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Introducing insect-based salmon feed

From a nutritional, economic, legal and marketing perspective

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Abstract

The expansion of the aquaculture sector around the world has resulted in a growth of the demand for fishmeal (FM). Due to the limited sea resources, the price of FM has risen significantly in past years pushing the sector to find substitutes. In this context, insects attract more and more industrial and scientific attention as they have many advantages. First, with around one million species estimated, insects are rich in protein, oil and minerals. Second, they are able to feed on a large variety of substrates such as agricultural by-products and organic waste. And finally, they are naturally present in wild salmon diet. Nevertheless, the use of insects in FM is not yet exploited at their full potential. Today, European regulations allow only seven species in fish feed. Moreover, regarding, bi-conversion, the EU only allows the use of vegetal by-products and some former foodstuff. From a marketing perspective, salmon fed with insects would be welcomed by consumers, but it could not reach a premium price. Economically, insect meal (IM) is still produced in small quantities and its price is still higher than FM. This situation is expected to change as the insect sector is developing fast and the production of IM should significantly increase in the near future. Therefore, according to feed producers, insect-based salmon feed seems to be on the verge of introduction to the market.

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Abbreviations

AA: Amino acid

CP: Crude protein

FM: Fish meal

FO: Fish oil

IM: Insect meal

IO: Insect oil

IPIFF: International Platform of Insects for Food and Feed

LAPs: Land animal by-products

SM: soymeal

1 Introduction

The expansion of the aquaculture sector around the world has resulted in a growth of the demand for fishmeal (FM). Due to the limited sea resources, the price of FM has risen significantly in past years pushing the sector to find substitutes (Naylor et al., 2009). Therefore, alternatives such as soybean meal have been implemented (Naylor et al., 2009). This plant source presents advantages such as being rich in protein and containing amino acid (AA) (Naylor et al., 2009). Nevertheless, lately, soybean as a substitute for FM has been criticized for different economic, environmental (Scharlemann & Laurance, 2008) and nutritional reasons (Lock, Arsiwalla, & Waagbø, 2016).

In this context, insects have recently attracted increasing attention from the scientific community. With around one million species estimated (Erwin, 2004), insects are often presented as the protein source of the future for human consumption and for animal feed.
Insect feed can be perceived as a sustainable and better option for farmed salmon, especially nowadays, when people are becoming more and more concerned not only about their health but also about the environmental issues which create many opportunities for innovations in food production (Verbeke et al., 2015).

In some regards, the use of insects to feed fish is not new since they have been used for a long time as bait for salmon river fishing and as feed for aquarium fishes. Nevertheless, it can be presented as an innovation for salmon aquaculture because "it brings a new solution for user groups" and therefore, feeding salmon with insect is a new solution to substitute the traditional feed. Moreover, following Rogers (1995) what determines a product or an idea as innovative is the perception and the reaction of the individual. Then "if the idea seems new to the individual, it is an innovation" (Roger, 1995)

In the light of these trends, salmon fed with insects is a great example of the innovation which can become a future standard for the industry, providing consumers with a better quality and more environmentally friendly product. For aquaculture purposes, insects present a new source of protein and possess many nutritional values similar to fish (Barroso, de Haro et al., 2014). Nowadays, different species of insects have already been studied and tested with promising results (Henry, Gasco, Piccolo, & Fountoulaki, 2015). In Africa and Asia, studies have been focusing on feeding carp, catfish, barb, turbot, tilapia and rainbow trout with insects such as house fly, mealworm, locust, grasshoppers and crickets, black soldier fly larvae and silkworm pupae (Lock, Arsiwalla, et alt., 2016; Harinder, Gilles, et al., 2014).

Across Europe, this last decade, a new insect production sector is developing at fast pace as young entrepreneurs understand the great potential of insects in animal feed. Today, the insect sector constitutes of approximately 40 insect producing companies (IPIFF, 2018) . Looking to introduce their product into the aquaculture market, insect producers argue on three main points. The first one plays on the natural and health aspect of the feed. Contrary to soya, insects are naturally present in salmon diet (Johansen, Elliott, & Klemetsen, 2005; Rumpold & Schlüter, 2013). In its natural habitat salmon is a predator and feeds on a wide range of pray from zooplankton, shrimps, squid, worms and fish. When returning to the fresh water to spawn, Atlantic Salmon feed on aquatic insects and surface insects (Johansen et al., 2005). Therefore, according to Rumpold & Schlüter (2013) a feed formulation that contains insect protein is closer to a natural diet.

The second argument is related to the environment, as insects are a low footprint source of protein and oil (Oonincx et al., 2010). Insects are able to convert low-value biomass proteins into high-quality animal protein and oil, and therefore, they can feed on a large variety of substrate such as agricultural by-product, organic waste or microalgae. In addition, as the wild fish stock is increasingly under pressure due to the increase of demand for FM, replacing FM by insect protein would reduce the impact of aquaculture on the wild fish stocks (Lähteenmäki-Uutela & Grmelová, 2016).

Finally, from an economic point of view, while the production of FM is finite and its price highly volatile (Asche & Oglend, 2016; Naylor et al., 2009), insect producers claim that they are able to produce large quantities of insects at a fixed price (Entomo Farm, 2018).

Considering salmon aquaculture, the participation of feed companies in research projects on insect as feed for salmon (such as Aquafly)(Nifes, 2018) shows their interest in insects as they are looking for alternative source of protein and oil (Shepherd, Monroig, & Tocher, 2017). Therefore, insect meal (IM) constitutes an innovation that can bring new opportunities to the salmon aquaculture market. Indeed, salmon fed with insects could be considered to be a healthier option for the consumers, it also could improve quality and texture, bringing a relative advantage compared to soya fed salmon (Henry et al., 2015).

In the context of introducing a new product into salmon feed, interactions between the different actors of the supply chain have to be studied. The path to introduce IM to successfully introducing IM in salmon feed is long and complicated as many elements influence the attitude of the supply chain's stakeholders towards IM and insect oil (IO). The supply chain counts five stakeholders. At one end insect producers aim to sell their product to feed producers. The latter provides feed to salmon farmers who are selling their salmon to retailers. Finally, at the other end of the chain, customers decide to buy a salmon fed with insects or not (figure 1). Each of these stakeholders have common as well as different needs that have to be fulfilled in order to successfully introduce IM into salmon feed. However, this study will be led with the assumption that the feed producers' willingness to find new oil and protein alternatives is the first key parameter in introducing insects into FM. Indeed, without feed producers need for substitutes, development of IM would not arise in salmon aquaculture.

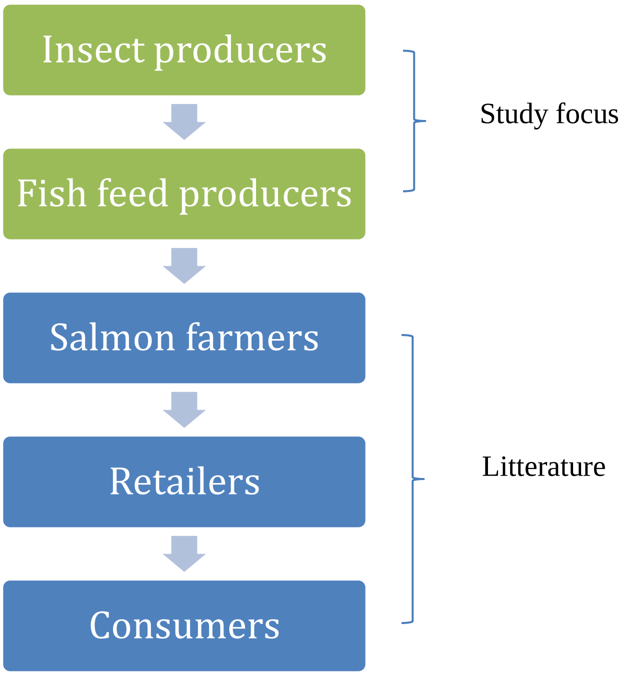

Figure 1: Supply chain

The second key parameter in the success of introducing insect derived feed in the supply chain is consumer acceptance. Studies have shown that consumers increasingly care about environmental issues and the sustainability of their food. Aquaculture feed companies' focus on sustainable feed is driven by consumer-awareness on environmental issues. IM could represent an alternative, however, acceptance by the consumers of salmon fed with IM has to be studied as consumer rejection for salmon fed with insects would jeopardize the adoption of IM by the salmon feed industry.

Moreover, we assume that the salmon farmers as well as the retailers play a secondary role in the introduction of IM into salmon meal. Nevertheless, their influence must not be ignored as all the actors of the supply chain are interdependent. No introduction of a new ingredient can succeed to enter the salmon aquaculture market if one of these actors are not actively contributing to the introduction of insects (Naylor et al., 2009).

In the light of these assumptions, this study will answer to the following research questions: "Is the Norwegian feeding industry interested in insect as a source of protein and why? Then what are the potential issues concerning the adoption of insect in salmon feed?". Therefore, this study is going to primarily focus on the relation between the producer and the processor. Consumer acceptance will also be discussed but to a less degree, as this study is constrained by time and number of pages, and the author is advised to focus on one specific topic.

To study the adoption of insect protein and oil by feed producers, this paper is divided into four chapters. The first chapter presents the background of this study in two parts. The first part describes aquaculture potential to feed the world population. Then, the second part concentrates on the evolution of salmon feed over time and focuses on the reason why feed producers are looking for alternative to their current feed. The next chapter describes the resources and the methods used in this thesis. The third chapter gathers the results and discussion and constitutes the core of this thesis, elaborating on key issues in the introduction of IM in salmon feed. Divided in sub-headings, the economics, regulations, nutritional and technical challenges of IM and oil are addressed. The conclusion recapitulates and comments on the overall results of the study (to determinate the state of IM in salmon aquaculture). This thesis concludes with recommendations for further research.

1.1 Background

1.1.1 Aquaculture to feed the world

In 2010, seafood contributed to 17 percent of the total animal protein supply (Waite et al., 2014). In developing countries, seafood is an especially valuable source of protein as more than 75 percent of the wild fish consumptions occurs there (Waite et al., 2014). In 2050 the world population will be 34 percent higher than today, reaching 9.1 billion people (FAO, 2009). However, the increase in wild captured fish production will not be able to keep up with increase in the world population as this finite resource has already reached its peak (figure 2) (Waite et al., 2014). Moreover, the global fish stock is in a bad state as half of the global fish stock is already fully fished and 32% is overfished or depleted (figure 3) (Olsen & Hasan, 2012; Waite et al., 2014). Therefore, the global supply of wild fish can no longer be increased in order to feed the population.

