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BLOCKCHAIN APPLICATION IN SEAFOOD VALUE CHAINS

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PREPARATION OF THIS DOCUMENT

Preparation of this circular was coordinated by the Products, Trade and Marketing Branch, FAO Fisheries and Aquaculture Department, as part of FAO's Strategic Objective (SO4): strategic programme for enabling more inclusive and efficient agricultural and food systems. This publication will contribute to equipping value chain actors with technical and managerial capacities to develop inclusive, efficient and sustainable agricultural and food value chains. It is an effort to share knowledge on the use of blockchain initiatives in the seafood sector. The publication was produced as part of the project Fisheries Management and Marine Conservation within a Changing Ecosystem Context (GCP/INT/JPN/228), funded by the Government of Japan and implemented by FAO.

The paper was written by Francisco Blaha, fisheries expert and FAO consultant, and Kenneth Katafono, ICT expert and FAO consultant, under the lead of Nianjun Shen, Senior Fishery Officer, and Nada Bougouss, FAO consultant. Technical review was provided by Anton Ellenbroek, FAO Consultant, and Melania Borit and Petter Olsen, FAO traceability experts and consultants. Assistance from Alessia Capasso and Gloria Loriente in the preparation of the final document is gratefully acknowledged.

ABSTRACT

Innovation through information and communication technologies is a key enabler in transforming food systems and holds great potential to achieve the Sustainable Development Goals. Recent developments, such as mobile technologies, smart networks, drones, remote-sensing, distributed computing, as well as disruptive technologies, such as blockchain, the Internet of things and artificial intelligence, are serving as the premise for a "digital revolution" whereby management of resources can potentially be highly optimized, intelligent and anticipatory.

This publication establishes chain traceability as the substrate over which digital solutions need to operate. It provides a comprehensive introduction to blockchain, and covers smart contracts, explores how they relate to blockchain with an example of their use in seafood value chains, and then examines major development and operational considerations for blockchain applications.

The publication also analyses the seafood supply chain with considerations on flag, coastal, port, processing and market States. It identifies general control elements (critical tracking events and corresponding key data elements) that form the basis for traceability monitoring and acquisition, and summarizes suitability for blockchain. It also investigates considerations for legality, transparency, species fraud and food safety.

The strategic fit of blockchain technology in seafood value chains is further investigated, with review and analysis of seven initiatives/projects. The publication then provides a key analysis as to whether blockchain for seafood traceability is the right tool, and a comprehensive investigation of operational opportunities with the use of blockchain. The publication concludes by providing a set of potential trade and public policy implications and recommendations.

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ABBREVIATIONS AND ACRONYMS

AI	artificial intelligence
AIS	automatic identification system
BaaS	blockchain as a service
CA	competent authority
CDS	catch documentation scheme
CoC	chain of custody
CTE	critical tracking event
dApp	decentralized application
DNA	deoxyribonucleic acid
EEZ	exclusive economic zone
ERP	enterprise resource planning
FAD	fish aggregating device
HACCP	hazard analysis and critical control points (system)
ICT	information and communications technologies
IMS	information management system
IoT	Internet of things
IP	intellectual property
IUU	illegal, unreported, and unregulated (fishing)
KDE	key data element
MCS	monitoring, control and surveillance
MSC	Marine Stewardship Council
NFC	near-field communication
NGO	non-governmental organization
PNAO	Parties to the Nauru Agreement Office
PoS	proof of stake
PoW	proof of work
PSMA	Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (Port State Measures Agreement)
QR	Quick Response (code)
RFID	radio-frequency identification
RFMO	regional fisheries management organization
SPP	Sustainable Shrimp Partnership
SPS Agreement	Agreement on the Application of Sanitary and Phytosanitary Measures (Sanitary and Phytosanitary Agreement)
TBT Agreement	Technical Barriers to Trade Agreement
TFA	Trade Facilitation Agreement
TRU	traceable resource unit
VMS	vessel monitoring system
WTO	World Trade Organization
WWF	World Wide Fund for Nature

1. INTRODUCTION

1.1 Justification for this study

The growth of information and communications technologies (ICT) in the last decade has provided many opportunities to overcome some of the challenges faced in the seafood sector, especially in relation to traceability and compliance for illegal, unreported, and unregulated (IUU) fishing and seafood safety. Recent developments, such as the increase in the use of mobile broadband access devices, the Internet of Things (IoT), drones, smart networks, capacity for big data analytics, and artificial intelligence (AI) have provided stakeholders in other primary production industries with some key tools and technologies to improve production and marketing processes.

One of the most discussed technologies is blockchain technology, which is likely to deeply modify the traceability landscape and stakeholder behaviour along the value chain in fisheries and aquaculture. This publication aims to demystify the technology, provide some thoughts on the opportunities and challenges in implementing blockchain-based systems, and document some case studies on the use of blockchain for seafood value chains. In addition, it investigates – based on existing initiatives – public policy and trade implications to set the basis for recommendations for governments and international organizations.

1.2 Scope and limitations of the study

1.2.1 Scope

This study is intended for governments and international organizations, and it uses a two-pronged analysis based on the expertise of the authors. One prong discusses the role of traceability (both for official assurances and private verification purposes) over the seafood value chain as the substrate over which electronic traceability-type solutions, such as those based on blockchain technology, need to operate. The other presents the state of play of the application of the technology and some current examples of its use.

The value chain component dives into the sources of data along the value chain, analysing in detail the critical tracking events (CTEs) as "points within a business and along the value chain where the product is moved between premises or is transformed, or is determined to be a point where data capture is necessary to maintain traceability", "key data elements" (KDEs) – "the data elements required to successfully trace a product and/or its ingredients through all relevant CTEs" (Bhatt *et al*., 2016; Hosch and Blaha, 2017) – and the best practices for verification of these data.

The segments of the analysis consider the types of "States" (flag, coastal, port, processing and end-market) that have custody of fishery products moving through national supply chains from harvesting, trans-shipment, landing and processing to the consumer end-market. Each section on a type of State identifies general control elements that should be in place and that often form the unconditional basis for traceability monitoring and data acquisition.

The technology component presents the basis of the technology, and a description of some of the initiatives using it, together with a comparative analysis of them.

1.2.2 Limitations

This study is a desktop study based on secondary sources, bibliographies and consultations with non-governmental organizations (NGOs), governments, the private sector and independent experts. No site visits or travel were undertaken, which limits the analysis to some extent in terms of specific and recent traceability solutions implemented at the country level. Moreover, the study does not elaborate on the potentiality of applications yet to be developed and future forecasting.

The authors are familiar with seafood value chains, traceability, overseas market access requirements, and blockchain solutions developments and application, and they have extensive knowledge of the ways in which they are applied in many countries. This knowledge is utilized as applicable.

2. FISH AND FISHERY PRODUCTS VALUE CHAINS

Fish and fish products are some of the most traded food items in the world today, and most of the world's countries report some fish trade. In 2016, about 35 percent of global fish production entered international trade in various forms for human consumption or non-edible purposes. The rapid rate of expansion of international trade in fish and fish products in recent decades has taken place in the context of a broader process of globalization – a large-scale transformation of the world economy driven by trade liberalization and technological advancements. Developing countries play a key role in this trade and, in the past 40 years, the growth rate of exports from developing countries has increased faster than that of developed ones. In 2016 and, according to preliminary figures, also in 2017, developing country exports made up about 54 percent of the total value and about 59 percent of the total quantity (in live weight equivalent) of exports of fish and fish products (FAO, 2018).

In this context of fisheries and aquaculture, this study considers (in line with a study prepared for FAO [De Silva, 2011]) that value chains for capture and culture fisheries differ from fish to fish and from country to country, and frequently within regions. Moreover, a fishery value chain can be defined as interlinked value-adding activities that convert inputs into outputs, which, in turn, add to the bottom line and help to create competitive advantage. A value chain typically consists of inbound distribution or logistics, manufacturing operations, outbound distribution or logistics, marketing and selling, and after-sales service. These activities are supported by purchasing or procurement, research and development, human resource development and corporate infrastructure.

Traceability is not a trivial term, and its absence or incorrect utilization is at the basis of many issues affecting today's seafood value chains, such as lack of transparency, trade in IUU-originated fish, fraud and species substitution, integrity and seafood safety. Traceability is required in order to ensure these latter attributes, yet *per se* does not guarantee them. Hence, it is important not to confuse traceability, which is a system, with verification, which is an action.

Language and technological barriers have hindered the use of standardized electronic systems for end-to-end traceability within supply chains. Moreover, scale varies greatly among them; hence, one solution may not work best for all companies within one supply chain. In addition, technical systems need to be functional and up-to-date to meet traceability needs across jurisdictions.

2.1 Traceability in the seafood sector

A typical misconception is that traceability is only a numeric code attached to products, that it actually means place of origin, or that it is a method to ensure that information about the product is true.

The professional controversy continues with the granularity and the depth of traceability – how small should the identified unit be (e.g. a crate of shrimps or "a season of skipjack tuna harvest"). This subject is followed by whether the entire supply chain (e.g. from field/farm/hook to plate) or only parts of the supply chain should be covered by traceability requirements, and whether this coverage should be based on risk assessment (e.g. steps in production in which pathogens are inactivated).

Other points of disagreement include the breadth of traceability, i.e. the amount of information the system records, and the body that should be responsible for implementing traceability, i.e. the legislature or the industry. In conclusion, traceability has been both a politically and strategically controversial issue and has acted as a major deterrent for multidisciplinary cooperation and understanding.

On a deeper level, the multiple perceptions about the meaning and applicability of traceability held by different people may be related to idiosyncratic cultural backgrounds and, therefore, to their basic notions of trust and transparency requirements. In this regard, it has been noted that transparency does not equate to traceability because the latter only sets the framework for the former.

The present work uses the definition of traceability from ISO 8402:1994 (ISO, 1994), as this incorporates all the critical properties of a traceability system as described in the scientific literature. Thus, traceability of any given product refers to "the ability to trace the history, application or location of an entity by means of recorded identifications."

In a product sense, traceability may relate to: the origin of materials and parts; the product processing history; and the distribution and location of the product after delivery. This definition clearly states what should be traced (history, application and location) and how the tracing should be done (by means of recorded identifications).

There are several principles (or requirements) that must be followed in order for the traceability system to be effective. It is critical that these recordings be interconnected and in a format that allows the product to be tracked along the entire supply chain. Thus, units that are traced (traceable resource units [TRUs], e.g. a box of mackerel) and identification/numbering schemes that provide codes/numbers used for the unique identification of TRUs (e.g. GS1 barcodes) are parts of a traceability system.

For this system to be effective, it is essential that the codes of a TRU (either as a raw material or semi-finished product) entering a link in the supply chain are associated uniquely with those of the same item (semi-finished or end product) leaving the link. This ability to identify products individually is the basis of product traceability. Equally critical is maintaining accurate records of the transformations (e.g. splitting, joining) that the TRU undergoes, and sharing the TRU identification code with partners in the supply chain. This approach is consistent with the FAO guidelines on traceability (FAO, 2014).

Based on these arguments, this study maintains that traceability is an infrastructure that can be used by control agencies for two purposes. The first purpose is to retrieve different data for various reasons (such as legal harvest, origin, eligibility and food safety). The second purpose is to support the verification of these data with other specific tools; for example, genetic identification of species such as in the seafood mislabelling cases.

As discussed in the literature, "a traceability system is quite similar to a filing cabinet in that they both deal with systematic storing and retrieving of data. Importantly, neither a traceability system nor a filing cabinet care about what types of data are being stored" (Olsen and Borit, 2013). This notion has several important consequences.

For example, there is no guarantee that the recordings are true or complete, as both error and fraud can lead to false claims about the properties of the food product, including its origin. There is a clear need to verify these claims, and in this area, analytical methods and instruments play a crucial role. Similarly, documenting traceability and documenting ecolabel-type chain of custody (CoC) are two different concepts. Although traceability can be used as a tool in the certification process, traceability and certification are nonetheless different processes (Borit and Olsen, 2012).

