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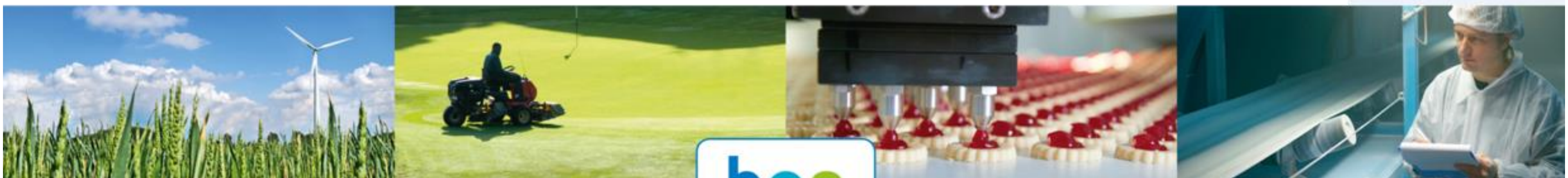
INVIS PA

Insect-based feed for a sustainable future of Dutch finfish aquaculture



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Preface

In front of you lies the thesis '*How to initiate system changes to promote the branch wide adoption of insect-based feed for Dutch finfish aquaculture.*' The research for this thesis is done through literature review and by interviewing stakeholders of the Dutch finfish aquaculture branch. This thesis was written in the context of our graduation from the Animal Husbandry, and International Food and Agribusiness study-programs at HAS Hogeschool 's-Hertogenbosch and commissioned by the lectureship INVIS. From February 2020 to July 2020, we have been researching and writing the thesis.

Together with Olga Haenen and Ellen Weerman of the lectureship INVIS and our supervisor Toon Keijsers we came up with the research question for this thesis. The research we conducted was complex. After extensive qualitative research, we were able to answer the research question. During this research, our supervisors Toon Keijsers and Gert-Jan Duives, as well as Olga Haenen and Ellen Weerman, were always there for us. They always helped us with our questions so that we could continue with our research.

This project has been subsidized by NWO, in project no. ENPPS.KIEM.019.007 (HAS project no. 200400022). We thank NWO for their financial support. The consulted aquaculture professionals are appreciated for their input.

We would also like to thank our supervisors for their excellent guidance and support during this process. At last, we want to thank all respondents and interviewees, who contributed to this research. We could never have completed this research without their cooperation.

We wish you much reading pleasure.

Ester Ceriani
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's-Hertogenbosch, June 26, 2020

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1. Summary

This research is commissioned by the professorship Novel Proteins: Insects and Fish, Healthy, Sustainable and Safe (INVIS) and conducted with the aim to investigate the constraints that hinder the uptake of insect-based feed in the Dutch finfish aquaculture branch and advise upon how to initiate a transition within the branch to adopt insect meal in fish feed widely.

This research starts by exploring the manner in which the branch is organized, using the Food System Approach by Berkum et al. (2018). This creates an understanding of material and monetary flows, identifying relevant stakeholders and power relations. The branch is relatively small, producing only 5 500 tons/year, predominately European eel and African catfish, supplying just 5% of the Dutch domestic fish consumption annually. Production is solely based on Recirculating Aquaculture Systems-RAS, which requires large investments. The variable cost of inputs (e.g. energy, feed, fingerlings) are almost equal to the sales prices ex-farm. This pressures the income & livelihoods of Dutch fish farmers. In general, RAS systems reduce the impact of aquaculture on the environment. The raw materials used in the feed formulation can add up to 87% of the total GHG emissions in marine aquaculture.

In order to evaluate the suitability of insect meal in fish feed, desk-research has been conducted to verify whether the use of insect meal is adequate to the nutritional requirements of the major fish species produced in the Netherlands. There hasn't been much research done on the nutritional requirements of European eel, African catfish and Yellowtail Kingfish, with the exception of essential amino acids. Sufficient levels of these essential amino acids were found to be present in insect meal. A 25% inclusion of insect meal in the protein fraction improves the FCR and increase the survival rate in sea bass, but it increases the price of the feed almost two-fold. Labour, substrate, and energy are the major contributors to the costs of insect production, according to interviewees.

Constraints limiting the use of insect-based feed by the branch were identified through an online questionnaire distributed among 48 Dutch finfish farmers and interviews with 12 (inter)national stakeholders. The price of insect meal, the low volume produced and the varying quality prohibit the access to the aquaculture feed market, which is based on large quantities at competitive. The lack of market access reduces the economic incentive for insect producers as well as private investors to inject the capital needed to achieve the performance standard required. EU Feed legislation limits the use of substrate to grow insects on and often these limitations are perceived by the actors as an issue, as it limits not only the type of substrate chosen (determining its cost) but also the possibility to import insects grown abroad (because of non-compliance). Another aspect that emerged is the knowledge gap between research findings and farmer's knowledge, as the latter seems to be not up-to-date on some aspects.

The dynamics at play and their interrelationship affecting the uptake of insect-based feed have been explored through the application of specific steps of the Food System Decision-Support Tool by Posthumus, et al. (2018). Investments constitute the common leverage point identified: acting on the investments (mainly increasing them) would allow current performance of insect meal to be closer to the required one. Re-defining the goal (access the feed market) into a more realistic one (e.g., target a particular fish species or consumer base) also constitutes a point of intervention to introduce change in the system, without a significant injection of capital. The case study proves that focusing on a realistic goal can create a market access for insect-based feed, though the replication of the strategy deployed can be difficult in the Dutch context.