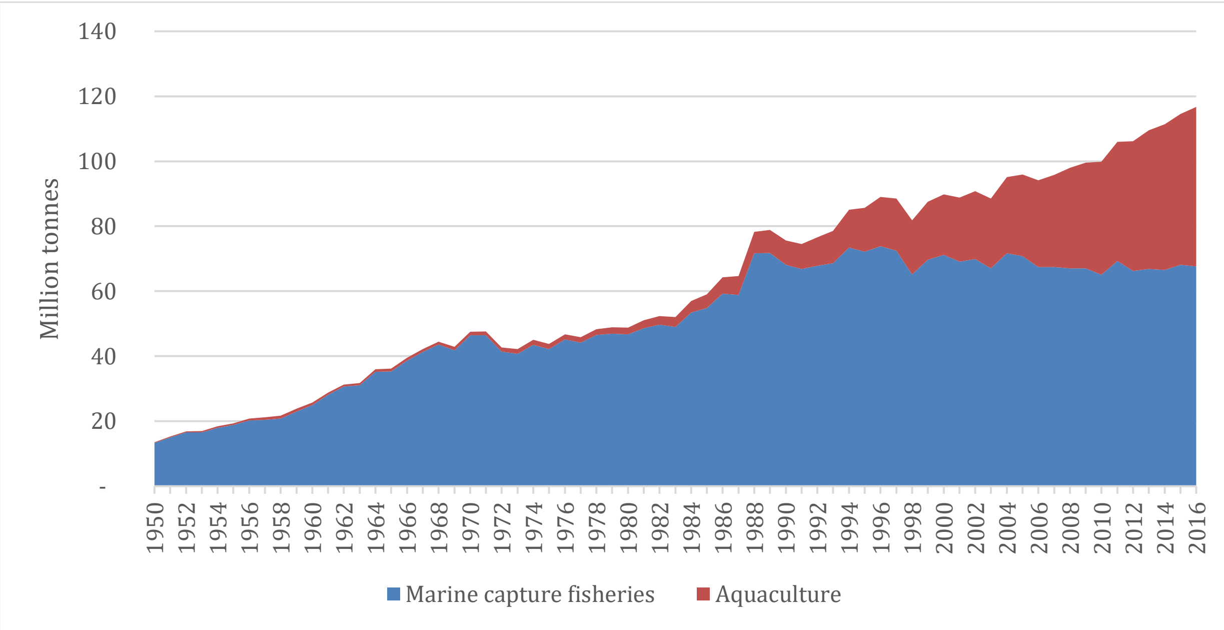

Figure 2: Marine capture fisheries and aquaculture world production. Data retrieved from FAO (2018)

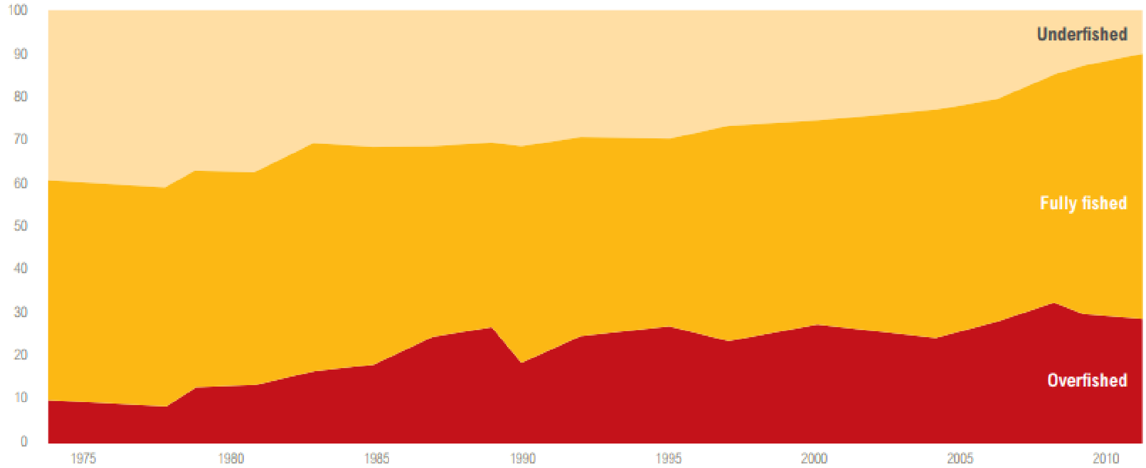

Figure 3: Overfishing increase over the past 40 years (percentage of marine fish stocks assessed) (Waite et al., 2014, p.7)

In this context of demographic growth combined with pressure on the marine food web (Pauly et al., 2011), aquaculture is often presented as a solution to feed the world (Gentry et al., 2017; Waite et al., 2014). Therefore, the Norwegian salmon aquaculture industry has its role to play in providing the high-quality protein to the future world population.

1.1.2 Norwegian aquaculture industry

The salmon and trout farming industries represent a large part of the Norwegian economy. Due to its long coastline of 101 000 kilometers, its cold climate and fjords, Norway has successfully developed its farmed salmon industry since the 1970s (Norwegian Seafood Federation & Norwegian Seafood Council, 2011; Shepherd et al., 2017) .

Popular for its taste as well as its nutritional value (rich in protein, omega-3, vitamin A, D and B12 selenium an iodine), Norwegian salmon is exported all over the world (Larsen & Asche, 2011; Norwegian Seafood Federation & Norwegian Seafood Council, 2011). In 2013, with 1.1 million tons, Norwegian salmon represented 61% of the world farmed salmon production (1.8 million tons) (Shepherd et al., 2017). Salmon export value is constantly growing as it increased from 32.8 billion NOK in 2010 to 64.7 billion NOK in 2017 (Norwegian Seafood Council, 2018; Norwegian Seafood Federation & Norwegian Seafood Council, 2011). In terms of jobs, this industry is an important direct source of employment in the Norwegian communities, for example 22 700 jobs were created in 2009 (Norwegian Seafood Federation & Norwegian Seafood Council, 2011). In addition, it has been estimated that "each job in the core activity of the aquaculture industry creates two jobs in other Norwegian business and industry" (Norwegian Seafood Federation & Norwegian Seafood Council, 2011, p. 9).

Economically Norwegian salmon aquaculture is a success story (Larsen & Asche, 2011), however, the expansion of aquaculture in Norway has also come together with controversy as its production is often criticized for it is environmental impact (Olesen, Myhr, & Rosendal, 2011; Tovar, Moreno, Mánuel-Vez, & García-Vargas, 2000; Tveterås, 2002). As the salmon aquaculture has undergone a fast expansion, environmental concerns can be attributed to the intensive nature of salmon farming (Tveterås, 2002). Organic waste is one of the major issues in salmon farming and is responsible for most of the pollution around fish farms. As fish feed is the main input in salmon aquaculture, if a part of the feed is transformed into fish biomass (Tovar et al., 2000), the organic waste coming from fish feces and waste feed, accumulates on the seafloor and damages the local fauna (Tveterås, 2002). Moreover the waste leads to higher concentration of nutrients in the sea increasing the risk of eutrophication (Black et al., 1997).

In the 1980s the extensive use of antibiotics has also been a controversial issue in salmon aquaculture since excessive antibiotic use can lead to antibiotic resistance in fish and other organisms. However, since then, the use of antibiotics in Norway has been almost abandoned due to the development of vaccines (Olesen et al., 2011; Tveterås, 2002).

The issue of salmon escapees is controversial because of its potential negative impact on wild salmon stocks. The short term effects of escaped farmed salmon include competition and breeding with wild salmon, and hybridization with trout which has probably has a negative impact on wild salmon population (Olesen et al., 2011; Tveterås, 2002).

Salmon aquaculture is also linked with sea lice outburst as studies have shown that sea lice occurs in areas with a high concentration of salmon farms (Skilbrei, 2012; Tveterås, 2002). According to Tveterås (2002) salmon escapes and sea lice and are probably the major environmental problems in salmon farming.

1.1.3 Salmon feed

Within the framework of this master thesis, a deeper attention will be dedicated to salmon feed. Salmon feed was originally composed essentially of FM made by the farmers themselves. The meal was essentially made of local pelagic fish such as herring and capelin. The meal contained around 50% protein and 15% fat/oil. At that time, the composition of farmed salmon feed was quite similar to the composition of a wild salmon's natural diet.

With the development of the aquaculture industry, the composition of the feed changed as the producers were looking for cheaper feed alternatives. First, in the 1990s, herring and capelin were replaced by south American Anchovy and sand eel but the feed was still composed of 90% marine ingredients (Shepherd et al., 2017). Then, starting in 2010s, the composition changed drastically as plant oils and proteins were introduced into the feed. Therefore, plant sources such as soya and maize replaced a large fraction of the fish protein used in the feed. The level of marine ingredients was sharply reduced as the marine ingredients only represented 40 % of the feed while the other 60 % came from plants in 2013 (Shepherd et al., 2017). Today, FM and Soymeal (SM) are the two-main source of protein and oil for salmon feed. Despite the increase of plant ingredients in salmon feed, the industry is still looking to for new sources of protein (Shepherd et al., 2017).

2 Materials and Methods

2.1 Materials

To respond to the different objectives, this research is mainly based on qualitative data and to a lesser extent, on quantitative data. Scientific literature, press articles as well as official documents from international organization such as FAO are used in the two first parts of the thesis. Quantitative data were also collected in order to study fluctuation of price and quantity of fish and SM for example.

For the results and discussion part, the data come from exclusive material. Interviews as well as written correspondence form the backbone of this study. Indeed, in order to gather information about the potential adoption of IM by fish feed companies, numerous requests for interviews to fish feed producers and insect feed producers were sent.

The data collection was based on three interviews, with Entomo farm, Nextalim and Skretting, plus additional written correspondences with Havsbún and Entomo Farm. Other major feed companies were contacted but did not reply to our solicitations. Finally, more data were collected through informal talks with representatives from the aquaculture industry during the two-day conference "Håp i Havet" at the Artic University of Tromsø. These informal discussions with representatives of Cargill and Biomar were not recorded, therefore no precise information could be retrieved and cannot be cited in this thesis. However, these informal discussions oriented the researcher in its exploration process and confirmed that the feed industry is seriously prospecting IM as an alternative protein source. In addition to formal and informal talks, more data were collected under the form of written correspondence as the contact person did not wish to have be interviewed but accepted to answer some questions by e-mail (Havsbrún). In the second case, extra-information following the interview was provided by e-mail (Entomo Farm). Refer to table 1 for information on the interviewed companies.

Table 1: List of Companies interviewed

Nextalim:

Founded in 2013, Nextalim is a French company located near Poitier. The company has 15 employees and produces black soldier larvae meal, oil and fertilizer. Their principal customer is the aquaculture industry.

Raphaël Smia was the contact person inside the company who was interviewed. He is the cofounder of Nextalim and is commercial and development director at Nextalim.

Entomo Farm:

Created in 2014, Entomo farm is the biggest producer of IM in France. Based in Lisbourne near Bordeaux, it produces three products from mealworm: IM, oil and fertilizer. Entomo Farm's main customer is the pet food industry.

The interview was made with Delphine Calais. She is doctor in biology and specialized in invertebrate. She has been working at Entomo Farm since October 2016. Today, she is research director and as director of research she has different roles. First, she is looking at the optimization of insects breeding. Second, she is responsible for product development of their three principal products IM, IO and insect fertilizer. And finally, she is research manager on projects instigating the use of new subtracts and new insect species.

Skretting:

Skretting is a producer and supplier of aquafeed for Atlantic salmon, rainbow trout, sea bass, sea bream, tilapia, whiteleg shrimps and other marine species. The interview was conducted with Jenna Bowjer. She is working as a project manager for Skretting globally and has overseen Skretting's insect project.

Havsbrún:

Havsbrún is a producer of FM, fish oil (FO), and fish feed situated in the Faroe Islands. Almost all of the production is used for their own fish feed, and only a small part is being exported. Havbrún is a filial of Bakkafrost, an aquaculture company, situated in the Faroe Islands, specializing in high quality Atlantic salmon production. For this research, our contact person was the director and research and development manager for feed. No interview was conducted but exchange of e-mails provided us information.

2.2 Methods

Interviews with actors from the insect companies (Nextalim and Entomo Farm) and the fish feed companies (Skretting) constituted an important part of the data collection.
Before leading the interviews, a certain amount of preparation was required in order to make the best of these meetings. The first step started with the definition of the following research questions: “Is the Norwegian feeding industry interested in insect as a source of protein and why? Then what are the potential issues concerning the adoption of insect in salmon feed?”. These questions are the result of a literature review which indicated that these questions have not been scientifically studied.

The interviews were semi-structured as they were based on a list of questions (interview guide) on topics the research wants to cover, as opposed to a structured interview. With a semi-structured interview, there is a flexibility “in how and when the questions are put and how the interviewee can respond” (Edwards & Holland, 2013, p. 29). The interviewer can rebound on answers, pursuing a line and deepen the discussion opened up by the interviewee (Edwards & Holland, 2013). Moreover, “these interviews allow much more space for interviewees to answer on their own terms than structured interviews, but do provide some structure for comparison across interviewees in a study by covering the same topics, even in some instances using the same questions”(Edwards & Holland, 2013, p. 29).

Therefore, all the interviews realized for this thesis were based on two interview guides covering between 16 and 17 questions for a 45 min – 60 min long interview. Two interviews with insect’s producers were based on the same interview guide (appendix 1 and 2) in order to compare and confront the answers. A second guide was made to lead to the interview with Skretting (appendix 3). All the interviews were realized via Skype; the two talks with insect producers were conducted in French as both the interviewer and the interviewee are French native speakers. However, the last interview with Skretting was directed in English since it was the native language of the interviewee. The decision of having the Skype call in the native language of the respondent was made in order to make the interviewee more comfortable and get the best and most precise answers during the interview.

As no face to face meeting could be arranged to direct the interviews, the video and chat software Skype was used as the best alternative. However, audio and video quality were variable during the interviews. Each interview was recorded. On one occasion, during the interview with Nextalim, the connection quality was very poor. For instance, the interview with Nextalim unfolded in an unfortunate way as the video call stopped several times. In addition, a technical failure with the recorder made the second half of the interview unreadable. Some elements of the unrecorded part could be transcribed from memory and from notes, however, other parts of the content are unfortunately lost.

