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Granularity and its role in implementation of seafood traceability

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ABSTRACT

In this study, granularity and its importance for traceability in seafood supply chains is studied. Granularity describes different levels of traceable units. The findings from this study show that granularity plays a key role in the implementation of seafood traceability. Implementation of a coarse granularity level is easier and cheaper than a fine granularity level, but the benefits are also lower. Fine granularity level will increase the complexity of the traceability system, and will give higher costs. A complex traceability system can affect the practical solutions and specification of the information technology systems when implementing traceability. The key is to find the preferable granularity level where the benefits exceed the costs. Consequently, the costs and potential benefits associated with implementing traceability at different granularity levels should be identified.

1. Introduction

The requirements for documenting food products are ever increasing. Extensive national and international legislation has been passed to ensure food safety, and both the industry and the consumers are also becoming more interested in additional knowledge about origin, processes, and other properties concerning the product.

The food scandals of the 1990s put traceability of food on the agenda because of an increased concern regarding food safety and quality (McKean, 2001; McGrann and Wisemann, 2001). Traceability is defined as the '*...ability to trace the history, application or location of an entity by means of recorded identifications*' (ISO, 1994). The outcome of the food scandals was that traceability was included in the European food law regulation EC-178/2002 (2002).

Lately, increased emphasis has been placed on other applications of food traceability. Traceability can be useful to optimize production planning and scheduling, e.g. minimize waste and ensure optimal use of raw materials (Wang and Li, 2006; Moe, 1998). Traceability can also be used as a part of a competitive strategy (Canavari et al., 2010) and to increase company coordination in supply chains (Engelseth, 2009; Banterle and Stranieri, 2008).

Opara and Mazaud (2001) raised a central question with regard to traceability; what unit to trace? The traceable size of the unit, so-called granularity, affects the precision of product traceability (Riden and Bollen, 2007). Finer granularity levels will yield increased precision of traceability. The size of the traceable unit will be different depending on the application of traceable information (Moe, 1998). Application of information for quality and process optimization purposes may demand smaller units. Bigger units can be used when the risk of contamination is low, or when the requirements for controlling production processes are less stringent. Thus, the levels of the traceable units are depended on a company's internal and external need for traceable information. Traceable units are raw materials and products that are uniquely identified and traceable (TraceFood, 2011).

According to Riden and Bollen (2007), there is a need to study different granularity levels to identify the potential of increased precision in traceability. They assumed that this has not been studied in detail due to lack of framework, concept, and terminology.

No published scientific papers have been found discussing different levels of traceable units in seafood supply chains, thus the aim of this study was to investigate granularity and its importance for traceability in seafood supply chains.

First, a review of granularity in traceability studies is presented. Then, the design of this study is described, including the choices of the studied seafood supply chains and the methods used to collect the empirical data. Thereafter, the main findings are presented, and finally, granularity and its importance in seafood supply chains is discussed.

2. Granularity

Granularity is used in different areas and ways to study software systems and material flow in food production. Table 1 shows

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some of the identified descriptions of granularity in traceability studies.

The description of granularity used in software engineering (Items 6 in Table 1) is less relevant for industrial implementation of traceability for seafood, because this description focus exclusively on using traceability in the software development process, the practical solutions to achieve traceability are not included. It is clear that this view of granularity is different compared with the other descriptions of granularity.

The most relevant description of granularity to carry out an industrial implementation of traceability for seafood is Item 5: '*...reflects the levels and size of IUs...*' by Bollen et al. (2007). One inherent weakness in this definition is that the granularity is only defined by the size of the units. Consequently, the definition of granularity applied in this paper is as follows: Granularity describes different levels of traceable units, and is determined by the size of a traceable unit and the number of the smallest traceable units necessary to make up the traceable unit at a specific granularity level. Fine granularity means smaller unit sizes, and coarse granularity means larger unit sizes. Since the total amount we want to trace is given at a specific granularity level, there is an increase relationship between the size of each unit we trace, and the number of units we need to trace. This is illustrated in Fig. 1.

3. Methodology

Fig. 2 describes the design of this study. First, Critical Traceability Points (CTPs) identification was carried out in three seafood supply chains (case studies I–III). A CTP is a place where information loss occurs (Karlsen et al., 2010). Such points occur when information about a product or process is not linked to a traceable unit and recorded systematically. CTP identification is necessary for traceability implementation, because certain recordings are necessary to prevent information loss. Then, critical points during a traceability implementation at a defined granularity level of the traceable units were identified in one of these supply chains (case study III). Thereafter, the identification of different granularity levels of traceable units were examined (case study IV).