The lectureship can play an important role in reducing the knowledge gap through active knowledge dissemination, pursuing the affiliation of all relevant stakeholders. As a public stakeholder, it can provide a neutral ground to facilitate the process of value chain development, promoting the adoption of insect-based feed to secure a more sustainable future for the branch. The methods applied in this research can be used as the first step to inspire multi-stakeholder discussion, creating a common understanding of the current situation and help to define a participatory future among the stakeholders affiliated to the lectureship.

Some of the interviewees mentioned the improved gut health when fishes are fed with insect meal. This may reduce the need for antibiotics, which can be used as Unique Selling Point to target a specific consumer base and provide a more realistic goal. This creates a market that can attract investments necessary to access the aquaculture feed market. The following research is recommended:

- Trial to investigate possible improvement of FCR, gut health and survival rate resulting from the inclusion of insect meal in feed, in relation to the potential production output and the additional feed costs.
- Consumer study to verify the interest of consumers for fish grown with reduced antibiotics and the willingness to pay a premium for it.

2. Introduction

This professional assignment (PA) is initiated by the professorship: Novel Proteins: Insects and Fish, Healthy, Sustainable and Safe (INVIS) and executed by three students of the HAS University of Applied Sciences. From February 2020 until July 2020, a study of the Dutch finfish aquaculture branch will be conducted to establish an understanding of why insect-based feed is not commonly used yet. Through both company interviews (both NL and abroad) and desk research, data will be gathered to identify hurdles that have to be overcome to get the branch to replace fish meal and make the transition towards a more sustainable future.

The knowledge obtained through the PA was supposed to be shared during an open symposium with the industry: Insect and aquaculture farmers, feed producers, government, and other interested parties. Unfortunately, this has been cancelled due to the coronavirus outbreak. For dissemination, a summary of the findings of the PA will be written for the Dutch branch bulletin "Aquacultuur."

3. Background

The professorship INVIS, led by lector Dr. Ir. O. Haenen established a close collaboration between HAS University of Applied Sciences and Wageningen Bioveterinary Research in Lelystad. From 2018 to 2022, the professorship will work on veterinary healthy, sustainable, and food safe breeding of insects and fish, to extend and integrate knowledge, experience, and education. It will investigate the risk factors and support the use of insects in aquaculture feed in cooperation with feed producers (HAS Hogeschool, 2020).

Part of the lectureship activities is a project regarding: "Insects as innovative and sustainable replacement of fish meal in aquaculture feed: effect on health and water quality." NWO funds the projects through the program Creative Industry - Knowledge and Innovation Mapping (KIEM), which is aiming at financing short-term research to encourage the establishment of partnerships between knowledge institutions and private parties (NWO, 2020).

The lectureship aims to connect Dutch onshore finfish aquaculture with insect culture to promote the use of insects as a protein source in fish feed. Insect meal is perceived to be a sustainable alternative for fishmeal in the growing finfish aquaculture branch. However, it is rarely applied. If standard feed can be replaced by insect-based feed, it will lead to more sustainable production of fish and prawns to feed the growing world population (Dicke, 2018; Panini, 2017). Furthermore, it will support the development of circular economy as waste-streams can serve as a basis for insect culture, therefore contributing to a reduction of the burden that the finfish aquaculture branch imposes on the climate (Fernando G. Barroso, 2017; Panini, 2017). This meets a clear need for a connection between the branch and an increase in the production of new-, fish- and insect proteins.

4. Objective and deliverables

To make the connection between the branch and increased production of new fish- and insect protein, this research is to identify constraints that hinder the uptake of insect-based feed in the Dutch finfish aquaculture branch and advise upon how to initiate a transition within the branch to adopt insect meal widely. To achieve these objectives, the following question has been answered.

'What is needed to initiate system changes to promote the branch wide adoption of insect-based feed creating a more sustainable future for finfish aquaculture in the Netherlands?'

To support answering the research question, Sub-research-questions (SRQ) have been established. The sub-research-questions that will be investigated within this research are:

1. **How is the Dutch finfish aquaculture branch organized?**
2. **How does insect-based feed compare to conventional feed in relation to nutritional needs and economic performance of selected fish species?**
3. **What are the major constraints limiting the utilization of insect-based feed in the Dutch aquaculture?**
4. **How to create an enabling environment for the utilization of insect-based feed in aquaculture?**

In the end, the answers to the following questions will be delivered through a consultancy report. An executive summary of the findings of the report for the Dutch bulletin 'Aquacultuur' will be provided. The group will also participate in the BO Expo Thursday the 18th of June. See the link for a presentation of the current projects by Dr. Ir. Olga Haenen.

https://www.has.nl/nl/has-expo/guided-tours/insect-based-feed-for-a-sustainable-future

5. Methods & Activities

The methodology applied in this research to answer the established research questions will be elaborated upon here below. For a visualization of the activities undertaken during the research, please see appendix 1.

SRQ 1: How is the Dutch finfish aquaculture branch organized?