The result and discussion will be combined in the same chapter. In this chapter, the content of the interview is categorized following four different themes: economic and technical, rules and regulations, nutritional and marketing challenges. Presented in subsections, each topic is presented and discussed based on the interviews' content and on scientific literature.
The marketing challenges of IM in fish feed should also be studied, in terms of a consumer survey in the future. However, due to the complexity and time-consuming nature of the chosen method, this part of the paper consists only in analyzing and comparing existing studies on consumer acceptance of fish fed with insect and consumer willingness to pay for organic salmon. This process of extrapolation from existing consumer behavior studies beyond their original observation range, will allow us to draw some tendencies concerning insect-fed salmon and draw broader conclusions. However, only a survey especially designed for this topic would allow to generate a precise statistical analysis.

3 Results and discussion

On the salmon feed market, IM could be valorized as the best alternative against other non-environmental friendly feeds as FM and SM. As said before, the utilization of FM and SM in aquaculture has been criticized for economic and environmental reasons. Today, insects possess a number of arguments in opposition to actual feed ingredients, nevertheless, its development also meet different challenges causing uncertainty concerning its adoption in salmon feed. Therefore, based on our set of interviews, the goal of this chapter is to analyze the introduction of insect into salmon feed from four different perspectives: nutritional, economic, regulatory, and market.

3.1 The introduction of insect into salmon feed from a nutritional perspective.

The interview with Skretting revealed interesting insight into the aquaculture feed industry approach on insects. Indeed, the feed producers are looking for alternatives to maintain the flexibility in their formulation (Skretting, personal interview, February 23, 2018). They also want to reduce their reliance on a finite resource and especially in the salmon production which requires nutrients that come from finite resource such as the Peruvian anchovy (Skretting, personal interview, February 23, 2018).

> "As we can't catch more fish from the oceans, the outcome for the industry is to find alternatives source of protein and oil" (Skretting, personal interview, February 23, 2018).

However, finding new alternative sources of omega-3 has been the main issues until now (Skretting, personal interview, February 23, 2018).

Second, Skretting underlines that they do not look for ingredients, but they look for nutrients that they need (Skretting, personal interview, February 23, 2018). They have quite a variety of different ingredients in a formulation for salmon (Skretting, personal interview, February 23, 2018). They look at nutritional profile of different ingredients, so they include a combination of ingredients that meet their specific criteria (Skretting, personal interview, February 23, 2018).

In this context the insect industry offers two products that could be used in salmon feed: IM and IO. The following section will highlight the interest of the feed industry for these two products. It will present the different nutritional characteristics of IO in function of the species. Then it will conclude by presenting different results of IM trials on farmed salmon.

3.1.1 Insect meal (IM)

It appears from the interview with Skretting that the feed industry is interested in IM. As they are looking for new ingredients, IM could be an alternative source of protein to FM and SM (Skretting, personal interview, February 23, 2018). IM has interesting nutritive values as it has a high level of protein, on average between 50-82% of the dry weight (Rumpold & Schlüter, 2013). In comparison a good quality FM can reach up to 73%, while soybean meal can contain up to 50 % of protein (Barroso et al., 2014). With a level of oil that varies between 10 and 30% depending on the specie, insects have a higher level of oil than FM (8.2%) and SM (3%) (Barroso et al., 2014). Finally, insects are a source of minerals such as potassium, calcium, iron, magnesium (Schabel, 2010), and selenium (Finke, 2002). Insects also contain vitamins but the vitamin profile strongly depends on the composition of insect diet (Henry et al., 2015). Since these nutritive characteristics vary by species, the following paragraphs will focus on the nutritional properties of black soldier fly larvae and mealworm as they are the two species produced by the companies interviewed.

- Black soldier fly larvae

Black soldier fly larvae are promoted as a high-value feed source, rich in protein and fat. This meal is highly digestible as it does not contain antinutrients. Moreover, its AA profile meets the nutritional needs of farmed fish (Nextalim, personal interview, February 16, 2018). According to Makkar et. al. (2014), Black soldier fly larvae contains around 40-44% crude protein (CP). It is also a source of fat, but the amount varies extremely and depends on the diet. Therefore, the level of fat in the larvae can reach 50% if it is fed on oil rich food. Moreover, it is particularly rich in calcium (Ca: 5-8%DM) and phosphor (P: 0.6-1.5DM), it also contains magnesium, iron, manganese, zinc and copper.

- Meal worm

The Black soldier larvae mealworm meal has a high protein content (70%) (table 2) and a well-balanced profile of essential AA. Entomo Farm's IM is also highly digestible and rich in lysine, therefore, the protein powder is particularly adapted to aquaculture. It contains no trace of contaminants such as heavy metals and PCB (in opposition to FM). Due to its hypoallergenic virtues, mealworm meal is already used by pet food companies (Entomo Farm, personal interview, February 05, 2018). Moreover, according to Entomo Farm, their IM has good palatability properties since fishes fed with this meal show good appetite (Entomo Farm, personal interview, February 05, 2018).

Table 2: Physicochemical features of Entomo Farm meal

Dry Matter	95%
Caloric Value	400 kcal/100g
Proteins	70%
Lipids	8%
Carbohydrates	12%
Crude Ashes	5%
Phosphorous	9500 mg/kg

Finally, insect farming also presents a certain level of flexibility in its physicochemical composition depending on the insect species or on the feed substrate (St-Hilaire, 2007; Entomo Farm, personal interview, February 05, 2018). According to Entomo Farm, salmon feed companies could select an insect or insect species with characteristics (protein, fat, minerals, etc.) that are more adapted to a specific stage of the salmon life cycle (alvin, fry, parr, smolt or adult) (Entomo Farm, personal interview, February 05, 2018).

3.1.2 Insect oil (IO)

The greatest challenge for the salmon feed companies is to find new sources of omega-3 (Skretting, personal interview, February 23, 2018). But can IO be an alternative to FO? It resulted from the interviews that both oil produced by Entomo Farm and Nextalim are not an alternative to FO. Indeed, the mealworm oil produced by Entomo Farm is poor in omega-3 while the black soldier larvae oil produced by Nextalim does not contain omega-3 (Nextalim, personal interview, February 16, 2018). Nevertheless, the aquaculture is interested in IO as it presents other nutritional qualities. The principal advantage of black soldier oil is its high content of lauric acid (C-12:0), which according to Nextalim has antimicrobial virtues which could stimulate the immune system of the fish (Nextalim, personal interview, February 16, 2018). On the other hand, oil made with mealworm is rich in omega-6 (Entomo Farm, personal interview, February 05, 2018).

For Skretting, IO could be a suitable ingredient for inclusion in feeds. However, it is something that cannot completely replace FO.

> "It is not going to be the sole oil source because we need some things like omega-3 which IO does not have. Therefore, it could be used in fish feed but in combination with other oil in order to reach the nutritional requirement set by Skretting" (Skretting, personal interview, February 23, 2018).

The fatty acid profile of the insect does not contain omega-3. However, in the future, insects could contain omega-3 depending on the substrate with which they are fed. Indeed, the fatty acid composition of the larvae depends on the fatty acid composition of the diet (Makkar, Tran, Heuzé, & Ankers, 2014). For example, a study on black soldier fly has shown that "the lipid content of black soldier fly prepupae can be increased and manipulated to include desirable fatty acids such as ALA, EPA, and DHA by feeding the larvae waste material from fish processing plants" (St-Hilaire, 2007, p. 313). Moreover, their findings "indicate an increase (from 21 to 30%) in the lipid content of prepupae fed with fish waste, and more importantly, substantial enrichment (2.5–3.8% of total lipid) of omega-3 fatty acids" (St-Hilaire, 2007, p. 313). Therefore black soldier fly can potentially "reduce animal waste and recycle omega-3 fatty acids, while producing a high-quality animal feed that is a suitable replacement for FM and FO in animal diets"(St-Hilaire, 2007, p. 313). However, according to Henry, Gasco, Piccolo, & Fountoulaki (2015, p. 14), "it seems that it is more economically viable to use omega-3 components (by-products of the fish filleting industry; microalgae, phytoplankton, etc.) to feed directly the fish rather than enriching insects in order to feed them to the fish".

3.1.3 Results of insect-based diet on Atlantic salmon.

Skretting said their research into using IM for salmon has been positive. This statement corresponds with recent studies on feeding salmon with insects. Belghit et al., (2018) studied the inclusion of black soldier fly larvae meal and oil into salmon feed. They showed that it is possible to have a feed with 60% IM in combination with IO in the diets of Atlantic salmon without any negative effect on growth performances, feed utilization, apparent digestibility and whole-body composition. Furthermore, the black soldier fly protein meal appears to be a good source of AA and are well absorbed by Atlantic salmon.

Another study led by Lock et al., (2016), tested the replacement of FM with black soldier fly larvae meal on post smolt. The results indicated that IM can replace FM up to 50% without any significant effect on growth. Moreover, replacement of FM with IM did not pose challenges in terms of diet formulation or diet production. They confirm that IM of black soldier fly meal has a well-balanced AA profile which makes it an excellent replacement of FM in the diet of Atlantic salmon.

3.1.4 Other alternatives

The feed industry is always looking for new alternatives to maintain the flexibility in their formulations (Lock et al., 2016). New sources of protein as well as new sources of oil are necessary to reduce the dependency on FO and fish protein and other ingredients. Today, IM and IO represent a potential substitute to today's ingredients. However, different alternatives are also being studied at the moment. The next paragraphs will shortly present these alternatives sources of protein and oil.

3.1.4.1 Plant protein and oil

Plant protein

Today, SM constitutes the first alternative to FM. The bean has an important economic advantage concerning salmon aquaculture. First, it is a cheap source of protein (35%), oil (17%) and carbohydrates (31%) (Liu, 1997) and second it is available in large quantities (Shepherd et al., 2017). In 2017, SM world production was estimated at 226.45 million metric tons and is projected to increase 4.5% to reach 236.73 million metric tons in 2018 (USDA, 2018). In January 2018, the price of SM was 384.25 dollars per metric ton while the one metric ton of FM was estimated at 1567.50 dollars (Index Mundi, 2018a, 2018b).

In term of price stability, it can be observed by looking at the following figure (4) that the price has increased since 1998 (going from 231 dollars per metric tons in January 1998 to 384.25 dollars in January 2018). SM has also shown some sharp fluctuations in the last 10 years (figure 4). Nevertheless, despite fluctuations in its market, SM is still one of the cheapest and abundant sources of protein.

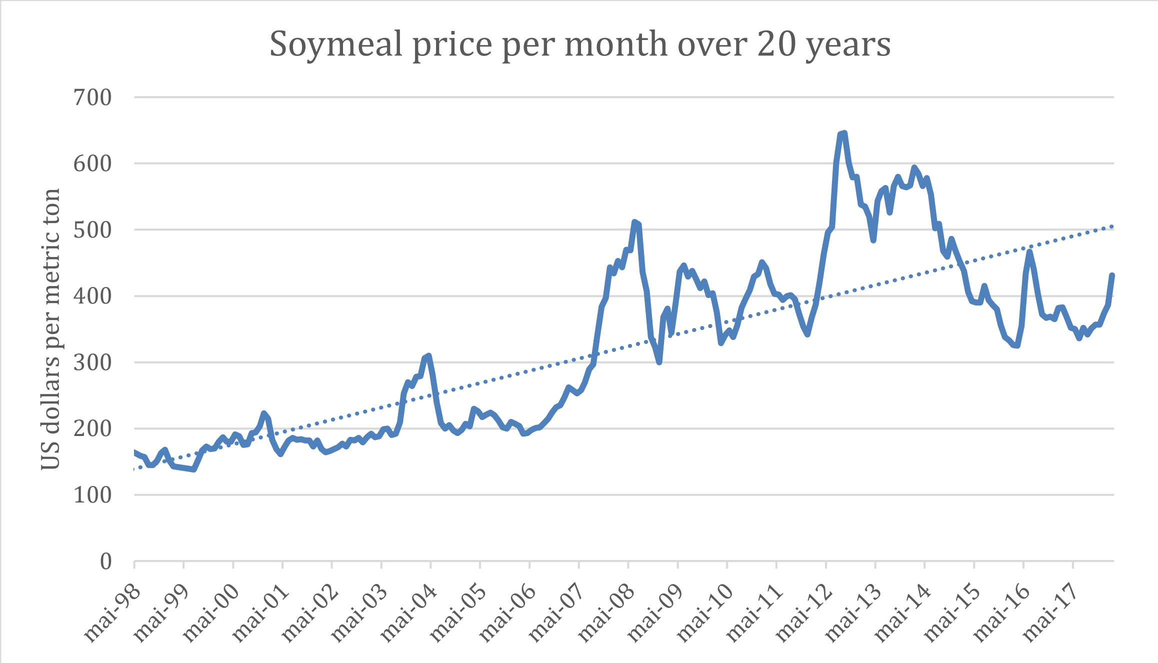

Figure 4: Soybean Meal price per month over 20 years - US dollars per metric ton. Data retrieved from Index Mundi (2018b)

SM cannot completely replace FM. SM and other plant sources have an unbalance AA profile and are harder to be absorbed by salmon (Glencross, Booth, & Allan, 2007; Lock et al., 2016). According to Naylor et al. (2009), "plant meal has less digestible organic matter, in the form of insoluble carbohydrates and fiber, leading to higher levels of fish excretion and waste" (p. 15016). Other studies have shown that the inclusion of high quantity soya in salmon diet decreased the growth performance of salmon (Mundheim, Aksnes, & Hope, 2004). This happened because, antinutritional factors interfere in salmon digestion and the absorption of the feed (Mundheim et al., 2004).