In this study, the Norwegian fishery industry was chosen because of increased demands for seafood product documentation.

3.1. Case study I

The first step in this study was to identify CTPs in a feed supply chain for salmon (*Salmon salar*) farming. A fish feed factory (FeedCo), three suppliers of ingredients for fish feed (IngredCo), and a sea-based salmon farm (SalmCo) were included in case study I. Farmed salmon was chosen as a case, because this seafood product is an important product in Norwegian aquaculture.

A well-proven method to identify CTPs did not exist when case study I was carried out. Consequently, methods to identify CTPs were developed. Several studies on materials management have used quantitative research methods (Ellram, 1996), however these methods are not suited for obtaining in-depth data about a research question. Ellram (1996) recommends using qualitative methods to gain more knowledge about a phenomenon. The qualitative methods direct observation, structured interview, and document analysis were used in case study I, because it was assumed to yield in-depth data, fit to study information lost in the studied feed supply chain for salmon farming. For more details of this case study, see Karlsen and Olsen (2011). Another supply chain was studied in case study II to investigate whether similar findings occur in another seafood supply chain.

3.2. Case study II

The second step in this study was to identify CTPs in a dried salted cod (*Gadus morhua*) supply chain. A wet salted fish producer (WetProd) and a dried, salted fish producer (DriedProd) were included in case study II. Dried, salted cod was chosen as a case in case study II, because this seafood product is an important product in the Norwegian capture-based industry, and this industry meets increased demands of documentation of this product, especially as required by law. European Union (EU) illegal, unregulated, and uncontrolled (IUU) regulations demand documentation of the origin of all wild-caught fish exported from third countries, included Norway, to the EU by way of a document called a catch certificate (EC-1005/2008, 2008). Information contained in this document includes catch information, production, transportation, and importer declarations. This requirement is an attempt to prevent IUU-fishing.

The methods used for identifying CTPs in case study I turned out to be quite time-consuming to carry out, and these methods are not easily transferable to another case study, because they were designed to study a specific case. A general method of analyzing the flow of material and information, as well as information loss in food supply chains, was developed by Olsen and Aschan (2010). This method was used in case study II, as well as in the study of several other food supply chains. It is thus assumed to be a legitimate method for identifying information lost within and between companies. For more details of case study II, see Donnelly and Karlsen (2010).

The results from case studies I and II showed that information was lost in the two seafood supply chains studied. To be able to trace a seafood product, it is necessary to carry out recordings of the relationships between the traceable units and unique identification of the traceable units at CTPs to prevent information loss. The experiences gained from case studies I and II were used to design a method for implementing seafood traceability, which led us to case study III.

3.3. Case study III

The third step in this study was to implement electronic chain traceability in a fresh saithe (*Pollachius virens*) supply chain. Fishing

Table 1
Identified description of granularity in traceability studies.

Term	Description
(1) Granularity	'*The size of unique identified TUs defines the operational visibility or granularity in a traceability information system*' Senneset et al. (2010)
(2) Granularity	'*...level of ambition and degree of accuracy and granularity they want for the data in their traceability system*' Arason et al. (2010)
(3) Granularity	'...different levels of detail (granularity) through the supply chain' Bollen (2004)
(4) Granularity	'*Granularity can go down to a very refined level (e.g. a package belonging to a lot). Sometimes, it may even be necessary to trace a milk package from its lot to a barrel of milk*' Kondo et al. (2007)
(5) Granularity	'...reflects the levels and size of IUs[a] that are handled by the particular system' Bollen et al. (2007)
(6) Granularity in software engineering	'*...the traceability granularity is reduced allowing a better matching between related artifacts*' Noll and Ribeiro (2007)

[a] Identifiable unit.