Traceability by itself makes no claim as to the state of the product or information that can be followed from one point to another through a system. In order to claim that a product has certain values, such as being from a sustainable fish stock and being free of IUU-caught fish, that it is a safe product or has not been substituted, etc., all these claims have to be verified, even if the product is traceable back to a specific vessel.

There are solutions that are simpler than traceability for partial product tracking, such as when the regulator only requires operators to identify their suppliers or customers. This process is less efficient and more inaccurate because tracing product sources can only be attempted by means of a formal, and often lengthy, examination of each link in the chain.

The principle of the correct denomination of traceability systems should also be complied with by certification and documentation schemes, which are also becoming increasingly common among private actors and governments. These requirements for correct denomination of procedures also involve the responsibility to inform producers and consumers of the concepts applied and their limitations.

A further very important criterion associated with traceability, in the case of official guarantees for exports (as in the case of the European Union), is the issue of **eligibility[2] of products and raw materials,** as an outcome of official controls over the value chain. The nature of the official controls implies that all elements in the production chain need to be approved for the purpose by the competent authorities (CAs) for either food safety or fish legality. Hence, traceability is used to prove the **eligibility** of every operator in every jurisdiction for a particular product to be exported, from the fishing vessel to the final processor prior to importation into the European Union.

Good information management systems (IMS) are increasingly the norm in terms of proving traceability, inspection results and certification of food products. In particular, the design and maintenance of proper database structures enhancing the information sharing and integration between the CAs can be very important to providing consistency in the certification process.

A systematic analysis of the traceability scenarios in ten countries by FAO (Blaha, Borit and Thompson, 2015) shows that there is much confusion and many inconsistencies regarding the meaning, scope, legal status, implementation capacity and control of traceability systems.

Implementation of traceability systems was catalysed by market access requirements. Initially, these were the domain of health certification of the European Union, and later on (after 2010) supplemented by the catch certification of the European Union.

However, most of the countries analysed have not legislated and standardized traceability as a requirement. Moreover, there seems to be little interaction between the health CA and the fisheries CA in terms of their assessment.

It seems that efforts towards the implementation of traceability systems in countries and across countries have not been supported in an interdisciplinary and standardized way. Ensuring traceability through the seafood production chain can be accomplished by careful planning, taking the time to gain consensus among the operators and authorities. In order to gain trust, the traceability system in place must meet the set standards.

Although many countries lack specific legislation on food traceability, the global tracing and tracking of imported products is being achieved (often with difficulty) through record-keeping (much of it manual), lot identification, labelling laws, and requirements for exporting countries to meet the standards of the domestic industries in those countries.

Bhatt *et al*. (2016) note that the terms “critical tracking events” (CTEs) and “key data elements” (KDEs) are gaining acceptance in the traceability arena. Their definitions are: (i) CTEs – “points within a business and along the value chain where the product is moved between premises or is transformed, or is determined to be a point where data capture is necessary to maintain traceability”; and (ii) KDEs – “the data elements required to successfully trace a product and/or its ingredients through all relevant CTEs.” They also note that the “one step forward, one step back” requirement is CTE/KDE capture in its simplest form. Best traceability practices require that data be maintained from all points backward and through all points forward within the supply chain of a company or trading partner.

[2] In terms of European Union market access for seafood, eligibility compromises the coverage of “official controls” (as defined by regulations of the European Union) for the specific traceable unit along the entirety of the value chain. If the raw materials harvested or at any production stage were conducted in a non-compliant manner or in a non-verified establishment, then that raw material or product is not eligible for export to the European Union; hence, it cannot receive a European Union health certificate. For example, if an establishment listed with the European Union holds products that are not eligible by origin (i.e. from a non-approved vessel) or conditions (approved but in non-compliance), then the operator must ensure the physical separation of seafood product that is eligible for European Union markets from that which is ineligible. For more on this, refer to Blaha, 2015.

Increasingly, companies are publicly committing to sustainable seafood sourcing policies, and the challenge is now for those companies to be able to track the origin of their products to ensure that the species and attributes of the products are meeting their policies and communicated to the customer accurately (FishWise, 2018).

For companies that buy and sell seafood, the lack of product origin information and supply chain transparency can pose significant risks. In the past, industry's traceability focus was primarily on food safety concerns. However, the increase in media coverage about the environmental, social and legal issues associated with seafood has led to significant shareholder concerns, potential impacts on brand value, and challenges to the corporate social responsibility initiatives of companies.

The recent attention on social responsibility also creates an opportunity for companies with traceability to actively promote the many benefits of their products, such as social and fair trade compliance, and engagement in fishery improvements.

The first step towards mitigating and eventually eliminating these risks is to ensure that end-to-end, electronic, interoperable traceability systems are in place throughout the supply chain. This work is already under way with some companies that are instituting traceability policies and setting goals, often with the assistance of NGOs, government bodies, and technology companies.

2.1.1 Traceability based on a continuous data acquisition solution

A fundamental challenge for data acquisition in this area is that it should apply to any information about the history, application or location of a traceable item. These may be either master data or transactional data, where the latter describe time-bound events (usually relevant in the transportation phases of the value chain).

Hence, an ideal solution for traceability has been proposed by Hosch and Blaha (2017) as an online platform, whose core functions are to identify and log:

- product when it enters the supply chain;
- all supply chain transactions;
- transactions relating to products leaving the supply chain.

Product movements are logged in real time as products migrate from a seller to a buyer or custodian. A purchase must be logged by a buyer, and the product will be deducted from the seller so that the buyer can subsequently pass it on legally. Unless it is properly recorded, it is as if the transfer never occurred and the buyer is officially not in possession of any product.

In this way, an importer may, for example, acquire a large volume of tuna from a fishing vessel in a port in Asia and store it in a warehouse. If the importer splits and sells the product to three processing plants, they record the volume purchased on the electronic platform, naming the seller and recording the necessary details. The system automatically verifies that no more product than that acquired by the importer under the specific transaction can be forwarded, and that the sum of products forwarded to the three buyers complies with this rule.

If the rules are breached and the importer sells more product to the factories than it has imported – a form of laundering – an alarm is triggered when one of the factories tries to log the transaction, and the system automatically identifies the party supplying false information. Instead of a lengthy inspection triggered when product leaves the value chain and someone detects the imbalance, this online system forces operators to comply with the regulations by not accepting inconsistent transactions. Thus, an automated system will come close to eliminating the need for national law enforcement at this level.

There are various challenges with regard to centralized online platforms:

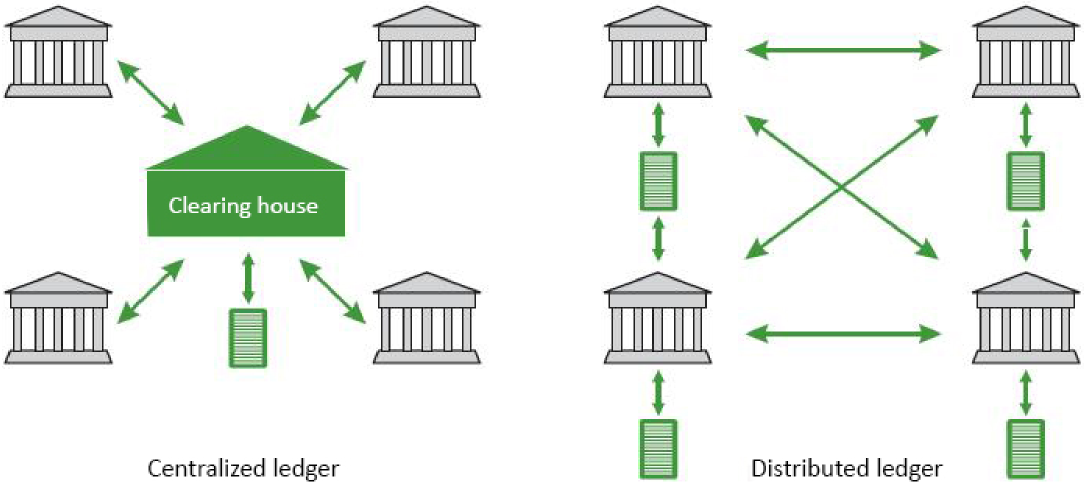
- A platform has to be designed that can accommodate all supply chain permutations and scenarios as they occur in reality, so that all movements and transaction types can be logged.
- Industry has to be persuaded to accept the technology and its requirements.
- The cost of developing and rolling out the system and related training can be substantial, and there may be issues related to ownership and intellectual property (IP).

This is the scenario where blockchain technology is offering some ground-breaking potential, yet not without challenges.

3. BLOCKCHAIN TECHNOLOGY

Blockchain technology is a decentralized and distributed digital ledger of transactions that is replicated on every node, or participant, in the network. It is decentralized in the sense that there is no single authority with control over the whole network, and distributed because it is spread out across numerous participants worldwide.

Figure 1. Centralized and decentralized ledgers



Source: Tripoli and Schmidhuber, 2018.

As depicted in Figure 1, in a centralized ledger, one or more parties record transactions into a central database that acts as the ledger, while in a decentralized ledger each party has its own copy of the ledger transactions that is synchronized with the entire network, i.e. each party's ledger is exactly the same as everyone else's. As transactions occur in the decentralized network and each transaction is validated, then that transaction is added to everyone's ledger.

Centralized ledgers may be susceptible to tampering as they are typically owned by a single party. Once a transaction has been recorded on the blockchain it becomes immutable – it cannot be changed without the majority of the blockchain network agreeing to the change. This ensures the security of the transaction data on the blockchain and the entire network.

Aside from decentralization, other characteristics of blockchains include persistency, where data is recorded across all nodes of the blockchain, leading to immutability, which ensures that data cannot be corrupted. Persistency also provides fault-tolerance where the loss of any node in the blockchain network will not make it unusable. Auditability and transparency are other important characteristics – noting that every single transaction is recorded on the blockchain, which can then be audited later, and transparent in the case of permissionless blockchains, which are open for anyone to view the transactions.

These properties make the use of blockchain technology an exciting prospect for traceability systems that can encompass and link seafood supply chains. It could provide an online traceability infrastructure that caters for the permanent storage and sharing of KDEs along CTEs; and the fact that it is already a digital ledger makes it suitable for recording transactions of products between supply chain actors.

3.1 Principles

To determine the suitability of using blockchain technology in seafood supply chains, it is important to understand some of the underlying principles of the technology.

3.1.1 No single blockchain platform

It is important to know that there is no single blockchain platform. Instead, there are multiple platforms, each with its own unique technical properties and value propositions.

The most commonly used blockchains in seafood value chains today are the Ethereum and Hyperledger blockchains:

- **Ethereum:** promotes itself as "the world's leading programmable blockchain" (Ethereum, 2020) and has a native cryptocurrency, Ether. It provides a platform on top of which decentralized applications (dApps) can be built and has one of the largest active developer communities building solutions on it.
- **Hyperledger:** is an "open source collaborative effort created to advance cross-industry blockchain technologies" (The Linux Foundation, 2020) hosted by the Linux Foundation. Unlike Ethereum, it does not have a native cryptocurrency associated with it. It has been made popular by use of the platform in IBM's blockchain solutions.

3.1.2 Consensus algorithms

Blockchains are made up of numerous nodes (participants) in a network, with each node containing an exact copy of the digital ledger. These nodes can number in the thousands and exist across the world.

Consensus algorithms are key to the operation of blockchain networks and are responsible for maintaining the integrity and security of the network. These algorithms ensure that the blockchain protocol rules are followed, that all the nodes in the network are synchronized with one another, and they are key in preventing any single entity from controlling the blockchain network.