Moreover, from an environmental perspective, soybean production presents some challenges. First, the high demand for soybean has a major impact on the destruction of forest, savanna and prairies (Scharlemann & Laurance, 2008). Moreover, the substitution of this environment not only jeopardizes ecosystems (Carvalho & Lacerda, 2006) but also contributes to global warming. By releasing around 20 % of the global greenhouse emission, deforestation is one of the main factors of climate change (WWF, 2012).

The production of soya is highly demanding in water (Carvalho & Lacerda, 2006; Di Marzio et al., 2010). Its cultivation in dryer areas depends on irrigation which place the water reserve under pressure (Carvalho & Lacerda, 2006). Moreover, the intensive utilization of fertilizer and pesticides necessary for its production also represents an environmental threat (Di Marzio et al., 2010). The use of fertilizer and pesticides not only pollutes the soil and water (Di Marzio et al., 2010) but is also present in the soybean.

Finally, most of the soy feed comes from genetically modified (GM) culture (GM soya represents 77% of the world production). Norwegian salmon industry has banned the use of genetically modified soya in salmon meal. Studies around the world have shown low consumer acceptance for GMO food (Hobbs & Plunkett, 1999). Therefore, fish fed with genetically modified soya could also meet a certain resistance from the consumers.

Plant oils

In addition to plant proteins, plant oil has also been introduced into salmon since 2010 (Shepherd et al., 2017). Canola, soy flax, and palm oils are increasingly used in order to partly replace FO (Naylor et al., 2009). These oils were increasingly used as the price of the FO has increased since the 2000s. Indeed, before 2000, the price of FO was lower than the various plant oils, but its increasing price combined with extreme price variability pushed the feed producers to find cheaper alternatives. Moreover, in term of availability plant oil "can be produced in sufficient quantity to meet the growing aquaculture demand" (Naylor et al., 2009, p. 1517). Nutritionally, plant oil cannot replace FO but it can complement to provide energy (Shepherd et al., 2017), without increasing the amount of long chain omega-3 fatty acids (Naylor et al., 2009; Shepherd et al., 2017). Salmon farmers use feeds containing "blends of plant and FOs during portions of the grow-out phase, followed by a switch to FOs some months before harvest to increase omega-3 oil levels in fillets"(Naylor et al., 2009, p. 15107).

3.1.4.2 Rendered terrestrial animal products:

Land animal by-products (LAPs) is a source of animal protein and lipids coming from meal, bone meal, feather meal, blood meal and poultry by-products. Animals proteins have a more complete AA profile and can be a richer source of lysine and phosphorous (depending on the animal by product) than plant proteins (Naylor et al., 2009). Moreover, it is also a much cheaper source of protein than FM.

Nevertheless, two major obstacles hinder the use of LAPs in salmon feed. The first hindrance is the reluctance of retailers and consumers of using animal products in meal. Indeed, studies have shown that consumers are opposed to the use of LAPs as they consider it unnatural to the fish diet. In addition, fears from the dioxin crisis and horse meat contamination have had a negative impact on consumers acceptance of LAPs (Shepherd et al., 2017). Since the consumers do not wish to eat salmon fed with LAPs, the retailers are also opposed to the introduction of animal by-product in salmon feed (Shepherd et al., 2017).

In consequence of the strong resistance from retailers and consumers, the second obstacle, is the voluntary ban on use of LAPs by the Norwegian and Scottish salmon industry (Shepherd et al., 2017).

In summary, despite good nutritional and economical properties it is unlikely to see the introduction of land animal by-products in the near future.

3.1.4.3 Seafood by-products

Seafood by-products can potentially be an important source of nutrients that could reduce aquaculture dependencies on forage fisheries (Naylor et al., 2009). Indeed, in terms of quantity, it has been estimated that seafood by-products and by-catch are equal to the average landings of the forage industry (Naylor et al., 2009). Trimmings and other processing by-products are cheap sources of marine raw material that can be transformed into FM and FO (Naylor et al., 2009). However, exploiting by-catch for feeds raises environmental concerns since it can potentially have a negative effect on fish stocks through loosened by-catch regulations (Naylor et al., 2009).

Furthermore, other barriers hinder the utilization of marine by-products in feed. First, despite the abundance of fish waste, there is not enough infrastructure to transform the raw material into FM and FO (Naylor et al., 2009).

Second, the nutritional value from by-product meals differs from the traditional FM composed of whole small pelagic fish. By-products meal lack of structural protein as these proteins are mostly contained in the removed filet. Therefore, the meal has a lower protein content and higher ash content than the traditional FM. The greater proportion of ash can induce cataract as well as digestive problems for fish (Naylor et al., 2009).

Finally, seafood processing wastes can contain traces of PCBs and dioxins which can bioaccumulate in farmed fish (Naylor et al., 2009). The need to monitor this highly variable source of feed can discourage investment in the development of seafood by-products into FM and FO (Naylor et al., 2009).

Nowadays, seafood by-product optimization meets scalability challenges (Naylor et al., 2009). However, according to Naylor et al. (2009), “if the scarcity of other feed sources increases the relative value of using seafood by-products in aquafeed, significant investments in solving the issues of contaminants, ash concentrations, and production scale are likely to be made” (p. 15108).¶

3.1.4.4 Krill

Krill can also be a source of high quality nutrients for salmon feed. Rich in protein and lipids, krill is especially interesting for the salmon aquaculture since it contains omega-3. In 2009, krill presented the largest underfished commercial marine resource (Naylor et al., 2009). Indeed, less than 15% of the global quota (fixed at 6 mmt) was harvested (Naylor et al., 2009).

However, despite its nutritional potential, krill quality has proved to be too variable and highly perishable (Naylor et al., 2009). According to Phleger, Nelson, Mooney and Nichols (2002), the fatty acid profile of krill is strongly determined by the season and the location of the harvest. In addition, the highly unsaturated fatty acids are subjected to fast oxidation. Expensive infrastructures are necessary in order to collect, store, transport and process the krill and avoid any degradation (Kawamura, Nishimura, Matoba, & Yonezawa, 1984; Naylor et al., 2009).

Harvesting krill has also been criticized for its environmental impact (Naylor et al., 2009). Indeed, krill is at the bottom of the food web therefore eventual depletion of the krill stock could have disastrous effects along the entire food chain. Cautious regulation and fisheries management has to be implemented in order to prevent from environmental disaster. According to Naylor et al. (2009), a precautionary approach has to be adopted as there are insufficient data on krill to understand the effect of fisheries on the krill population and on the ecosystem.

3.1.4.5 Algae and algae like microorganisms

Algae like microorganisms seems to be one of the most serious alternatives to FM and FO. Seaweeds and microalgae species are rich in protein and have good AA profiles which make them valuable protein alternatives for fish feed (Shepherd et al., 2017; Tocher, 2015). But, it is as an alternative to FO that microalgae are the most valuable (Tocher, 2015). Microalgae could offer the ideal long-term, sustainable solution to the problem of long chain omega-3 fatty acids (Tocher, 2015). Two different types of microalgae are used to produce long chain omega-3 fatty acids. The first type is photosynthetic microalgae, which are commonly used in hatcheries as a source of long chain omega-3 fatty acids for live feeds (such as rotifers and Artemia nauplii)

(Tocher, 2015). Heterotrophic microalgal species[1] are used for large scale production of DHA. Algae oil trials have shown promising results as replacing FO by algae does not affect fish growth or welfare while it increases the concentration of DHA in the filet (Naylor et al., 2009).

Nevertheless, according to Torcher (2015), high price and limited production are the two main challenges which algae oil is facing at the moment. In other words, "production volumes would have to be increased and costs reduced before these products could be viable for wider application in aquaculture"(Tocher, 2015, p. 102). Because of the increasing cost of FO, feed companies have invested in micro algae as an alternative. Therefore, the introduction of algae oil into fish feed is likely to arrive in the near future as the feed company Skretting has managed to replace FO with the help of algae since 2017 (Skretting, personal interview, February 23, 2018).

[1] Heterotrophic algae such as Crypthecodinium and thraustochytrids

3.2 The introduction of insect in salmon feed from an economic perspective.

According to the insect sector, IM constitutes a good alternative to FM from an economic point of view. Indeed, insect producers promote their product as a highly available, low and stable priced source of protein (Entomo Farm, 2018; Ynsect, 2018). However, these arguments contrast with Havbrún's opinion, as they see no great interest in using IM in feed because of IM scarcity and high price.

The goal of these next sections will be to clarify the situation by using data from the interviews made with insect producers and salmon feed manufacturers.

3.2.1 The production of IM

Today, around 40 companies constitute the insect sector in Europe where the size of these companies varies from startups to midsize businesses. Some of these companies have a production unit while others are raising funds to develop their industrial tool (Entomo Farm, personal interview, February 05, 2018). In term of production, according to Nextalim and Entomo Farm the total production of IM in Europe is slightly less than 1000 tons per year (Entomo Farm, personal interview, February 05, 2018; Nextalim, personal interview, February 16, 2018). Compared to the 4481000 tons production of FM in 2014 (figure 5), todays production of IM is negligible. However, the production of IM is expected to grow considerably in the foreseeable future.

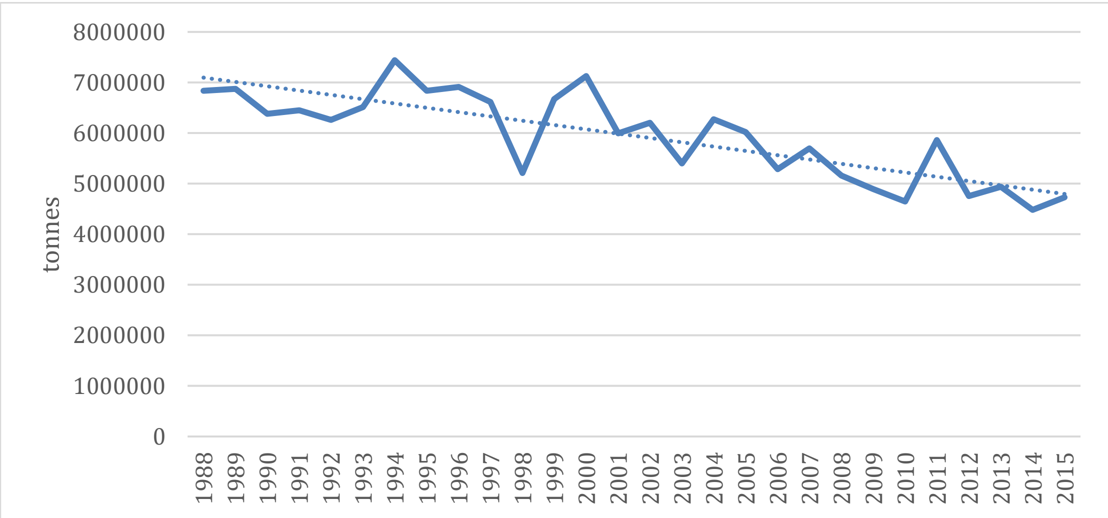

Figure 5: Total world production of FM from 1998 to 2015- data retrieved from IFFO FM and FO Statistical Yearbook.

