FOODINTEGRITY

Ensuring the Integrity of the European food chain

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Content

1 Work Package 6 & Deliverable 6.4 summary

WORK PACKAGE 6: Reduce product misdescription in the seafood sector
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The main goal of WP6 is to combat and reduce misdescription of seafood products. This will be done by documenting the degree of seafood misdescription in Europe through spot checks of selected products, creating a list of claims that can be made about a seafood product, linking said list to methods for analysing/verifying product claims, as well as creating a database that will document incidents of product misdescription.

Deliverable 6.4 provides an overview of various analytical and paper trail methods that can be used to verify a product claim. The report provides an overall explanation of the methods, and any strengths, limitations, etc. related to verifying a given product claim. The list of product claims is based on the ontology written as part of Deliverable 6.1 "Seafood claims ontology".

2 Introduction

The objective of task 6.5 is to develop a "toolbox" linking claims that can be made about a seafood product to methods that can be used to verify said claims. Specifically, deliverable 6.4 is described in the Description of Work (DoW) as:

> *"The list of claims developed in T6.4* [Develop a seafood claims ontology] *can be divided into claims that can be verified analytically and claims that cannot. For analytically variable claims a link to methods and parameters will be provided, specifying what method should be used under what conditions to verify a claim of this type. For claims that cannot be verified analytically a specification of record keeping procedures will be developed, specifying what records need to be kept in order to support a claim of this type"*

The structure of the deliverable is as follows: first, we describe the ways in which product claims and associated verification methods have been collected. Second, the list of claims adopted from D6.1 containing verification methods is presented. Lastly, a concise description of each method is provided, containing necessary information pertaining to the use of the given method for the purpose of food product authentication. The methods referring to product claims that cannot be verified analytically will be discussed in more detail. The methodical approaches relating to verifying these claims are being developed and will depend strongly on the circumstances and the settings they are used in.

The term "claim" is in this context understood as any statement made about either the biochemical or non-biochemical properties of a product. It can be either an explicit or an implicit claim. An explicit claim refers to when a food product is declared as having a certain property, whilst an implicit claim, on the other hand, refers to when a product property, if present, should be declared, but is not.

Incidents in which the claimed property of a product does not match its actual property is here defined as a "*misdescription incident*". This term encompasses both intentional and unintentional acts that causes a discrepancy, i.e. both acts committed with malicious intent, such as fraud, but also discrepancies caused by production process error, human errors, etc.

Claims made about a products characteristics can cover a wide range of areas. These include, but are not limited to specie, geographical origin, use of additives or enhancers, processing methods, whether the product is from a sustainable certified fishery, etc. The different claims made about a product can be divided into two groups. The first group contains analytically verifiable claims that relate to physical or biochemical food properties; typical examples might be species, geographical origin, biochemical properties like fat, water, or salt content, processes undergone, presence of bioactive compounds or pathogens, presence of additives, and many more. The second group contains claims that cannot be verified analytically, either because no methods exist, or because the food property in question is not physical or biochemical in nature. Examples include volume, weight, amount, value, batch / lot number, owner, exact origin, country of origin, eco-label status, organic status, religious status (Halal, Kosher), and most properties relating to sustainability or ethics. While some of these food properties have an analytical component, it is in general not possible to verify the claim in question purely by analytical methods. To verify claims of the second type the material flow and information flow in the supply chain needs to be analysed, comparing inputs and outputs of each process. In general, we refer to these latter types of methods as ‘supply chain methods, which then is in contrast with the former method types which we collectively refer to as ‘analytical methods’.

3 Method

The list of claims in section 0 are based on an updated version of the initial list of claims developed as part of T6.4/D6.1 "*Seafood claims ontology*". In D6.1, the list of claims were divided into two sections: wild caught- and farmed fish. The reason being that while the majority of claims made about seafood products are applicable to both categories, certain ones are only applicable to one (e.g. "catch area" or "gear type" for wild caught seafood, and "feed" for farmed seafood). For the purpose of this deliverable however, the lists have been combined.

The initial ontology was developed based on seafood product claims and terminology gathered from product packaging and information extracted from seafood producers' websites, as well as international standards for wild caught- and farmed finfish, ISO 12875 and ISO 12877 respectively.

For the purpose of this deliverable, the ontology has been updated to include a wider variety of product properties. As mentioned, the initial ontology consisted mainly of claims which were of interest to the consumer, and that were available on the product packaging. However, the updated list of claims includes properties that generally will not be disclosed to the consumer, but still are relevant in the context of detecting food fraud or other criminal activity associated with the seafood industry.

Information on analytical methods was gathered by contacting FoodIntegrity work package leaders and other project participants. Project participants were sent the product claims ontology (see Table 4.1) and asked to fill in the "method of verification-column" with methods used to verify a given claim. They were also asked to provide additional information pertaining to the method in question, such as strengths, weaknesses, margins of error, seminal works, etc.

4 Seafood product claims

Table 4.1 below contains three main sections: a given claim that can be made about the characteristics of a product, the method used to verify a given claim, and an example of the type of fraud which might relate to the claim in question. The column "product claim" is divided into two main sections: "Catch Information" and "Production Information". The various elements within the main category "Catch Information" relates to aspects such as the species in question, geographic area of origin (i.e. catch area), information on the vessel, gear type used, handling of the fish while onboard, and time and date for sailing, catch, and landing. "Production Information" relates to time and date of production, the identity of the producer, the product condition (herein processing methods, additives, etc.), relevant certification schemes, and the weight of the product. For each claim, an example of the type of information that can be recorded provided (e.g. for a specie, both the common name and scientific name might be listed).