Proof of work (PoW) and proof of stake (PoS) are two of the leading consensus algorithms in use:

- **Proof of work (PoW):** was the first consensus algorithm implemented in a blockchain and is used in the Bitcoin blockchain. It requires nodes, known as "miners", in the network to compete to solve a complex mathematical problem, the solution of which is known as a hash value. Once a miner finds the correct hash value, the nodes in the network verify that it is correct before executing the transaction and adding it to the blockchain. The miner that finds the correct hash value will receive a reward, known as a "block reward". Due to the computations that miners perform to achieve the correct hash value, PoW utilizes a lot of energy to confirm transactions onto the blockchain. This is by design to enhance the security of this consensus algorithm.
- **Proof of stake (PoS):** is an alternative to PoW where a node, known as a "validator", is chosen to confirm a block based on its economic stake (number of tokens) in the network together with a randomization function. A token is a unit of value issued by the blockchain. The randomization function prevents centralization and avoids the possibility that the validator with the highest economic stake will always validate transactions. The validator is disincentivized from malicious action because a portion of its stake will be at risk. As with PoW, the validator receives a reward, and PoS is considered a better option than PoW because it uses far less energy to confirm transactions.

There are numerous other types of consensus algorithms not covered in this study, such as Byzantine fault tolerance, proof of authority, and delegated proof of stake.

3.1.3 Types of blockchains

There are three types of networks that offer different propositions based on blockchain's inherent properties. Each type offers varying levels of control and access to participate in the network.

Public

As the name implies, a public or permissionless blockchain is publicly accessible with no restrictions on who can participate as a user, miner or validator in the network. No single entity has complete control over a public blockchain, making it highly censor resistant. It is fully distributed, and all the transactions are transparent – allowing anyone to examine the details of any transaction.

Public blockchains have a token associated with them that is typically designed to incentivize and reward participants in the network. Examples of public blockchains include Bitcoin, Ethereum and Litecoin.

The challenges associated with public blockchains have been well documented, particularly those that employ the PoW consensus algorithm, where there is a high energy cost to validate transactions.

Private or permissioned

Unlike a public blockchain, a private or permissioned blockchain has restrictions on who can access it and participate in performing transactions and validations. This type of blockchain is more centralized than public blockchains, and the entities that run the network have significant control over the participants and governance structure.

Transactions are private and only available to participants in the network. This type of network is often valuable for organizations that want to collaborate and share data but do not want their sensitive business data publicly visible. Tokens may or may not be utilized in this type of blockchain.

Consortium

A consortium blockchain is almost a hybrid of a public and private blockchain where the network is governed by a group rather than a single entity. Some nodes in the network control the consensus process, while others can participate in the transactions.

This type of blockchain can be an attractive option to entities that operate in a similar space, for example, seafood supply chains, that would allow them to collaborate on some aspects of their businesses. Collaborating in this way allows them to leverage blockchain technology to achieve workflow efficiencies, shared information and resources, accountability, and transparency across their business processes.

3.2 Smart contracts

In its basic form, a smart contract is computer code within a blockchain network that can automatically execute when certain conditions are met without the need for a trusted third party to intervene. People liken smart contracts to an agreement between the different parties represented in computer code that is self-executing.

The executed code in smart contracts can do many things based on the conditions programmed into it, including transferring the ownership of a digital asset from one entity to another and automating payments to one or more parties. It can also be used as a form of escrow.

Figure 2. Example of a blockchain smart contract

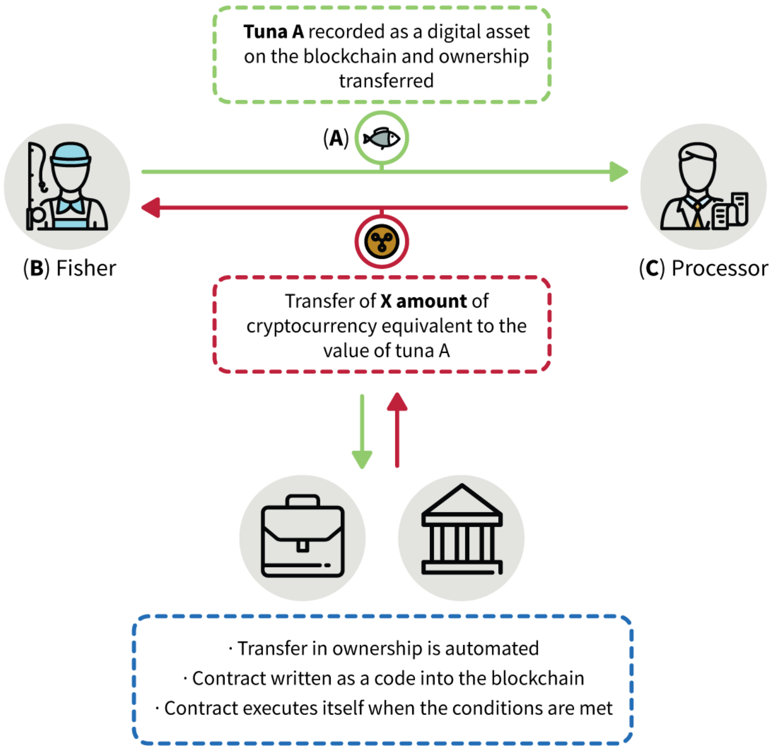


Figure 2 shows a simple example of how a blockchain smart contract can be used in seafood value chains: if a tuna (Tuna A) is caught by Fisher B and recorded as a digital asset on the blockchain, then Processor C transfers an agreed X amount of cryptocurrency equivalent to the value of Tuna A to Fisher B; ownership of Tuna A as a digital asset can automatically be transferred to Processor C.

The transfer in "ownership" is automated on the blockchain based on the conditions (transfer of X amount between Fisher B and Processor C) being met.

However, the above example ignores the reality of seafood value chains, especially the logistics involved in moving a physical asset, such as tuna, from seller to buyer. It also requires there to be a physical medium to uniquely identify the tuna sold and to associate it with the digital asset on the blockchain.

A key link between the physical world and blockchain is an oracle – a trusted intermediary and an integral part of the smart contract ecosystem that facilitates data feeds to the blockchain ecosystem. By design, a blockchain cannot access data from outside its system and, thus, data to make the blockchain are supplied through a predefined entity called an oracle. An oracle can be hardware-based, software-based or consensus-based. Examples of hardware oracles are sensors, IoT and weather stations, while software examples are a New York Stock Exchange index, expiration date, or output of some computation. A consensus-based oracle works on the basis of consensus from a group of predefined nodes on a particular question. A consensus-based oracle can also source data from several other oracles to trigger an event in a smart contract. Moreover, inbound oracles pass external data to smart contracts, and outbound oracles communicate smart-contract-based data to the outside world.

Ethereum is the first blockchain platform that focuses on providing a Turing-complete[3] smart contracts-based system and decentralized applications. Hyperledger Fabric and R3 Corda are some of the other distributed ledger technologies that are used to create smart contracts.

3.3 Development and operational considerations

While many large technology providers, including Amazon, Microsoft and SAP, are starting to offer “blockchain as a service” (BaaS) options that will enable companies to build and deploy blockchain solutions quickly, these services are still relatively new in the marketplace.

However, these BaaS solutions will help reduce the burden of needing specialized skills to trial blockchain technology, which could potentially lead to greater adoption of blockchain in seafood value chains.

Many projects in the seafood value chain space utilize dedicated development teams with specialized blockchain developers. The different flavours of blockchain platforms also require different skill sets among blockchain developers. Given the global interest and growth in blockchain technology, there is high demand for blockchain engineers.

3.3.1 Blockchain development

From a technical perspective, designing and developing a blockchain solution is not difficult. Experienced computer programmers familiar with object-oriented programming can learn the required blockchain programming languages relatively easily as they are based on programming languages that are quite mature and well known.

For example, the Solidity language is used to write smart contracts in the Ethereum blockchain and is very similar to the C++ and JavaScript languages. While the smart contract is written in Solidity and deployed to the blockchain, the dApp that the user interacts with can be built with any number of modern web programming languages (e.g. React) and can be deployed to traditional web servers.

The major difference with blockchain development is the fact that the written code will reside and execute in a decentralized network. It requires greater attention to detail and mitigation of potential security threats as the code could be open to anyone in the case of a public blockchain. The way in which smart-contract versions and releases are deployed is also different from traditional computer programs.

There is also a new element to blockchain development in that many networks use tokens as an integral part of their network, and there is a cost (transaction fee) associated to executing transactions on the blockchain. Smart-contract designs will have to account for these costs in order to minimize the overall cost of making a transaction. The use of tokens adds the need for secure digital wallets that hold the tokens to be used in transactions. These add greater complexity to blockchain development and require stronger security considerations as tokens are associated to fiat currencies.

Tools for developing blockchain solutions continue to improve, and solutions for easier implementation continue to grow as well. Coupled with a growing global blockchain developer community, it will become easier for organizations involved in the seafood value chain to implement and test blockchain solutions.

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[3] A Turing-complete language means a language that can approximately simulate the computational aspects of any other real-world, general-purpose computer language.

Operational considerations

It is important to consider the operating requirements of a specific use case in which a blockchain can be used. Blockchains are often compared with traditional relational databases with the difference being that while a blockchain is good at recording transactions, databases can record both transactions and final state values or balances.

Data retrieval and transaction times in databases are much faster than compared with a blockchain; hence, the speed of a traceability system should be an operational consideration. Most of the projects analysed later in this study recognize this speed penalty and mitigate it by using a combination of a database that initially captures the data with a smart contract recording the transactions on the blockchain in the background.

Once a smart contract is deployed on a blockchain, it should work as designed without interference. Developers will have to ensure that they have effective protocols to update a smart contract, which often is the case for any piece of software.

In the case of a public blockchain that utilizes tokens, the respective participants in the network will have to ensure that they have enough tokens to participate effectively. Tokens are typically purchased in exchange for fiat currency through token exchanges. This may be an issue in developing States where token exchanges do not exist, which would effectively limit the participation in the blockchain of seafood value chain actors in those countries.

Security considerations

Blockchain applications, as any other software, can be vulnerable to security threats. There have been numerous attacks on cryptocurrency exchanges that stored tokens used in blockchains as well as attacks that targeted weaknesses in dApps. Due to the nature of the technology, once tokens have stolen, it can be very difficult to identify the attacker.

Much like the improvement in blockchain development tools, there is also improvement in the security tools used to secure dApps and smart contracts.

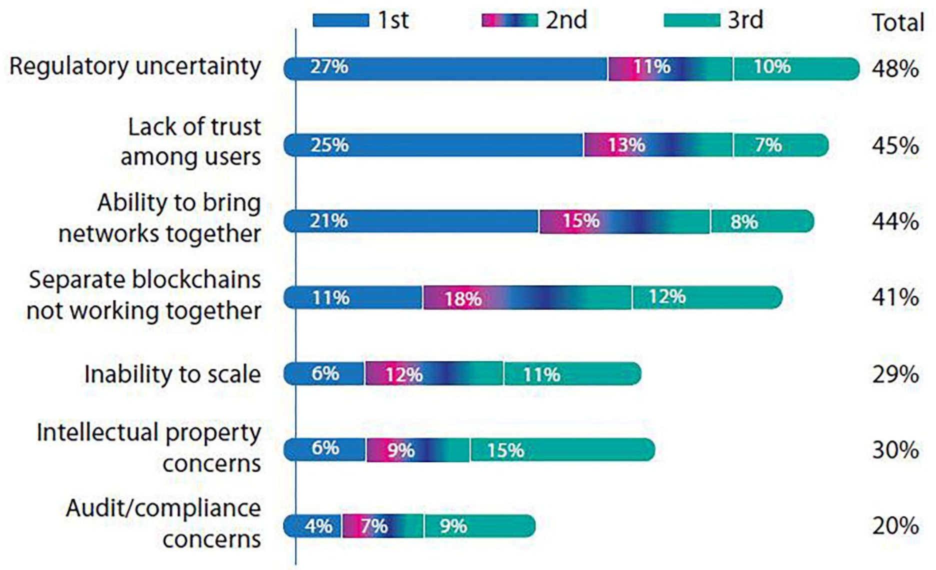
Electronic data interchange

By its very nature of being an immutable and decentralized ledger, blockchains lends itself very well to being an electronic data interchange of sorts. This application is very relevant to seafood value chains, where the blockchain could be the “central” repository through which agreed sets of seafood product KDEs are shared and access is facilitated among various actors in the value chain. It also has the potential to provide a transactional ledger for mass balance reconciliation of fish entering and leaving a processing factory or State.