Before July 2017, the EU legislation did not authorize to the use of insects in order to feed farmed animals. This situation hindered the development of the insect sector since the production was only limited to research and development. It resulted in an absence of large scale production of insects for commercial purposes.

Since July first, 2017, the European Union has authorized the use of seven insects species[2] for aquaculture (Regulation (EU) N° 2017/893). This regulation gave the green light for further development of the insect sector. This announcement liberated the sector and allowed the insect companies to develop their industrial tools.

The insect producers are racing against the clock to develop their industrial capabilities to increase their production. In this context, most of the insect sector has adopted different methods of production. The first one is the centralized production which carries out all the steps from the reproduction of insect to the production of the final product (figure 6). Nextalim is producing insect following this system of production. The production itself is highly automated as latest technology and automation perform many tasks. Indeed, tasks like feeding, sorting and cleaning insect's cages are robotized. Moreover, environmental parameters such as humidity and temperature are automatically controlled. Today, Nextalim's production tool is still under development. According to Nextalim their production during the testing phase is approximately one to two tons per week. However, if the tests are conclusive, the production should progressively increase to reach 14-15 tons per week by the end of 2019 (Nextalim, personal interview, February 16, 2018).

[2] The following species are allowed to be used as feed for aquaculture: black soldier fly, house fly, yellow mealworm, lesser mealworm, house cricket, banded cricket & field cricket

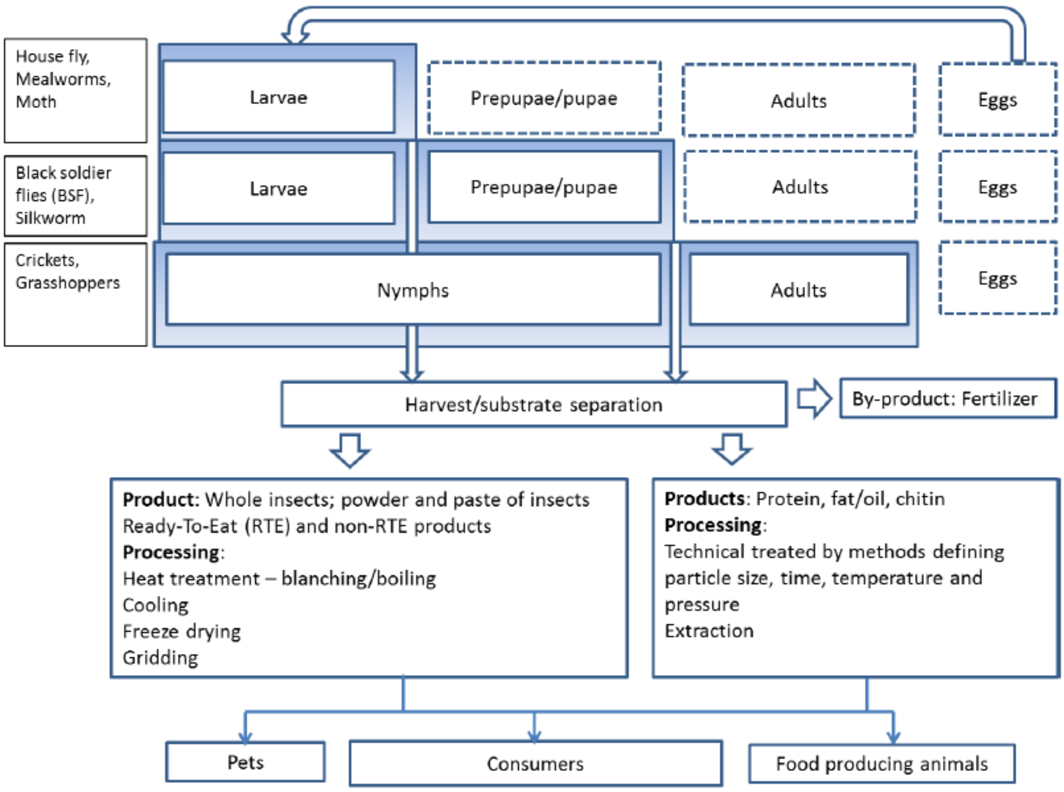

Figure 6: Overview of the chain from production to consumer (EFSA Scientific Committee, 2015, p. 12)

The second method has been developed by Entomo Farm and consists in a cooperative decentralized production. The production is divided in three phases (figure 7). The first phase consists in the reproduction of the insect where the eggs are collected and confined in boxes. These boxes are then sent to the local farmer (called Entomo farmers) for the breeding phase. During this phase, the local farmer will house and feed the mealworms until they reach maturity. Finally, the last step, consists in processing the insects. After the boxes are retrieved from the local farmer, the insects are slaughtered, then dried. The dried insects are compressed and transformed into IO and IM (Entomo Farm, personal interview, February 05, 2018).

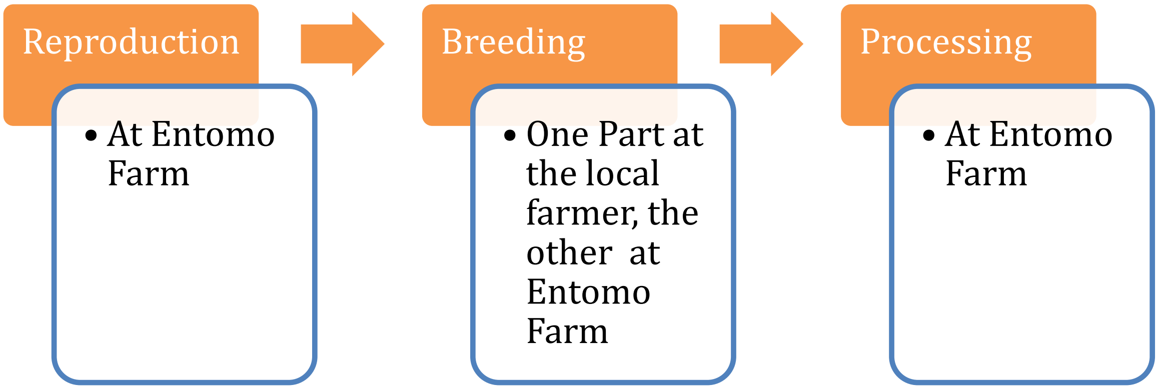

Figure 7: Entomo Farm production model

Having a part of the production delocalized allows Entomo Farm to reduce the space use for breeding the insects as the space is used by the local farmer. By reducing the space allocated for breeding, Entomo Farm is able to increase its production by limiting investment in storage infrastructures (Entomo Farm, personal interview, February 05, 2018). However, the development of this business model turns out to be also challenging since Entomo Farm has to find and convince more local farmers to collaborate with them. If the system works, the goal will be to extend the model with multiple nursing processing units across France and Entomo farmers around it (figure 8).

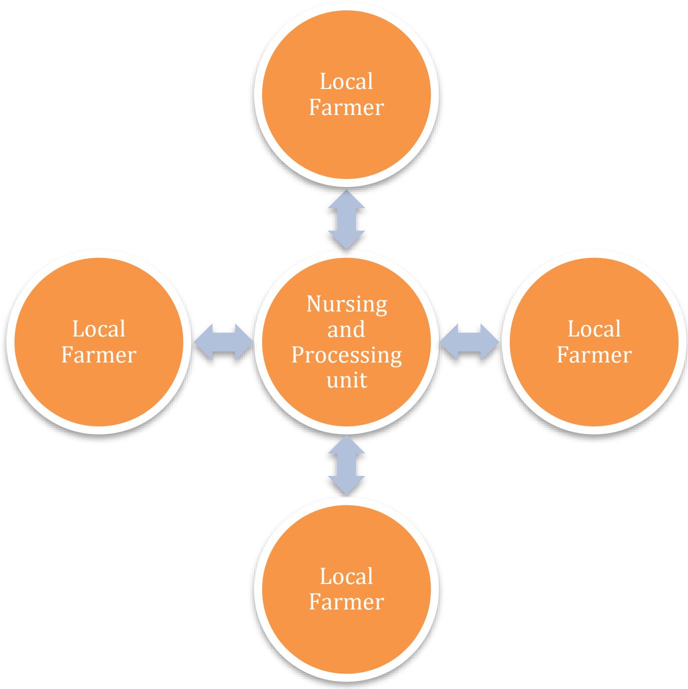

Figure 8:Entomo Farm delocalization system

Today, the quantity produced each week cannot be defined by this type of decentralized production since, our interlocutor inside Entomo Farm did not wish to communicate their current production neither the growth predictions. Moreover, this can be explained by the difficulty to predict the future production since their future production greatly depends on local farmer acceptance to work together with Entomo Farm.

Finally, insect has a great potential in term of production. As said previously, they can be produced at an industrial scale where an important part of the production can be fully automated which allows to the labor costs to be reduced. Second, insects have a high feed conversion efficiency in comparison with livestock since they use a smaller amount of feed to produce 1 kg of biomass (Nakagaki & Defoliart, 1991; Rumpold & Schlüter, 2013).
Moreover, the insects used for feed can be raised on organic wastes (Rumpold & Schlüter, 2013). The producer can use cheap ingredients to feed the insects as insects can be fed with many cheap substrates. For instance, the black soldier fly larvae can feed on a large variety of substrate such as manure, meat product and green waste (Rumpold & Schlüter, 2013).

The mealworm larvae feed mostly on organic wastes from products derived from fruit and vegetable (Entomo Farm, personal interview, February 05, 2018). The mealworm's feed can contain a certain level of animal waste since tests have shown that it can feed on chicken broiler (Ramos-Elorduy, González, Hernández, & Pino, 2002; Rumpold & Schlüter, 2013)

Nevertheless, it results from the interviewees that, today, the producers are only using agricultural coproducts from cereal as a consequence of the European legislation which limits the ingredients used for feed. In the future, the European regulations might change to allow the producer to use more types of waste in order to feed the insects. The limitation of feed for insect by the European law will be studied in more details in the section 3.3.3 of this master thesis.

3.2.2 Price

Both interviews with the two insect producers confirmed that the price of their IM is still higher than FM. However, their perception on the evolution of the price compared to FM vary between the two producers. On one hand, Nextalim had a positive opinion on the evolution of the price of IM in the future. Nextalim confirmed that the price of IM is still higher than FM. For the moment, as they are testing their industrial tool, the price of IM at Nextalim is around 2 euros for one kilogram of black soldier larvae meal (2000 euros tons). Nevertheless, according to Nextalim there are competitors that offer IM at a lower price than FM since they have a larger production. In general, Nextalim shows some confidence in the fact that the price of IM will be cheaper than FM in the future. Their argumentation is based on the evolution of these last year's FM trend. According to Nextalim, if the price of FM continues to increase in the future and the production of IM will grow, the price of IM will be lower than FM. Indeed, from an economic point of view, the FM industry is confronted with a complex situation where the demand from the aquaculture industry (Asche & Tveterås, 2004; Pauly et al., 2011) is increasing while the production is decreasing (Naylor et al., 2009).

It can be observed that the world production of FM has reached its limit (Olsen & Hasan, 2012). Between 1998 and 2015 FM production has declined over 2 million tons representing one third of the global production (figure 5). Moreover, the limitation of world annual catch is limited to around 90-92 million tons per year (Olsen & Hasan, 2012; Waite et al., 2014) (figure 2) shows that no increase in effort from the FM industry would increase the production.

In addition, the increase of the world aquaculture production has amplified the demand for FM putting even more pressure on the fish stock (Naylor et al., 2009; Pauly et al., 2011). Indeed, the expansion of the intensive aquaculture farming and development of premium aquaculture species (mostly predator such as lobster and salmon) around the world has increased the demand for FM, resulting in 35% increase of the demand from the aquaculture between 1988 and 2002 (Waite et al., 2014).

In consequence, as the supply has been unable to follow the demand due to the limitation of the fish stock, the price of FM has globally increased (Barroso et al., 2014). As figure 9 indicates, the price of FM in the international market has increased from 703 dollars per metric ton in January 1998 to 1567.50 dollars per metric ton in January 2018, representing a 120% increase in 20 years. Moreover, the trend is not expected to change in the future since the need for fish protein and oil is not expected to decrease in the future (Péron, François Mittaine, & Le Gallic, 2010).