The column "Method of verification" provides an example of the various methods that can be used to verify a given claim. For each claim, the name of the method is provided, whilst a more detailed description of the methods applicability, strengths, weaknesses and other necessary information is found in Chapter 5. References to seminal works describing the use of the method is also listed in each method description.

The final column, "Example of fraud", gives examples of the various types of fraud that can occur for a given claim, with a link to a news story.

Table 4.1 Seafood product claims and verification methods

Product claim	Method of verification	Example of fraud
Catch Information		
Species		
Common name, scientific name	• Morphological characteristics of fish by FAO taxonomic keys • Protein analysis methodologies electrophoretically (SDS-PAGE, Isoeletric focusing, Capillary electrophoresis, HPLC, Immune assays) • Lipid analysis methodologies (Analyses of fat and oils) • DNA methodologies (RAPD, RFLP, SSCPs, AFLPs, FINS, OLA, DNA probes, NGS) • #213 and #214: DNA sequencing of the cytochrome c oxidase subunit I gene (COI). Fresh and cooked fish (but not highly processed, such as tins of tuna)	Product mislabelled as being off a different species: • Escolar sold as "white tuna" (Triple Pundit) Product labelled with a non-specific/ambiguous/vernacular name: • Products sold only as "grouper" (64 different species can be labeled as "grouper") (Huffington Post) Product marketed with a false name: • Brazilian catfish fraudulently labeled as "*douradinha*" (New Scientist)

	• #297 and #299: Detection of the small DNA fragments generated by PCR-RFLP is performed on a lab-on-a-chip capillary electrophoresis system, which allows to discriminate 5 salmon species and tuna species in commercial canned products • Traceability	
Location/Catch Area		
Common Name, FAO Map Number, Latitude, Longitude	• Genetic analyses (Microsatellites, SNPs) • Analyses of the protein/enzyme profiles in some organs • Analyses of fat and oils • Stable isotope analysis • Traceability	Not disclosed whether imported or local • Consumers kept in the dark on seafood origins after senate vote (Sydney Morning Herald) Misleading country of origin • When what you eat in an Italian restaurant may never have been near Italy (Herald Scotland)
Landing location		
Receiving station name, ID, address	• Traceability (in combination with contextual knowledge)	Not normally disclosed, but might be linked to a unique trace code, which in turn might be falsified.
Time/Date		
Date of Catch, Date of Sailing, Date of landing	• Traceability (in combination with contextual knowledge)	Changing production/expiration dates • Food fraud a criminal activity (Food Quality and Safety) Not normally disclosed, but might be linked to a unique trace code, which in turn might be falsified.
Vessel Information		
Vessel Type, Vessel Name, Vessel Unique ID/Call Sign, Vessel Flag State, Vessel Owner	• Traceability (in combination with contextual knowledge)	Not normally disclosed, but might be linked to a unique trace code, which in turn might be falsified.
Gear Information		
Gear Type, Fishing Method	• Traceability (in combination with contextual knowledge)	Not normally disclosed, but might be linked to a unique trace code, which in turn might be falsified.
Onboard storage		
Onboard storage method	• Traceability (in combination with contextual knowledge)	

Production Information		
Producer Information		
Production location, Business name, ID, address	• Traceability (in combination with contextual knowledge)	Not disclosed whether imported or local • Consumers kept in the dark on seafood origins after senate vote (Sydney Morning Herald) Misleading country of origin • When what you eat in an Italian restaurant may never have been near Italy (Herald Scotland)
Time/Date		
Date of Production, Date of durability, Date of shipment (to wholesaler or other)	• Traceability (in combination with contextual knowledge)	Changing production/expiration dates • Food fraud a criminal activity (Food Quality and Safety) Not normally disclosed (except for expiration), but might be linked to a unique trace code, which in turn might be falsified.
Product condition		
Processed product (type of product)	• Traceability (in combination with contextual knowledge) • Material flow analysis (in combination with contextual knowledge)	
Preservation/processing method (previously frozen, etc.)	• Traceability (in combination with contextual knowledge) • Material flow analysis (in combination with contextual knowledge)	Thawed products marketed as fresh • 2500 tons of the food we it is fake (Time)
Other treatment method (use of chemicals, additives, enhancers, etc.)	• #139 and #140: LC-MS methods. Dyes used illegally as an inexpensive topical fungicide and acaracide: Malachite green, triarylmethane dyes (crystal violet, ethyl violet, pararosaniline, victoria blue B, victoria blue R, brilliant green), phenothiazine dyes (azure B, methylene blue, new methylene blue), phenoxazine/oxazone dyes (nile blue A) and xanthene dyes (rhodamine 6G)	Use of illegal/undisclosed chemicals (hydrogen peroxide, citric acid) to fake freshness • 2500 tons of the food we eat is fake (Time)
Use of vaccine/medicine (*for farmed fish*)	• Immunological analysis (ELISA etc…)	Use of unauthorized antibiotics/other drugs or too high quantities