3.3.2 Regulatory uncertainty

According to one multinational professional services network (PwC, 2019), the financial sector stands to gain the most from blockchain-based service implementations, followed by industrial products and the manufacturing sector, energy and utilities, and then the healthcare sector. Nevertheless, its survey of about 600 blockchain-savvy executives revealed that the biggest barrier to blockchain adoption was regulatory uncertainty (Figure 3). Interoperability and the potential failure of different blockchains to work together were identified as major challenges.

Figure 3. Main barriers to blockchain adoption



Source: PwC, 2019.

3.3.3 Costs

In considering the use of blockchain solutions for seafood value chains, it is important to be aware of the costs involved.

Build or buy

Building a blockchain solution from scratch can be costly given the shortages in experienced blockchain developers and the likelihood that there are limited developers with deep knowledge of seafood value chains. Development costs for blockchain traceability solutions start from about USD 50 000, and time frames to build a solution start from about 3 months or longer.

It is easier now to subscribe to an existing blockchain service or even to a dedicated blockchain traceability service without needing to make a huge investment. This option is also faster to set up and test the technology in a seafood value chain.

Prices for the SAP Cloud Platform Blockchain Service range from USD 280 to USD 3 000 per month depending on the type of blockchain instance required (SAP, 2020). In contrast, IBM Blockchain Platform pricing can start from USD 1 500 per month.

For blockchain traceability service providers, Provenance offers its Enterprise product for from USD 980 per month, with an onboarding fee of USD 3 500 (Provenance, 2020), while TraSeable Solutions offers its solution for from USD 160 per month with an onboarding fee of USD 230 (TraSeable Solutions, 2020).

Integration and peripherals

The other key costs to account for are software integration costs if a value chain actor has existing enterprise resource planning (ERP) software. Hardware costs also need to be factored in, and this involves data capture devices such as tablets, laptop computers, radio-frequency identification (RFID) scanners, and near-field communication (NFC) readers. Fish tagging and label printing solutions are added hardware costs.

Staffing costs should also be considered, especially the need to train fishers, processing-factory workers, and other staff involved across the seafood value chain.

Technical infrastructure

The technical infrastructure to maintain blockchains in near real time is challenging. Receiving and sending large data volumes at sea is only possible via satellite communication in many parts of the ocean. Installing satellite communication devices may be not feasible in small-scale fisheries or fisheries with limited financial resources. Transmission prices could still be too high and the available bandwidth still too narrow to support the transmission demands of electronic logbooks and synchronized blockchains.

Blockchains require intense and frequent communication between the nodes of the blockchain network. Thus, the synchronization of blockchains can be tardy and may not work well in situations in which a large proportion of network nodes are faced with unstable network connections.

3.3.4 Increased responsibility on the user

By its very design, blockchain implementation may not have a central authority (FAO and ITU, 2019), which puts additional responsibility on the user. There is no entity to go to in the event of individuals losing private keys (or incurring losses as a result of revealing a private key). Moreover, there is no feature to restore forgotten passwords and usernames, something that individuals are used to. Individuals need to exercise great caution, just as on the Internet, before publishing anything. The importance of entering the correct data is very important too, as it is very difficult to make corrections later.

4. THE REGULATORY AND PRIVATE INITIATIVES ENVIRONMENT

4.1 The role of compliance at different types of States for data source

Any form of standardized validation and verification structure for data that is to be part of a traceability framework along the value chain needs to be based on regulatory oversight by the authorities in the different types of States, as the concept of "official guarantees" still holds strong in trade and social governance as does that of market access under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) and the Agreement on Technical Barriers to Trade (TBT Agreement) of the World Trade Organization (WTO).

This highlights the importance of identifying CTEs in the value chain – **from the point of capture to the final point of importation** – where information is to be collected and of proposing measures to address weaknesses, inefficiencies and gaps.

One FAO study (Hosch and Blaha, 2017) investigated the identification of these CTEs and KDEs along a value chain segmentation for catch documentation schemes (CDS) based on the types of "State" (flag, coastal, port, processing and end-market) as a contribution to the FAO Voluntary Guidelines for Catch Documentation Schemes approved in July 2017 (FAO, 2017). To these analyses, elements related to the general aspects of traceability from the food safety and fraud[4] perspectives have been added. However, it is important to state that this analysis does not claim to be totally inclusive, and there are aspects that may have not been covered.

Table 1 shows a fishery supply chain with the segments covered or controlled by the various types of State. It is clear that few operations or CTEs along the supply chain are under the exclusive purview of a single type of State and that a large number of operations fall under the purview of different types of State along the supply chain. Note that a single State can act as all of the types of State at once.

Table 1. Standardized supply chain with the segments covered or controlled by the various types of State

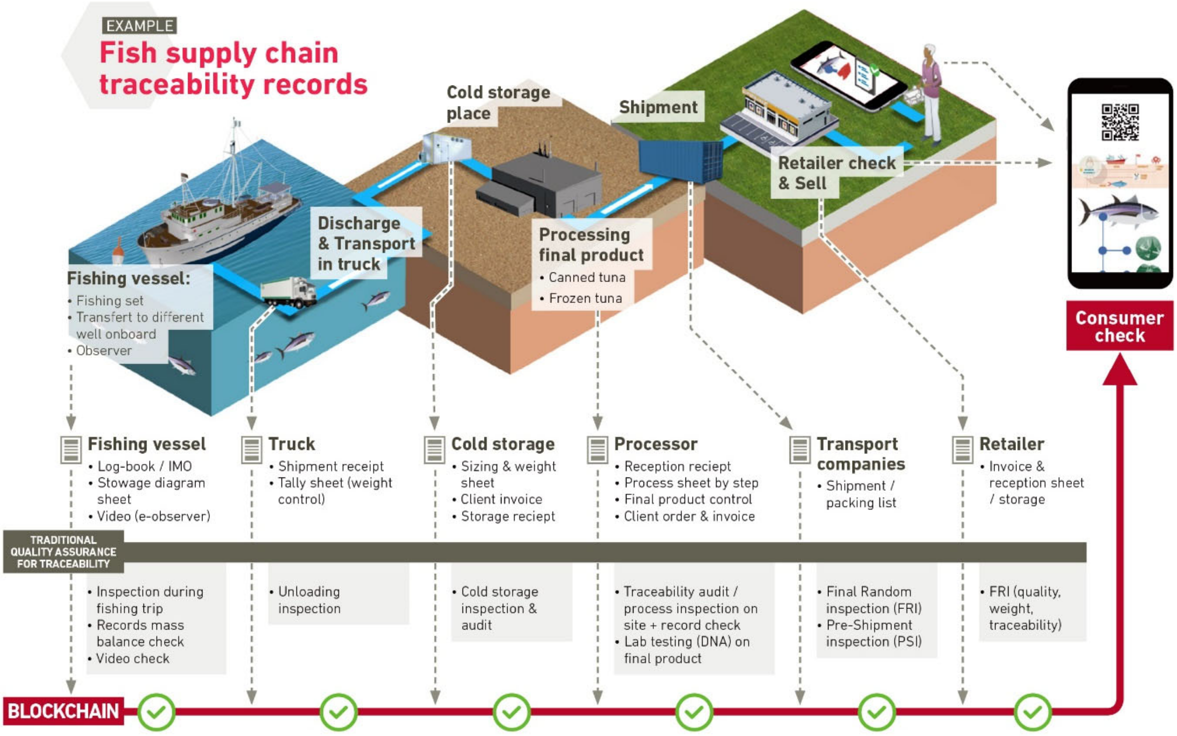
Supply chain function	Harvesting	Trans-shipping	Landing	Transport to processing	Processing	Importation
Costal State	✓	✓				
Flag State	✓	✓	✓			
Port State		✓	✓	✓		
Processing State				✓	✓	
End-market State						✓

Source: Hosch and Blaha, 2017.

While an in-depth investigation of CTEs and KDEs per segment as well as an analysis of blockchain suitability is covered in the following sections, Figure 4 provides a generic example of how data recording in the traditional quality assurance for traceability can be translated into blockchain.

[4] Food fraud is the intentional adulteration of food for financial gain (FAO and WHO, 2017).

Figure 4. Seafood supply chain traceability from traditional records to blockchain



Source: Reproduced courtesy of Bureau Veritas. Food traceability: the blockchain revolution. White Paper (2017). (available at: http://origin.bureauveritas.com/assets/vendor/white_paper_food_blockain.pdf)

4.1.1 Flag State

Considerations for legality, transparency and species fraud

Under Article 94 of the United Nations Convention on the Law of the Sea, flag States must oversee the operations of fishing vessels flying their flags. The 1995 United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks also mandates this and obliges flag States to investigate alleged violations of conservation and management measures and apply sanctions against non-compliant fishing vessels. The 1995 Code of Conduct for Responsible Fisheries also mandates this approach, and places more emphasis on the enforcement regimes of flag States.

Vessel registrations, licence registers, vessel monitoring systems (VMS), logbooks, observer programmes, and trans-shipment and landing authorizations enable flag States to discharge their responsibilities under international law and to oversee fishing vessels flying their flags.

To provide sound assurances that vessels are operating legally, flag States must ensure that they have verified data that can be supplied to traceability systems, through the following mechanisms:

- Registration and licensing of fishing vessels are conditionally linked, and the registration and licence lists are accessible and shared by the CA.
- Fishing vessels are controlled through licences, authorizations or permits, which may vary in scope and according to the type of fishery.
- There is implementation and enforcement of VMS, automatic identification systems (AIS) and logbook regimes for fishing vessels operating in waters beyond national jurisdiction.

- Standard logbooks recording fishing operations are also a licensing requirement in coastal States and regional fisheries management organizations (RFMOs).
- A fisheries observer programme is implemented and coordinated with those operated by RMFOs or coastal States in which the fleet operates;
- Unloadings are communicated and, where appropriate, authorized by the relevant authorities.
- Trans-shipments, transfers and landings are regulated, directly or indirectly monitored and recorded.

The more efficiently flag States carry out their functions, the stronger the assurances are that IUU catches are denied entry into supply chains.

Considerations for food safety

The role of the flag State in food safety is based on the sanitary requirements for fishing vessels, either nationally or by market access conditions, as in the case of the European Union.

In general terms, fish processing establishments in a country intending to export its products should be registered and approved under the control of the national CA against the applicable standards (which include specific requirements normally referring to infrastructure, hygienic conditions, hazard analysis and critical control points [HACCP], operations, traceability, labelling, etc). The same principle applies to fishing vessels where processing takes place (i.e. freezer vessels and factory vessels). Non-processing vessels (ice vessels, small-scale craft, etc.) may also need to be registered and approved before they can be used to supply exporting establishments.

To provide sound assurances that vessels are processing the captured products in compliance with the required standards, flag States must ensure that they have validated data that can be supplied to traceability systems, through the following mechanisms:

- Fishing vessels are controlled through sanitary inspections and, if in compliance, their processing licences, authorizations or permits under a unique ID are maintained.
- The implementation and enforcement sanitary regimes for fishing vessels should be independent of whether the vessels are operating in waters of the flag State in waters beyond national jurisdiction.
- Standard food safety plans and their records are kept for verification.

Summary

Table 2 shows the main supply chain stops, CTEs and KDEs in a typical supply chain overseen by a flag State.

