From Ocean to Plate: Leveraging Blockchain for Transparent and Sustainable Seafood Supply Chain Traceability — A Review

Dr.Madhuri N.Jadhav[1], Dr.Shashikant Gupta[2]
[1] Postdoc Reseracher,Lincoln University college,Malaysia ; [2] Professor Lincoln University college,Malaysia
pdf.madhuri@lincoln.edu.my,shashigupta@lincoln.edu.my

Abstract: Due to a lack of transparency and inconsistent record-keeping, seafood supply chains are widely distributed, multi-stakeholder ecosystems that are still extremely susceptible to fraud, species mislabeling, and illicit, unreported, and unregulated (IUU) fishing. Seafood supply chains are widely dispersed, multi-stakeholder ecosystems that are still very vulnerable to fraud, species mislabeling, and illegal, unreported, and unregulated (IUU) fishing because of a lack of transparency and poor record-keeping.
Although earlier research shows that blockchain has the potential to enhance transparency and accountability, it also highlights persistent drawbacks, such as a strong reliance on IoT and sensor infrastructure, high deployment costs, scalability issues, and restricted acceptance by small-scale players. This paper presents a mobile-first blockchain architecture and traceability methodology for practical, inclusive deployment in order to fill these shortcomings. By utilizing safe mobile data capture, standardized QR/GS1 metadata, and cryptographically anchored records kept on a distributed ledger, the suggested method does away with the need for specialized IoT gear. Multimedia evidence produced by stakeholders and transaction attestations are integrated to improve data credibility during harvest, processing,

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Introduction

Traceability issues in seafood systems around the world allow for mislabeling, hazards to food safety, and unsustainable practices. Food safety, regulatory compliance, and sustainability certification all depend on traceability from capture to consumer; yet, verification is hampered by fragmented actors (fishers, processors, exporters, importers, retailers) and paper-based record-keeping. The immutability and distributed consensus of blockchain technology have been suggested as ways to produce transparent audit trails and verifiable provenance records for perishable items like seafood. Over the past four to five years, a number of case studies and pilots have shown how promising blockchain technology is for seafood traceability, but they also highlight real-world adoption obstacles like cost, governance, data quality, stakeholder incentives, and integration with current standards (GS1, e-certificates). Before seafood is served to a customer, it must pass through a lengthy and frequently undetectable trip. .The seafood supply chain includes a wide range of actors and handover points, from tiny fishing vessels operating in coastal seas to processors, exporters, retailers, and regulators dispersed over several nations. Due to its complexity, seafood is one of the hardest food systems to keep an eye on while also being particularly susceptible to fraud, mislabeled species, and illicit, unreported, and unregulated (IUU) fishing.Consumers and authorities often lack trustworthy methods to confirm where and how fish were caught and handled, despite the growing demand for seafood obtained sustainably.

Blockchain technology has garnered interest recently as a tool that could improve seafood supply chains' transparency and credibility. Blockchain provides a mechanism to record provenance in a way that is hard to change after the fact by generating tamper-resistant records that can be shared between organizations. Blockchain-based traceability systems can theoretically allow end-to-end seafood tracking, even under real-time constraints, according to early research by Patro et al. (2022)[1]. Their prototype demonstrated how off-chain document storage and on-chain metadata could offer a workable compromise between system performance and openness. The study did, however, also highlight a significant drawback that is frequently mentioned in the literature: blockchain can only safeguard data that is input into the system; it cannot ensure that the data is accurate at the source.

