Using Blockchain to Implement Traceability on Fishery Value Chain

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Abstract: Nowadays, consumers increasingly want to be informed about the products they are buying or consuming, especially when it comes to food, such as fish. Besides nutritional information, consumers want to know about the fish origin, whether it has been properly stored and transported, etc. At the same time, for public health reasons, authorities may need to know the current location of certain fish lots (which have been caught or produced in a specific location, have been stored in a certain place, have been transported by a certain truck, etc.). In other words, consumers and society in general demand transparency throughout all the value chain of fish products. In this paper, we are proposing a blockchain-based platform to allow to trace fish lots, back and forth, throughout the entire fisheries value chain. To implement the traceability platform, we define a smart contract to be used on the Ethereum blockchain.

1 INTRODUCTION

Fish and fish products are one of the main sources of protein in the human diet. According to Gephart *et al.*, the consumption of seafood is growing every year and, as a consequence, seafood industry is also changing (Gephart et al., 2017). Caught worldwide, fishery production has been almost static since the late 1980s, which means that the most part of the increasing fish consumption has been based in aquaculture production (Gephart et al., 2017), which now comprises half of global seafood production. Aquaculture represents, today, 53% of the total fishery products consumption, if non-food uses are excluded (Food and Organization, 2018).

At the same time, consumers are becoming increasingly demanding and want to be informed, not only about the nutritional value of the fish they are buying, but also about its origin and its preservation status along the value chain. For this, it is necessary to keep track of all the activities throughout the entire fish value chain, since capture or aquaculture production up to the supermarket, or to the plate. It is necessary to know the origin (wild or aquaculture), when, who, how, where it was captured (or raised), transported, stored, transformed, etc. In other words, it is necessary to implement traceability in all the fish and fishery value chain.

Authorities, such as the European Union, are proposing directives requiring knowledge of the origin of certain products (Union, 2002), improving product traceability and faster recalls when necessary. The ISO (International Standards Organization) 22005 family of standards gives the principles and basic requirements for the design and implementation of a feed and food traceability system. It can be applied by an organization operating at any step in the feed and food chain (22005:2007, 2007). However, from capture or production until it reaches the final consumer, fish can pass through several companies. This means that the same fish or fish lot can be part of several companies' processes. So, it is necessary to integrate all processes internal to each company involved in the value chain, to know the whole history of the fish. This processes' integration has been proposed in (da Cruz et al., 2019).

To implement traceability in the fisheries and aquaculture value chain we propose, in this paper, the use the blockchain technology, mostly because this technology fits perfectly in the purpose of product traceability, as it allows registering all chain activities in a distributed, transparent, secure and trustfull manner. The traceability platform is being created with two main goals. The first one is to give the authorities information about the current location of a fish

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lot. Respecting to public health threats (fish contamination or other threats) the authorities need to recall the fish lots (and/or its derivatives) as soon as possible. The second goal is to give the final consumers the possibility to know the origin of the fish (where it was captured or raised), who captured it (or created it), when it was captured, under what conditions it was stored, under what conditions it was transported, what process of transformation it suffered and in what conditions, etc..

Nowadays, blockchain is being seen as one of the technologies that better fits the needs of traceability in a supply chains (da Cruz and Cruz, 2020). In fact, the blockchain technology is being used as a distributed database (Saberi et al., 2019; Tian, 2017) in many areas including traceability in agriculture and food supply chains, as is the case of (Tian, 2017; Biswas et al., 2017; Tan et al., 2019; Caro et al., 2018).

Blockchains can be cataloged as permissionless public blockchains, permissioned public blockchains (hybrid blockchains) and permissioned private blockchains (closed networks) (Pedersen et al., 2019; Pahl et al., 2018). Herein we use a permissionless public blockchain, namely Ethereum.

The structure of presentation is as follows: In the next section, related work is presented. Then, in section 3 previous work by the same authors is presented, including the value chain's integrated business process model and a non-blockchain-based solution. Section 4, explains the development of the Blockchain-based platform, including the smart contract. In section 5, some conclusions are drawn and some ideas for future work are disclosed.

2 RELATED WORK

As a way of preventing potential public health disasters caused by food products, authorities like the European Union create directives requiring the registering and control of the origin of certain products (Union, 2002), improving product traceability and enabling faster recalls when necessary. As a consequence, several proposals for the implementation of traceability have been carried out within food value chains, including fish products. Next we highlight the traceability platforms for fish and fish products.