Table 2. Supply chain points, critical tracking events and key data elements at the level of the flag State

Flag State				
Supply chain stop	**Critical tracking event**	**Main key data elements**	**Data sources**	**Suitability for blockchain**
Harvesting	Fishing vessel operation	Unique fishing vessel ID(s)	Vessel registration	Many fixed values: international radio call sign (IRCS), International Maritime Organization (IMO) number, if allocated. Flag, etc. Yet complexities in case of changes of flag, or vessels that are chartered, or in joint ventures that change often
		Permission to fish	Licensing	Fixed information issued by flag State and regional fisheries management organization (RFMO) licensing reviews
		Sanitary licence ID / approval ID	Food safety competent authority (CA) licence/approval records	Complexities around suspension for non-compliance to standards and updated registers
	Fishing (licensing conditions)	Catch areas	Vessel monitoring system (VMS) / automatic identification system (AIS) / logbook controls	Complexities confirming exclusive economic zone (EEZ) and FAO fishing areas on highly mobile fleets
		Start and finish date	Reporting/logbook	Fixed values with VMS cross-checks
		Observer ID (if applicable)	Observer report to coastal and/or flag State and/or RFMO	Complex as observer reports may be corrected by debriefs after reception of reports Note: Observer programmes may be overseen by various entities
	End of fishing trip (reporting)	Type of unloading	Reporting/logbook	Events are easy to log, but volumes are only estimates Interconnectivity with logbook submission by e-report maybe complex Note: In many cases the flag State receives information only after the unloading event
		Species and product type	Reporting/logbook	
		Estimated volume to be unloaded	Reporting/logbook	

4.1.2 Coastal States

Considerations for legality, transparency and species fraud

Although international law provides that coastal States have the sovereign right and duty to manage fisheries in waters under their jurisdiction, their role in current traceability for compliance arena is minimal.

Vessels registered in coastal States or foreign vessels operating in the coastal State's waters may fish illegally: it is the duty of coastal and flag States to ensure that fishing operations are legal and monitored.

Access for foreign vessels is to be established in a supportive manner with other flag and port States in the same fishery, particularly if transboundary and straddling stocks are involved. Participation by coastal States in RFMO decision-making and the incorporation of the resulting conservation and management measures into their legal frameworks is a basic way in which coastal States can control the operations of foreign vessels in the way flag States do.

The most common approach to access is through fisheries agreements between coastal and flag States that set out the terms and conditions of individual fishing permits, and definition of the obligations of flag States with respect to fishing operations carried out by their vessels.

From a perspective of traceability for compliance, the coastal State's CTEs and main KDEs relate to fishing operations. The licences issued by coastal States impose operational conditions on vessels operating in their waters – these established the legality of catches. Monitoring, control and surveillance (MCS) tools such as VMS, logbooks and zone entry and exit conditions, supplemented by an observer or e-monitoring programme, enable a coastal State to determine the legality of harvests in waters under its jurisdiction.

However, the enforcement capacities of coastal States are limited in cases of suspected infringements, particularly when vessels unload in jurisdictions outside a coastal State. Hence, it is essential that coastal States participate in decisions as to the validation of data available for traceability initiatives on the basis of their control of foreign fishing operations in their exclusive economic zone (EEZs).

Considerations for food safety

The role of the coastal State on this aspect have been generally very minimal, as the sanitary conditions of the vessel are normally the responsibility of flag State.

Summary

Table 3 shows the main supply chain stops, CTEs and KDEs in a typical supply chain overseen by a coastal State.

Table 3. Supply chain points, critical tracking events and key data elements at the level of the coastal State

Coastal State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
Harvesting	Fishing vessel (access / permission to fish)	Unique fishing vessel ID(s)	Vessel registration Pre-fishing authorization checks	Many fixed values: international radio call sign (IRCS), International Maritime Organization (IMO), if allocated. Flag, etc. Note: normally provided by flag State but can be confirmed by coastal State If possible, standard under international maritime organization rules
		Fishing vessel licence information	Licensing	Fixed information issued by flag State and regional fisheries management organization (RFMO) Licensing checks. As issued by coastal State and/or RFMO
	Fishing (licensing conditions)	Catch areas	Vessel monitoring system (VMS) / automatic identification system (AIS) / logbook and inspections	Complexities confirming exclusive economic zone (EEZ) and FAO fishing areas on highly mobile fleets
		Start and finish dates	Reporting/logbook	Fixed values with VMS cross-checks
		Observer ID, if applicable	Observer report to coastal State and/or RFMO	Complex as Observer reports may be corrected by debriefers after reception of reports Note: Observer programmes may be overseen by various entities
	End of fishing trip (reporting)	Type of unloading	Reporting/logbooks Electronic Reporting	Complex as distant-water fishing nations (DWFNs) in a coastal State EEZ do not normally notify future unloading as they exit the EEZ; information would be received later Complexity arising of two States over one data field Under the Ports State Measures Agreement (PSMA), the port State should notify the coastal State and others when violations are established, and this could be complex
		Species and product type		
		Estimated volume(s)		

4.1.3 Port States

Considerations for legality, transparency and species fraud

Fishing vessels bring their catch to port for landing directly as catchers or indirectly as reefers. The port is the point at which fisheries products move from the seaborne to the land-based supply chain. Few other points are as important for a full traceability of fish and fishery products.

The use of port State measures to enforce domestic and international fishery laws is now understood as a right and a duty of port States.

The FAO 2009 Port State Measures Agreement (PSMA) requires that port States designate their fishing ports as the ports to which fishing vessels are limited. The PSMA requires that foreign fishing vessels must be consistently monitored in such ports, and that full dockside inspections may be carried out.

The inspections should not be limited to foreign fishing vessels even although in practice they are a particular concern, because port States and flag State are distinct entities in this respect and because the fishing operations are at least part conducted in distant waters. This complicates oversight by flag States, and increases the relevance of port States with regard to foreign fishing vessels.

International law recognizes that States have full sovereignty with respect to ports in their territories, and a State may:

- deny port access to vessels registered in other States;
- prohibit vessels registered in other States from landing or trans-shipping fish in its ports;
- require vessels seeking port access to provide information as to their identity and activities;
- inspect vessels that are voluntarily in one of its ports.

In port, fishing vessels can be fully overseen because they are close to land-based facilities, and the authorities can access the vessels themselves. It is largely the quality of port State monitoring and the work of its port-based fisheries officers that determine the risk of illegally sourced fish entering the land-based supply chain.

Hence, port States must be in a position to monitor all fishery transactions in their ports – mainly landings and trans-shipments – and subject selected transactions to full-scale inspections, as they are the last line of defence in terms of detecting infringements and denying certification of IUU-derived catches and preventing their entry into land-based supply chains.

Fundamentally, a system of authorizations for unloading should be in place to ensure that permissions are denied in cases of suspected or established IUU fishing and recorded for traceability purposes.

Certain supply chain points overseen by port States are particularly important for traceability.

End of fishing trip and port entry – submission of information to the port State authority where the landing is planned prior to the arrival in port of any fishing vessel.

Authorization to unload against compliance to minimal PSMA conditions and evaluation of legality of catches linking fishing trip to volumes and species unloaded.

Unloading – can happen in two ways:

- Trans-shipment in port – Catch information must be handed from the fishing vessel to the reefer master, and counter-validated by the port State and entered into the traceability system. Therefore, Port State authorities need a sound understanding of the fishery and its regulatory framework governing in-port trans-shipments, standard MCS routines and inspections.
- Landings, verified weights and first buyers – Because fishing vessels unload their own catch whereas reefers unload several harvests, checking the paperwork and data for the former is

simpler than for the latter; however, the procedures must be equally rigorous. Once authorization to land is granted, two essential data groups must be completed, overseen and counter-validated by the port State authority:

- the actual weights landed, in whatever form, must be verified and the means of transport and storage established so that all transactions can be summed to account for their full-landing equivalent weight; this is the first occasion where the accurate actual weight of a harvest can be verified;
- the amount acquired by every buyer in terms of species, volume and form must be recorded, and the port State should have access to its own data for a traceability system.

Port State authorities are crucial in counter-validating these data groups, which constitute the foundation of national mass balance traceability.

Considerations for food safety

The role of the port State on this aspect varies accordingly to national legislation and/or final market access conditions.

Some States have specific infrastructure requirements and operational conditions for the authorization of use for unloading places and their unique identity. In the case of European Union market access, the port State is to be an authorized country (European Commission, 2020). Otherwise, the products are not eligible for its market; hence, the country authorization status is to be traceable.

Summary

Table 4 shows the main supply chain stops, CTEs and KDEs in a typical supply chain overseen by a port State.

Table 4. Supply chain points, critical tracking events and key data elements at the level of the port State

Port State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
Harvesting	End of harvesting operations / fishing trip	End of fishing/trip date	Port entry notice	Port States Measures Agreement (PSMA) procedures: documentary checks, authorization/refusal of Port entry may not be easy to codify
		Unloading authorization code/ID	Port entry and unloading authorization / use of port register under PSMA	Post-physical verification and unloading code can be provided and could be easily be incorporated
Unloading	Trans-shipment	Carrier ID and licence	Port entry notice Unloading authorization Inspections	Fixed data, as carrier should appear on regional fisheries management organization (RFMO) white list
		Observer ID		
		Date and name of port, or geographic coordinates		Fixed data and simple designated port for fisheries activities

Port State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
		Volume, form and species – estimated		Complexity as estimates may be verified by monitoring using crane scales, mate's receipt, hatch plan, but substantial variability and port events edits
		Unloading authorization code/ID		Unloading code can be provided and could be easily be incorporated
	Landing	Vessel ID and licence		Many fixed values: international radio call sign (IRCS), International Maritime Organization (IMO), if allocated. Flag, etc. Must have be linked to licences for coastal States fished
		Date and name of port		Fixed data and simple designated port for fisheries activities
		Sanitary status of State and landing place		Sanitary authorization for landing place and country
		Volume, form and species – estimated		Complexity as estimates may be verified by monitoring using crane scales, mate's receipt, hatch plan, but substantial variability and port events edits
		Volume, form and species – verified		Complex as it need to be linked to "weight in event"
		Name of first buyer	Inspection Commercial invoice Catch documentation scheme (CDS)	Simple, provided that as first buyer is a fixed identity Inspection records/notifications
Distribution	Factory/warehouse entrance	Verified net weight sold to individual buyers	Factory/warehouse entrance records Commercial invoice On-site monitoring by fishery authorities	Could be complex if weights and species is amended / verified later during processing Full inspection if estimated and verified differ substantially Monitoring records

Port State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
	Further domestic distribution of products following first sale, and re-exports	Refer to processing or end-market State table		

4.1.4 Processing State

Considerations for legality, transparency and species fraud

The "processing State" concept is not *per se* recognized in international fisheries law – yet it is the most important type of State in terms of country-level traceability solutions.

In principle, "processing" means any action that substantially alters an initial product. It can be as simple as transforming a fish from "whole" to "gutted" or "filleted", and it includes changes by processes such as cooking, canning, drying and extrusion or a combination of such processes. In some cases, "non-transforming" operations such as grading and packing are referred to as processing, but they have no effect on product or unit weight.

The emergence of important processing States such as Thailand and Viet Nam in the tuna industry has brought attention to the data management and traceability in this type of State, where raw materials are imported, processed and then exported.

There are three basic functions involving processing States in terms of supporting traceability:

1. ensuring that no illegal products enter the territory;
2. providing a national traceability system that rapidly identifies fraudulent economic operators by means of detected mass-balance inconsistencies;
3. validating mass balance and origin covering consignments exported from the territory.

In supporting its traceability structure, a processing State must:

- ensure that no illegal products enter its territory, whether landed or imported;
- cover the entire chain of events by means of its **national traceability** system to trace product from landing or importation at ports of arrival through ownership changes and processing exportation or re-exportation. The need is for traceability tools that cover events between entry and exit "gates" into and out of the country so that regulatory controls can establish where anomalies occur and identify those responsible. These controls must cover:
    - registration and licensing of storage and processing premises to identify value chain operators; in most countries, fish storage and processing premises must be licensed and controlled by health authorities, which amounts to a traceability and record-keeping system that can support traceability;
    - distribution and transfers among operators' premises: registration of internal movements of declared species and volumes makes them traceable; this requires six KDEs that must be recorded at every step along a supply chain, namely:
        i. unique product identifier,
        ii. product source – seller and previous owner of the product,
        iii. product destination – buyer and new owner of the product,
        iv. species,

v. volume,
vi. product form;

- operations in storage and processing premises involve changes in weight from unprocessed to processed product, providing opportunities for laundering non-originating fish into supply streams, so fishery authorities must establish controls to:
  i. check processing premises and cold stores to verify the accuracy of records and inventories, account for volumes that have been split or mixed, and verify the volumes and forms of certified species entering supply chains and subsequently leaving them,
  ii. verify the reporting and monitoring of yield factors to eliminate fraud;
- recording products leaving operators' premises, regardless of destination; regular verification by fishery authorities of pre-dispatch checks and consignment loading records will ensure the effectiveness of traceability systems at the level of individual operators.