Subsequent research has increasingly focused on the organizational and human aspects of fish supply chains rather than just technological viability. Shamsuzzoha et al. (2023)[2] emphasize that usability, incentives, and trust among fishermen, processors, and exporters are critical factors in technology adoption, based on field research conducted in Southeast Asia. According to their research, mobile-based interfaces are much more practical than intricate sensor-driven systems for small-scale fisheries, where infrastructure and digital expertise may be scarce.Similarly, Meera (2023)[3] notes that when legal recognition of digital records and regulatory frameworks are ambiguous, even well-designed blockchain systems encounter adoption obstacles, especially in export-oriented supply chains.Some researchers advise against considering blockchain technology as a stand-alone remedy. According to Hopkins et al. (2024)[4], rather than a lack of technology, many traceability problems are caused by poorly planned procedures and inadequate actor cooperation. According to this perspective, blockchain works best when it facilitates shared accountability, uniform documentation, and more transparent procedures.This viewpoint is supported by Patel et al. (2023)[11], who point out that while blockchain enhances data integrity, it does not take the place of inspections, verification processes, or human judgment particularly in the absence of IoT-based measurements.The necessity of making sensible system design decisions is further highlighted by recent architecture research. According to Alwi et al. (2024)[5] and Ellahi et al. (2024)[6], hybrid models in which only cryptographic proofs are anchored on-chain while massive datasets like photos, certificates, or shipment records are maintained off-chain are crucial for scalability.

These studies do, however, also point out that many current solutions fall short of commonly accepted criteria like GS1, which restricts their applicability in the international fish trade. Furthermore, the majority of blockchain-based fisheries solutions significantly rely on IoT devices, which are frequently unfeasible for small-scale or low-resource fishing communities, according to systematic evaluations by Pratiwi (2024)[7].This expanding corpus of work indicates a glaring void. Jagtap (2024) and Alsharabi et al. (2024)[10] contend that instead of sensor-heavy infrastructures, fisheries especially those controlled by smallholders need inexpensive, straightforward, and adaptable digital technologies.

Mawrides (2025)[8] emphasizes that significant impact requires widespread stakeholder participation and efficient governance, but she also connects blockchain-enabled traceability to sustainability and ethical sourcing objectives.Blockchain is positioned within a larger digital ecosystem by Vasileiou (2025)[9], who emphasizes the significance of interoperability with enterprise systems, certification platforms, and cross-border trade procedures.In light of this, the current paper examines studies on seafood traceability using blockchain technology and fills in any gaps by suggesting a mobile-first blockchain architecture for end-to-end traceability.

The suggested method makes use of cryptographically anchored records, standardized QR/GS1 metadata, and secure mobile data capture rather than IoT or specialized hardware. This initiative intends to contribute to more transparent, inclusive, and sustainable seafood supply chains by emphasizing accessibility, ease of use, and compatibility with real-world supply chain standards.

Related work

Patro et al. (2022) describe one of the first all-encompassing blockchain-based architectures created specifically for the fishing supply chain [1]. Their approach keeps traceability metadata on a permissioned Ethereum blockchain, but the actual documents (such invoices or fishing records) are kept off-chain and retrieved by hashed links.The paper shows a complete prototype that includes user roles, smart contract logic, and the entire process from catch to export. An important feature is the evaluation of performance metrics such as transaction throughput and latency, which shows that private blockchain networks can meet real-time seafood traceability requirements. Nonetheless, the authors acknowledge the challenges related to data authenticity at entry and the need for more widespread stakeholder digital readiness.

Using case studies, Shamsuzzoha et al. (2023) [2] examine seafood traceability concerns in Southeast Asian fisheries and propose a transparency paradigm facilitated by blockchain. Their research demonstrates how blockchain boosts confidence among fishers, processors, and export businesses in regions where manual paperwork and poor record-keeping are common. One obvious strength of this study is the inclusion of value-chain actor interviews, which demonstrate that adoption among small-scale fishers depends on user-friendly mobile interfaces.

The report finds sociotechnical challenges, such as incentives, literacy levels, and a lack of digital identification infrastructure, that must be addressed in addition to blockchain deployment.

Meera (2023) [3] examines barriers to blockchain adoption in the seafood export sector, including statistically supported viewpoints from Indian and Southeast Asian participants. The research lists a number of problems, including resistance to digital transformation, low awareness, high implementation costs, and regulatory ambiguity.

One significant contribution is the identification of institutional constraints, such as the legal acceptability of blockchain-anchored traceability documentation by port and customs authorities. According to the paper, regulations and legal acceptance frameworks need to alter in order for blockchain-based traceability to spread internationally. Technical proficiency is not enough on its own.