The Food System Approach (from here onwards referred to as FSA) model elaborated by Berkum et al. (2018) will guide the analysis of the Dutch finfish aquaculture branch. The model has been already applied in the literature to analyse the whole food system in specific countries, and it has been selected by the researchers as the perfect tool to analyse the complexity of the aquaculture system systematically. Similar versions of this model had been compiled in the past. Still, the current FSA has been indicated by HAS researchers and lecturers to be the most encompassing way to analyse the components of a system. The information needed was retrieved through desk research, interviews with representatives of branch organizations, and consultation of official governmental websites (e.g. Nederlandse Vereniging van Vistelers (Nevevi), FAO, Federation of European Aquaculture Producers (FEAP), CBS, NVWA, Voedingsburo, Nederlands Genootschap voor Aquacultuur (NGvA), Kamer von Koophandel (KvK), Wageningen Institute of Animal Sciences (WIAS). A detailed explanation of the FSA can be found in Chapter 6-Theoretical framework.

SRQ 2: How does insect-based feed compare to conventional feed in relation to nutritional needs and economic performance of selected fish species?

The outcomes of SRQ1 provided the reasoning behind the selection of 3 fish species. The selection was made on the base of market data (species produced in the Netherlands with the largest share in production volume) and consultation with the client. The nutritional needs of the species, as well as the economic performance of insect-based feed in comparison to conventional feed, were investigated via desk research and interviews with experts (e.g., researchers and commercial feed formulators). A better elaboration on the interviews and the method used to conduct them can be found in the next Paragraph.

The interviewees were predominantly brought forward by the client because of their experience with the topic of SQR2, and the interviewees themselves recommended some. Appendix 2 shows all the interviewees and gives an overview of their competences/ role in the aquaculture system, utilizing the FSA model.

The interviews highlighted the importance of legislation regarding the usage of insect-based feed in livestock production and the production of insects itself. Therefore, it has been decided to include a part concerning this within the report.

SRQ 3: What are the major constraints limiting the utilization of insect-based feed in the Dutch aquaculture?

Questionnaire

The questionnaire was formulated considering mainly interviews with experts, with the background provided by SRQ1 and SRQ2. The main objective was to collect the constraints that Dutch fish farmers encounter in retrieving insect-based feed and the connected information. The second point of attention was the collection of the essential characteristics that fish farmers expect from their feed.

This could help understand which are some possible points of improvement in an insect-based feed that could generate a wider interest from the farmer's side. A detailed elaboration on the questionnaire methodology, including sample definition, final questions formulation, and data analysis, can be found in Appendix 3. A brief highlight of the methodology can be read below.

The sample definition included all the finfish aquaculture farmers in the Netherlands, and the final contact list was obtained in 4 steps:

1- Outdated excel list of fish companies in the Netherlands provided by the client
2- Verification of contact information from online search
3- Validation of such contacts from clients' side
4- Code-colour classification according to the relevance for the stated objectives (green= high relevance for the research, yellow= possible relevance for the research, red=no relevance for the research or bankrupted)

The group discussed the questions and drew up the questionnaire. The clients and an external professor have been invited to fill it in and express their suggestions on the changes to implement and the efficacy of questions formulation. The questionnaire was sent out digitally, and the answers were processed through Excel.

Interviews

The major constraints slowing the adoption of insect-based feed were investigated via interviews with relevant stakeholders. The interviewees were predominantly brought forward by the client or by the interviewees themselves as relevant stakeholders regarding the topic of SQR3. The final selection of the interviewees happened according to their role in the system, as the researchers wanted to have a complete picture of the issues and the dynamics in the system. To answer SRQ3, semi-structured interviews were used to facilitate the discussion with the interviewee and to create a broader understanding of the subject. The questions were discussed and decided upon by the researchers to achieve a better understanding on specific aspects of insect rearing or fish rearing (according to the field of expertise of the interviewee) and to discuss the issues that are preventing the uptake of insects in fish feed. The conversations were recorded, summarized, and sent to the interviewees for assessment and approval of the content to be used within the research. After that, the content within the summaries has been coded to categorize the information to be used in the answering of SRQ 4. The final coding book can be found in appendix 4. A description of the method is elaborated upon here below.

Coding is a qualitative research method that requires the researcher to establish a coding book. For this purpose, the research group re-read the summaries of the interviews and the research questions and found agreement on the aim of the coding. The group prepared the first version of the coding scheme, beginning with codes with their definitions, which were then grouped into categories. The categories chosen were established beforehand, following the FSA model visualization of drivers, chain, and outcomes.

The group selected at random a summary of an interview, and each member independently coded the text. Then, the group compared results and discussed coding problems and interpretation. The group realized that the coding agreed upon was too complicated and sometimes unclear. The group proceeded to write a codebook more precise and concise, with concrete code definitions and examples whenever necessary. Coding scheme adjustments are not unusual and guarantee better reliability of results (Campbell et al., 2013). Complex coding schemes are recognized as less reliable than simple ones (Garrison et al., 2006).

SRQ 4: How to create an enabling environment for the utilization of insect-based feed in aquaculture?