2.1 Fishery Traceability

In (Moga, 2017) the authors propose a system (called TraSiPesc) to trace fish and fishery products. The authors designed the system by identifying the factors that influence the acceptance of traceability by the fish and fishery products business sector, including end user and consumers and taking in consideration the general principles of traceability, the European Union (EU) and the national legal framework, as well as the particularities of the fishery industry.

Yan *et al.* proposes a platform for the aquatic foods supply chain (Yan et al., 2013), which supports the traceability in the supply chain of aquatic products from production to sales, including the distribution. This platform includes information about production like, for example, water quality monitoring. The authors present the overall structure of the traceable platform and its system-level and network structure features. The approach is applied in a case study in China to tilapia products.

In (Parreño-Marchante et al., 2014), a platform to track the aquaculture products from the farm to the consumer is proposed. The platform implementation is based on web services, which are prepared to receive data captured by RFID systems. This data is integrated with data collected with Wireless Sensor Networks (WSN) infrastructure. The paper also presents an analysis of the benefits obtained by the introduction of the created platform, based on predefined objectives and the evaluation of KPIs.

In (Nicolae et al., 2017) the authors propose a structural design for a monitoring tool to support the traceability in Romanian fisheries supply chain. The tool has the purpose of monitoring the safety and quality of fish and fishery products. The paper proposes a general scheme for the traceability system.

Gardner *et al.* performed a study in Madagascar about the value chain specifically on octopus and mangrove mud crab(Gardner et al., 2017). The paper was focused on value chain, post-harvest, and the trade of the two fisheries species. The authors identified all octopus and mud crab fishery stakeholders. The project focused on reducing post-harvest mortality in the mud crab fishery, sponsored by European-Union funded Smartfish programme, is being implemented since 2013 (Gardner et al., 2017). The study concludes that post-harvest value chains of both fisheries are poorly understood, are not well defined and that there is a lack of monitoring systems and reliable data.

2.2 Traceability using Blockchain

According to Ruoti *et al.*, blockchain has strong points like shared governance and operations, resilience to data loss, provenance tracking and auditable (Ruoti et al., 2019). These points are very important to the fishery value chain. The value chain operators want to be part of a system but do not blindly trust each other. Using blockchain technology, they can share governance and operations. The consensus protocol is an agreement between those operators about the operations that will be executed by the system. Besides, the data is stored and replicated in each node (e.g., each one of the value chain operators) meaning, resilience to data loss. On the other side, when a transaction is performed, a new block is appended to the blockchain with information about the transaction including the timestamp. This new block is approved by the consensus protocol approved by the value chain operators, so, the blockchain is auditable.

Several authors opted to use the blockchain technology to implement traceability in value chains, as is the case of (Caro et al., 2018), (Rejeb, 2018) and others.

Abderahman Rejeb implements traceability in the Tilapia supply chain, from farmers to the final consumers in Ghana (Rejeb, 2018). Tilapia is one of the most consumed fish species in Ghana. The author used the Blockchain technology to implement traceability of the aquaculture fish (Rejeb, 2018).

Caro *et al.* present a blockchain-based solution to implement traceability in Agri-Food supply chains (Caro et al., 2018). The authors presented two blockchain implementations, Ethereum and Hyperledger Sawtooth, evaluated and compared the performance of both the implementations, regarding latency, CPU, and network usage (Caro et al., 2018).

In (da Cruz et al., 2020) the authors are using blockchain technology to trace and calculate the carbon footprint of products and organizations. The authors are using a solidity smart contract to implement a platform in Ethereum permissionless public blockchain. The paper also presents a distributed application providing to consumers information about the carbon footprint of a product or organization stored in the blockchain.

Peter Howson discusses how blockchain can be used to improve consumer confidence in the fish value chain and gives an example of how blockchain technology can help preserve marine life (Howson, 2020).

3 PREVIOUS WORK

The fish can be sold fresh or can be preserved for a longer time, if subjected to a transformation process, like if it is salted, frozen, canned, smoked, etc. In some cases, the same fish undergoes several transformations, such as for example the cod fish, which after being caught, can be salted, soaked and then frozen. In the meantime, it is transported and stored several times (Cruz et al., 2019).

Regardless of the preservation method, the fish can come from aquaculture or from the wild (sea, rivers or lakes). As a consequence, we can have many different value chains.