Hopkins et al. (2024) [4] examine the traceability issues in the UK fish supply chain and offer solutions to improve transparency. Even though their study is not entirely blockchain-focused, they assess blockchain technology as a component of the answer to lessen fraud and mislabeling. The authors find that the greatest increases in traceability come from process redesign, actor cooperation, and reducing the number of susceptible transfer points in the chain. The study concludes that although blockchain is a potent facilitator, it must be supported by stringent auditing, consistent documentation, and enhanced process management.

An architectural design that integrates blockchain technology with big-data analytics platforms for traceability in perishable supply chains is described by Alwi et al. (2024) [5]. Although the architecture is not exclusive to seafood, it is instantly applicable to fisheries due to similar requirements for provenance and cold-chain verification.

The study highlights the importance of hybrid storage solutions, which store bulk data off-chain and cryptographic proofs on-chain. This interface facilitates the efficient examination of large-scale traceability datasets, including images, certifications, and shipment records, while reducing blockchain overhead.

The study concludes that although blockchain-big-data integration has significant promise for traceability, its scalability requires accurate data modeling and optimum storage.

Pratiwi (2024)[7] provides a comprehensive systematic review of blockchain applications in fisheries and assesses research efforts from 2017 to 2023. The evaluation classifies existing solutions into three groups: traceability systems, certification platforms, and fishery governance apps.One significant finding is that the majority of previous research uses blockchain in conjunction with IoT devices for real-time monitoring, which limits application in places with inadequate infrastructure. According to Pratiwi, there is a significant research gap in mobile-first blockchain solutions that don't require IoT gear. This gap immediately motivates the need for the type of mobile application-based solution proposed in this study.

Ellahi et al. (2024) [6] conduct a thorough systematic analysis of blockchain-driven food supply chain systems, examining the benefits of data integrity, security, and traceability. Their investigation highlights the benefits of blockchain in terms of immutability, decentralization, and auditability while evaluating a number of peer-reviewed prototypes.

The authors point out that while blockchain increases transparency, many studies ignore human-centric flaws, and data quality at the point of entry remains a significant barrier. Interoperability problems are further highlighted by their analysis, which shows that many projects don't follow international standards like GS1 or electronic certification methods.The findings verify that for seafood traceability, blockchain technology must be combined with user-friendly tools and standardized data formats.

Mawrides (2025)[8] examines blockchain as a foundation for sustainable supply chains in the fish sector, connecting technical transparency to ethical and environmental goals.

The study shows how blockchain supports ethical sourcing, environmental certifications, fair-trade claims, and fishing quota compliance. Most importantly, it demonstrates how blockchain technology could increase consumer trust by making it possible to verify handling protocols, geographic source, and catch mechanism.

The author does note that in order to achieve sustainability impact, multi-actor participation is required, and in the absence of a governance structure, blockchain systems run the risk of becoming underutilized or isolated.

Vasileiou (2025) [9] discusses blockchain as part of the broader digital transformation of food supply chain management. The chapter places blockchain alongside AI, ERP systems, and digital certification platforms and emphasizes interoperability as a critical precondition for international business flows.

It argues that traceability platforms must be integrated with corporate systems such as inventory control, quality assurance, and export paperwork tools. This is consistent with the intricate documentation found in seafood supply networks. The paper highlights how blockchain might reduce administrative delays and enable cross-border digital documents.

Alsharabi et al. (2024) [10] present a plan that integrates cloud platforms and blockchain technology to support sustainable fisheries management. Their design includes smart contracts for monitoring fishing permits, quotas, and compliance data.

Although AI is also covered, the blockchain layer enables tamper-proof documentation and accountability among fishers, regulators, and certifying bodies. The paper provides empirical evidence that cloud-based blockchain networks facilitate deployment and maintenance for small enterprises with limited infrastructure. The findings support the idea that a lightweight mobile application-driven solution might be achievable with the use of cloud-based blockchain infrastructure.