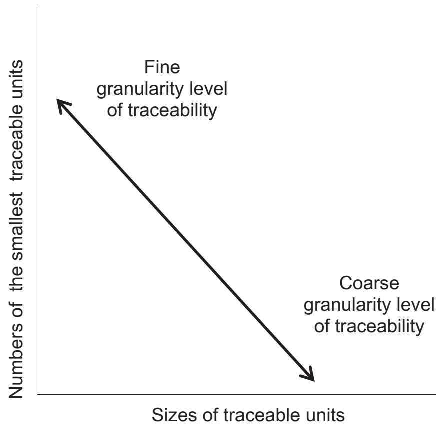

Fig. 1. Different granularity levels of traceable units.

vessels (FishVes), a landing and filleting company (LandCo), a packing and distributing company (DistriCo), and a supermarket (SuperMa) with a manned fish and meat counter were included in case study III. In addition, a sales organization (SalOrg) was involved. SalOrg was responsible for organizing the trade between the fisherman and LandCo, which was documented by a document called landing note.

The fresh saithe supply chain was chosen as a case, because SuperMa wanted more information about the fish, and to the implementation of traceability for this seafood product was presumed to be relatively easy, due to limited mixing and splitting of fish during the production process in comparison to other seafood products (e.g. dried salted cod).

A scientific method for the implementation of electronic chain traceability of seafood has not been identified. Consequently, a method for the implementation of traceability based on the TraceFish standard for captured fish distribution chains (CEN, 2003b) and the TraceFood Framework (2011) was developed. This implementation process had four different phases: (1) mapping phase, (2) planning phase, (3) implementation phase, and (4) analysis phase.

CTP identification in this supply chain was carried out in the mapping phase, where a combination of the two methods described in case study I and by Olsen and Aschan (2010) was used. Case study I describes the use of interviews, observation, and document analysis in a specific case study. Olsen and Aschan (2010) designed a general method to analyze the flow of materials and information in food supply chains with a special focus on the structured interview. In addition, the software systems used by LandCo, DistriCo and SuperMa were identified in collaboration with the companies involved.

The findings from the mapping phase were used in the planning phase, which included a plan for unique identification of traceable units and companies, adjustments to production practices and procedures, and re-engineering of the information technology (IT) systems. The identification of CTPs was used to implement traceability, with the aim to carry out certain recordings at these CTPs to prevent information loss. A net-centric service was chosen as the architecture, because this architecture made it possible to exchange information between the companies in the studied supply chain by linking their software systems, while each company

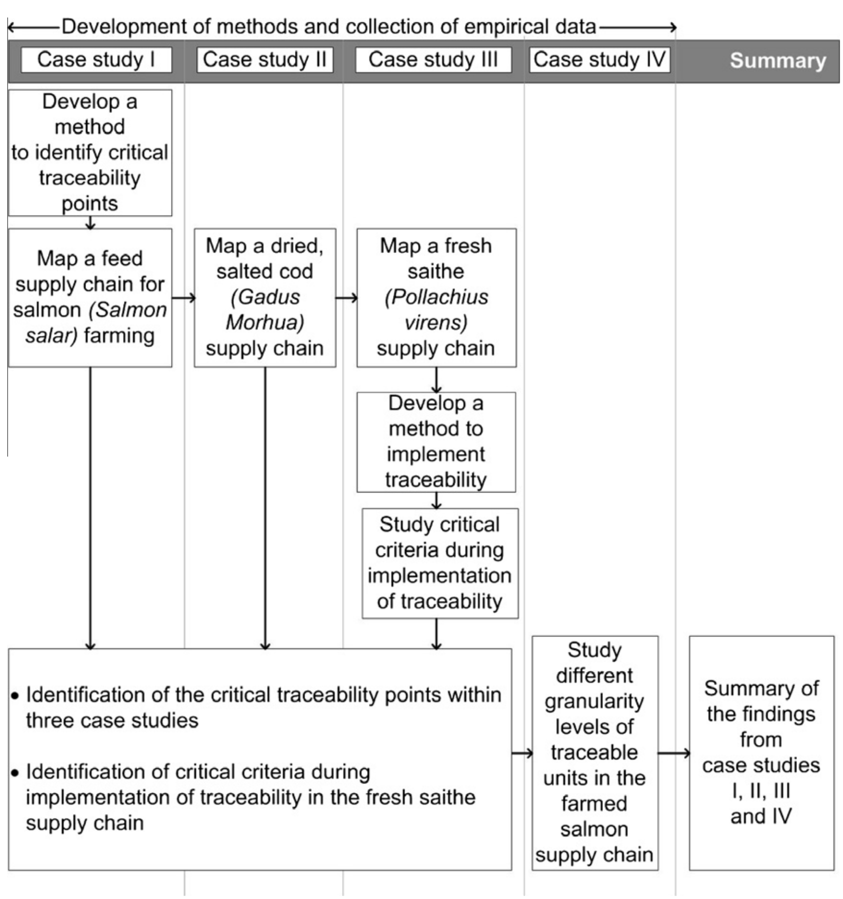

Fig. 2. The design of the study.

still retained full control of their own information. Consequently, this architecture was assumed to be the best choice when implementing electronic chain traceability in a whole supply chain.