In (Cruz et al., 2019) the authors, after studying several different fishery value chains, leveraged the similarities between those and proposed an integrated business process model for fish and fishery products, and the corresponding domain entities model for the integrated value chain. The authors also identified all stakeholders (operators involved) in fish products (capture and aquaculture) value chain, with the purpose of identifying the information that needs to be gathered in a common platform for supporting the traceability of fish and fishery products from the sea or aquaculture farms to the plate (Cruz et al., 2019; Cruz and da Cruz, 2019).

The fish-lot oriented business process model created is represented in BPMN (Business Process Model and Notation) language, in Figure 1. The model abstracts all activities in the fishery and aquaculture value chain that handle or transform fish product's lots, to enable the traceability and quality monitoring of fish and fishery products. This business process model identifies seven value-chain level process activities: *Production, Registration and Quality Assessment, Sale, Storing, Transportation, Transformation* and *Down*. With the exception of the *Production* and *Down* activities, which may only happen once per each product lot, every other activity may happen several times in the fish product lot lifespan (Cruz et al., 2019).

As we can see in Fig. 1 the value chain starts in the fishing vessel or aquaculture farm, where information about capture or production must be gathered. This information may be provided by the producer itself (case of aquaculture companies) or by the vessel or fishery auction company. Products are, then, registered and have their quality assessed.

Then, after the registration and quality assessment, a fish lot may be sold, stored or transformed (see second complex gateway in Fig. 1). After any of these activities, the lot is received, and its quality assessed. It may stay within this iteration of activities during some time.

The quality of the fish product lot is assessed every time the product suffers a transformation, a storage or a transportation. Sometimes, new lot's are created and registered (as in the case of transformation). Usually, after being stored, a lot is sold. And, after being sold, if the buyer is not the final consumer, the product lot may be transported to the purchasing organization, and that event must also be registered in

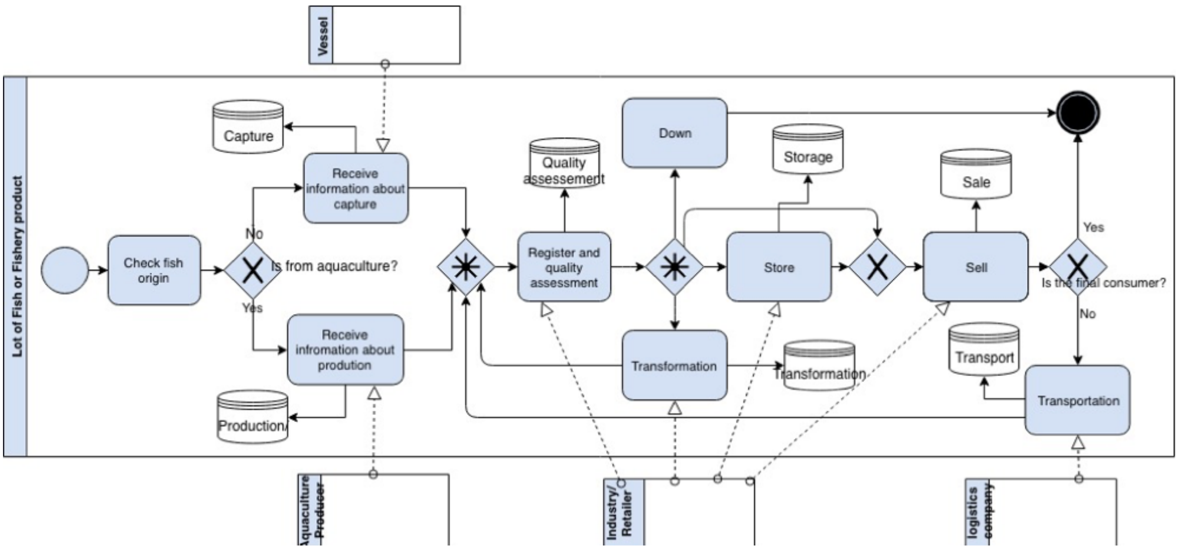

Figure 1: Fishery and Aquaculture value chain integrated process (extracted from (Cruz et al., 2019).

the platform for traceability purposes.

Despite the traceability and quality data being directly persisted in the value chain traceability platform, the data itself must be communicated by the involved value chain operator's relevant process. This way, each identified integrated process activity corresponds to an event in the value chain. The information is provided by the external participants that in Figure 1 send messages to the activity that store information, represented in the business process.