		• USFDA, Industry Efforts Reduce Use of Unapproved Drugs (Global Aquaculture Advocate)
Feed content (*for farmed fish*)	• The same techniques as used for species identification	
Storage		
Storage method	• Traceability (in combination with contextual knowledge)	
Unit information		
Weight	• Material Flow Analysis (MFA) (in combination with contextual knowledge) • Input-output analysis (in combination with contextual knowledge) • Benford's Law (in combination with contextual knowledge)	Water injection/overglazing • *Oceana Study Reveals Seafood Fraud Nation Wide 2013:42* • Don't be hooked by seafood fraud (Restaurant)
Packaging		
Method of packaging	• Traceability (in combination with contextual knowledge)	
Labelling scheme		
Eco-label	• Traceability (in combination with contextual knowledge) • Material Flow Analysis (MFA) (in combination with contextual knowledge)	Fish from unsustainable fisheries passed off as sustainable • Bait and switch seafood fraud (Santa Barbara Independent) • Seafood fraud protection through new traceability tool (Food Manufacture)
Other		
Type of fishery (farmed/wild caught)	• #157: Mislabelling of farmed salmon as wild salmon by measuring Delta 15N on choline and Delta 18O on total oil. • #314: GC-FID and IRMS (Salmon, Code, Sea Bass, Sea Bream) • Morphological characteristics of fish • Individual tagging of fish • Genetic analyses • Analyses of fat and oils • Analyses of the protein/enzyme profiles in some tissues	Farmed seafood products mislabelled as wild caught • NC seafood company sentenced for mislabeling imported shrimp as wild caught (Food Safety News)

5 Verification methods

5.1 Analytical methods for verification of food item properties

5.1.1 Morphological characteristics of fish

This methodology is based on the identification of unique characteristics of a fish species. To carry out this analysis, it is necessary to have an extensive knowledge of the morphological structure of fish that permits to link its morphological characteristics according to established taxonomic keys. Finally, we obtain a distinctive morphological pattern. There are no official guidelines to differentiate farmed from wild cod or salmon based on morphological characters, although there are some general aspects that may be used to differentiate farmed from wild salmon and cod. Morphological abnormalities, such as spinal deformities, are known to occur frequently in many species of intensively reared fish. Colour is also a variable that may be used to differentiate farmed from wild fish.

Technical basis
In-depth knowledge of fish structure is necessary, such as predorsal distance, type of body, total length, interorbital space, distance, number and shape of the fins, etc.

Advantages: It does not require expensive equipment, only a trained technician.
Disadvantages: This methodology requires the complete individual fish and for it to be in optimal condition with all fins, skin intact etc.

References:

Species catalogues compiled by the Food and Agriculture Organization of the United Nations (FAO) (http://www.fao.org).

Related web sites: http://www.fishbase.org,

5.1.2 Protein analysis methodologies electrophoretically (SDS-PAGE, Isoeletric focusing, Capillary electrophoresis, HPLC, Immune assays)

Electrophoretic methodologies
These methods are based on the separation of proteins (charged molecules) in an aqueous medium under the influence of an electric field applied between positive and negative electrodes. The net charge of the proteins will be dependent on the pH of the solution, as it will be determined by the degree of ionisation of its constituent amino and carboxyl groups. Protein separation on electrophoresis is supported in polyacrylamide or agarose gels.

SDS polyacrylamide gel electrophoresis
This technique is based on the loss of individual charge of muscular proteins, forming a different net negative charge as a result of the anion dodecyl sulphate complexing with the protein present. Depending upon the size of proteins to be separated, a concentration of acrylamide is selected.

Advantages: Easy to use
Disadvantages: Not suitable for highly processed products or closely related fish species.

References:
Rehbein and Karl, 1985; Scobbie and Mackie, 1988 Weber and Osborn, 1969; Piñeiro et al, 1999; Martinez et al, 2001; Etienne et al, 2001; Mackie et al, 2000.

Isoelectric focusing
Protein migration is focused to position of their electrical neutrality in a stable pH gradient created between the anode and cathode. The gradient is achieved with a mixture of synthetic ampholytes selected to provide a range of pH values.

Advantages: Suitable for the identification of closely related fish species. Has a very high resolving power (slight variations are detected; 0.01 pIs (isoelectric point of proteins)).

Disadvantages: Different IEF patterns are obtained for the same species due to the existence of protein inherent variation factor. Not suitable for highly processed products

References:
Rehbein and Kündiger, 1984; Rehbein et al, 1990; Rehbein et al, 1995; Mackie, 1996; Etienne et al, 2000; Martinez and Jakobsen, 2004.
Reference method AOAC, 1990 (Annex 2).

Capillary electrophoresis
Based on free-zone electrophoresis in buffer-filled capillaries that are used as the separation chambers. Detection via ultraviolet or fluorescence sensors.

Advantages: High resolution, short analysis time (20 min), capable of being fully automated.

Disadvantages: Not suitable for highly processed products. Technically demanding, High qualified personal is needed.

References:
LeBlanc et al, 1994; Gallardo et al, 1995; Ewing et al, 1989; Chen, 1991; Chen et al, 1992; Novotny et al, 1990.

High-performance liquid chromatography (HPLC)
Based on the separation of proteins according to their polarity using a chromatographic column. Detection via ultraviolet or fluorescence sensors.

Advantages: Fast, simple and reproducible, and the equipment is extensively used in food control laboratories. It could be applied to species quantification.

Disadvantages: Not suitable for highly processed products. Requires the reference standards (internal and external).

References:
Sotelo et al, 1993; Osman, 1987; Ashoor and Knox, 1985 ; Armstrong et al, 1992.