Patel et al. (2023) [11] provide an overview of blockchain applications for food safety and traceability, emphasizing contamination avoidance and authenticity verification.

They stress that the primary ways blockchain brings value are end-to-end visibility and fast recall techniques when quality issues arise. According to their analysis, blockchain does not inherently improve measurement or inspection accuracy; rather, it only makes data tamper-evident. This emphasizes the importance of user-driven data entry protocols and verification workflows, especially when IoT devices are not used, as is the case with the present mobile-only approach.

Jagtap (2024) [12] explores the application of blockchain technology to the seafood sector from an industrial engineering perspective. Supply chain financing, certification management, traceability, and cold-chain verification are the four categories into which the chapter separates blockchain applications. The author highlights that despite the fact that there are many pilots around the world, only a small number have been implemented on a commercial scale due to problems with stakeholder alignment and governance.Importantly, the chapter highlights that smallholder-driven enterprises like fisheries need simple, low-cost digital tools rather than complex sensor-heavy systems. This insight immediately supports the need for a mobile-based blockchain solution.

3. Gaps, limitations and pros/cons

Author & Year	**Focus / Contribution**	**Pros (Strengths)**	**Cons (Limitations)**	**Identified Research Gaps**

Patro et al. (2022)	Permissioned blockchain architecture for fishery supply chain traceability	End-to-end prototype; smart contracts; performance evaluation (latency, throughput); practical architecture	Data authenticity at entry not ensured; assumes digitally capable stakeholders	Need for lightweight data capture and stronger human-centric verification mechanisms
Shamsuzzoha et al. (2023)	Blockchain-enabled traceability framework using case studies	Strong socio-technical insights; stakeholder interviews; emphasis on mobile usability	Limited technical implementation details; no prototype evaluation	Design of scalable mobile-first blockchain systems for small-scale fisheries
Meera (2023)	Analysis of barriers to blockchain adoption in seafood exports	Empirical stakeholder data; regulatory and policy insights	Does not propose a technical solution	Need for architectures aligned with legal and institutional acceptance
Hopkins et al. (2024)	Process-oriented analysis of traceability weaknesses	Highlights role of workflow redesign and coordination	Blockchain treated conceptually; no system design	Integration of blockchain with optimized supply-chain processes
Alwi et al. (2024)	Blockchain–big data integration architecture	Scalable hybrid on/off-chain design; analytics support	Not seafood-specific; high system complexity	Simplified traceability models for perishable and smallholder seafood chains
Ellahi et al. (2024)	Systematic review of blockchain food supply chains	Comprehensive evaluation of blockchain benefits and challenges	Limited domain-specific insights for fisheries	Fisheries-specific standards-based traceability models

Pratiwi (2024)	Systematic review of blockchain in fisheries	Clear categorization of applications; identifies IoT dependency	Mostly conceptual; limited deployment discussion	Mobile-first blockchain systems without IoT hardware
Mawrides (2025)	Blockchain for sustainability in fish sector	Links traceability to ethical and environmental outcomes	Governance mechanisms not fully defined	Multi-actor governance frameworks for blockchain traceability
Vasileiou (2025)	Digital transformation in food supply chains	Emphasizes interoperability and enterprise integration	High-level discussion; limited fisheries focus	Blockchain integration with GS1 and export documentation systems
Alsharabi et al. (2024)	Blockchain + AI for sustainable fisheries	Cloud-hosted blockchain reduces infrastructure burden	AI focus dilutes traceability depth	Lightweight blockchain-only architectures for traceability
Patel et al. (2023)	Review of blockchain in food safety and traceability	Highlights blockchain's role in recalls and transparency	Overly generic; lacks fisheries-specific focus	User-driven verification workflows for non-IoT systems
Jagtap (2024)	Industrial perspective on blockchain in seafood	Clear categorization of blockchain use cases	Limited empirical validation	Cost-effective, smallholder-friendly traceability platforms

Table 1. Gaps, limitations and pros/cons

Key takeaways from literature

Key Contribution

Blockchain primarily offers value by reinforcing provenance claims and offering unchangeable audit trails, which are important for regulators and retailers looking for supply chains that can be verified. Many successful pilots used hybrid architectures: off-chain storage for heavy data and on-chain hashes for verification to balance cost and performance.Non-technical factors (incentives, digital literacy, regulation) are often the primary adoption barriers not the ledger technology itself. Studies emphasise simple UX and governance models to onboard small-scale fishers.