The implementation plan was used in the implementation phase. Several parallel activities were carried out during this phase, which can be divided into two categories: (1) implementing chain traceability: installing traceability databases for uploading, handling, requesting, and illustrating information at SalOrg, LandCo, DistriCo, and SuperMa, and applying the net-centric solution; and (2) implementing internal traceability: developing and testing practical solutions to prevent information lost at LandCo, DistriCo and SuperMa. In addition, the companies involved and their IT-suppliers discussed different solutions for exchanging information between the software systems within the companies.

Critical criteria for implementing traceability were identified during this implementation. A critical criterion was identified if there was a mismatch between the implementation plan and real implementation activities, and a willingness to find an optimal solution to trace the fish was not present. A critical criterion could be a barrier to success for the implementation of traceability in the whole supply chain or it could slow down the implementation process. For more details of the implementation process, see Karlsen et al. (2011a).

Based on the experiences gained from case study III, it was clear that knowledge of costs and benefits associated with traceability must be increased, as this can help companies determine preferable granularity levels for the traceable units before the implementation process begins: what can the traceable information at different granularity levels be used for, and what information is relevant for whom? No published scientific papers have been found discussing different granularity levels of traceable units in seafood supply chains. This is thus studied in case study IV.

3.4. Case study IV

In case study IV, different granularity levels of fish feed and farmed salmon were studied using empirical data from case study I. This supply chain was chosen, because relevant data to calculate the different sizes of traceable units at FeedCo and SalmCo had already been collected (such as production capacity at FeedCo and the total number of received juveniles at SalmCo).

The traceable units at FeedCo and SalmCo were determined by applying the definitions of traceable units from the TraceFood framework (2011). Different batch levels were identified at FeedCo and SalmCo. The coarsest granularity level of fish feed batches studied was 'one year', because it was assumed that a coarser granularity level would not be relevant for FeedCo with respect to traceability. For more details of case study IV, see Karlsen et al. (2011b).

4. Results and discussion

In this chapter, the main findings of this study are presented and discussed.

4.1. Critical traceability points

Twenty-one CTPs were identified in the studied feed supply chain for salmon farming (Fig. 3). The most important findings with regards to traceability were insufficient recordings of the relationships between the traceable units (CTPs 1–18) and the lack of unique identifiers for the traceable units (CTPs 19–21). These identifiers are vital for achieving traceability (CEN, 2003a; Denton, 2003; Kim et al., 1995; Moe, 1998). The identified CTPs can be divided into two types: (1) recordings of the relationships between traceable units (hereafter called CTP-relation), and (2) unique identification of the traceable units (hereafter called CTP-ID).

Fifteen CTPs were identified in the studied dried salted cod supply chain (Fig. 4). The findings with regards to traceability were insufficient recordings of the relationships between the traceable units (CTP-relations 1–10) and lack of unique identifiers for the traceable units (CTP-IDs 11–15).

Twenty CTPs were identified in the studied fresh saithe supply chain (Fig. 5). The findings with regards to traceability were insufficient recordings of the relationships between the traceable units (CTP-relations 1–13) and the lack of unique identifiers for the traceable units (CTP-IDs 14–20).

The findings from the case studies I–III show that the number of CTP-relations is higher than that of CTP-IDs (Fig. 6). The fish feed factory had the highest number of CTPs (18 CTPs in total). This is a result of their use of eight different raw materials to produce fish feed, and not recorded the mixing and splitting of these input factors. Wet salted fish producer also had a high number of CTPs (10 CTPs in total). This company had few input factors (wild-caught fish and salt); the high number of CTPs was caused by a production process where the wild-caught fish was split and mixed several times. The fish farm had the lowest numbers of CTPs.