From this integrated business process, we extracted the domain model, by using the approach presented in (Cruz et al., 2015). The obtained domain model has then been manually refined and has been used as a basis for the smart contract data structures in the platform architecture (see Figure 2).

In (da Cruz et al., 2019) the authors designed and created a platform to implement traceability in the fishery and aquaculture Value Chain. In this article we are going to implement a platform with the same goal but using the Ethereum blockchain technology.

4 FISH TRACEABILITY PLATFORM USING BLOCKCHAIN

The smart contract that is the basis of the traceability platform must register and provide traceability information, so that, given the identification of a lot number, the platform must provide its current location (or locations) and all the history of the product lot, that is all the activities/events occurred since capture or production (e.g. where, when and how it was created (or captured), transacted, stored, transported, etc.).

The value chain operators are responsible to gather and store information of the process activity they are executing (e.g. capture, transform, etc.), so each operator is a participant in the blockchain (represented by a ValueChainOperator entity).

There are four different types of users (User entity): The SysAdmin, that can create and add new operators; The worker, that represents a person that works to a value chain operator and is responsible for storing information about the executed activities; The workerAdmin, which is an Administrator within the scope of a value chain operator; and, a final consumer, who is any unregistered user, which can read the traceability information about any fish lot.

A Solidity smart contract is composed by the declaration of the data involved and a set of functions, including a constructor. This code resides at a specific address on the Ethereum blockchain. The smart contract, presented in subsection 4.1, is the basis for the entire application. In it, all the needed data structures are defined, as well as all support functions. These structures are designed according to the model in Figure 2, but have been adapted to be both functional and resource-efficient on the blockchain.

4.1 Smart Contract Implementation

A Smart Contract is "a digital contract that controls user's digital assets, formulating the participant's rights and obligations" (Lin and Liao, 2017). Several languages may be used to create smart contracts like: Solidity (Bragagnolo et al., 2018), Hawk