Proposed Methodology

The proposed architecture presents a mobile-first, blockchain-enabled seafood traceability system designed to ensure end-to-end transparency from catch to consumer while remaining practical for small-scale and low-infrastructure fisheries. As illustrated in the architecture diagram, the system integrates mobile data capture, standardized metadata, permissioned blockchain infrastructure, and off-chain storage to provide secure, tamper-evident traceability without reliance on IoT or specialized hardware.

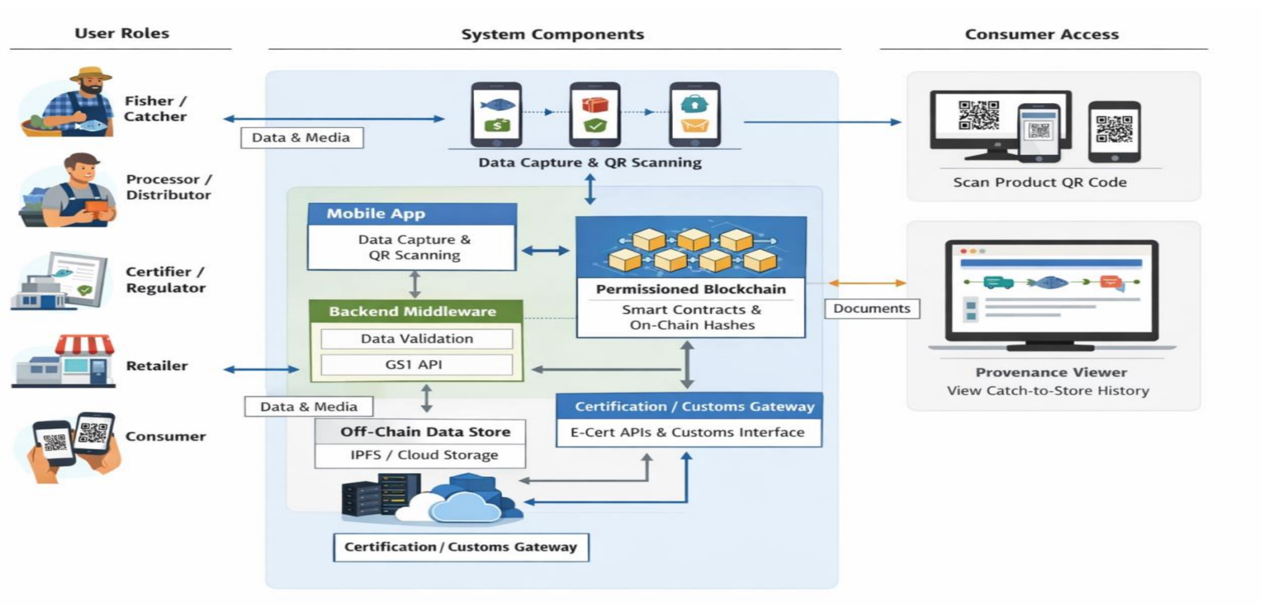

Figure.1. Blockchain-enabled seafood traceability system

1. User Roles and Data Capture Layer

At the left side of the architecture, multiple supply-chain actors like fishers, processors, certifiers, distributors, and retailers interact with the system primarily through a mobile application. The primary interface for data entry, QR scanning, and multimedia capture is the mobile app. Catch details, processing operations, inspections, transportation, and retail handling are examples of occurrences that each actor documents that are pertinent to their function. Users can store records locally and synchronize them once network connectivity is available thanks to the application's capability for offline data gathering. This design decision takes into account practical limitations that are frequently encountered in coastal and fishing regions.