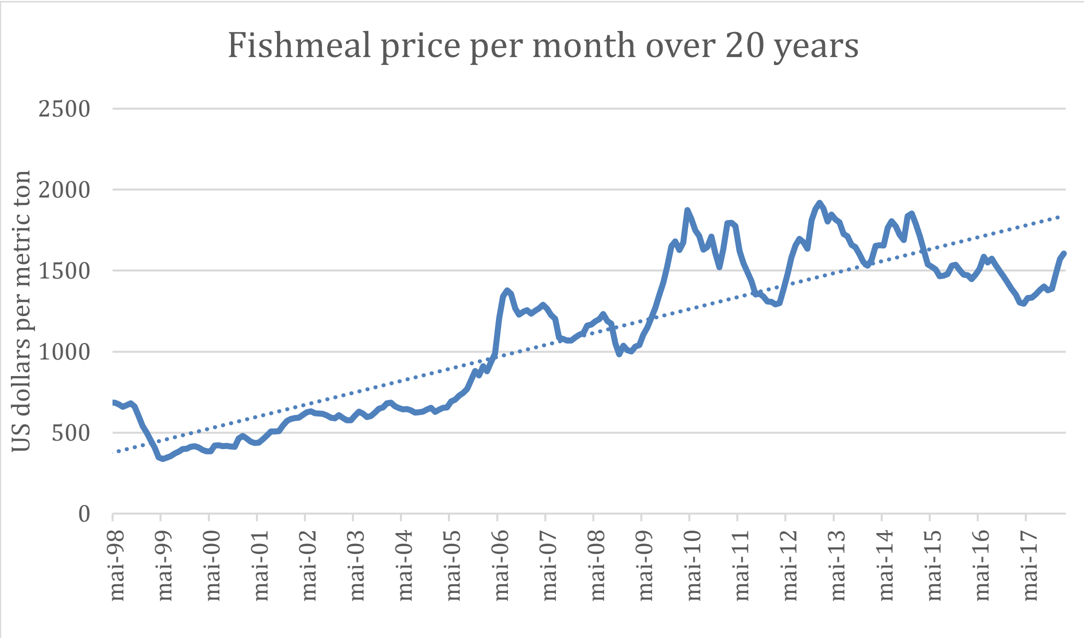

Figure 9: FM price per month over 20 years-US dollars per metric ton. Data retrieved from Index Mundi (2018a)

In addition to the expected price increase, FM is also known for its volatile price as it depends strongly on the catch (Asche & Oglend, 2016). As it can be seen on figure 9 above, FM suffers from a lack of price predictability. For example, between January 2009 and April 2010, the cost of one metric ton of FM skyrocketed from 1,009.00 dollars per metric ton in January 2009 to 1,821.00 dollars per metric ton in April 2010, about 80.5% increase in 16 months. During this period the price could vary up to 12% (March-April 2010) between each month. The peaks and valleys drawn on the chart show that the fluctuation between January 2009 and April 2010 is not an isolated phenomenon.

If the increase of demand can explain an upward trend in price, it cannot however explain the 'boom and burst' pattern. Instability of the catch from year to year mostly explains the sharp variations (Terazono, 2015). Indeed, the catch has been very variable since the majority of the main species of pelagic fishes used in FM have experienced collapse (Deutsch et al., 2007). For example, the Peruvian anchovy stock has collapsed many times the last 40 years. If El Niño[3] is the main reason for these critical declines, overfishing increases the phenomenon by deepening the crashes and delaying the recovery of the stock (Deutsch et al., 2007).

Moreover volatile price is expected to be intensified (Terazono, 2015). Indeed, as the warming of the sea water had a negative effect on some pelagic species and warming phenomena such as El Niño are expected to happen more regularly, harvest drops are predicted to become strengthened in the future (Terazono, 2015). Second, FM is also linked with issues such as environmental sustainability, food sustainability, and food safety (Asche & Tveterås, 2004; Naylor et al., 2000; Olesen et al., 2011).

According to Olesen et al. (2011), "the use of fish in producing feed has caused critical questions concerning the environmental sustainability of using marine resources in salmon feed production" (p. 394). Indeed, it has been observed that there is an increasing amount of fish species which are under intense fishing pressure due to the increasing demand for FM (Olsen & Hasan, 2012; Péron et al., 2010). According to Olsen & Hasan (2012) half of the world stock of wild fish is fully exploited and 32% is overexploited or depleted. Therefore "maintaining heavy fishing pressure at the lower levels of the food web, spurred in part by ever increasing demand for FM in the growing aquaculture sector, may make it difficult for marine fish species at higher trophic levels to recover even if fishing pressure on these stocks was significantly decreased" (Deutsch et al., 2007, p. 247).

In parallel, FM also raises issues in term of food security. It is estimated that 30% of the total catch of wild fish is transformed into FM and FO (Ogunji, Kloas, Wirth, Schulz, & Rennert, 2006). As the fish stock is under high pressure, some argue that it should be intended for direct human consumption instead of farmed fish production (Metian, 2009).

[3] El Niño is "the name given to the occasional return of unusually warm water in the normally cold water [upwelling] region along the Peruvian coast, disrupting local fish and bird population" (Trenberth, 1997, p. 2772).

Entomo farm was less positive on the evolution of the price. They could not communicate the price of their mealworm meal. However, the price varies as a function of the quantity ordered. However, at a certain amount of quantity the price is stable over time.

When asked if the cost of IM will decrease in the future, they replied that they hope that the price is going to be lower than FM. For the moment they are producing volumes that are largely inferior in comparison to FM. They recognize that the price is a serious challenge to the adoption of IM.

> "People are interested and would be ready to go for it because they like the product for its ecological and nutritional properties, but the price is stopping them" (Entomo Farm, personal interview, February 05, 2018).

Nevertheless, Entomo Farm think that the future capability to mass produce insects and the fact of a constant increase in the insect offer will unlock the situation.

Finally, it is difficult to compare the price of IM with FM or SM since nutritionally, the properties of these meals are different. Although IM is more expensive than FM and SM, IM has a higher concentration of protein as it can contain up 82% of protein in function of the insect species, while the protein content is 73% for FM and 50 % for SM (Henry et al., 2015). In terms of AAs, IM and FM (10-30%) have a balance profile while SM has an unbalanced profile (Henry et al., 2015). As the proportion of oil contained in IM is also higher than FM (8.2 %) and SM (3.0%) (Henry et al., 2015), using IM could reduce the amount of oil added into the feed. Therefore, IM, FM and SM should be compared on a nutrient level since one ingredient cannot nutritionally fully replace the other. For instance, today, soy cannot replace FM, therefore supplement of lysine has to be added into the diet. However, IM diet requires less supplementation than regular diet (Lock et al., 2016).

The digestion of the ingredients is also a factor that has to be considered. Indeed, a low digestibility reduces the absorption of the nutrient by fish. Good digestibility would improve the feed factor and therefore indirectly reduce the feeding cost. In conclusion, not only the market price has to be studied while looking at the cost difference between various alternatives, we have to look at the big picture and consider the price per nutrient (protein, oil, AA, etc.) unit and digestibility coefficient as well.

In summary, today, IM cannot replace the FM as the limited production (<1000 tons) cannot substitute FM or SM. Moreover, due to its limited availability, the price of IM and despite its good nutritional properties, IM are still costlier than FM. Nevertheless, all the people interviewed believe that its price shall decrease rapidly in the coming years with the industrialization of the production. Therefore, it seems that IM shall reach a competitive price soon since according to Skretting, feed containing insect should arrive on the salmon feed market in the immediate future (Skretting, personal interview, February 23, 2018).

3.3 The introduction of insects from a regulatory perspective

Although this study focuses on the adoption of insect feed by the Norwegian salmon aquaculture, this paragraph focuses on regulations made by the European Commission. Despite not being a member of the European Union (EU), Norway is member of the European Economic Area (EEA), therefore it complies with the EU laws on issues such as the single market and environmental policy.

Before the 1st July 2017, Article 7 of the Regulation 999/2001 prohibited the use of processed animal protein as a raw feed material. Insect was therefore considered as a processed animal protein and could not be used in fish feed (IPIFF, 2017; Lähteenmäki-Uutela & Grmelová, 2016). In addition, there was a lack of scientific knowledge regarding the microbiological, chemical and environmental safety risk arising from the consumption and production of insect feed (EFSA Scientific Committe, 2015). Due to insufficient knowledge, the European Commission adopted the precautionary principle which did not allow the introduction of insect food and feed until more scientific studies made the light on insect's potential health and environmental hazards. To clarify the situation , the European Commission asked the European Safety Authority (EFSA) to report a scientific opinion on the risk cited above (EFSA Scientific Committe, 2015). The overall conclusion of the EFSA opinion paper underlined the "strong influence" of the substrate used to feed insects. Biological hazards (such as bacteria, viruses, fungus contamination) and chemical hazards depend on the substrate. Regarding the environmental impact of the insect farming, the EFSA considered that the risks are comparable to other animal farming production (EFSA Scientific Committe, 2015). Finally, the EFSA committee highlights that there are still a number of uncertainties due to the lack of knowledge concerning insect farming that need to be addressed such as chemical accumulation from substrates; the occurrence of human animal bacterial pathogens in insects processed for feed (EFSA Scientific Committe, 2015)

On 24 May 2017, a new regulation (2017/863) from the European commission amended the prohibition and partially uplifted the feed ban rules regarding the use of processed animal protein. Henceforth, this amendment allows the use of processed animal protein source other than ruminant in aquaculture feed (IPIFF, 2017; Lähteenmäki-Uutela & Grmelová, 2016). However, the authorization is to the following seven insect species: black soldier fly, house fly, yellow mealworm, lesser mealworm, house cricket, banded cricket and field cricket (Regulation 999/2001).

Despite the recent modification of the European regulation, it resulted from the interview that the legal framework regarding the production and the use of insect protein remains complex. Indeed, insect companies have to comply with rather complex legal requirements regarding the insects themselves and the feed or substrate fed to the insects. According to Nextalim, it is difficult to introduce a new product on the market since they have to follow many regulations. The producer has to go through a long process which require them to prove that the feed is safe and respect environmental norms. For small companies like Nextalim, the regulatory process which demands provision of all the data represents a serious obstacle to their development as it is costly and time demanding.

3.3.1 International Platform of Insects for Food and Feed (IPIFF)

As the insect sector is still a niche market composed mainly of small businesses, there is an important collaboration between the different companies. According to the Nextalim cofounder, as the insect represent a small niche market, there is a good collaboration between the different insect companies as they exchange information facilitating the development of the sector. Therefore, they do not describe them as competitors but as “comrades”.

Moreover, IPIFF is an organization that promotes insects as a source of nutrient for human consumption and animal feed in order to represent better the interests of the insect sector at the European level. Composed of 42 members (including Entomo Farm and Nextalim), they are in contact with the European institutions (The European Commission, the EU Member States authorities, the European Parliament and the European Food Safety Authority). IPIFF especially concentrates its effort in lobbying for a better EU legislative framework regarding insect production (Entomo Farm, personal interview, February 05, 2018; Nextalim, personal interview, February 16, 2018; IPIFF, 2018).

3.3.2 Limited authorized insect species for feed purpose

It resulted from the interview with Entomo Farm that the actual regulation allowing only the production of seven species is too restrictive. Insect producers are studying new insect species[4] that have a potential for feed use (Entomo Farm, personal interview, February 05, 2018).
Today, new insect species cannot be introduced on the market without modification of the regulations. The limitation of species seems to be a concern to the entire industry as modifying

[4] The interviewee did not wish to specify which species they are developing.

the regulation to widen the number of insects authorized constitutes one of IPIFF demands. Nevertheless, the new species have to meet certain criteria: first the insect cannot be an alien species or invasive species. Second, the new species must not have adverse effects on plant health, animal health or human health. Finally, it must not be recognized as vectors of human, animal or plant pathogens.

3.3.3 Limitation in feed for insects

The limitation of substrate to feed insects represents another issue which the insect sector is facing. Insects can bio-convert low quality biomass (such as food waste, feces, animal by-product and organic by-product) into nutritionally valuable proteins. Therefore, IM is often promoted by the producers as a product from circular economy (as mentioned on Nextalim website and Innovafeed website). In a circular economy, organic waste from salmon aquaculture industry could be directly used to feed insects which would then be used to feed salmons (figure 10).