Identifying CTP-relations and CTP-IDs is essential when implementing traceability in a seafood supply chain. This leads us to case study III, where the aim was to carry out necessary recordings at the CTPs to prevent information loss by completing an industrial implementation of traceability in a seafood supply chain.

4.2. Critical criteria in traceability implementation

Case study III presents an implementation of electronic chain traceability in a fresh fish supply chain. Experience gained from this study showed that implementation is complex and involves many different aspects that affect each other (Karlsen et al., 2011a).

A number of critical success criteria were identified as a result of this implementation. The ability to identify benefits to be gained from implementation of electronic chain traceability was identified as one of these. Communicating and understanding the benefits of a traceability system is important for successful implementation of traceability (Sohal, 1997).

Many authors have identified several benefits of using traceability for the food industry (Frederiksen, 2002; Opara and Mazaud, 2001; Wang and Li, 2006; Chryssochoidis et al., 2009; Töyrylä, 1999; Mai et al., 2010; Hobbs, 2004). Still, there are companies that have not yet recognized the benefits of using traceability (Wang and Li, 2006).

If a company cannot identify any benefits in carrying out an implementation, the motivation will soon wane. This will affect the willingness to invest in any technology needed to achieve better documentation of produced products.

Implementing an efficient traceability solution may require big investments (Sohal, 1997). There are different types of costs associated with traceability implementation (e.g. administrative, material, operational, equipment/technology, initial and ongoing costs) and these investments are highly variable (Can-Trace, 2007). One finding in case study III was that the investments necessary for successful traceability are dependent on several factors. These investments were affected by which software solutions and electronic recording equipment were available in the company. Other factors affecting investments were the degree of integration required in the software systems for successful internal traceability (simple or full integration), investments in new IT-solutions, and necessary re-engineering of current IT-systems. In case study III, the costs of increased traceability seemed to be higher at the landing and filleting company than at the supermarket and packing and

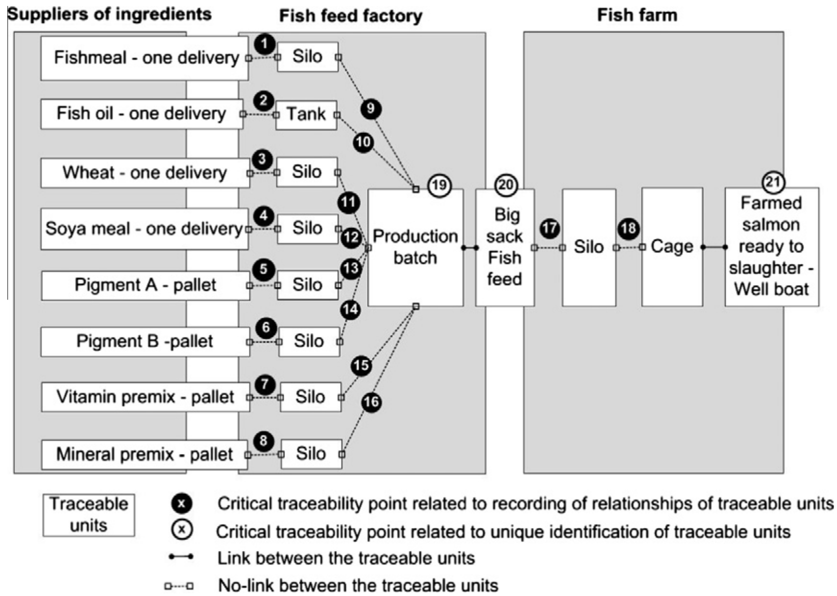

Fig. 3. Critical traceability points in the feed supply chain for salmon (*Salmon salar*) farming (Karlsen and Olsen, 2011).