Immunological methodologies
Based on the specific recognition of diagnostic protein sites by antibodies. This antigen-antibody reaction could be detected by a specific stain by binding to a secondary antibody that reacts with the first one.

Advantages: Fast, simple, less technically demanding, and the equipment is extensively used in food control laboratories. Suitable for some processed products. It could be applied to species quantification.

Disadvantages :It is very difficult to obtain specific antibodies. High cross-reaction with other species.
It is less sensitive and highly dependent on the food matrix.

References:
Verrez-Bagnis, 1993; Taylor et al, 1994; Huang et al, 1995; Carrera et al, 1996

5.1.3 Lipid analysis methodologies
Although lipid composition (especially phospholipids) has information for identifying some species of tuna (Medina et al, 1997), the scope of this methodology is limited.

The composition of fatty acids in the lipids of selected fish tissues appears to be population dependent in some species. Examples include herring (Grahl-Nielsen and Ulvund, 1990) and red fish (Joensen and Grahl-Nielsen 2004) in the Atlantic, striped bass stocks in American rivers (Grahl-Nielsen and

Mjaavatten, 1992) and between two stocks of cod reared under identical conditions on the Faroe Islands (Joensen et al., 2000).

References:
See reference list below

5.1.4 DNA methodologies (RAPD, RFLP, SSCPs, AFLPs, FINS, OLA, DNA probes, NGS)

Random amplification of polymorphic DNA (RAPD)

This technique consists of the simultaneous amplification of several fragments by means of a PCR reaction with just one very short random primer (not much longer than 10 bp). The various obtained fragments are analysed by electrophoresis (agarose or acrylamide) following staining with ethidium bromide or silver stain (depending on the required resolution). The obtained patterns are species-specific.

Advantages: It does not require previous knowledge of the target sequences. Suitable for closed species.

Disadvantages: Low specificity. Low reproducibility because the obtained patterns are highly dependent on the PCR conditions (annealing temperature, cycling, enzyme, etc.). Not suitable for highly processed products because it is necessary to use intact DNA as a template in the PCR reaction. Neither is it suitable for identifying mixed samples. Reference patterns are required.

References:
Bielawski and Pumo, 1997; Dahle et al, 1997; Bowditch et al, 1993; Partis and Wells, 1996; Ramser et al, 1996; Martínez, 1997; Dinesh et al, 1993; Bardakci and Skibinski, 1994; Callejas and Ochando, 1998; Schneider et al, 1997; Martinez and Malmheden Yman, 1998; Welsh and McClelland, 1990; Williams et al, 1990.

Single strand conformation polymorphisms (SSCPs)

This technique is based on monocatenarian DNA strand mobility with its conformation (sequence). The single strand migrates under non-denaturing conditions through an eletrophoretic gel. A slight difference in the nucleotide sequences indicates a discrepancy in fragment mobility that it is visible after a stain procedure. The length of the DNA fragment must be no longer than 300 pb. The use of mitochondrial genes are better than nuclear because they are haploids.

Advantages: It does not require previous knowledge of the target sequences. Suitable for related species and highly processed products. It is very specific because it can detect SNPs (Single Nucleotide Polymorphisms). The patterns obtained are easily interpreted due to the low number of bands obtained. It is fast and relatively easy.

Disadvantages: It is highly dependent on the PCR conditions (annealing temperature, cycling, enzyme, etc). Reference patterns are required.

References:
Orita et al, 1989; Hara et al, 1994; Rehbein et al, 1995; Rehbein et al, 1997; Rehbein et al, 1998; Rehbein et al, 1999; Oohara, 1997; Céspedes et al, 1999.

Amplification fragment length polymorphisms (AFLPs)

This technique is very similar to the RAPD technique. In this case, the Genomic DNA is digested by two restriction enzymes, which generate two types of sequence overhangs. The specific sequence overhangs are then linked to specific DNA adapters which will be used as templates in the amplification reaction. The products obtained from the reaction are separated and silver stained on a denaturing polyacrylamide gel.

Advantages: It does not require previous knowledge of the target sequences. Suitable for closed species. It has higher reproducibility than AFLP.

Disadvantages: It is more complex than AFLP. Low specificity. Not suitable for highly processed products because it necessarily uses intact DNA as a template in the PCR reaction. It is not also adequate to identifying mixed samples. Reference patterns are required.

References:
Bossier, 1999; Congiun et al, 2001.

Forensically informative nucleotide sequencing (FINS)

This methodology consists of direct sequencing of a DNA fragment, previously amplified by PCR, which contains information for discriminating between species. The obtained sequence must be compared to a database of reference species well identified by measurement of genetic distances.

Advantages: It is a robust and powerful technique that allows inter- and intra-specific variability to be determined. Suitable for related species and it is adequate to highly processed products.

Disadvantages: Technically demanding and expensive equipment is required. It requires previous knowledge of the target sequences.

References:
Barlett and Davidson, 1992; Unseld et al, 1995; Ram et al, 1996; Quinteiro et al, 1998; Kenchington et al, 1993; Watabe et al, 1995; Venkatesh and Brener, 1997; Sotelo et al, 2001; Terol et al, 2002.

Restriction fragment length polymorphism (RFLP)

The DNA fragment amplified by PCR reaction is digested by one or several restriction enzymes which recognise a specific target in the sequence. Each fragment pattern is related to a specific species. The patterns are viewed on agarose or polyacrylamide gels.

Advantages: It is easy and relatively cheaper than many others (depending on the restriction enzyme). It could be used to distinguish mixtures.