The answering of SRQ4 is done through the application of selected steps of the Food Systems Decision-Support Tool, developed by KIT Royal Tropical Institute & Wageningen University & Research. The researchers selected this tool as the best way to approach the SRQ4 because it has been previously used in reports together with the FSA model to the purpose of analysing food systems and initiating system change. The steps applied have been discussed, as well as the applicability of this tool for the objective of this research, with one of the primary authors, Ms. Helena Posthumus. The selected steps include: draw causal processes, label system behaviour, and identify leverage points. These steps will be based upon information retrieved through SRQ 1,2 & 3. The way these are applied within this research will be elaborated upon here below. The tool will be visualised in its totality within Chapter 6 - Theoretical Framework.

The drawing of causal processes leading to the establishment of a causal loop diagram is done following a selection of steps as elaborated upon in "Systems tools for complex health systems: A guide to creating causal loop diagrams" (Helen de Pinho, 2015). The steps include the determination of systems boundaries, which is done through a written Q&A in which the researcher ask and answer the following questions:

- What is the central question posed by this research?
- What is the primary level of interest in the system researched, e.g., national? Global?
- Who are the key stakeholders, and is their perspective captured in the information used?

After this, an Interrelationship Digraph is developed (see figure 1) from a selection of crucial system variables, to determine which of these variables are drivers and which are outcomes.

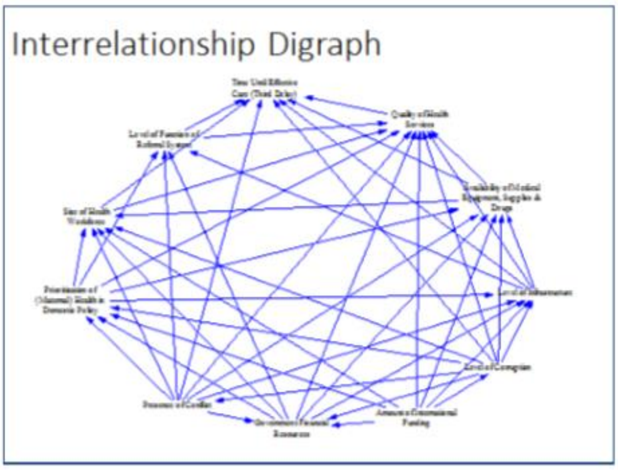


Figure 1: An example of Interrelationship Digraph (Helen de Pinho, 2015).

The following step is the identification of the seed structure on which build the Causal Loop Diagram, through reflection on the critical system variables in the system boundaries previously established. The

Causal Loop Diagram is built by exploring the relationship of other key system variables with the seed structure and by identifying the delay (relative length in time between variables in the system). Afterwards, it is important to investigate the presence of feedback loops within the Causal Loop Diagram. An example of a Causal Loop Diagram can be found in figure 2.

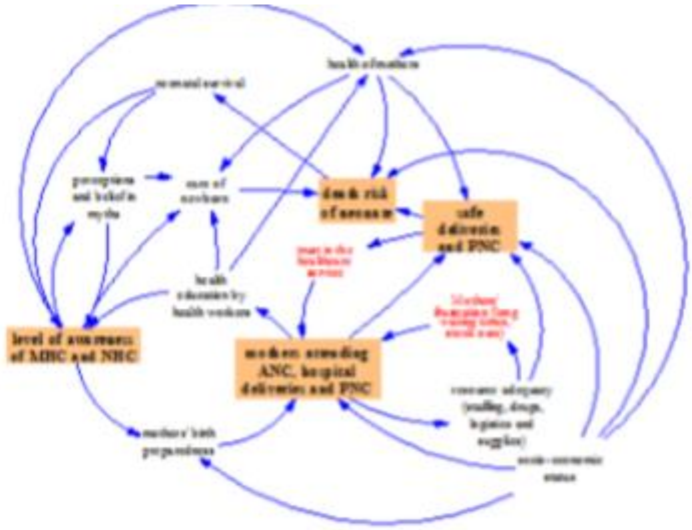


Figure 2: An example of a Causal Loop Diagram (Helen de Pinho, 2015).

The causal loop diagram is then analysed to identify the presence of commonly found archetypes in food systems, as described in "Archetypes, common systemic behaviours in food systems" (Posthumus et al., 2018). The nine system archetypes described in literature help the researchers to highlight the underlying dynamics in the systems. This leads to an understanding of the behaviour of the system in analysis and, consequently, its outcomes, thus paving the way for the identification of leverage points which can offer a solution for the archetype identified as present in the system.

Case study

In the current research, the establishment of a case study is needed to provide a real-life example of how to overcome constraints identified possibly, which are common in the industry and to highlight which conditions are necessary to facilitate the adoption of insect-based feed in aquaculture successfully. The case study has been identified thanks to the interviews with experts and discussed with the client. The case study was deemed relevant for the research because many of the French constraints in the adoption of insects are similar to the constraints that the sector in the Netherlands is facing (e.g. legislation limiting substrate use), and the solutions adopted in the case could be adapted to the Dutch context. An interview with a representative of the French ingredient provider Innova Feed (one of the main partners in the case study) has been executed, a summary of which has been sent to the interviewee for approval. The description of the case study has been based on this summary, integrated with external sources whenever needed.