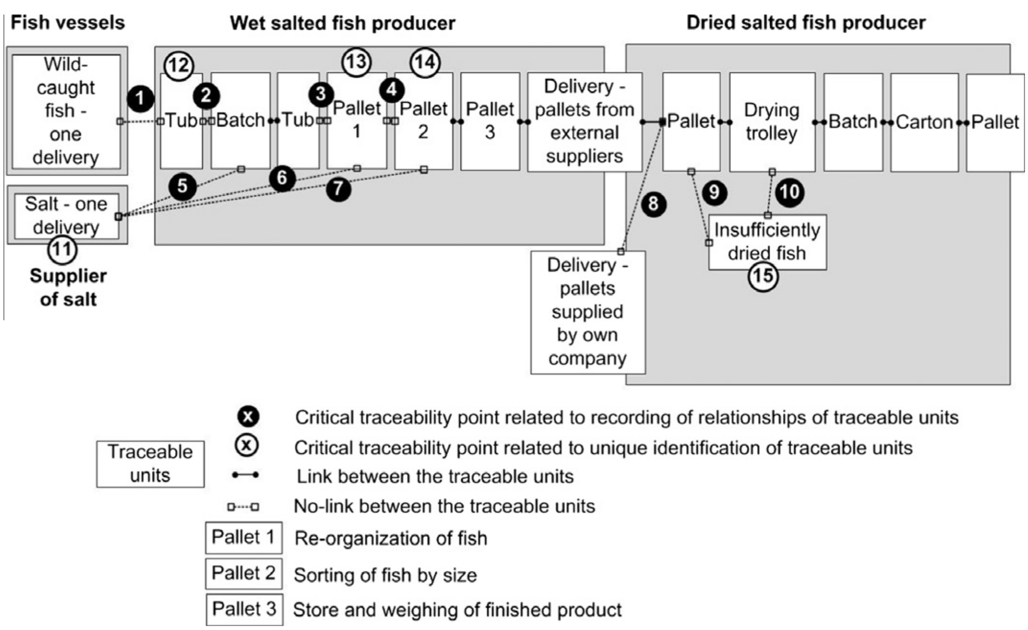

Fig. 4. Critical traceability points in the dried salted cod (*Gadus morhua*) supply chain studied.

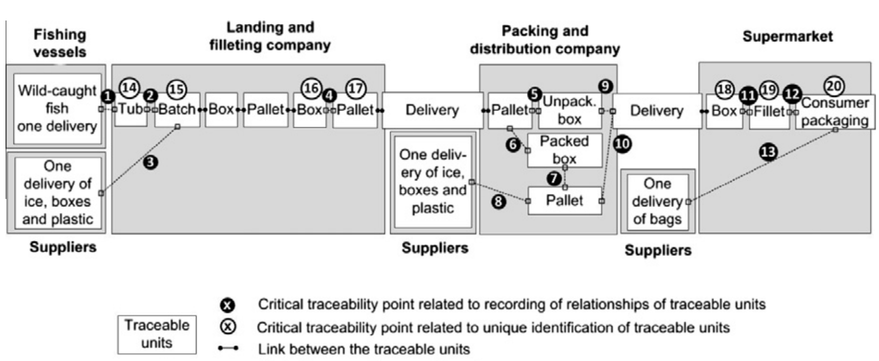

Fig. 5. Critical traceability points in the fresh saithe (*Pollachius virens*) supply chain studied.

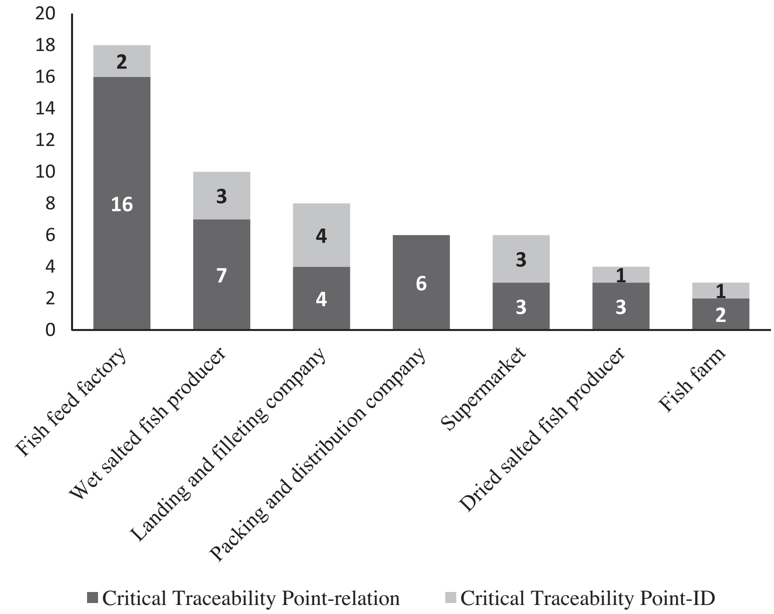

Fig. 6. Numbers of identified critical traceability points in the studied seafood supply chains.

distribution company. Another finding in case study III was that the companies would not make the investments necessary for better product documentation if they could not identify the benefits they stood to gain by making these investments.