Disadvantages: It requires previous knowledge of the target sequences. Reference patterns are required. Cross-reactions with other species.

References:
Chow et al, 1993; Borgo et al, 1996; Ram et al, 1996; Quinteiro et al, 1998; Céspedes et al,1998; Carrera et al, 1999; Cocolin et al, 2000; Russell et al, 2000; Hold et al, 2001a; Hold et al, 2001b; Sotelo et al, 2001; Quinteiro et al, 2001; Pardo and Pérez-Villareal, 2004.

Oligonucleotide ligation assay (OLA)

This technique is based on the detection of a product ligated to a DNA sequence by employing a ligase enzyme. The ligated product consists of two probes that are attached to the DNA target. If the probes do not match the target, the ligated product is not obtained. An optical detection system is used, which is able to detect one of the fluorogenic probes.

Advantages: It is an accurate and fast technique.

Disadvantages: It is expensive and requires previous knowledge of the target sequences.

References:
Cipriano and Palumbi, 1999.

DNA probes

This technology is based on the specific union between a DNA probe and a target by hybridization. The target must have previously been amplified by PCR. The probes can be labelled with a fluorogenic dye.

Advantages: Semi-automated, fast, SNPs (Single Nucleotide Polymorphisms) identification can be used for geographic origin. Easy to interpret

Disadvantages: It is expensive and limited to the species included in the system. In the case of geographic origin determination, a high number of SNPs are required compared with the number of microsatellites required to obtain the same resolution.

Microsatellites

This technology is based on the specific amplification of a genomic region with short repetitions (satellites) that can be linked to a population or geographic origin

Advantages: Very discriminatory.

Disadvantages: Not automated, Difficult to interpret.

5.1.5 Stable isotope analysis: NMR or IRMS

Stable isotope analyses is considered to be an well suited tool for origin assessment: the ratio 13C/12C gives straightforward responses concerning the primary photosynthetic metabolism of plant products, and the ratios of the stable isotopes of oxygen (16O/18O) and hydrogen (2H/1H) are good indicators of environmental conditions. The two main techniques used to determine the isotope ratios of natural products are isotope ratio mass spectrometry (IRMS) and site-specific natural isotope fractionation studied by nuclear magnetic resonance (SNIF-NMR). IRMS has the advantage over NMR that all except 12 elements can analysed by the technique.

5.2 Supply chain methods for verification of food item properties

In this chapter, we give a short description of a set of quantitative and qualitative methods that to some degree can be used to verify claims that cannot be verified by analytical methods alone, an we also outline some enabling systems and technologies that these methods build on. The field of supply chain methods for verification of food item properties is still developing, and the applicability of these methods will to a large extent depend on both the industry and the value chain in question. Generalizing is therefore difficult as the result may carry out different in different situations, depending on the information available. As acquiring contextual knowledge on the inner workings of the industry in question is necessary when developing the methodical approach, some of the methods in this chapter are not necessarily used directly for verifying specific claims. Rather, they are useful in acquiring information that is necessary when developing an approach.

In the last part of the chapter, we present a case study from the Norwegian fisheries. The case illustrates how one company in Norway operates in relation to public records and the applicability of the methods described in the following with regards to mapping and identifying discrepancies in the value chain.

5.2.1 Traceability

Traceability is not a method as such; it is the principle of keeping track of -, and connecting all the recordings that are made, and the existence of some degree of traceability underlies all the supply chain methods for verifying food item property claims.

There are numerous definitions of traceability, most of them recursive in that they define traceability as "the ability to trace" without defining exactly what "trace" means in this context. An attempt to merge the best parts of various existing definitions while avoiding recursion and ambiguity is "The ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications" (Olsen and Borit, 2013). This emphasises that any information can be traced, that traceability applies to any sort of object or item in any part of the life cycle, and that recorded identifications need to be involved.

Traceability depends on recording all transformations in the chain, explicitly or implicitly. If all transformations are recorded, one can always trace back or forward from any given food item to any other one that comes from (or may have come from) the same origin or process. In addition, traceability requires relevant information to be recorded and associated with every food item in the supply chain. This makes it possible to find the origin of a given food item (the "parents"), the application of the food item ("the children"), and also all properties of every food items (when and where was it created, weight or volume, what form is it in, what species, fat content, salt content, etc.). For the other supply chain methods to work, traceability needs to be present, and efficacy of the supply chain methods is limited by characteristics of the traceability system. Food items need to be identified in some way (uniquely or as a group), the transformations that the food items go through need to be documented, and the attributes need to be recorded. The specifics of the identification and the documentation of transformations and attributes will decide how much data is present, how well it is connected, and how accurate it is, which in turn will be a limiting factor for the other technologies and methods outlined below.