For any data entry into a traceability system, the following functions are essential for private-sector operators:

- product entry and creation of a product account linking product entry to the premises with the relevant certificates; scanned supporting documents may be uploaded when creating the product account, and competent authorities then validate and authorize the product account; all transactions are deducted from this account;
- product exit, subtraction from the product account and certification for product exit from a supply chain to:
  - another operator in a business-to-business transaction, with the acquired raw materials in alignment with the details of species, volumes and form,
  - a domestic market for local consumption, logged as above,
  - exportation, with supporting documentation and details of volume, form and species so that log processing yields and any anomalies can be traced;
- product account balance held by any operator, based on logged data and/or verified by inspection;
- other important functions for private-sector users involve mechanisms for queries and error correction.

Fishery authorities, on their side, must have access and functions to enable them to:

- validate requests submitted by economic operators for product accounts, trade certificates and error correction;
- make queries to obtain an overview of the system and products within it;
- block or suspend product accounts or trade certificates submitted for validation. Overall, the system must be capable of:
  - automated monitoring of product flows and yield factors throughout national supply chains as product changes form, weight and ownership,
  - capturing processing yields on the basis of volume declarations for product in and product out to establish a database,
  - triggering alarms that signal the logging of anomalous data and trigger investigation.

Considerations for food safety

Processing has been the preserve of food safety authorities, for whom traceability is important in terms of consumer safety, information and product origin. Hence, systems involved in tracing product from landing at the port of arrival, importation, ownership changes and processing to domestic markets or exports are in place under specific legislation and/or market access requirements.

Regardless of whether fish are imported or landed, fish storage and processing premises in the export value chain are licensed and under the control of health authorities in most countries, with particular regulatory conditions that apply according to the type of processing in place. Hence, fish storage and processing premises involved in the export supply chain need to be licensed and under the control of the fisheries authority. Non-compliance with licence conditions should automatically result in sanctions, enforcement measures and even suspension of the licence.

In complex national supply chains, which are the norm in advanced processing States, systems must be developed to trace the movement of products from the entry gate to the exit gate so that inspections can establish whether compliance has been maintained along the different operators. Without such traceability tools, it may be impossible for a CA to establish the nature and cause of any potential problems.

Summary

Table 5 shows the main supply chain stops, CTEs and KDEs in a typical supply chain overseen by a processing State.

Table 5. Supply chain points, critical tracking events and key data elements at the level of the processing State

Processing State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
Importation	Authorization of imports	Point of importation	Customs pre-clearance	Complex as requires fisheries authority access to commercial ports and import clearance data Multijurisdictional data entry Verification of received volumes and species may require edits of entered information Physical verification, or remote access in case of electronic catch documentation scheme
		Name of buyer/importing company	Customs pre-clearance	
		Unique product identifier	Processing of the catch certificate	
		Volume, form and species	Receiving the catch certificate and bill of lading	
		Sanitary status of imported products	Sanitary status of exporting country and harvesting vessel	
	Customs control	Document no.	Authorization of imports	
Distribution	Product splits (initial and later)	Unique product identifier	Catch documentation scheme (CDS) related record-keeping by economic operators, paper-based or electronic	Simple in principle as is based on fixed values, yet consignments change destiny and are split post-initial data entry, and remits and invoices change
		Volume, form and species		
		Name of buyer		
Storage and Processing	Processing	Identity each operator along the domestic value chain	Proof of sanitary status and control by the competent authority (CA)	Simple IDs are fixed

Processing State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
		Volumes and species acquired		Complex due to corrections in Weight in / grading and lot allocation / inventory
		Volumes and species entering processing		Lot tracing / inventory
		Volume, form and species for rendering / fishmeal		Lot tracing / product reports / inventory
Certification for trade	Domestic distribution of finished products	Documentation/ dates	Inward trade certificate, to be created by processing States	Simple following physical verification and certification
	Exportation or re-exportation of semi-finished/ finished products	Trade certificate ID	CDS; bill of lading; customs declarations	Simple as fixed values are the norm
		Source CDS certificate ID	CDS; supplied by exporter at the time of filing trade certificates for validation	Entrance of the certificate into the national territory is captured and logged by the CA at the time of importation and related authorizations
		Volume, form and species of product	Processing yields	To be computed and evaluated
		Name of buyer/consignee	Trade certificate	Simple
		Sanitary status	Health certificate	

4.1.5 End-market State

Considerations for legality, transparency and species fraud

End-market States can also be flag, port and processing States simultaneously. This section considers the final importation of fishery products as consumer goods.

The main responsibility is to ensure that any fishery products imported do not enter national territories without valid traceability and unique identifier along all other type of States.

End-market States need various mechanisms to implement their role in traceability. The first is the involvement of fishery authorities in overseeing importation and legal requirements before border clearance. This is because imported products normally enter countries through commercial ports, which are often outside the purview of fishery authorities.

Fishery authorities must be involved in verification and authorization with customs, health and biosecurity authorities to ensure that only legally sourced and certified products enter a territory. The CA must have statutory powers to deny entry to non-compliant consignments, which normally requires the development of new regulations.

A system of prior notification and authorization for imports must be in place. Fishery authorities can either undertake their own verifications under a traceability system, or do so in coordination with customs authorities.

The importation of IUU fish into national markets affects the sustainability of fisheries and increases public health and safety risks. Non-compliant consignments must be refused entry, and fraudulent operators should bear civil and criminal liability, and face the risk of prosecution and substantial sanctions.

In the case of fish fraud, to establish wrongdoing and to know a product's place of origin or the species in a sample or consignment, CAs must rely on other means of investigation. This is where genetic testing and commercial DNA test kits become important. Current tests are difficult, expensive and time-consuming, but research is focusing on faster, cheaper and handheld means of identifying seafood species on the basis of closed-tube DNA barcoding. When these tests become available, it will be possible to address substitution fraud in supply chains more effectively.

Considerations for safety

As in the case of legality, the main responsibility at the level of the end-market State is to ensure that imported fishery products do not enter national territories without valid sanitary certification and the traceability associated to the value chain.

Summary

Table 6 shows the main supply chain stops, CTEs and KDEs in a typical supply chain overseen by an end-market State.

Table 6. Supply chain points, critical tracking events and key data elements at the level of the end-market State

End-market State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
Importation	Import authorization	Place of importation	Customs pre-clearance procedures	Potentially complex as requires fisheries authority access to commercial ports and import clearance data Multijurisdictional data entry Verification, online in case of e-traceability Yet at this stage is most fixed codes and values
		Name of importer	Pre-clearance procedures	
		Unique product identifier.	Pre-clearance procedures	
		Verified volume, form and species	Border clearance	
		Sanitary certification	Unique certificate identity	
	Customs control	Unique product identifier		

End-market State				
Supply chain stop	**Critical tracking events**	**Main key data elements**	**Data source**	**Suitability for blockchain**
Domestic distribution	Distribution events, by importer	Unique product identifier	Importers' business records	Potentially simple as there are fixed values Food fraud checks
		Product type and volume	Inspections and sampling	
		Name of buyer	Importers' business records	
	Wholesaler buyer		Purchase records	

4.2 Private certifications and non-governmental organizations lead initiatives

As of today, the pilot studies discussed in Section 4.3 (below), are funded either through a blend of initial coin offerings and venture capital funds or local governments that unite with NGOs. In order to generate the necessary momentum to incentivize blockchain use, these NGOs then also work with large conglomerates to pressure suppliers into holding their product sources accountable.

All current initiatives supported by NGO or private certification cover only part of the value chain for specific operators in the market, but none encompasses a whole fishery for a specific type of State, and nor are they compulsory as a form of generalized official market access, hence requiring integration across different authorities in different jurisdictions .

4.2.1 The case of ecolabels

As a specific type of private certification, ecolabels incorporate the concept of "chain of custody" (CoC). There is at least one example (Pacifical) as a client of the Marine Stewardship Council (MSC)[5] label that uses blockchain to support the documentation of the CoC required to maintain certification in regard to the integrity of the product bearing the logo of the ecolabel, particularly in the case of purse-seine-caught tuna certification, as vessels fish in the same trip both certifiable product (FAD-free)[6] and non-certifiable products (FAD-associated).

There are very specific rules for what one is allowed to do in order to maintain the CoC as defined by the ecolabel certification standards. A typical rule might be "you are not allowed to mix together fish from two different suppliers." In this respect, the ecolabel-type CoC requirement ("do not mix") is stricter than the traceability requirements ("mix as much as you like as long as you document it").[7]

The issue here, is that in the case of certain fisheries such as tuna, the CoC only applies to product of vessels that are part of the unit of certification (i.e. have paid for the certification). However, other vessels fishing the same stocks, with the same fishing gear, during the same seasons are not clients of the ecolabel. Therefore, as they are not covered by the CoC, their products "escape" the coverage.

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[5] The Marine Stewardship Council is a non-governmental organization that sets a standard for assessing sustainable fishing and provides an ecolabel to those fisheries meeting its standards.
[6] The acronym FAD stands for fish aggregating device (FAO, 2005).
[7] For a deeper analysis, see Borit and Olsen, 2012.

4.3 Present status of blockchain in the wild-caught seafood value chain

Tuna is by far the most common seafood commodity tracked on the blockchain from the projects that were reviewed for this study, with the other commodities being Patagonian toothfish and farmed shrimp.

4.3.1 Provenance project

One of the earliest pilot projects using blockchain technology in seafood value chains was in 2016 by Project Provenance Ltd (Provenance) in Indonesia. The six-month pilot was conducted in the pole-and-line and handline fishery and focused on two supply chains: yellowfin tuna loins and skipjack tuna for canning.

The pilot goals according to Provenance were to see 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 (Provenance, 2020). The pilot tracked the tuna from catch to landing, on to the factory and into retail using the Ethereum blockchain, mobile phones, and smart tags. Within the factory, Provenance was able to integrate with existing ERP systems.

How it worked

1. Fishers and suppliers were registered into the Provenance app.
2. Fishers would send an SMS message to register their entire catch, which then triggered that catch being recorded as a new asset on the blockchain. The catch was physically tagged to identify it.
3. On land, the fishers transferred the catch to suppliers both physically and digitally using the Provenance app. Trusted local NGOs verified social and environmental conditions for the fisher.
4. Suppliers transferred the catch to the factory together with its digital data. Provenance integrated with at least one ERP system, Tally-O, to further track the tuna through the processing stages and out to shipment.
5. The final stage involved working with a retailer and using NFC-enabled smart labels on tuna products to communicate the provenance story.

Lessons

The pilot report noted the challenge of connecting the physical asset to the digital asset using tags and labels with various methods, both high-tech and low-tech, for identification such as 2D (Quick Response [QR]) codes, RFID and NFC. It also noted that much time was spent digitizing each stage, and recommended the use of public blockchains to ensure interoperability, equality and consensus.

There were steps within the process that were unclear, including whether the tuna was individually tagged and recorded on the blockchain, or whether the entire catch was tagged and recorded as a single unit. The process from the supplier to the factory and within the factory was also unclear regarding how the catch was tracked into the different products.

4.3.2 WWF-New Zealand, ConsenSys, Sea Quest (Fiji) Ltd, and TraSeable Solutions

The first application of blockchain technology in a tuna longline fishery came in 2017 when the World Wide Fund for Nature (WWF), ConsenSys, and Fijian companies Sea Quest (Fiji) Ltd and TraSeable Solutions partnered to implement the project in Fiji.