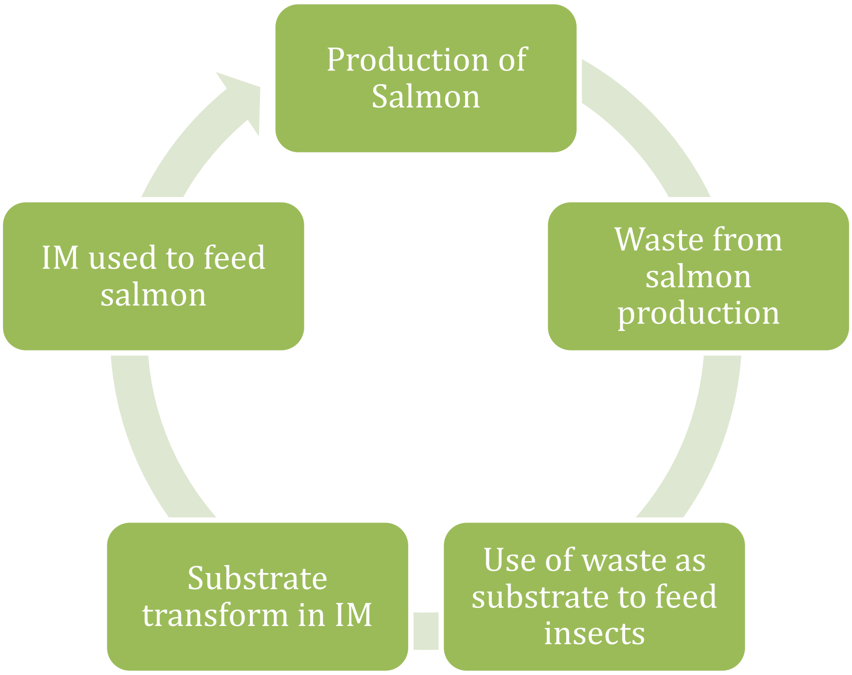

Figure 10: Circular production of salmon using insect-based feed

However, it resulted from the interviews that due to European restrictions on substrates, the current production of insect cannot be qualified as part of a circular economy production. Indeed, no waste are for the moment used to feed insects as they are currently only fed with plant products (mostly cereal byproducts) and few animals byproducts (Entomo Farm, personal interview, February 05, 2018; Nextalim, personal interview, February 16, 2018).

The European legislation on feed is rather complex as insects are considered as a "farmed animal"[5] by the European legislation and therefore is submitted to strict feed regulation. Indeed, Annex III of Regulation (EC) No 1069/2009 prohibits the use of certain materials that could be used to feed insects, including:

1. "Feces, urine and separated digestive tract content resulting from the emptying or removal of digestive tract, irrespective of any form of treatment or admixture"
2. "Seeds and other plant-propagating materials which, after harvest, have undergone specific treatment with plant protection products for their intended use (propagation), and any by-products derived therefrom".
3. "Solid urban waste, such as household waste".
4. "Packaging from the use of products from the agri-food industry, and parts thereof".

Therefore this regulation prohibits the use of some animal protein sources that might be suitable as feed for insects, like manure and gut content, dead-shell poultry, and fallen stock (van der Spiegel, Noordam, & van der Fels-Klerx, 2013).

In addition, according to Lähteenmäki-Uutela & Grmelová (2016), the European regulation on animal by-products (1069/2009), article 3, animal by-products[6] or derived products[7] cannot be fed to insects as there are fears that this can cause a public health or animal health hazard. The background to the fears on feeding farmed animals with by-products and derived products is related to previous crises such as the foot-and-mouth disease, mad cow disease, and the dioxin crisis (Lähteenmäki-Uutela & Grmelová, 2016).
However, according to Nextalim, products like biscuits despite containing milk can be used as feed for insects and poultry as the milk has been transformed (into biscuits). Indeed, this product can be categorized as a waste but as a former foodstuff. According to the EU Catalogue of Feed Materials (Regulation (EU) No 2017/1017) former foodstuffs are "foodstuffs, other than catering reflux, which were manufactured for human consumption in full compliance with the EU food law, but which are no longer intended for human consumption for practical or

[5] According to the European regulation No 1069/2009," farmed animal" means: any animal that is kept, fattened or bred by humans and used for the production of food, wool, fur, feathers, hides and skins or any other product obtained from animals or for other farming purposes.
[6] According to the European regulation No 1069/2009, "animal by-products" means entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption, including oocytes, embryos and semen
[7] According to the European regulation No 1069/2009, "derived products" means products obtained from one or more treatments, transformations or steps of processing of animal by-products;

logistical reasons or due to problems of manufacturing or packaging defects or other defects and which do not present any health risks when used as feed". Former foodstuffs not containing meat or fish can therefore be used as feed (Lähteenmäki-Uutela & Grmelová, 2016).

With regard to the limitation of substrate, IPIFF is lobbying for the extension of authorized feed for insects. Therefore, IPIFF members are studying the possibilities to allow the use of unsold food product from grocery stores, food losses form restaurants and other food stuff containing fish and meat in order to feed insects. As well, they want to facilitate the use of vegetal based products which are already authorized by the legislation. Therefore, in order for more substrates to be authorized, independent studies have to document that there are no potential safety risk nor adverse health effects associated with the use of such materials (IPIFF, 2017). To conclude, insect production as part of a circular economic production might become a reality if the situation of the current prohibitions on feed raw materials change in the future.

3.4 The introduction of insects from a marketing perspective

According to the insect producers interviewed, IM and IO major assets are their environmental nutritional and economical assets. IM is promoted as an environmental friendly source of protein since insect farming emits less greenhouse gasses and less ammonia than most livestock (Oonincx et al., 2010). Moreover, the natural presence of insects in the salmon diet is also another argument while promoting IM as opposed to SM. In terms of nutritional assets of IM, insect producers enhance the high content of high quality protein, oil and minerals and its high digestibility. Finally, despite its small production and its high cost, IM is promoted by insect producers for its economical assets. Indeed, as insect farming could potentially be a cheaper source of protein and oil than FM in the future, insect producers promote a stable price and large production, at least on their website.

> "Insects have a very good environmental story" (Skretting, personal interview, February 23, 2018).

From the interview with the fish feed producers, it resulted that they are aware of the IM arguments. At this early stage in the development of the insect sector, the marketing aspect of IM was described as quite positive (Skretting, personal interview, February 23, 2018).

Henceforth salmon feed composed of IM would be costlier than the "classic meal" (composed of FM and SM). The following question was asked: Could salmon fed with insects be considered as premium product and be sell at a higher price (to compensate cost of the meal)? This question was asked to Skretting, Havbrún and Entomo Farm.

Skretting did not specially answer the question, however the company underlined that it was a relevant question that they are facing now. Moreover, this question does not apply only for IM but also to other alternatives in general. They concluded saying:

> "If the value chain is not willing to pay, that will drive out innovation in the aquaculture industry" (Skretting, personal interview, February 23, 2018).

Havbrún's answer offers interesting elements of reflection as it compares salmon fed with insect with salmon fed with organic feed. According to Havbrún:

> "Organic products tend to be higher priced than their conventional counterparts. If you for instance compare two organic salmon productions where one uses insect meal as a part of the feed and not the other, I would not expect that the insect fed salmon would be better priced because the insect meal is only one of several certified organic materials in the feed. Higher prices do necessarily not mean higher margins because there might higher production costs for these products". (Havbrún, personal correspondence, February 2018)

Entomo Farm was more positive on that issue as they think that some people would pay more for insect fed salmon. According to them, more and more people realize the ecological problems of existing fish feed and would be willing to pay more for an environmentally friendly salmon. However, it would only address a niche market as it concerns a very limited population.

Finally, from the interviews it arises that there is a lack knowledge regarding consumer acceptance of insect fed salmon as well as consumer willingness to pay for insect fed salmon. Insects represent a new source of feed, therefore attitudinal barrier towards insects represents a main issue regarding the adoption of insect fed salmon. In some Asian countries insects are widely consumed. In the Western societies, however, insects can generate fear and are perceived as disgusting or unsafe (Caparros Megido et al., 2014; FAO, 2013; Lensvelt & Steenbekkers, 2014). Therefore, do the attitudinal aspects such as the fear and disgust towards insects have a negative effect on salmon fed with insects?

Due to time and resource limitation, this method could not have been applied for this master thesis. In this context, this study only uses existing literature to study the consumer acceptance of insect feed. Currently, the literature on the subject is still limited as few studies realized on Scottish, Belgian, French, Norwegian and Portuguese population give us a first overview (Bazoche & Poret, 2016; Neves, 2015; Popoff, MacLeod, & Leschen, 2017; Verbeke et al., 2015). The following paragraphs will explore and compare the results of existing studies on the topic.

3.4.1 Consumer acceptance in Scotland, Belgium, France, Norway and Portugal.

Three studies were led in order to learn more about consumer attitude towards the use of IM in salmon feed. A recent consumer survey (n=200) led by Popoff et al. (2017) studied the attitude of Scottish consumers toward insect fed Scottish salmon. The results of this survey showed that the consumers were in general favorable, as for the majority of the respondents, eating insect fed salmon did not cause them any concerns (Popoff et al., 2017). A third of the people interrogated replied that they are in favor of consuming insect fed salmon only if the price, the taste and the safety of the fish remains unchanged. Only 10% of the persons interrogated were unwilling to eat insect fed salmon (Popoff et al., 2017).

Another study led on Belgian citizens (n=82) indicated that the attitude and acceptance toward the use of insect in fish feed is favorable. The study also showed that there was no difference between genders in terms of acceptance of insect in feed. In terms of age, the study showed that younger consumers (<25 years old), are significantly less willing to consume insect fed fish (Verbeke et al., 2015). However, the authors of the study attribute this attitude to the younger consumers' dislike of seafood in general rather than to the use of insect feed.

Insect-based feed are perceived to be more sustainable, to have a better nutritive value, but a lower microbiological safety. Fish fed with insect were also considered as healthier, more sustainable, to have a better nutritive value (Verbeke et al., 2015). On the other hand, they were associated with a possible altered taste and presence of allergens. In general, Verbeke et al. (2015) findings indicated that positive attitude outweighed perceived risk, uncertainty and concern in relation to the adoption of insects in animal feed.

A French study focused on the consumer of insect in trout feed[8](Bazoche & Poret, 2016). In France, a survey conducted in 2016 on a sample of 327 participants showed that at the same price level, the majority of the people interrogated would chose trout fed with insects when they have been informed on the environmental impact of the actual feeding method. Moreover, if trout fed with insect represents a cheaper alternative to the conventional trout, most of the people interrogated would choose trout fed with insects in both cases (informed or not). However, if the price of trout fed with insect is higher than the traditional type, a large majority of the respondents would choose the conventional trout. These results indicate that the majority of the respondents are favorable to insect feed and are even more favorable when they are informed on the feeding issues. However, despite general consent towards insect fed fish, 15.29% of the people interrogated considers that is disgusting to eat trout fed with insect.

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[8] It has to be underlined that this study focuses on trout and not salmon, however, the two Salmonidae species being very similar, the result of this study can be extrapolated to salmon.

Finally, Neves (2015) studied the consumer acceptance of insects as feed on Norwegian (n=363) and Portuguese consumers (n=303). Neves' results showed high acceptance to using insects to feed fish in both countries but with significantly higher acceptance among Norwegian consumers. On a scale from one (strongly reject insects as feed) to seven (strongly accept insects as feed), the average response of the Norwegian consumers was 5.5 while Portuguese responded in average 4.1 (Neves, 2015).

3.4.2 Information and Price

Information and price on the feed are two important parameters in consumer choice. Today, there is a positive atmosphere around the use of insects in animal feed. However, in their study Popoff et al. (2017) showed that the majority of the Scottish people had very little knowledge on the environmental challenges of aquaculture. Indeed, as shown in table 3, 53% of the respondents do not think fish farming has any significant environmental impact. 78% of the people interrogated did not know what FM is made of and 81% were not aware of any issues arising from the production of FM. Moreover, the large majority of the respondent (91%) has never heard of the possibility to replace FM with IM (Popoff et al., 2017).