6. Theoretical framework

Food System Approach

The finfish aquaculture branch in the Netherlands will be mapped through the model elaborated by van Berkum et al. (2018). The food systems approach (FSA) (see figure 3) is an analytical tool to analyse the activities within the food system systematically and the drivers which influence them. This includes the socio-economic, environmental, and food security outcomes of the system. The model is particularly useful to map the relationships between different parts of the system, their drivers, and outcomes. The FSA allows for the elaboration of integrated methods that make use of solutions emerging at another level of scale. The recognition of feedback loops and multiplier effects enable the identification of opportunities and the mitigation of risks by taking measures outside the food system itself. In practical terms, it provides a "checklist" for the topics that should be addressed and identifies actors and parties who should be involved. Also, it helps to quantify the impact of the food system on the environment, and it allows to identify the limiting factors to reach food security and elaborate effective food interventions. For the sake of the current research, the model will be used to achieve a complete understanding of the Dutch finfish aquaculture, its actors, and the role of insect-based feed, to outline the future of the branch.

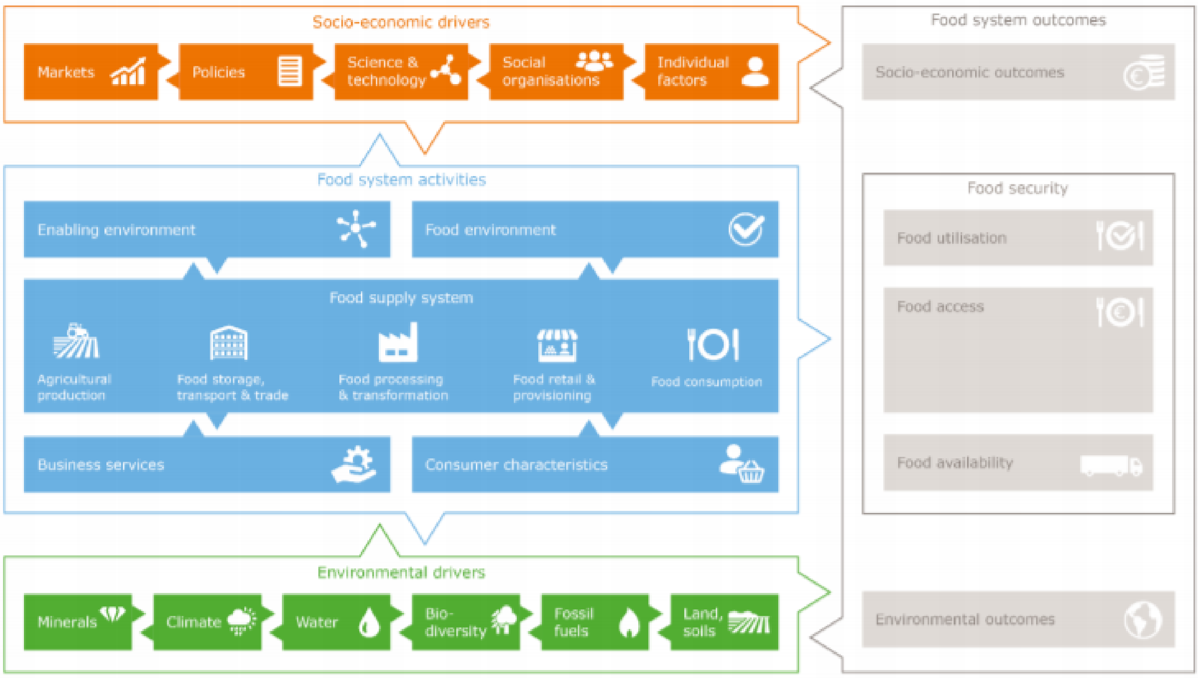


Figure 3: A way of mapping the relationships of food system activities to its drivers and outcomes (Berkum et al., 2018).

Food Systems Decision-Support Tool

The Food Systems Decision-Support Tool is a tool developed by the KIT Royal Tropical Institute & Wageningen University & Research to apply the food systems approach by Van Berkum et al. (2018) on the Food & Nutrition Security programming of the Dutch Ministry of Foreign Affairs at country level. The tool combines relevant academic theory on food systems and systems thinking from Meadows (1999), Maani K.E. (2007), Nguyen N.C. (2013) and translates it into practical steps that allow for the creation of an understanding of a food system's underlying system dynamics (through causal processes, feedback loops) and recognize typical system behaviours (called archetypes) to identify leverage points to bring about transformative change. Causal loop diagrams are a modelling technique used to map the behaviour of the system by connecting system variables and exploring if these variables influence each other positively or negatively in terms of flow. This, in turn, leads to the possible identification of "feedback loops." A feedback loop can be either reinforcing (generating exponential growth or decline) or balancing the system's behaviour (Laurenti, 2015). To change a system's behaviour, one must break the pattern created by the feedback loops. "Archetypes," first mentioned by Peter Senge in his book 'The Fifth Discipline,' represent patterns of behaviour found in any system and provide a template for diagnosing complex problems. Through this, leverage points can be identified, and action can be undertaken to change the system's behaviour and, thus, its outcomes (DH, 2000). An overview of the Food System Decision Support Tool can be found below.