5.2.2 Blockchain technology

Blockchain technology is not a supply chain method for verifying claims in itself, but it is a way of increasing transparency and accessibility of the recordings in the traceability system, and thus for increasing claim veracity, and so indirectly it contributes to verifying claims about food items. Blockchain technology in its current form has been around since 2008; it is what underlies the digital currency called Bitcoin, and it can be used to document transformations in the supply chain in a secure and transparent manner. Blockchain technology is best described as one that enables records to be shared by all network nodes, updated by miners (system users who, for a fee, keep track of transaction records), monitored by everyone, and owned and controlled by no one (Swan, 2015). A significant problem in traceability is that it is difficult to verify that the stated transformations actually took place. Using blockchain technology, the record of all transformations would be in the public domain, openly visible to anyone (although most of the food item attributes would not be visible) (Tian, 2016). If a buyer received a food item where the transactions were documented using blockchain technology, every single transaction from the food item in question back to the original farming or harvesting would be available for inspection, also for the other food items that came from the same source. This to some degree prevents food businesses from introducing undocumented raw materials or products into the supply chain; if they did, the mass-balance accounting would not add up (you cannot produce 1200 kg fillet from 1000 kg meat or fish). It also prevents anyone from overwriting the transaction once it has been recorded, which means that if the original data recorded is correct (and it is normally in the interest of high quality producers to record the initial data correctly, to protect their brand and to justify the higher price they get) it becomes very difficult for FBOs later on in the chain to counterfeit or dilute the product. Blockchain technology will not guarantee accurate recordings, but it will certainly remedy some weaknesses that currently exist, and it will be interesting to see what happens when the technology becomes prevalent.

5.2.3 Material flow analysis

Material flow analysis, more commonly referred to as MFA, is a methodology developed to assess the flows and stocks of goods and materials within a set time and space (Brunner and Rechberger, 2005). The method is based on the mass balance principle; that matter is conserved in any system, and thus input is equal to output mass. It was developed to describe the metabolic processes of large and complex systems like cities, regions, nations and industrial companies. MFA is based on accounts in physical units (e.g. tons) quantifying the inputs and outputs of those processes (Dewulf and Herman, 2006).

Material flow analysis has often been used as a synonym for material flow accounting; in a strict sense, the accounting represents only one of several steps of the analysis, and has a clear linkage to economic accounting. Two basic types of MFA can be distinguished. Type I is concerned with the environmental impacts of certain substances, bulk materials, or products, and therefore the flow of substances and materials linked to these entities are studied. Type II is interested in performance of firms, sectors, or whole regions or national economies, and thus the throughput of substances and/or materials of these entities is analysed (Bringezu and Moriguchi, 2002). Whereas the first type often are preformed from a natural science or technical engineering perspective, the second type are more directed towards the analysis of socio-economic relationships.

One limitation in using methods such as the MFA is the measuring of the qualitative aspects of material flow (Gould and Colwill, 2015). Quantitative changes that are measurable, for instance weight, can be accounted for using a mass balance approach.

5.2.4 Input-output analysis

Input-output analysis, also referred to as IOA, is a form of economic analysis based on the interdependencies between economic sectors. Linking MFA with sectoral IOA studies has been advocated as an effective means for describing the whole material flows within the economy and their interdependence with the environment (Moriguchi, 2001). IOA focuses on the activity of a group of industries that both produce goods (outputs) and consume goods from other industries (inputs) in the process of producing each industry's own output. An increase in the output of one industry increases the demand for output in its supplying industries, and in industries that supply the suppliers, and so on. The method is often applied to estimate the impacts of positive or negative economic shocks and analysing the ripple effects throughout an economy.

The basic version of the Leontief input–output model is constructed using observed economic data for a specific geographic region, e.g. a nation, region or state. The transactions are measured for a particular period of time, usually a year, and in monetary terms. The number of industries considered may differ from only a few to hundreds or even thousands (Miller and Blair, 2009).

In principle, it is also possible to record transactions in physical terms, e.g. kilos, litres, tons. While the physical measure might be a better reflection of one industry's use of another industry's product, there are significant measurement problems when industries actually sell more than one good.

As far as the fishery sector is concerned, IOA has been conducted in order to assess the degree of fisheries dependence in regions and evaluate the implications of any changes in supply or demand (Seafish, 2006; Greig, 1999; Briggs, Townsend and Wilson, 1982; Zuhdi, 2016).

5.2.5 Benford's Law

Benford's Law, also known as the "first-digit law" or the "significant-digit law", refers to the mathematical phenomenon where certain digits are observed to appear first in a collection of numbers more frequently than others (Durtschi, Hillison and Pacini, 2004). As opposed to being uniformly distributed, in a collection of numbers the first significant digits will have a tendency to be skewed towards smaller digits (Berger and Hill, 2011). The logarithmic distribution of the first significant digits from low to high is referred to as a Benford distribution. The underlying principle is that given the right circumstances, a collection of numbers should conform to the distribution, and a deviation from the expected distribution might be an indication that fraudulent activity has taken place.

While not previously used for detecting food fraud specifically, Benford's Law has been tested within different topics to detect anomalies or fraud, ranging from elections (Roukema, 2012), the stock market (Hill, 1995), to accounting (Durtschi et al, 2004).

Certain limitations exist with regards to applying Benford's Law. In order for a test to provide a valid result, the dataset in question must be expected to conform to a Benford distribution, something not all datasets do. Benford's Law applies to distributions that are combinations of other distributions, so-called second-generation numbers. Numbers that have been assigned or otherwise are a product of human thought, however, will not conform to the distribution, and are thus not appropriate for a statistical test (Durtschi et al, 2004).

While Benford's Law does not give definite proof of whether or not fraud has occurred in a given situation, it does highlight anomalies within datasets that might be an indication of possible fraud, and which warrants further examination. It should thus not be used as the sole tool, but rather in combination with other methods.