According to the project report (WWF-New Zealand, 2018), the goal was "to create a completely transparent and traceable supply chain, utilising innovative blockchain technology, for the fresh and frozen tuna supply chain." The report describes in detail how the project was implemented, including associated costs.

How it worked

1. The supply chain was mapped into Treum (previously Viant), and the needed roles and permissions were set. This created the data entry interfaces and rules to capture data.
2. On capture aboard a longliner, each tuna was tagged with unique identifiers initially using RFID tags, and later with QR code tags. Key data about the capture event and tuna were recorded into the app. Given an Internet connection, data were transmitted in real time to the blockchain; otherwise, this was done on return to port.
3. On landing, each tuna unloaded was likewise tracked by scanning its tag.
4. In the processing facility, at key stages along the processing line, the tuna was tracked, and key data collected. If a tuna was transformed into other products such as loins, then each new product (loin) was given a new identity on the blockchain and tracked separately.
5. On distribution, actors along their supply chain could participate and continue to track the tuna products through the supply chain to the consumer.

Lessons

As in the Provenance project, each stage of the supply chain had to be digitized as the fishing company, Sea Quest, was reliant on manual data collection. As RFID tags and equipment could not be locally sourced in Fiji, these tags had to be imported. Due to the costs and difficulty sourcing the equipment, the project team opted for QR code tags. Mapping Sea Quest's supply chain was a challenge as was persuading other actors to participate.

4.3.3 Pacifical and Atato – purse-seine-caught, MSC-certified, canned skipjack tuna

In 2018, another project in the Pacific was announced. This one was between Pacifical, the tuna market development company of Parties to the Nauru Agreement Office's (PNAO), and Atato, a Thailand-based blockchain services provider. This was the first large-scale blockchain initiative to track purse-seine-caught skipjack tuna destined for canning. The initiative brought into the public domain the CoC requirements of the MSC's private certification.

This project utilized the good information systems of the PNAO and processing companies that already captured KDEs for the tuna from catch to processing. These KDEs are transmitted via application programming interfaces and published on the blockchain using Atato's notary service.

How it works

1. During harvesting, the purse seine tuna catch is electronically recorded into the PNAO's information system.
2. In Thailand, offloading and processing KDEs are recorded in the respective company information systems.

Products that are recorded on the blockchain then have the respective KDEs from the various information systems that sent the data.

4.3.4 OpenSC – WWF-Australia and BCG Digital Ventures – Patagonian toothfish

OpenSC in partnership with WWF-Australia and BCG Digital Ventures announced their blockchain project for traceability of Patagonian toothfish in early 2019. Much like the Provenance and WWF-New Zealand projects, this project required the tagging of toothfish with RFID tags on capture and recorded data about the movement of fish through the supply chain. The project further mentions the integration of machine learning with GPS data to further determine whether the fish was caught in a legal area.

4.3.5 Bumble Bee Foods – “Fair Trade” yellowfin tuna

In March 2019, Bumble Bee Foods announced its use of SAP’s blockchain services to track “Fair Trade”-certified yellowfin tuna sourced from Indonesia. While the details of how this works are not readily available, it is likely that this also involves tagging individual tuna on capture and recording key data as the fish passes through the supply chain. Similar to other projects, Bumble Bee Foods uses QR codes on the tuna product packaging to communicate the provenance story of the fish.

4.3.6 Fishcoin

Fishcoin describes itself as a “blockchain based data ecosystem” that is backed by a stable coin token and incentivizes the collection of data about seafood products through the supply chain.

According to the Fishcoin (Fishcoin, 2018) it “is not an application per se, but a series of open source tools and software development kits” that can be used by supply chain actors and developers to integrate their decentralized applications to the ecosystem.

4.3.6.1 How it works

1. Fishers catch fish and collect data about their catch. They can potentially exchange their Fishcoin token for airtime from a local mobile network operator that is a participant in the ecosystem.
2. Fishers sell their catch to the first receiver and, in return for the catch data, they receive Fishcoin tokens.
3. At each stage in the supply chain, every actor in custody of the fish adds more data to the ecosystem.
4. Actors that buy the seafood product (products) exchange Fishcoin tokens with the previous actor for the catch data until it reaches the retailer that sells it to the consumer.

4.3.7 Sustainable Shrimp Partnership

In May 2019, the Sustainable Shrimp Partnership (SSP) joined the IBM Food Trust blockchain platform to provide transparency and traceability for its Ecuadorian farmed shrimp citing the rise of food fraud and poor-quality products entering the market (FishFocus, 2019).

According to the SSP, shrimp producers in Ecuador will record data on the blockchain about how the shrimp is produced, which will then be accessible to retailers around the world who can trace every stage in the production process. The SSP intends to provide a consumer app to allow consumers to view the provenance data.

4.4 Commonality analysis of blockchain projects

Table 7 summarizes an analysis across all the projects reviewed to identify commonalities and differences in their application of blockchain.

Table 7. Commonality analysis of blockchain projects

Project	Commodity	Blockchain	Comments
Provenance **Indonesia**	Tuna Fishing method: handline, pole and line	Ethereum Type: N/A	Fish are individually identified back to the fisher Fish are tracked through transformation in processing facility Uses near-field communication (NFC) on product packaging to communicate provenance story
WWF-New Zealand, ConsenSys, Sea Quest, TraSeable Solutions **Fiji**	Tuna Fishing method: longline	Ethereum Type: private Platform: Treum (previously Viant)	Fish are individually identified back to the fisher Trialled radio-frequency identification (RFID) and Internet of things (IoT) sensors Fish are tracked through transformation in processing facility Uses Quick Response (QR) codes on product packaging to communicate provenance story
Pacifical, Atato **Pacific and import markets**	Tuna Fishing method: purse seine	Ethereum Type: public Platform: Atato notary application programming interfaces	Fish are not individually identified Uses existing Parties to the Nauru Agreement Office (PNAO) fisheries information management system platform for data capture of Marine Stewardship Council (MSC) chain of custody (CoC) Atato notary service receives digital traceability data at key points and records onto blockchain Provenance story linked to lot/batch number printed on canned tuna
OpenSC, WWF-Australia, BCG Digital Ventures **Australia**	Patagonian toothfish Fishing method: longline	N/A	Fish are individually identified back to the fisher Uses RFID and IoT sensors Uses QR codes on product packaging to communicate provenance story
Bumble Bee Foods, SAP **Indonesia**	Yellowfin tuna (certified "Fair Trade") Fishing method: handline	HyperLedger Fabric, Multichain Type: private Platform: SAP Cloud Platform Blockchain Services	Fish are individually identified back to the fisher Uses QR codes on product packaging to communicate provenance story
Fishcoin	Any seafood	Ethereum Type: N/A	Incentivizes the capture and transmission of catch data
Sustainable Shrimp Partnership **Ecuador**	Farmed shrimp	HyperLedger Fabric Type: consortium Platform: IBM Food Trust	Production data recorded into IBM Food Trust on shrimp farms in Ecuador Data about products are accessible to retailers around the world

This analysis highlights several similarities across the projects:

1. **High-value fish species** – projects focused on tuna and Patagonian toothfish species, which are considered high-value commodities.
2. **Link between digital and physical** – all the projects rely on some way to link the physical with the digital, either through tagging individual fish or some other means of recording units of catch data.
3. **Immutability of data and secure data sharing** – these were the most common reasons for utilizing blockchain technology.
4. **Clearly defined value chains with known actors** – most of the projects had relatively short and clearly defined or vertically integrated value chains where the actors were known.
5. **Use of QR codes on product packaging** – this method was favoured, possibly because of its utility.

A number of challenges across the projects also emerge:

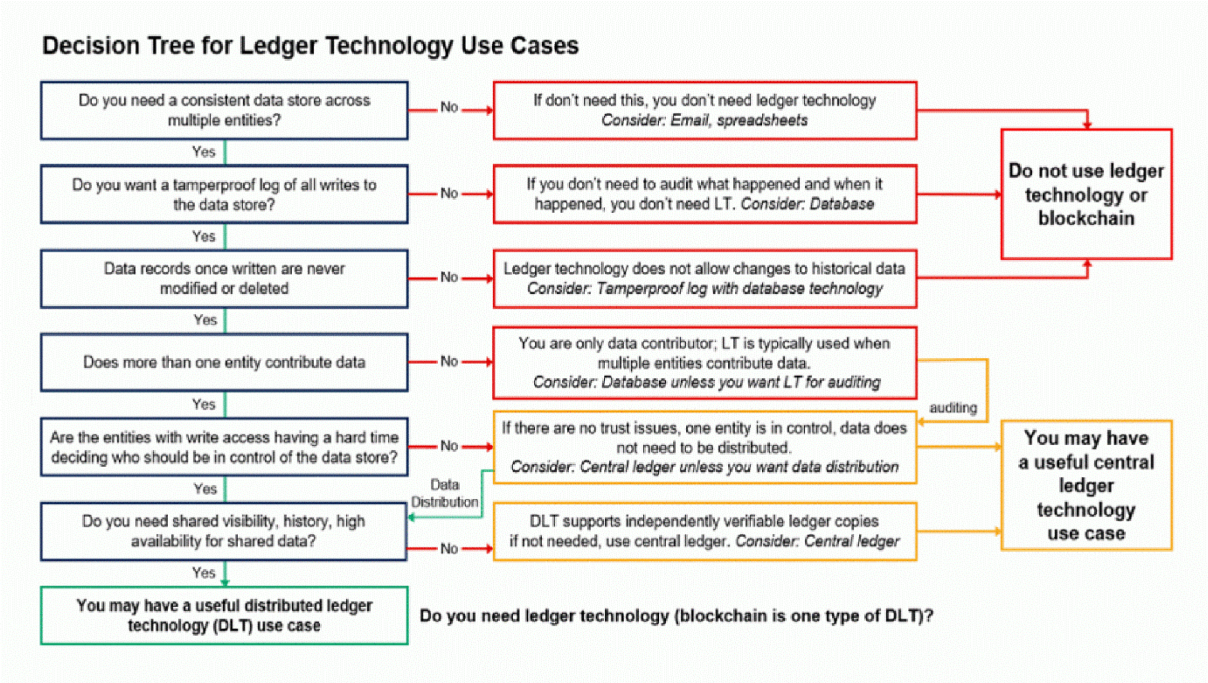
1. **Reliant on human input** – most of the projects rely on human input of fish data, which themselves could be open to tampering.
2. **Tagging and labelling of fish** – physical fish tags/labels could be lost or damaged while transporting the fish or could potentially be tampered with.
3. **Verifiability of private and consortium blockchain platforms** – by their very nature, these types of blockchains are not open to the public and transactions on them cannot be independently verified.
4. **Complex seafood value chain scenarios untested** – the solutions were not tested in real-world complex seafood value chain scenarios where the value chain actors were unknown.

5. OPERATIONAL OPPORTUNITIES WITH THE USE OF BLOCKCHAIN

The first question to ask when considering the use of blockchain technology for seafood traceability is whether it is the right tool. Failure to make a sound decision might lead to the risk of making an unnecessary, high-cost investment. Cost savings from disintermediation, that is by having the network as the trusted party, might not offset the costs of supporting and maintaining a blockchain-based application.

A number of decision trees are available that are used to make this key analysis. As an example (not an endorsement), one from Gartner (a research and advisor services provider) is presented in Figure 5.

Figure 5. The Gartner decision tree for ledger technology use cases



Source: Litvan, 2019.

From an operational perspective, blockchain technology can provide a common technology layer that, through standards, could facilitate the exchange of KDEs for seafood products moving through the value chain. It could potentially be the unifying system that existing digital traceability systems utilized by various value chain actors would integrate with, and it could hold all relevant legal documentation and identification that needs to accompany fish across borders.

In fact, almost all the existing traceability systems that use blockchain technology use it in this way – as a store of immutable data and a means to facilitate data exchange built upon digital traceability systems that use centralized databases.

While this immutability is very desirable from the traceability perspective, it may bring operational difficulties at transactional level (B. Tydd, personal communication, 2019), noting that seafood trade value chains operate at both levels.