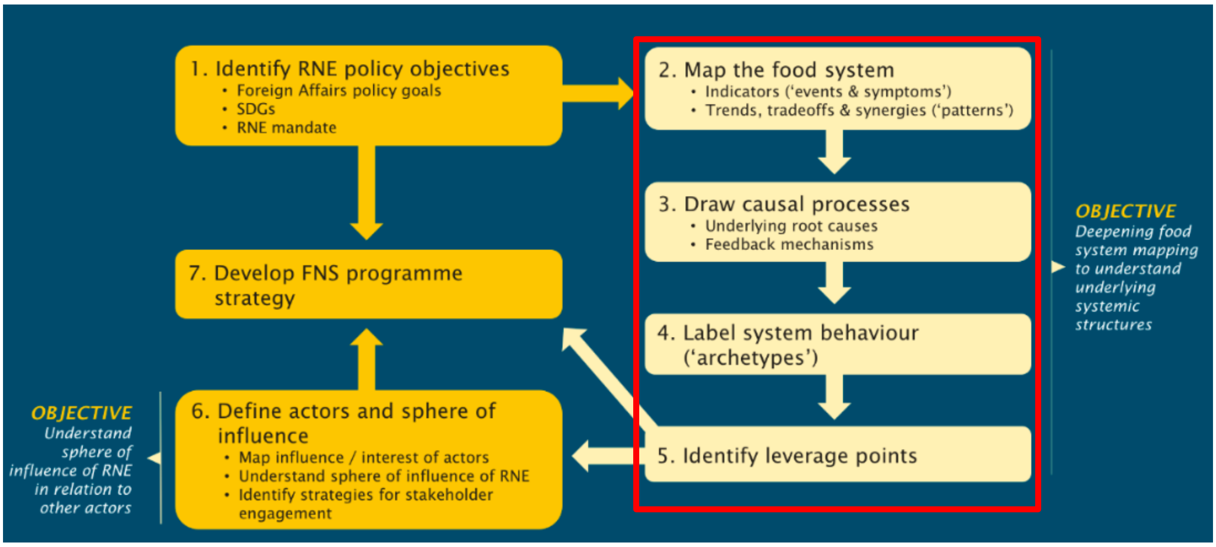


Figure 4: Decision Support Tool steps. Highlighted, the ones applied in this research (Posthumus et al., 2018).

Step 2 to 5, the most relevant for our research, have been fully applied according to the indications provided by Ms. Posthumus and the Manual indicated previously. Step 2 is executed through the use of the FSA. Step 3 is followed through the Causal Loop Diagram methodology. Step 4 is the identification of Archetypes. Step 5 has been tackled with the identification of leverage points according to literature and in practice, thanks to the case study.

Backcasting

Backcasting is a normative approach, developed in the 1970s to study the future. Backcasting is well suited to describe complex long-term issues that require significant change, to define not what is *likely* to happen but *how* the desired future is attained (Robinson, 1990). Typically, backcasting includes three following elements: (1) formulation of a target which cannot be reached without extensive societal changes; (2) development of one image of the future with a defined aim; (3) analysis of the image about the present state (Ilstedt et al., 2013). This allows to discover and analyse consequences and conditions for the future to materialize and establish priority points (Dreborg, 1996). The back-casting method is suitable to help policymaking in reaching complex goals, such as sustainability (Robinson J. , 2003). Even if it is a non-predictive approach, backcasting still requires some level of conditional prediction in the analysis of the desired future (e.g., the change in population growth that could impact demand for a specific service or the development of tech) (Robinson J. , 2003). Since backcasting is based on the definition of a desirable future, it is of the utmost importance to define the desires.

Nevertheless, which desires are to be considered, this is the crucial question. According to Robinson, there are two main approaches: 1) the research team defines the criteria for choosing and evaluating the desired future, making the source of the normative aspect of the back-casting exercise external to the study itself (e.g., previous research on stakeholder opinions); 2) various groups and the public are involved in the definition of the desirable future, in an interactive social science approach to backcasting (Robinson J. , 2003). In this report, the first method will be used.

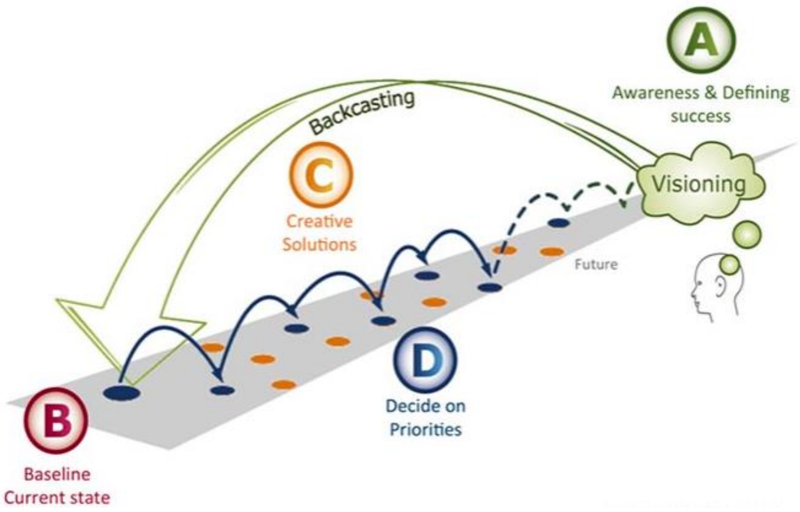


Figure 5: An example of backcasting (the Natural Step, 2016).

