From Pond to Plate: Blockchain's Role in Traceable Aquaculture

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1. Introduction

Aquaculture has emerged as one of the fastest-growing food production sectors globally, now providing over 50% of the fish consumed worldwide. This shift is driven by the increasing pressure on wild fisheries, the rising global population, and the growing demand for sustainable protein sources. Despite its growth, aquaculture faces significant scrutiny over practices such as antibiotic use, labour exploitation, and environmental degradation. In this context, ensuring traceability and transparency across the supply chain from hatcheries and farms to processors, exporters, retailers, and ultimately, consumers are more important than ever. Traceability in aquaculture involves documenting and verifying each step in the journey of aquatic products. However, traditional traceability systems are often paper-based, fragmented, and vulnerable to fraud. Blockchain technology, with its decentralized and tamper-proof attributes, offers a transformative solution to these challenges. It promises a future where every transaction and movement within the aquaculture supply chain is recorded, immutable, and accessible to all relevant stakeholders. This review article explores the application of blockchain technology in aquaculture traceability.

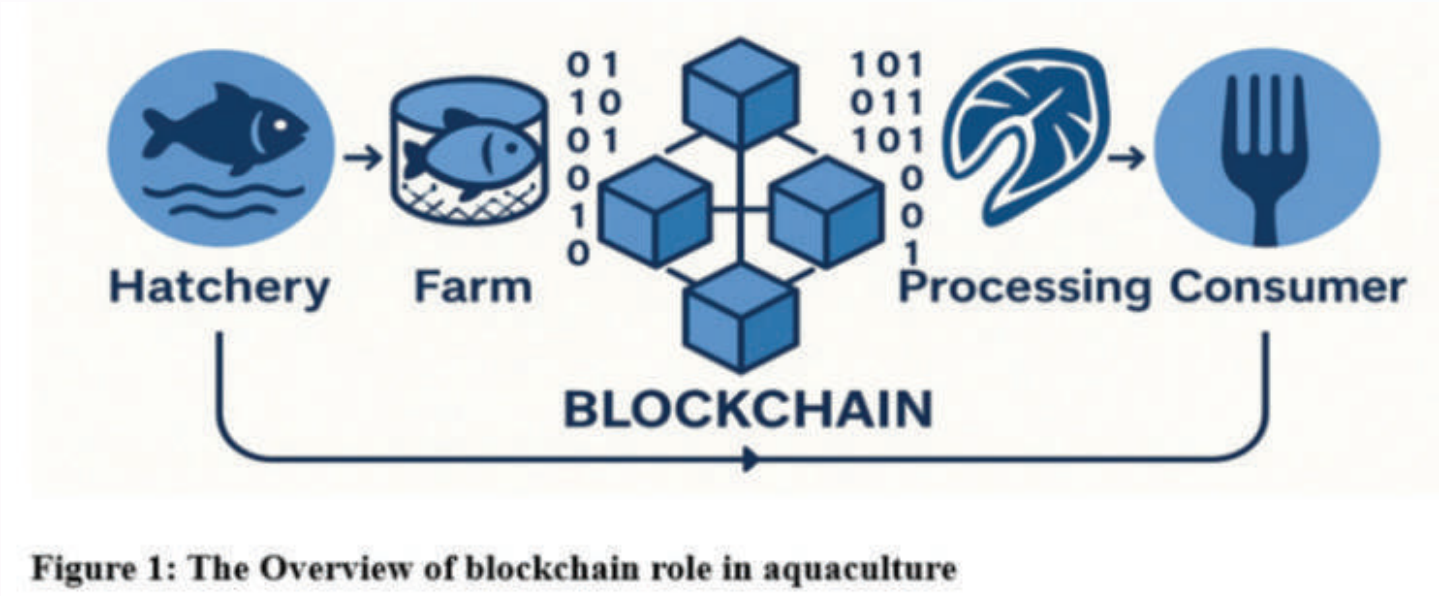

Figure 1: The Overview of blockchain role in aquaculture

2. Traceability Challenges in Aquaculture and Seafood Supply Chains

The aquaculture supply chain is complex and multi-staged. From hatchery to grow-out farm, then to processing, cold storage, distribution, and retail, several factors are involved, often across different regions and regulatory jurisdictions. This complexity makes it difficult to trace the product's journey accurately and efficiently.

Key challenges include:

- There is no universal standard for seafood traceability, leading to interoperability issues.
- In many developing regions, data is still recorded manually, making it prone to human error and tampering.
- Mislabelling of species, false origin claims, and IUU (Illegal, Unreported, and Unregulated) fishing practices are common.
- Small-scale producers often lack the technical know-how or infrastructure to implement digital systems.

• Multiple intermediaries lead to data silos and lack of accountability.

• Without effective traceability, it's difficult to verify compliance with food safety and environmental regulations.