In case study III, it became clear that the motivations behind implementing a traceability solution may vary, and identifying the costs and benefits of traceability is critical for the implementation. Consequently, more studies including cost-benefit analyses are needed to help companies determine the preferable granularity levels of traceable units, which leads us to case study IV. The key is to find the preferable granularity level where the benefits exceed the costs.

4.3. Granularity level of traceable units

Case study IV showed that granularity can have different levels in the studied feed supply chain for salmon farming, the granularity level will increase (finer granularity) with decreased batch sizes and increased number of the smallest batches necessary to make up the batch at a specific granularity level (Karlsen et al., 2011b). An important factor that must be considered in this discussion is how granularity levels will affect production practices and IT-systems in a company. One should determine whether it is going to be problematic to develop practical solutions for achieving traceability. A fine granularity level will have greater impact on practices and IT-systems than a coarse granularity level. A finer granularity level will increase the chance of reaping the benefits of using traceability. In other words, implementation of a coarse granularity level is easier and cheaper than a fine granularity level, but the benefits are also lower. Consequently, the costs and potential benefits associated with implementing traceability at different granularity levels should be identified.

Which granularity level to use, is depended on the stakeholderś need for traceable information. There are different applications of traceability. Traceability can be used to fulfil legislation, and to document food safety issues, quality, sustainability, and welfare. In addition, traceability can be useful to meet requirements in certification schemes, to gain competitive advantages, to improve chain communication, used as a respond to the threat of bioterrorism, and to optimize production.

In the next sections, the affect different granularity levels has on the ability to trace seafood will be discussed, illustrated by examples from the studied seafood supply chains.

4.4. Different granularity levels

The European Food Law is an example of a coarse granularity level of the units. This legislation requires one-up-one-down traceability (EC-178/02, 2002). The companies in the Norwegian seafood industry fulfil this granularity level already, because all companies have control over the deliveries from/to their suppliers and customers for economic transactions. Thus, there are no new investments for the companies using this granularity level.

The IUU-regulation is an example of legislation that requires a finer granularity level of the traceable units than does the Food Law (EC-1005/2008, 2008). This regulation affects all Norwegian seafood producers and exporters exporting wild-caught fish to the EU. The catch certificate from Norway is based on the Norwegian system of landing notes (CatchCertificate, 2011). A central element in this regulation is that a catch certificate must be issued for each consignment of wild-caught fish to the EU where the catch information of this fish is included. If one consignment consists of several catches of wild-caught fish, the producer has to stay on top of the production process in order to be able to issue a catch certificate. The question here is which granularity level of the traceable units to use in order to satisfy the requirements of this legislation? The answer to this question is not straightforward, due to various production concepts and production practices in the Norwegian capture-based industry (e.g. fresh fish, wet salted fish, dried salted fish, and stock fish).

The dried salted fish production at the dried salted fish producer in case study II is an example of a fine granularity level for traceable units. They achieved internal traceability by documenting the splitting and mixing of fish during production by assigning internal numbers to the units (Donnelly and Karlsen, 2010). They believe that their ability to keep track of production routines has become an invaluable management tool. For example, they explained that the improved traceability system had enabled them to track the quality of a supplier's fish and allowed them to take immediate action when problems with quality were reported. They also reported that implementing internal traceability has led to greater efficiency in production.

Another example of fine granularity level is the approach used in case study III, where the goal was to trace the traceable units step by step through a whole supply chain. The application of information in one company can affect the granularity level in another company. This can be illustrated by two scenarios: Scenario (1) The supermarket wanted information about the catch area (e.g. the North-East Atlantic Ocean). The landing and filleting company did not need to carry out detailed recordings during production, because all the landed fish at this company was caught in this catch area. If the packing and distribution company received fish from another catch area, they would have to keep this fish separate during packing. Scenario (2) The supermarket wanted information about the gear type (e.g. long-line); all fish caught with the same gear type must be kept separate during the production and packing processes at the landing and filleting company and packing and distribution company.