Table 3: Overview of "consumer's familiarity with current FM composition and their perception of the challenges faced by the aquaculture industry". Table adapted from Popoff et al. (2017, p. 6)

Question	Yes (%)	No (%)	Number of responses
Q1: Do you think fish farming has any significant impact on the environment?	47%	53%	83
Q2: Farmed-fished are fed FM. Do you know what it is made of?	22%	78%	39
Q3: Are you aware of any positive or negative issues arising from the production and use of FM?	19%	81%	33
Q4: Are you aware of the possibility of replacing FM with insect material?	9%	91%	180

Despite the small sample sizes of questions two (n= 38) and three (n=33), these four questions indicate that consumers need to be informed about the environmental impact of conventional feed. Indeed, according to Bazoche & Poret (2016), the probability of choosing fish fed with insect is higher when the consumers are informed. In the light of these results, salmon fed with insects would therefore benefit from marketing campaign promoting the environmental benefit of using IM. Moreover, in order to popularize insects and reduce the perception of disgust towards insects among consumers, Caparros Megido et al. (2014) recommend to systematically present the animal proximity between insects and crustaceans. Finally, an appropriate information campaign on FM and SM environmental issues would raise the consumers awareness about the need to find alternatives.

As we do not know much about consumer's concerns regarding how salmon is fed, price and a long list of extrinsic variables are often used as the main factor guiding purchasing decisions (T. Altintzoglou et al., 2015; Themistoklis Altintzoglou & Helen Nøstvold, 2014; Bazoche & Poret, 2016; Verbeke, Vermeir, & Brunsø, 2007). Insect meal is currently a more expensive alternative to FM and SM, therefore salmon fed with insect should represent a costlier alternative to conventional salmon. On the market insect fed salmon could be promoted as more environmental friendly and natural product. Indeed studies has shown that IM is considered by the majority of the respondents as a natural source of feed for fish (Bazoche & Poret, 2016; Popoff et al., 2017; Verbeke et al., 2015). In this context, could insect fed salmon be sold as a premium product to compensate the extra cost? Studies on the subject showed that despite a majority of people favorable to insect feed, "most seafood consumers were not willing to pay a higher price for insect-fed product" (Popoff et al., 2017, p. 7). Bazoche & Poret (2016) results confirm the previous statement. According to them, the potential premium aspect of fish fed with insects is limited, even if the consumers are informed. Finally, despite consumers unwillingness to pay a premium price and little knowledge on fish feed, the majority of the consumers would want an insect label indicating that the fish has been fed with insects (Popoff et al., 2017).

3.5 Methodological considerations and future research

This thesis studies the introduction of insect-based salmon feed, it is based on three interviews (Entomo Farm, Nextalim, Skretting) and one mail correspondence (Havbrùn). Initial contact regarding feed companies was particularly time demanding and difficult. Some companies did not want to share the state of their research, others did not have time to set interviews. Competition between fish feed companies might explain this high degree of confidentiality on ongoing research programs. In contrast, insect producers were in general more responsive and more willing to share their knowledge. This situation could be explained by the willingness of the young insect sector to promote their product to the scientific community and to other businesses.

The insect sector is developing fast and the total production of IM should considerably increase in the future. Today, insect farming gets increasing interest from scholars and industries, however, insects as a source of protein are still a relatively new subject of study with many aspects to explore. Among these aspects, future research should focus on substrates and species. These studies could have an important influence on the development of the insect sector. First, a better knowledge of the potential hazards regarding insect species and substrates should help to relax the European regulations. Second, studies regarding substrates could lead to decrease of production cost, development of a circular production and more nutritional flexibility of IM.

Finally, from a marketing perspective, insect-based salmon feed suffers from a knowledge gap. Although there is a general consumer acceptance among European consumers, we still have limited surveys on the determinants of the consumer acceptance. Therefore, more studies regarding the marketing aspect of salmon fed with insects should be performed.

4 Conclusion

As the feed industry is looking for alternative sources of protein, IM seems to represent a promising substitute to FM. From the series of interviews, it results that there is a general interest from the Norwegian feed producers towards IM. This interest is nutritional, economic, legal and marketing.

Nutritionally, Insect-based diet has shown satisfying results according to feed producers and to the literature. Indeed, IM presents a good alternative to FM as it is a source of high quality protein, oil, AA and minerals. Insects also offer nutritive flexibility as the nutritive profile can vary as depending on the species and on the substrate. The interviews underlined that finding new source of omega-3 is the main challenge for the fish feed industry. Regarding this question, IO does not represent a realistic alternative to FO as it does not naturally contain omega-3. Therefore, sources of omega-3 like krill and algae seems to be better substitutes to FO.

From an economic point of view, insect-based salmon diet faces important challenges. Potentially insects can be produced in large quantities and at a low and stable price. Indeed, insect farming does not require intensive labour force (as it is highly automated) and expensive feed (agriculture by-products). Today, IM remains a costlier alternative to FM partly due to current production being very small (<1000 tons per year). However, in the future, IM cost should decrease as the production increases due to industrialization of the production. Finally, compared to FM, it seems that IM will be soon competitive as insect-based feed should enter the feed market in the immediate future.

The introduction of insects in salmon feed also faces legal restrictions. Insects constitute a new source of feed in the western societies, and therefore, there is still limited knowledge on the subject. In this context, following the precautionary principle, the European commission has imposed restrictions on the number of species allowed to be used in fish feed. Currently, seven species (black soldier fly, house fly, yellow mealworm, lesser mealworm, house cricket, banded cricket and field cricket) are authorized by the European commission. European authorities have also imposed limitation on substrates used to feed insects. Insects like black soldier fly can feed on a large variety of subtract such as leftovers, organic waste and feces. This capability makes it possible to convert waste directly into proteins. This type of circular production would allow to reduce organic waste produced by the salmon industry. But, due to potential risk of contamination across the food chain, the current European regulation forbids the use of animal protein sources and feces to feed insects. In this context, the insect sector (represented by its promoting organ IPIFF) concentrates their effort in lobbying for a wider substrate and insect species authorization at the European level.

Finally, from a marketing perspective, the studies showed that there is a positive perception of insect-based feed among the fish feed producers. However, they expressed a certain uncertainty on consumer acceptance toward salmon fed with insects. Different surveys led on the population of five European countries (Scotland, Norway, Belgium, Portugal and France) indicated that the majority of the people would consume fish fed with insects. Research indicated that most of the consumers did not have knowledge on IM and on fish feed environmental issues. When the consumers have been informed on the negative impact of traditional feed, there is a higher probability of choosing fish fed with insect. Regarding consumer willingness to pay, most of them would not want to pay a premium price for fish fed with insect even if they have been informed. It seems that a salmon labelled as “insect fed” could not be sold as a premium product in the future. Therefore, it seems that two conditions would allow salmon fed with insects to be successfully introduced in the market: first, salmon labelled as “insect fed” would have equivalent price than conventional salmon. Second, its introduction would have to be preceded by information campaigns.

To conclude, it seems that the potential for insects as feed has come a long way: still forbidden in august 2017, IM is now on the verge of entering the salmon feed market. As some barriers have started to be lifted, it will be thrilling to see how insect-based feed will develop in the future. Yet, today, the culture of insects for feed purposes is still a field relatively unknown and would deserve more scientific attention to facilitate its future development.

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Appendix 1: Interview guide Entomo Farm and Nextalim in French

Générale

1. Est-ce que vous pouvez brièvement présenter votre entreprise ? Combien d'employés ? Et votre fonction dans l'entreprise ?
2. Quels sont vos produits actuellement ? Huile, farine ? Sous quelle forme vendez-vous vos produits ? En tant que matière première ou produit fini ?
3. Vous cultivez la mouche soldat/le verre de farine, quels sont les avantages de la mouche soldat en comparaison avec le verre de farine (inversement pour le verre de farine) ?

Production

4. Vous nourrissez les insectes à base de déchets organiques ? Il y a-t-il des risques de contaminations alimentaires ?
5. Est-ce que vous travaillez sur de la farine d'insectes spécialement adaptée à l'élevage de saumon ?
6. Quels sont les avantages et les désavantages de la farine d'insecte en termes de prix et qualité ?
7. De quelle filière proviennent vos principaux clients ? Sont-ils des producteurs d'aliments pour élevage ?
8. Quel le cout de la farine d'insecte comparé aux alternatives existantes ? (soja, farine de poisson)

Propriété nutritive

9. Pour le saumon, un critère important c'est la présence d'acides gras hautement insaturés. Est-ce que c'est quelque chose que vous mesurez dans votre aliment ? Quel est la proportion ?
10. L'huile d'insecte pourrait -elle être une alternative à l'huile de poisson ?
11. Pensez-vous que la farine de mouche soldat serait une bonne alternative ?

Marché et compétition

12. Quels sont vos principaux concurrents ?
13. Comment le secteur de l'aquaculture répond à votre produit ? Sont-ils intéressés ? Pourquoi et pourquoi pas ?
    Pour quelles raisons marketing écologique nutritive.
14. Avez-vous été en contact avec des producteurs d'aliments pour Saumon ? Lesquels ? Comment voient-ils vos produits ?

Future

15. Quels les futures opportunités Nextalim/Entomo Farm ?
16. Quels sont les futurs défis de Nextalim/Entomo Farm ? Quand ? Comment ? Pourquoi ?
17. Comment pensez-vous que l'industrie de l'insecte va se développer dans ces 5 prochaines années ?

Appendix 2: Interview guide Entomo Farm and Nextalim translated in English

General

1. Can you briefly present your company? How many employees? And your role inside the company?
2. Which type of insects are you using to produce the meal? And why?
3. What are you producing? Oil, meal? Under which form do you sell the insects? As a raw material or as a final product?

Production

4. You feed the insects based on organic waste? Are there any risks of food contamination?

5. Do you have or are you working on insect meal specially adapted for salmon farming? Can it be used to produce feed for other fish/ animals?
6. What are insect meal’s advantages and disadvantages compared to other meal in term of quality and price?
7. Who are your principal customers now? Are they feed producers? If yes what type of fish? All fish?
8. How much of farmed fish is already fed with Insect meal in Europe?
9. I read that you have an “eco-industrial system operated by Entomo farm. Could you please describe this system? (only for Entomo farm)

Nutritional property

10. What is the cost of producing insect meal compared to using other existing alternatives? (e.g. FM and SM)
11. For salmon, an important criterion concerning the feed is the presence of highly unsaturated fatty acids. Is this something you are measuring in the feed you are producing? (If yes) What is the proportion of HUFA in your meal?
12. I read on your website that you are also producing insect oil could it constitute an alternative to FO?

Market and competition

13. Who are you principal competitors in the Insect meal industry?
14. How is the aquaculture industry responding to your products? Are they interested? Why? Why not?
15. Have you been in contact with meal producers? Which ones (e.g. Skretting)? How do they see your products? Why?

Future

16. What are the opportunities Entonomo farm are experiencing at the moment?
17. Are there any opportunities you expect in the future? When? How? Why?
18. Are there any challenges you expect to face in the future? When? How? Why?

Appendix 3: Interview guide Skretting

General

1. What are the biggest issues you are facing at the moment regarding feed production? Are you looking for alternatives? Why?
2. Are you aiming to replace FM from your feed or to reduce it?

Insects

3. What is Skretting's position on the use of insect meal in feed?
4. Why is Skretting interested (or not) in using insects for its feed? (Is it for environmental reasons, marketing reasons, economic reasons, nutritional reasons? Other?)
5. Are you interest in insect oil? Do you think it could (partly) replace FO?
6. Which insects are you using? Why? How?

Alternatives

7. Is Skretting looking for other alternatives than insect meal? Which one? Why?
8. In which way your actual product could benefit from insect meal?
9. Soymeal is criticized for its environmental impact. Do you think insect meal could replace soymeal in the future? Are you planning to reduce or replace soymeal in the future?

Competition

10. Do you think that your competitors are also looking at using insect meal?
11. What are insect meal's advantages and disadvantages compared to other meal in term of quality and price?
12. What are your expectations from the insect meal producers? Should they reduce their price? Increase production? Increase product quality?
13. Do you think that salmon fed with insect will be well accepted by the salmon farmers and by de consumers?

Future

14. When do you think the first insect feed will arrive on the market?
15. What are insect meal's issues? are they nutritional, legal, economic, technical?
16. What are Skretting goals in the future?

Appendix 4: Questions discussed through e-mail correspondence with Havbrún Feed Division (Bakkafrost Faeroe Island)

1. What do you think about insect meal?
2. Is there interest from the feed industry towards insect meal?
3. When talking about the high price of insect meal, do you have an idea of the price difference between IM and SM/FM? Moreover, do you think if the price drops to a reasonable price the feed producers will turn to insect meal?
4. Insect meal is presented as an organic and sustainable alternative to soya and fish meal, do you think that salmon fed with insects could be sell at a higher price to compensate the cost of the meal?