To date, all the blockchain traceability projects in the seafood industry have been led by NGOs and/or the private sector. What is unseen is if an entire industry agrees to use a technology such as blockchain to improve value chain transparency in that industry.

The IBM Food Trust blockchain initiative (IBM, 2020) provides the best example of what an enterprise-wide blockchain solution offers for a "collaborative network of growers, processors, wholesalers, distributors, manufacturers, retailers, and others, enhancing visibility and accountability across the food supply chain."

A similar argument can be used for the official organizations that currently provide official guarantees for market access in terms of unifying and or connecting their current platforms into a blockchain-driven one.

Blockchain technology would be the medium through which standard KDEs are shared between value chain actors, civil society and official institutions. It could provide incentives for the different players in the industry. For the private sector, it could improve operational efficiencies and bolster brands in the marketplace. For the government authorities responsible, its immutability could be a means to facilitate the traceability of the catch or harvest and assure export market requirements are met. For NGOs, it could be a platform through which they help everyone remain accountable. Finally, for consumers, it could mean knowing that the fish they are buying has been legally and ethically caught.

In the projects analysed for this study, most of the solutions employed tagging the seafood with unique identifiers and having that data recorded on the blockchain as a claim. In a public blockchain, authorities could facilitate verification of these claims by checking any paper documentation against what has been recorded on the blockchain. In a permissioned consortium blockchain, the authorities would have to be a participant in the consortium in order to be able to access the blockchain and, hence, use it to facilitate any verification.

Responsible fishing operators would obviously be more willing to adopt the technology, while other operators would not have any choice but to do so. Overall, it would lead to greater adoption of digital tools and potentially greater transparency across the seafood value chain.

In the past, the cost and the state of the technology may have been barriers to adopting and scaling blockchain applications in seafood value chains. However, these have improved and it is now viable to operate a blockchain traceability platform at about the same cost associated with having enterprise-grade ERP solutions. That said, costs associated to a public blockchain are an important factor of consideration.

Any flow takes the path of less resistance; fisheries is no different. Some initiatives use blockchain as a way to differentiate their brand, improve earnings, position themselves as the ethical operators they are, and see benefits along their customer base. However, other operators have a very profitable and established market somewhere else in the world that does not require any form of ethical, legal or safety assurances, and thus would have no incentive to adopt such a system.

Hence, the current initiatives show that it is possible to have a blockchain-based system operating at a micro level for specific seafood value chains, but none currently solves the adoption of full traceability at a macro level across global seafood value chains.

6. POTENTIAL TRADE AND PUBLIC POLICY IMPLICATIONS

The WTO's Trade Facilitation Agreement (TFA) aims to reduce trade costs (WTO, 2015), which remain high despite the decline in transportation costs, improvements in information and communications technology, and reduction of trade barriers in many countries. The digitization of trade transactions has yet to be realized and is heavily dependent on paper despite "efforts to put in place electronic processes to handle some aspects of trade procedures, such as electronic single windows" (Ganne, 2018).

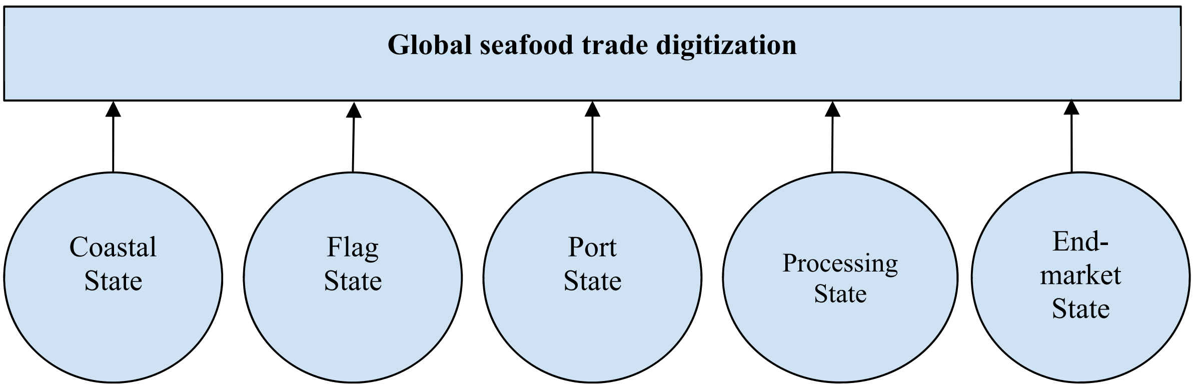
However, "official assurances" remain a fundamental aspect of international trade. These are government-to-government assurance confirming that the products meet both domestic and the destination country's requirements. Official assurances are only issued for countries where the national CA has negotiated an agreement with the destination market as part of an official assurance programme.

Seafood trade involves numerous actors and relies heavily on paper documentation for verification and authorization purposes. It also relies on the coordination of multiple parties in the respective States to share information with one another to ensure the movement of the seafood products. Traceability and transparency of products through complex seafood value chains is challenging. Similarly, trade finance is often tied up awaiting the manual processing of documents.

Blockchain, with its inherent characteristics of immutability, security and decentralization together with its smart contract feature, has the potential to improve efficiencies and accountability in seafood value chains. Permissioned consortium blockchains in particular have the greatest potential in the current state of the technology to be scaled to address seafood traceability without the concerns of high energy use and slow transaction times that public permissionless blockchains have.

A consortium could comprise all the regulatory authorities in a given State or among States. States and actors will need to agree and standardize CTEs and KDEs. Smart contracts could further be used to speed up document processing and free up trade finance based on preconditions. Figure 6 shows how each State actor in seafood trade would participate in this type of consortium where the unifying platform for KDEs would be blockchain-based.

Figure 6. Potential global seafood trade digitization structure



This system would allow each State actor to fulfil its respective obligations in ensuring the legality and traceability of seafood and to contribute KDEs for CTEs within each State's control. The blockchain-based system would be "owned" by all actors and not by any single actor. From a technical perspective, this can translate to each State actor having the ability to establish a node to this system in their jurisdiction and act as a validator.

Respective permissions will be allowed into the system for each State actor, and the inherent security of blockchains will protect the data. Such a system could integrate with any national seafood traceability or CA-controlled systems to ensure KDEs are seamlessly recorded on the blockchain. This paperless system would lower costs and speed up trade transactions by providing a common digital platform to allow regulatory authorities to validate the data about the seafood and verify any legal documentation accompanying it.

While the potential exists for the use of blockchain technology to enhance seafood trade, there are a number of challenges that need to be overcome. There needs to be greater awareness of the body of knowledge on the technology and how it can be applied in seafood value chains.

Scalability is an issue for permissionless blockchains, but less so for permissioned blockchains. While there have been advances in the technology, this issue still remains. Security is a strong feature of the technology now, but the advances in quantum computing poses a real threat because many of the cryptographic algorithms in use today could be broken. However, researchers are working on post-quantum cryptography methods that would be "quantum-resistant" (Schneier, 2018).

From an operational perspective, the current applications of the technology rely on human input as well as physical tagging methods that could potentially be corrupted. This can bring into question the authenticity and accuracy of data being put onto the blockchain.

Interoperability will be a challenge to implementing the technology because of the lack of traceability standardization in seafood value chains – both from a technical perspective, where existing traceability systems may not be able to talk to each other, and but also from the perspective where there is standardization in the KDEs that need to be recorded and shared.

There must also be an enabling regulatory environment for the technology to be widely adopted across the seafood value chain. Concerns have been raised about the legality of blockchain transactions and data privacy. Without the right environment, it will be difficult to implement any solutions that utilize blockchain.

In fact, digital data technologies may work best in fisheries that voluntarily intend to demonstrate their compliance to laws, management rules, and consumer demands, or in ones that are looking for a self-controlling mechanism to foster trust among competitors.

Because fishers may want to organize themselves to reduce conflicts and improve trade opportunities, such systems may even evolve in areas where governmental fisheries are currently weakly developed or totally absent.

The application of this technology could help facilitate seafood trade, enhance transparency in global seafood supply chains, improve food safety, and be a means to ascertain the legality of seafood. Collectively, these benefits may help countries to achieve Sustainable Development Goal 14 (Life below water).

7. RECOMMENDATIONS

From this study, it transpires that all current initiatives are private-industry-based and only cover part of the value chain for specific operators in the market, but none encompasses a whole fishery for a specific type of State, and nor are they compulsory as a form of generalized official market access, hence requiring integration across different authorities in different jurisdictions. Therefore, the potential of blockchain for official-guarantee-type, market-access systems such CDS and/or health certifications has yet to be tested.

While the technology has well-established examples of successful implementation and is constantly evolving, implementation is secondary to having an integral and well-developed traceability along the value chain. Hence, prior to deciding which technology is to be used, it is critical to define what data are to be acquired, and to determine the sources and jurisdictions involved at each type of State in function of the extent of the traceability system to be built.

For these to happen, all types of State (flag, coastal, port, processing and end-market) have essential roles in the implementation of traceability mechanisms that can be supported by blockchain, but as yet are operating under other technologies. Some responsibilities and duties are directly related to the implementation of rigorous traceability mechanisms, whereas others are only loosely related – but together they provide the conditions in which traceability functions can be enforced.

In fact, blockchain-based traceability may work best in fisheries that voluntarily intend to demonstrate their compliance to laws, management rules, and consumer demands, or in ones that are looking for a self-controlling mechanism to foster trust among competitors.

Because fishers may want to organize themselves to reduce conflicts and improve trade opportunities, such systems may even evolve in areas where governmental fisheries is currently weakly developed or totally absent.

The recommendation of this study for governments and international organizations in regard to the development, use and promotion of blockchain technology is to follow strict due diligence at legal, commercial and operational level prior to commitment.

Critical forethought needs to be given to the following (not exhaustive) list of critical considerations:

Traceability along value chain to be covered:

- Exhaustive understanding of all possible – as distinct from desirable – supply-chain events and scenarios under consideration so that traceability can be sustained.
- Clear definition of the “critical tracking events” (CTEs) and “key data elements” (KDEs) – to be covered.
- For regulatory purposes, the segments of the analysis need to consider the administrative, logistic and legal aspects associated with the types of “States” (flag, coastal, port, processing and end-market) that have custody of fishery products as they move through national and international supply chains from harvesting, trans-shipment, landing and processing, to the consumer end-market.
- Clear understanding of the current operational and logistic limitations of the current traceability system in existence (in any).

Use of blockchain technology:

- Use a well-designed decision tree, or other decision model, to determine whether it is the right tool to use.
- If blockchain is chosen as the appropriate tool, then attention still needs to be given to:
    - operational considerations,
    - security considerations,
    - electronic data interchange,
    - regulatory uncertainty,
    - increased responsibility of the user,
    - technical infrastructure,
    - costs: design, development, maintenance, operation, integration with existing ERP, and hardware (including data capture, tagging and printing devices).

All this being taken into consideration, blockchain, with its inherent characteristics of immutability, security, and decentralization together with its smart-contract feature, has the potential to improve efficiencies and accountability in seafood value chains. Permissioned consortium blockchains in particular have the greatest potential in the current state of the technology to be scaled to address seafood traceability without the concerns of high energy use and slow transaction times that public permissionless blockchains have.

This study has not found limitations on the blockchain technology that cannot be overcome under the right scenario. However, whether there exists the collective will to adopt and expand an integral, value-chain-encompassing traceability system is a different matter.

The authors of the present study agree with this conclusion: "Blockchain, data mining, and AI will not stop IUU fishing, will not prevent overfishing and discarding. But they may help to make global streams of fish and seafood products with the associated flow of money becoming more visible and transparent" (Probst, 2019).

Finally, the authors of this study view as unfair the current media discourse that seems to pin the solution to multifaceted seafood value chain problems (from IUU fishing, seafood safety and species fraud to labour issues) on one data architecture tool – blockchain. This risks hyperinflating expectations on what this technology can offer, with potential operators then walking away because it does not deliver on the hype built around it.

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