It is clear that how users apply the traceable information affects the granularity level needed. The companies can choose to use traceability to gain other benefits then only fulfilling legal requirements by implementing finer granularity levels for their traceable units, such as increased internal control or supply chain communication. The chosen granularity level will determine the complexity of the traceability system, and can affect the practical solutions and specification of the IT-systems in the implementation of traceability.

It is clear that the implementation of seafood traceability is affected by the chosen granularity level of the traceable units, but how will the randomness of the fish supply affect the ability to trace seafood at a fine granularity level? In the next sections, this will be discussed by comparing implementation of traceability at a fine granularity level for wild-caught fish and farmed fish.

4.5. Fine granularity level and its affect on traceability

The implementation of traceability at a fine level of granularity for wild-caught fish is probably more challenging than for farmed fish because of the differences between these two production concepts. In aquaculture, producers have much more control of the raw materials they receive; the fish size and quality of the farmed fish is quite stable, and different species are not mixed together. This makes it easier to coordinate and plan the time of production of farmed fish. The slaughter plant can coordinate with the fish farms when they have capacity to receive and produce the farmed fish.

The capture-based concept has much less control over the quantity of wild-caught fish delivered, and the variation in fish size, quality, and number of species is great, especially in the Norwegian conventional fisheries.[1] In these fisheries the sizes of fishing vessels and gear types vary greatly, and the volume of wild-caught fish delivered from e.g. a vessel using Danish seine can be very big compared to a delivery from a small vessel using jig. If a company wants to trace deliveries back to each fishing vessel, the volume is important, because separating smaller landings of wild-caught fish will affect the efficiency of production and practices. This illustrates how the context can impact implementation of traceability in seafood supply chains at different granularity levels.

For the capture-based supply chains, the number of batches within a year of the granularity levels varies from year to year due to the randomness of wild-caught fish deliveries. Mixing several catches together is a practical adjustment for achieving an efficient production, because separating all the small catches would be very time-consuming (Donnelly and Karlsen, 2010). A fine granularity level can present big challenges due to the randomness of landing rates for wild-caught fish. This will also affect the other companies in the specific supply chains. Consequently, an important factor to include in a discussion of preferable granularity level of batches in capture-based industry is finding practical solutions for traceability.

[1] Fishing with the following gear types: gill-net, long-line, Danish seine, jig, fish traps, and pots.

5. Conclusions

Granularity and its importance for traceability in seafood supply chains is examined in this study. It is clear that a traceability system can be simple (one-up-one-down traceability); costs would be low and implementation would be easy. Traceability can also be complex. Fine granularity levels will increase the complexity of the traceability system, and will entail higher costs, because there is more information to record, a higher number of transactions, and new systems and procedures would possibly have to be introduced (Golan et al., 2004).

There are different costs and benefits to using traceability, and companies apply traceable information differently. Any implementation of traceability in seafood supply chains should thus include an open discussion of the distribution of costs and benefits between companies in the chain (Mai et al., 2010). An evaluation of costs and benefits using traceability will determine the complexity of the traceability system and can affect practical solutions and IT-system specifications in the implementation process. Granularity thus plays a key role in the implementation of seafood traceability. Another important factor to consider when discussing granularity level is optimization of the practical solutions used to trace the seafood products.

All traceability systems should be designed based on the needs of its users. It is pointless to build a great palace for a single family, where only 10% of the area is used daily; a better solution would be to build a house suited to the needs of the family, where the whole house is used every day. The key is to identify the preferable granularity level for the traceable units. Preferable granularity offers sufficiently detailed information in a traceability system at acceptable costs.

6. Further work

Identifying applications for traceability and benefits of traceable information in seafood supply chains is a clear area for further studies. There is also a need to increase knowledge of preferable granularity levels for traceable units by carrying out real industry studies. A central issue raised by Souza-Monteiro and Caswell (2004) is '*who bears the cost and who reaps the benefits of traceability*'? Further theoretical developments on how granularity impacts costs and benefits in the implementation of traceability are needed. Other interesting questions are: Are the benefits and investments different depending on the companies' position in a supply chain? Are there more advantages to internal traceability compared to chain traceability? Are there different benefits and investments of traceability for different foodstuffs ('high'-value products vs. 'low'-value products)? What is the preferable granularity level for different seafood companies? How will the production concept and use of technology affect the preferable granularity level?

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