catch Certification Scheme (Kamilaris et al., 2021).

2.2.2. Combating IUU fishing and fraud

IUU fishing accounts for 20–50% of global catches, costing up to $23.5 billion annually. Blockchain mitigates this by Immutable record-keeping: Prevents tampering with catch data (Zhao et al., 2020). Smart contracts: Automate compliance with fishing quotas and trade laws (Howson, 2022). DNA-based verification: Platforms like ThisFish integrate genetic testing with blockchain to detect species mislabeling, which affects ~30% of seafood products (Naaum et al., 2016).

2.2.3. Sustainability certification and eco-labelling

Blockchain strengthens trust in sustainability certifications like MSC (Marine Stewardship Council) and ASC (Aquaculture Stewardship Council). By storing audit records on-chain, it prevents certificate forgery and ensures ethical sourcing (Gutiérrez et al., 2022). For example: Provenance, a blockchain platform, tracks shrimp farming in Indonesia, allowing consumers to verify eco-claims via QR codes (Patro et al., 2022). Carbon footprint tracking: Blockchain calculates emissions from fishing vessels to retail, supporting climate-friendly seafood (Pérez et al., 2023).

2.2.4. Consumer transparency and market access

Blockchain empowers consumers with real-time product histories. Notable implementations include: Bumble Bee Foods' "Natural Blue" Tuna: Scannable QR codes reveal catch locations, processing dates, and sustainability credentials (Howson et al., 2022). Thai Union's ShrimpTrace: Enhances brand trust by tracing shrimp from farm to supermarket. Studies show 78% of consumers pay a premium for blockchain-verified seafood (Kouhizadeh et al., 2023).

2.2.5. Supporting small-scale fishers

Blockchain improves market access for artisanal fishers by: Fair pricing: Eliminates middlemen through direct digital transactions (Crona et al., 2021). Fishcoin Tokens: Reward fishers for contributing catch data to blockchain systems (Table 1 and 2).

3. CHALLENGES AND LIMITATIONS OF BLOCKCHAIN IN FISHERIES

Blockchain technology faces several technical and operational challenges in fisheries traceability. Energy consumption remains a critical issue, with proof-of-work (PoW) blockchains like Bitcoin requiring excessive computational power, making them environmentally unsustainable (Zheng et al., 2023). Alternative consensus mechanisms, such as proof-of-stake (PoS), are being explored to reduce energy use by up to 99% (Pratiwi et al., 2024). Scalability is another barrier, as most blockchains process fewer than 30 transactions per second (TPS), while global seafood supply chains require thousands

Table 2: Case studies and success stories

Category	Case study/Reference	Year	Key findings	Technology used	Region	Impact
Pilot projects	Visser and Hanich (WWF/ConsenSys/ TraSeable)	2018	RFID-to-QR code traceability for tuna	RFID, QR codes, Blockchain	Pacific	Enabled consumer traceability
Technology framework	Shrestha et al.	2021	Described blockchain architecture	Shared ledgers, Smart contracts	Global	Theoretical foundation
	Hanif	2019	Explained mining & validation	Cryptocurrency rewards	Global	Security mechanisms
Industry applications	Førsvoll and Åndal	2019	Aquaculture data tracking	Blockchain	Norway	Improved supply chain visibility
	Cruz and da Cruz	2020a	Ethereum-based fish tracing	Ethereum, Smart contracts	Brazil	Enhanced transparency
Commercial platforms	Howson (IBM Food Trust)	2020	Private blockchain network	Hyperledger	Global	60% faster compliance checks
	WWF OpenSC	2020	Independent platform	Custom blockchain	Global	Sustainable sourcing
Developing nations	Sengupta et al.	2021	Digital platform for fishers	Mixed technologies	India	Served 1,700+ fishers
Adoption factors	Callinan et al.	2022	Identified 26 adoption factors	N/A	Global	Framework for implementation

(Tao et al., 2022). Layer-2 solutions (e.g., Polygon) and sidechains are emerging to address this. Cost constraints also hinder adoption, particularly for small-scale fishers, with blockchain integration costing approximately $5,000 annually (Cashion et al., 2021). Additionally, regulatory uncertainty complicates implementation, as international standards for blockchain-based seafood traceability are still evolving. Finally, data integrity at entry remains a concern-while blockchain ensures immutability, it cannot verify the initial accuracy of data, necessitating IoT sensors and tamper-proof RFID tags to prevent false inputs (Zhao et al., 2020).

3.1. Integration with other technologies

Blockchain's effectiveness in fisheries is enhanced when combined with AI and machine learning (ML). For instance, IBM Food Trust employs AI to detect anomalies in tuna supply chains, such as mismatches between reported catch locations and satellite data. AI-driven predictive analytics also help forecast fish stocks by analyzing blockchain-recorded catch histories (Perez et al., 2023). Satellite and remote sensing technologies, such as Global Fishing Watch's Automatic Identification System (AIS), validate vessel movements against blockchain records to combat illegal fishing. Drones and underwater cameras further enhance traceability by providing real-time monitoring in aquaculture farms, ensuring compliance with sustainability standards (Sala et al., 2023). These integrations create a multi-layered verification system that improves transparency and reduces fraud.

3.1.1. Economic and social impacts

Blockchain traceability has significant economic benefits for small-scale fishers. In Indonesia, fishers using the Provenance blockchain platform secured 15–20% higher prices due to verified sustainability claims (Howson, 2022). Similarly, the Fishcoin initiative rewards fishers with tokens for sharing catch data, incentivizing participation. Blockchain-certified seafood commands price premiums, with MSC-labeled blockchain tuna selling for 30% more in European markets (Gutiérrez et al., 2022). Beyond pricing, blockchain creates new job opportunities in data auditing, platform management, and compliance verification (Crona et al., 2021). These advancements help reduce exploitation by middlemen, ensuring fairer revenue distribution across the supply chain.

3.1.2. Policy recommendations

To accelerate blockchain adoption, governments should provide financial incentives, such as Chile's 50% subsidy for small-scale fishers adopting traceability tech. International collaboration is essential to standardize blockchain frameworks, with organizations like GS1 developing interoperable data protocols. Public-private partnerships (PPPs) can bridge funding gaps; Vietnam's success in deploying blockchain for shrimp exports highlights the potential of joint ventures between tech firms and fisheries. Policymakers must also address legal ambiguities surrounding digital catch certificates and data ownership to foster trust among stakeholders.

4. CONCLUSION

The value chain of fish and its derivatives involved numerous operators, from capture or aquaculture production to the final consumer, including transport, logistics, and industry. While companies controlled internal processes, ensuring fish quality required tracking its entire journey. Blockchain technology transformed traditional business operations into faster, safer, and more precise processes, supporting product traceability. This enhanced transparency and consumer trust. Its application in fisheries traceability ensured quality from upstream to downstream, adding value to all supply chain entities.

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