5.2.6 Methods for acquiring contextual knowledge

As stated previously, developing supply chain methods for verifying claims relating to food item properties presupposes comprehensive and reliable industry knowledge. As the verification methods relates to food fraud detection, it is also important to understand the nature of the problem and the circumstances underpinning the food fraud (University of Manchester, 2017). Acquiring a comprehensive understanding of the inner workings of the industry and value chain in question necessitates a broad multi-method approach, using a combination of documentary studies and interviews with value chain actors, supplemented by various quantitative analysis approaches. Whether the method approach chosen is primarily qualitatively or quantitatively driven will depend on the nature of the study, data availability and the end goal.

A documentary study of the regulatory framework of a given industry will highlight regulatory demands with regards to registrations along the value chain, i.e. what is to be recorded where, by who and when, as well as any inconsistencies or weaknesses between nodes in the chain and ambiguities in the regulatory demands. However, a documentary study of relevant regulations and policies must be supplemented by interviews with actors involved in the value chain. This in order to shed light on the ways in which an individual company approaches the regulations in practice with regards to record keeping and ensuring product traceability.

A necessary reservation must be made when doing a case study concerning its generalizability. Whilst an in-depth case study of how value chain actors approach the regulatory framework in practice does provide valuable insight and will yield much information, it might not be generalizable if the industry in question is highly fragmented and heterogeneous. If so is the case, several case studies might be required, though this approach can be costly and time consuming. As an alternative to conducting in-depth interviews with selected case studies, one can conduct a study using more cost-effective tools such as questionnaires or phone interviews. These methods, while not providing such a comprehensive insight into the inner workings of the system, allows for covering a much larger segment, useful in instances in which the industry is characterized by many different types of actors.

The techniques described above are highly useful for providing knowledge on the inner workings of the value chain and the framework governing it. They can highlight weaknesses in specific nodes in the chain making them susceptible to fraud, as well as give insight into whether or not an identified discrepancy is due to wilful actions or if the cause is unintentional. Still, in instances where fraud occurs, these techniques must be supplemented by other methods in order to better understand the true nature of the problem and the underlying factors that drive the actors in the value chain to commit fraud.

Script-analysis is a way of organising and systematizing knowledge that relates to a behavioural process into an event sequence. The Crime Script analysis takes a sequence of events and breaks it down into logical steps. It relies less on quantitative data and more on behavioural decision-making like rational choices (Cornish, 1994). A crime script analysis provides useful information for better understanding a specific crime, how the crime is organised, and what conditions that shape the organisation over time (Edwards and Levi, 2008). Analysis like this orientates the thinking towards crime being more organised than disorganised with connections between different criminals. It also searches for information about context and particular conditions that is required to commit the crime rather than focusing on individual skills (Paoli, 2002). The crime script approach has been applied to a range of criminal enterprises such as drug manufacturing (Hutchins and Holt, 2015), human trafficking (Savona et al, 2013) illegal waste activity (Thompson and Chainey, 2011) and so on. The crime script analysis has also been carried out regarding food fraud, in the distribution of counterfeit alcohol (Lord et al, 2017).

Social network analysis is the process of investigating social structures through the use of networks and graph theory. The term social network refers to the articulation of a social relationship, ascribed or achieved, among individuals, families, households, villages, communities and so on. Each of them can play dual roles, acting both as a unit or node of a social network as well as a social actor (Laumann and Pappi, 1976). SNA is an analytical tool that can be used to map and measure social relations. The analysis is suitable and used as a systematic approach for investigating crimes. It provides a systematic approach for investigating large amount of data on people and relationships (Johnson et al, 2013). A social network approach can also complement a script analysis by providing the analytical tools to understand how actors are embedded in the structure of a crime (Lord et al, 2017).

5.2.6.1 Supply chain methods: a case study of the Norwegian whitefish industry

The framework in the Norwegian seafood industry is regulated by international standards combined with national regulations. The industry is tightly regulated, in the sense that there are numerous registrations related to catch, landings, production, feeding, slaughtering, storage, transport and export. Despite the wealth of regulatory requirements, periodically there are confirmed incidents of fraud and misreporting (Christophersen, 2011), as well as accusations and rumours, especially in the coastal fleets cod fishery. Usually the fraud relates to misreporting of the total amount of landed fish. However, there exist no agreed assessment suggesting the extent of the fraud, only disputed indications. A 2013-survey among fishers and buyers conducted by Nofima indicated that the misreporting that year might have been around 5 % of the total catch. The three most common ways to commit fraud was to report less fish than delivered, reducing the reported quantum because of poor quality instead of reducing the price, or using another conversion factor than the national standard (Svorken and Hermansen, 2014).

In another study of illegal sale in both the fishing- and aquaculture industry in Norway, the authors conclude that the data collection from the industry is very detailed (Ekerhovd, Nøstbakken and Skjeret, 2015). However, they are surprised to find that the data is not gathered and analysed considering misreporting and tax evasion. There are no systems for gathering the various data collections, and the different authorities involved do not have any common practice for analysing and collating the data. Comparing registrations seems to be difficult, and the gap between registrations is often very big.

As the collection of data in the Norwegian system is very detailed, it is a suitable system to study regarding the potential of supply chain verification methods. A forthcoming report aims to explain why it is often difficult to compare or compile different registrations at different points in the value chain, even if the requirements are the same, by using a combination of a documentary study of relevant regulations and a case study of a production company (Svorken et al, 2018). The focus is on registrations that are linked directly to the product in the different stages throughout the value chain and connections between the different registrations.