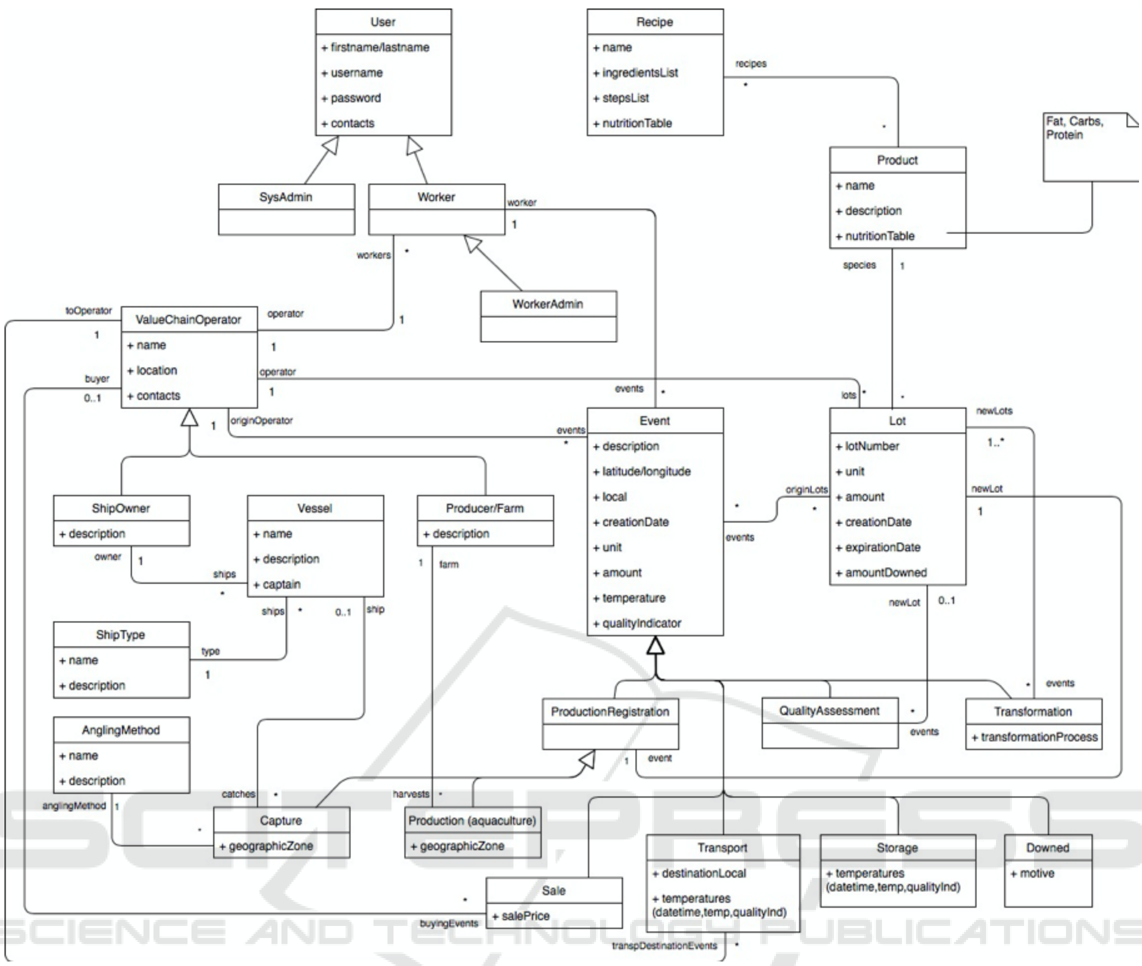

Figure 2: Domain Model (extracted from (Cruz et al., 2019)).

(Kosba et al., 2016), and others. In the approach presented here, solidity is being used. Solidity is a high-level programming language used for implementing smart contracts on several blockchain platforms (Bragagnolo et al., 2018), including in Ethereum, the blockchain being used herein.

A Solidity Smart Contract is composed by the declaration of data types needed (set of data *struct*s), a set of data storage variables and a set of functions, including a constructor. After deployment, the Solidity contract runs on the Ethereum Virtual Machine (EVM), on a specific Ethereum address.

All non-query Ethereum operations incur a cost, counted by the amount of "gas" that the operation consumes. This gas is calculated based on various criteria and one of these is the type of transaction and the volume of information to be added to the blockchain. To minimize this cost, we have tried to build all the structures using the minimum needed space for the attributes.

Basically, and based on the model presented in Figure 2, each one of the entities represented in the domain model is roughly implemented as a "struct" in the contract, with the corresponding attributes. As an example, some of the defined data structure types are presented next.

```
pragma solidity >=0.5.0 <0.7.0;
pragma experimental ABIEncoderV2;

contract FishTraceability {

// -- General Product Structure --
struct Product{
     uint32 id;
     string name;
     string description;
     string nutritionTable;
}
struct ProductLot{
     uint32 lotNumber;
     uint32 lotNumber;
     uint32 idValueChainOperator;
```

```
     uint32 idProduct;
     string unit;
     uint32 amount; //integer base
     uint16 exp; //negative exponent of 10
     Date lotCreationDate;
     uint32[] lotEventIDs;
}

struct ValueChainOperator{
     uint32 id;
     string name;
     string addressLocation;
     string phone;
     string email;
     OperType operType;
}

enum OperType{
     ShipOwner,
     AquacultureFarm,
     Logistics,
     Industry,
     Retailer
}

// -- Events in the Value Chain --
 struct Event{
     uint32 idEvent;
     uint16 eventType; // 0-Capture,
     // 1-Production, 2-Transformation,
     // 3-Transport, 4-Storage,
     // 5-Sale,6-Downed,7-QualityAssessment
 }

 struct CaptureEvent{
     uint32 idEvent;
     string description;
     string geographicZone;
     uint32 latitude;
     uint32 longitude;
     string unit;
     uint32 amount;
     uint16 exp;
     uint32 idValueChainOperator;
     Date eventDate;
     uint32 vesselId;
     string anglingMethod;
     uint32 newLotNumber;  //New Lot number
 }

 struct TransformationEvent{
     uint32 idEvent;
     string transformationProcess;
     string unit;
     uint32 amount;
     uint16 exp;
     OriginLotsQty originLot1;
     OriginLotsQty originLot2;
     uint32 idValueChainOperator;
     Date eventDate;
     uint32 newLotNumber;
 }
```

Since there is no inheritance between "structs", the inheritance from *Event*, represented in Figure 2, is implemented by having a unique *idEvent* between all types of events (Capture, Production, Transport, Transformation, etc.).