2. Backend Middleware and Standardization

A backend middleware layer receives the captured data and handles data normalization, authentication, and validation. This layer permits interchange with current supply-chain systems and certification platforms by guaranteeing that all entries adhere to GS1-compliant metadata formats. For every traceable event, the backend creates a canonical JSON representation and calculates the record's cryptographic hash (SHA-256, for example). Only their cryptographic references are ready for blockchain anchoring; heavy data elements, such pictures, videos, or certificates, are kept in an off-chain repository.

3. Off-Chain Storage Layer

Large documents and multimedia files are stored in the off-chain data store, which is accomplished utilizing decentralized storage (like IPFS) with optional cloud backup. By using content-addressed hashes to preserve data integrity, storing such data off-chain drastically lowers blockchain storage overhead. Because each off-chain object is uniquely identified by its cryptographic hash and URI, any modifications can be identified during verification.

4. Permissioned Blockchain Layer

A group of reliable stakeholders run a permissioned blockchain network at the center of the design. Batch identifiers, event timestamps, actor identities, and hashes of off-chain data are all stored in immutable transaction records on this blockchain. Role-based permissions, provenance queries, and access control are all enforced by smart contracts. To guarantee authenticity and non-repudiation, certification organizations and regulators can digitally sign attestations that are anchored on the blockchain, such as export permits or sustainability certificates.

5. Certification and Regulatory Integration

Interoperability with external e-certification systems and government platforms is made possible by the architecture's certification and customs gateway. This gateway strengthens regulatory compliance and streamlines cross-border trade procedures by enabling verified documents to be directly linked to traceability data.

6. Consumer Access and Transparency Layer

Transparency at the end of the supply chain is made possible by a consumer-facing portal on the right side of the diagram. Customers can access the immutable blockchain record linked to the seafood batch by scanning a QR code printed on product packaging. The system shows a comprehensible timeline of events, complete with optional images and videos, after retrieving off-chain content and utilizing on-chain hashes to confirm its integrity. Customers can independently confirm the provenance of products using this method without disclosing private company information.

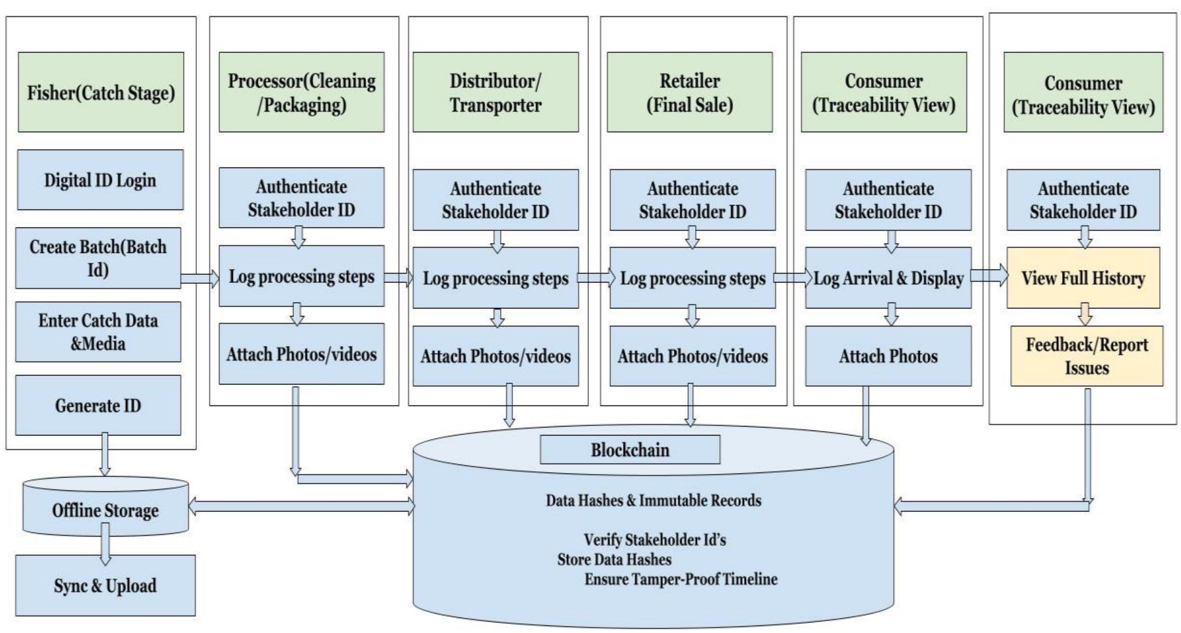

Figure.2.Architecture of seafood traceability system

Supply-chain data capture and blockchain anchoring:

By enabling each authorized stakeholder to safely record occurrences using a digital ID granted by the consortium, the proposed mobile application facilitates end-to-end traceability. At the catch stage, the fisherman logs in, adds essential information including species, amount, and catch date/time, and generates a new batch with an automatically created batch ID. To increase transparency, it is optional to take pictures of the catch, the vessel, and the containers in addition to a brief catch video.

When connectivity is lost, the application allows offline storage and organizes this data into a standard JSON format. All data and media are sent to the backend after synchronization, where the media stays off-chain and the cryptographic hash of the event record is kept on the blockchain to guarantee immutability.

To permit custody transfer and provide a unique batch identification, a QR code is created. As the batch moves through the processing, distribution, and retail stages, each stakeholder documents their activity (processing steps, transit details, storage, retail handling), uploads supporting photos or videos, and scans the batch QR code to accept custody.

Time-stamping, hashing, and anchoring every occurrence on the blockchain creates a chronological record that cannot be altered. New sub-batch QR codes are created while maintaining a connection to the parent batch in the event that a batch splits during processing.

Consumer transparency and verification: At the point of sale, the retailer completes the final custody event and prints a QR code on the product package for customers to see. When a client scans this QR code using a mobile device or website, the system delivers the complete product history from catch to retail by merging all off-chain data and verifying their integrity against the hashes stored on the blockchain.

The tool recalculates hashes and presents the data in an intuitive timeline-based interface that emphasizes dates, stakeholders, places, and relevant photos or short videos uploaded at each stage to confirm authenticity.

This approach, which provides verifiable transparency without revealing confidential operational information, helps customers gain confidence in the origins of products.

In order to close the loop between supply-chain participants and end users, the consumer interface also allows for optional feedback or issue reporting, which can be recorded for audit or compliance purposes,mart-contract-based event flagging facilitate dispute settlement.

Discussions

By concentrating on mobile-first blockchain traceability solutions that don't require pricey IoT devices or specialized hardware but nonetheless offer dependable and verifiable product provenance, this work immediately fills a well-known research gap.

While a large portion of the present literature makes assumptions about high levels of digital infrastructure or ongoing sensor-based monitoring, these assumptions are frequently impractical for export-oriented processors and small-scale fisheries operating in environments with limited resources.Rather, the proposed method prioritizes practical usability, enabling stakeholders to gather and disseminate traceability data using widely available mobile devices and simple identification techniques. It employs a hybrid design strategy that securely links important proofs while storing extensive records and supporting materials outside of the blockchain, striking a compromise between transparency, cost, and scalability.Additionally, the work focuses on governance and coordination among supply-chain players, including topics that have not gotten much attention in prior studies, such as role definition, verification responsibilities, and conflict resolution.By addressing organizational, technological, and operational issues jointly, this research contributes a more inclusive and deployable traceability model that is more in line with real fish supply chains.

Conclusions

- Blockchain may enable seafood monitoring, but socio-technical adoption issues continue to remain the main barriers.
- A mobile-first approach that anchors cryptographically hashed records on a permissioned blockchain and keeps heavy data off-chain can provide small and medium-sized seafood actors with a practical and affordable means to participate in verified supply chains.
- The methodology described here integrates best-practice architectural patterns from the literature (including permissioned chains, off-chain storage, and GS1 integration) with a comprehensive implementation strategy that emphasizes governance and is intended for real-world pilots and quantitative evaluation.
- Proposed model gives the complte transpernacy in traceabilty model.

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