7. Dutch finfish aquaculture branch organization.

Figure 6: FSA model food supply system & consumers characteristics.

Within this chapter, the research seeks to create an understanding of how the Dutch finfish aquaculture branch is organized. It must be acknowledged that this branch is not self-standing and partly operates within a more extensive food system, namely that of Dutch Fish & Seafood. This is deemed vital to consider understanding the dynamics at play. Therefore, this chapter starts with the organization of the market & food supply system. It is covering topics such as landings, production, import, export, distribution, and consumption, see figure 6. After these, a more in-depth overview of the Dutch finfish aquaculture branch follows, covering topics such as the market and supply system, policy and regulations, sector organization, and environmental drivers.

7.1. Market & food supply system

The Netherlands is known as a trading hub for fish & seafood products in Europe, with a total export value of € 3.8 billion, weighing 1.143.100 tons in 2018. 81% of the total export value was sold within the EU. Landings from the Dutch fishing industry were 457.900 tons in 2018. In addition to the production/ landings by Dutch fisheries and aquaculture sector an amount of 836.200 tons, worth € 2.8 billion, was imported in 2018, which means that one-third of the total supply of fish & seafood for Dutch fish processing and fish wholesalers consisted of domestic production and two-thirds of imports (Wageningen Economic Research, 2019).

in 2017 the Dutch domestic fish & seafood market represented a total value of €0,95 billion retail selling price[1], from here onwards referred to as RSP, and a volume of 82.400 tons averaging for €10,78/kg of fish/seafood RSP. The Dutch market represents 1.8% of the value of the European fish & seafood market. Fish & seafood products from aquaculture and wild catches are sold on the Dutch market in similar ways. For example, after production, it is registered at auction centres or directly sold to registered buyers and Producers Organisations. This is called 'First sale[2].'

Twelve auctions exist in the Netherlands, and they cover both mussels and groundfish species. Most of the fish imported is processed by one of the about 300 companies active in the fish processing industry (Dutchfish.nl, 2020), of which 27% are located in Urk and IJmuiden (Beukers, 2015). In the Netherlands, traditional selling channels for fish are retail (35%), fish speciality shops (17%), fishmongers (21%), foodservice (15%) and others (22%) (Wageningen Economic Research, 2019). The supply chain of fish and aquaculture products in the Netherlands is illustrated below in figure 2. The

[1] The market is valued according to retail selling price (RSP) and includes any applicable taxes. All currency conversions have been made using constant annual average 2017 exchange rates.
[2] first sales do not cover fish that is caught on processor's owned vessels or sold directly to processors.

thickness of the arrows indicates the channels through which most of the fish are moved.

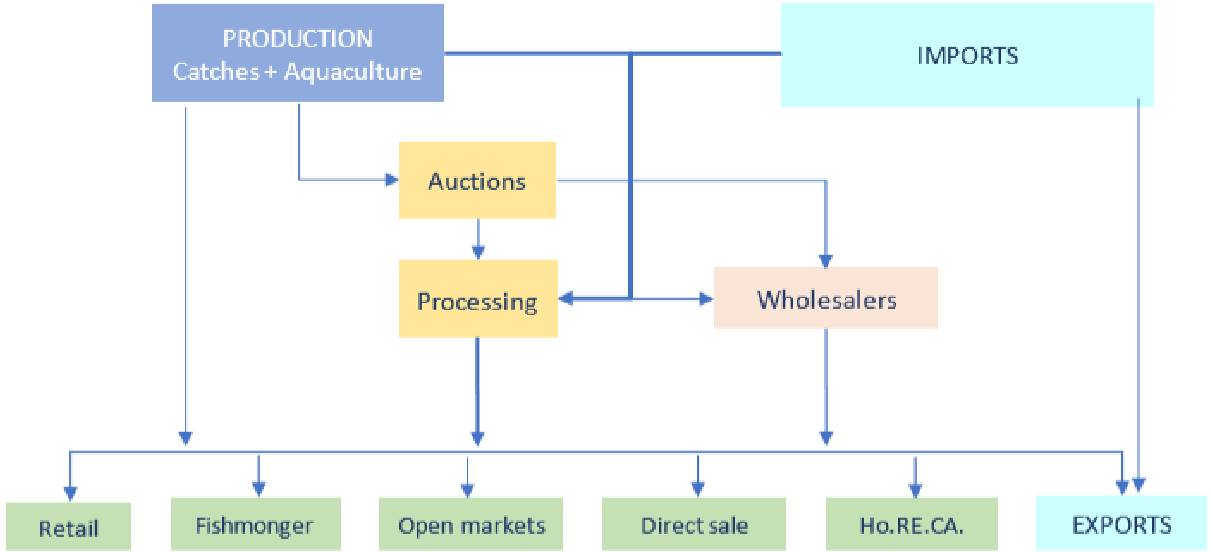


Figure 7: Supply chain of fish in the Netherlands (Nederlands Visbureau, n.d.).