In the mappings for events, defined within the contract storage variables set, there is a mapping for each event type, that maps the idEvent to the respective structure, and a mapping for all events, that allows to determine the type of event from the idEvent. An extract of the storage variables illustrating the events mappings, can be seen next:

```
mapping(uint32 => Event) private events;
uint32 private eventsCount;

mapping(uint32 => CaptureEvent)
       public captureEvents;
mapping(uint32 => AquacultureProdEvent)
       public productionEvents;
mapping(uint32 => SaleEvent) public saleEvents;
mapping(uint32 => TransportEvent)
       public transportEvents;
mapping(uint32 => StorageEvent)
       public storageEvents;
mapping(uint32 => TransformationEvent)
       public transformationEvents;
mapping(uint32 => QualityAssessmentEvent)
       public assessmentEvents;
mapping(uint32 => DownedEvent)
       public downedEvents;
```

A set of functions is implemented in order to allow to add (store) and read information from the blockchain. Basically, each activity or event operation (capture, transformation, etc.) is implemented as a function. A function may have pre-conditions that can be generic or specific. As example, the function that allows registering a Fish capture event, is shown in Figure 3. The function has two pre-conditions (see *require()*).

All objects created in the functions of the contract, and stored in the defined storage variables, are stored in the blockchain and cannot be modified. This, coupled with the fact that it is not possible to change a contract that has already been published, except through a new publication (which would make the new contract have a different address from the previous one and therefore not have access to data from the previous one), implies that the implemented structure is extremely solid, leveraging the benefits of the blockchain (decentralization, immutability, security, and transparency).

More elaborate functions like tracking all events from all the lots that have given origin to a new product lot are being done outside the Smart contract, in a services software layer that accesses the contract. An example is, from a can of tuna, obtain all the value

```
// Create Fish capture event
function createFishCaptureEvent(string memory _description, string memory _geographicZone,
uint32 _vesselId, string memory _anglingMethod, uint32 _idValueChainOperator, uint32 _idProduct,
 uint32 _lotNumber, string memory _unit, uint32 _amount, uint16 _exp,
Date memory _eventDate) public {

require((users[msg.sender].worksToValueChainOperId == _idValueChainOperator) &&
     (users[msg.sender].userType == 1 || users[msg.sender].userType == 2),
       "You need to work to the organization!");

 require(products[_idProduct].id != uint32(0), "Product does not exist!");
eventsCount++;
 events[eventsCount] = Event(eventsCount, 0);

productLots[_lotNumber] = ProductLot(_lotNumber, _idValueChainOperator,
        _idProduct, _unit, _amount, _exp, _eventDate, new uint32[](0));
 productLots[_lotNumber].lotEventIDs.push(eventsCount);
 captureEvents[eventsCount] = CaptureEvent(eventsCount, _description, _geographicZone, _unit,
  _amount, _exp, _idValueChainOperator, _eventDate, _vesselId, _anglingMethod, _lotNumber);
```

Figure 3: Smart contract function for registering a fish capture event.

chain activities since the tuna fish has been captured. This involves several product lots and may involve several value chain operators.

The registration of Transformation events is, for now, limited to one or two origin product lots, because of a Solidity unimplemented feature, which impairs copying a struct array elements from memory function parameters to blockchain storage.

5 CONCLUSIONS

In the value chain of fish and its derivatives there are many operators involved, from fish capture or aquaculture production to the final consumer, including transport, logistics and industry. Each company controls its internal processes, however, in order to understand and be sure that the fish is in good condition for consumption, it is necessary to know its entire value chain path. For that, we need to know the value chain process that arises from integrating all the companies' processes involved in the fish path.

In this article we implement the integrated process of all operators in a fish value chain using a smart contract on the Ethereum blockchain. The implemented smart contract is thought for the fish and fisheries value chain, but can be easily adapted to other food products value chains. The implemented smart contract enables the value chain of fish and its derivatives to become more transparent, and thus the value chain can improve its reputation and gain credibility and improve consumer confidence. The platform has other advantages like improve communication and the coordination between the involved parties and improve the integrated process. It also allows to control the quantity and the species of wild fish that are caught and the places and the season in which certain species can be caught, helping to preserve marine diversity in the oceans.

Working with blockchain involves reviving some ways to save memory, since a transaction can be more expensive and slower if it involves a larger volume of data. The solidity programming language itself has some issues, as for instance, only allowing a maximum of 16 function parameters, and not allowing parameters with variable length.

Blockchain is a technology suitable for traceability, where each operator will have their copy of the data, allowing all operators to work together even without having to trust each other completely.

In order for the final consumer, or the authorities, to easily access the information stored on the blockchain, it is necessary to create a tool that provides this information in an easy and user-friendly environment. This is a work in progress.

As future work it would be also appropriate to collect the stored information to make data analysis and present statistics about this data.

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