These challenges necessitate a robust, secure, and scalable solution. Blockchain, with its immutable ledgers and transparent records, presents a compelling case for improving aquaculture traceability.

3. Overview of Blockchain Technology

Blockchain is a distributed ledger technology that allows data to be recorded across multiple nodes in a network. The data is grouped into blocks, each cryptographically linked to the previous one, forming a chain. Figure 1 shows the overview of blockchain in aquaculture. core principles of blockchain include:

• No central authority controls the ledger. All participants maintain a copy, ensuring redundancy and resilience.

• Once data is added, it cannot be altered or deleted, preventing tampering or fraud.

• All network participants can view the transaction history, promoting trust.

• These are self-executing contracts with conditions written in code, facilitating automatic or payment triggers.

Feature	Blockchain-Based System	Traditional Database
Immutability	High	Low Data can be changed
Decentralization	Yes	Centralized
Tamper Resistance	Yes	Vulnerable
Transparency	High (peer-shared)	Limited
Trust Mechanisms	Consensus-based	Administrator-based
Automation	Smart contracts for compliance	Manual/partial automation
Cost of Recalls/Fraud	Reduced	Higher
Consumer Engagement	High (verified QR codes etc.)	Low

Table 1: The Blockchain benefits compared with Traditional system of aquaculture

For aquaculture, consortium or private blockchains are more suitable due to the need for permissioned access and regulated collaboration. By integrating blockchain into aquaculture, data such as hatchery records, feed inputs, antibiotics used, harvesting date, processing time, and shipment conditions can be recorded in real-time and verified by all stakeholders.

4. IoT and Blockchain Integration for Real-Time Traceability

Blockchain by itself is powerful, but when combined with Internet of Things (IoT) technologies, its potential is multiplied. IoT devices such as GPS trackers, temperature sensors, RFID chips, and barcodes can collect and transmit data at every critical point in the aquaculture supply chain. For example, tagging fish crates or feed bags with RFID allows for automated data logging when items move across the supply chain. For cold chain logistics, continuous temperature monitoring can be logged on the blockchain to ensure freshness. Fishing vessels equipped with GPS can verify fishing locations, preventing IUU fishing. All this data can be stored on the blockchain, ensuring that it is tamper-proof and immediately available to buyers, regulators, and consumers. This real-time data exchange enhances traceability and ensures compliance with food safety standards.

5. Benefits of Blockchain in Aquaculture

Blockchain technology offers several transformative benefits for the aquaculture industry, enhancing traceability, sustainability, transparency, and operational efficiency across the value chain from hatcheries to harvest, and ultimately to consumers. Table 1 shows the Blockchain benefits compared with Traditional system of aquaculture. Below are the key benefits of blockchain in aquaculture:

• Adopting blockchain technology in aquaculture provides several benefits:

• Accurate and real-time data helps in tracing contaminated batches quickly.

• Immutable records reduce the risk of species substitution or mislabelling.

• Transparent labelling with blockchain-backed data can

boost consumer confidence.

• Governments and certification agencies can verify practices through trusted data.

• Reduces paperwork and automates data entry and verification.

• Products with verified traceability can command higher prices in the market.

Ultimately, blockchain transforms traceability from a burden into a value-adding feature, making the seafood industry more resilient and responsible.

6. Barriers to Blockchain Adoption

Despite its benefits, the key barriers to blockchain adoption in aquaculture, categorized across technical, economic, social, and regulatory dimensions:

• Setting up blockchain infrastructure can be expensive for small-scale producers.

• Many fishers and farmers are not yet trained to use digital devices or applications.

• Blockchain ensures data integrity, but not data accuracy. Incorrect inputs will still yield incorrect outputs.

• Different blockchain systems may not communicate seamlessly.

• Public blockchains may face issues handling high transaction volumes.

• There are no unified global standards or legal frameworks for blockchain traceability.

To overcome these barriers, there is a need for capacity building, public-private partnerships, government incentives, and inclusive digital transformation strategies. Pilot projects, especially those involving cooperatives, SHGs, or certification schemes, can play a key role in demonstrating value and scaling adoption.

7. Conclusion

Blockchain represents a paradigm shift in how traceability and transparency can be achieved in the aquaculture industry. It transforms traditional paper-based systems into dynamic, secure, and trustworthy digital ledgers that empower all stakeholders from farmers and processors to retailers and consumers. By addressing fraud, inefficiency, and regulatory complexity, blockchain can build a more sustainable, ethical, and consumer-centric aquaculture system. The future lies in collaborative innovation, inclusive technology design, and supportive policy frameworks to ensure blockchain benefits reach even the smallest producers. Traceable aquaculture, powered by blockchain, is not just a technological upgrade it is a necessary evolution toward safer, fairer, and more resilient seafood systems.

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