By studying the main regulatory framework regarding product registrations, we identified the main authorities in charge of monitoring and controlling as the Norwegian Directorate of Fisheries, the Toll Custom, the Food Safety Authority and the Norwegian Tax Administration. This study of the regulatory requirements identified what properties are required to be recorded at what point, and highlighted inconsistencies between authorities with regards to what should be recorded, and how. The record keeping requirements identified as pertaining to product information covers a wide array of topics, such as geographical indicators, financial records, time and date, etc. Certain product properties, such as species or weight, can be controlled at any given time, whilst others can only be recorded at a specific moment, e.g. catch area and gear type used. However, these properties might be required to be declared further up in the value chain. Some properties are also static, i.e. they do not change, for example specie. Others however, are more dynamic and can change throughout the value chain and need to be recorded at several points, like weight, conservation and product condition.

In order to carry out a more systematic analysis of the various registrations, they were grouped according to four main themes: geographic origin, time/date, ownership, and product properties.

The property required in most regulations is weight, being recorded at every point in the value chain. It also connects to the total volume of catch and is therefore controlled frequently. As weight is recorded at every stage, it should also be possible to compile the different records regarding weight. However, one challenge is that weight is recorded in living weight (round weight) in the landing phase and in product weight upon export. To compile them is therefore not a straightforward exercise. As a part of this study, a material flow analysis for cod was carried out on a national level for the years 2012-2015. Together with the documentary study, this analysis formed the foundation for the interview with the company.

The material flow analysis shows that there is a gap between input and output in the Norwegian cod fisheries. The results for the different years and the different product groups of cod are shown in Table 5.1. The results shows that the gap varies. With the exception of 2012, the output is higher than the input. In 2014, the discrepancy between input and output was as much as 15 %.

Table 5.1 Discrepancies per product group of percent input

Product	2012	2013	2014	2015
Fresh	39 %	30 %	31 %	28 %
Frozen	-24 %	-44 %	-64 %	-32 %
Traditional	-8 %	-1 %	-26 %	-18 %
Total	**1 %**	**-3 %**	**-15 %**	**-5 %**

To get more information about the different records and the discrepancy identified in both the record study and the material flow analysis, an interview was conducted with a company that produces and sells various types of products. Both the production facility and the sales office were interviewed. The interviews centred around the company's record keeping procedures and their views on possible sources of discrepancies. Regarding registrations around geographic origin, time/date and ownership, the potential for a discrepancy to occur was reported to be very low. The discrepancy in product properties, however, is largely dependent on the product in question. The discrepancy relating to weight, condition and conservation is much higher in the production of highly processed products such as saltfish and clipfish with a long storage time, than in the production of fresh fish. In general, the more complex the production, the higher the discrepancy. It is also in the production phase of the product that discrepancies are most likely to occur, not in the export and sale of products. Further, any misdescription that occurs during the production process will most likely not be picked up by the sales office due to them only relaying on existing information provided to them.

A significant source of discrepancy is the conversion factors used to convert product weight to live weight. There are probably some systematic errors in the factors, but it is difficult to estimate how big these errors are. However, these factors are standards and should relate to the product. The systematic errors should also be reflected in the volume: more volume leads to a bigger gap. Neither do the conversion factors explain the discrepancy suddenly being much higher in 2014 than in the other years. This shows that time series data can be highly useful as a way of identifying an anomaly that should be investigated further.

Potential of different methods in the Norwegian fishing industry

The findings from this case study shows that while public record requirements in the Norwegian fishing industry covers a wide array of topics, only a few can be used to trace a product or to identify a discrepancy. The case study shows that tracing claims like origin, time/date and ownership through the production is possible provided there are good systems for recording these properties. Properties like weight, conservation and product condition are more difficult to trace as they may change during the production. As weight often is related to catch volume and IUU-fishing, this claim is of special interest.

If there are recordings of both input and output in a production, a material flow analysis is of high relevance. However, the case study shows that the reliability is highly dependent on industry structure, the complexity in the production, data availability, and data quality. Further, whilst the analysis shows that there is a gap between input and output, it does not identify whether or not this gap is due to unintentional actions (e.g. production errors, manual error, etc.) or if it is due to criminal activity.

As the quantitative approach described above does not identify the source of the discrepancy, it must be supplemented by a qualitative approach, either in-depth interviews with industry actors or more cost-effective methods such as questionnaires or phone interviews, the former used in Svorken and Hermansen (2014). These methods can be used to identify weak spots in the value chain, such as those described above, relating to production complexity, conversion factors between product types, etc. However, as mentioned in chapter 5.2.6, certain weaknesses with these methods, such as selection bias, generalizability, etc., must be taken into account.

With the MFA-approach being highly dependent on data availability and data quality, it is useful within industries with many control points, but less so in cases where product registrations are few. As the case study shows, the discrepancy can be comparatively higher for highly processed products than products that undergoes a much simpler production. For products that undergo a relatively substantial transformation during production, control points throughout the production process itself would be necessary to better account for discrepancies due to inherent product characteristics.

Summarized, the Norwegian case study shows that both traceability and material flow analysis can be used in verifying claims on seafood products. However, they need to be developed further before they can be used in fraud detection. More knowledge about the field can be achieved by using some of the methods mentioned for contextual knowledge. In this case, a script analysis could complement a previous study that shows some of the most common ways of to commit fraud in the Norwegian coastal fishing for cod (Svorken and Hermansen, 2014). A script analysis could for instance provide more knowledge about the different ways fraud occurs, and the motivation for committing fraud, knowledge that can be useful with regards to further method development.

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