On average, Dutch consumers spend 11% of their income on food, of which 3-4% (22 kg/year) is spent on fish (Geurts et al., 2016). It is prognosed that the value of the Dutch fish & seafood will grow with approximately 17% between 2017 and 2022 up to € 1.1 billion. Volume is prognosed to grow by around 9% during the same period to 90.100 tons (MarketLine, 2018). More information regarding consumer characteristics can be found in appendix 5.

7.2. Production & food system activities

As mentioned previously, this chapter will provide a more in-depth overview of the Dutch finfish aquaculture branch, covering topics such as the market and supply system, policy and regulations, sector organization, see figure 8 The Netherlands has a long tradition of farming fish and ranks as the sixth-largest producer of farmed fish in the EU. The Dutch sector can be divided into two sub-sectors, shellfish, and finfish aquaculture. The Dutch aquaculture sector is predominately known for its shellfish production. In 2018 shellfish aquaculture produced 48.600 tons of mussels and oysters (U.S. Department of Agriculture's Foreign Agricultural Service, 2019).

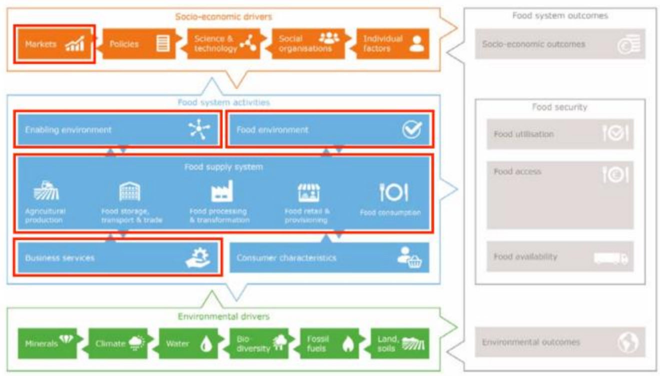


Figure 8: FSA model enabling environment, food environment, food supply system & business services.

The Dutch finfish aquaculture branch is characterized by its relatively small scale and plays a minor role in the Dutch economy. There are currently 50 licensed fish farms registered by the Dutch Food Safety Authority (NVWA) under Directive 2006/88 / EC (NVWA, 2017). The production is solely based on RAS systems[3], and the Netherlands is also internationally renowned for companies specialized in the design, installation, input provision, and support regarding such a system. Most fish farms are small, family-owned companies in which the owner and his family perform most or all the work. Approximately 155 people are employed by finfish farms in the Netherlands (FAO, n.d.). Total production was about 5.500 tons, valued at around €35.500.000, - in 2018. It is estimated that, currently, 5% of Dutch fish consumption is supplied by the Dutch finfish aquaculture branch (NeVeVi, 2018). While 50% of the Dutch fish & seafood consumption consists of farmed fish mainly imported from Asia (Rijksoverheid, 2014). The following species are produced in the Netherlands:

- African catfish (*Clarias gariepinus*) (2.470 tons from 10 farms)
- European eel (*Anguilla anguilla*) (2.150 tons from 12 farms)
- Yellowtail (*Seriola lalandi*) (500 tons from 1 farm)

Additionally, the following species are produced on a smaller scale:

- Sturgeon (*Acipenseridae*) (150-50 tons from 2 farms)
- Pikeperch (*Stizostedion lucioperca*) (150-100 tons from 3 farms)
- Turbot (*Scophthalmus maximus*) (100-60 tons from 1 farm)
- Rainbow trout (*Oncorhynchus mykiss*) (70-40 tons from 2 farms)
- Tilapia (*Oreochromis niloticus*) (1 tonne from 1 farm)

(FEAP, 2017; NeVeVi, 2018)

Figure 9: Two examples of Dutch fish farms (Dutch aquaculture experts, sd; Invest in Holland, sd).

Almost all produced African catfish are sold to a handful of processors, which mainly provide fresh or smoked fillets. Catfish is not known as a valuable and tasty fish among Dutch consumers, and approximately 70% is exported to neighbouring countries (Germany, Belgium, and France). Smoked eel, on the other hand, is a Dutch delicacy, and nearly all production is smoked and sold whole or as fillets on the Dutch market (FAO, n.d.).

The Dutch finfish aquaculture branch is well organized. Most of the Dutch finfish farmers are affiliated with one or multiple associations, e.g., NeViVi, The Dutch Society for Aquaculture (NGvA), The foundation DUPAN and The Eel Stewardship Association (ESA) (Appendix 6.1.).

[3] RAS systems: A RAS system is an aquarium for fish production where water exchange is limited and the use of biofiltration is required to reduce ammonia toxicity.

The same accounts for industries that are providing supportive services to the aquaculture branch, e.g., fingerlings, feed, agro-chemicals, and technological support (Appendix 6.2.). Financial Services in the form of grants and subsidies can be obtained via Rijksdienst Voor Ondernemend (RVO) – Netherlands Enterprise agency. Subsidies are made available to the Netherlands through the European Maritime and Fisheries Fund (EMFF). More information regarding the policy of the Dutch government to receive funding for the EMFF can be found in (Appendix 6.3.)

Opportunities to receive formal education in aquaculture-related topics do not lack in the Netherlands. They can be obtained through, e.g., Wageningen University (WUR), Applied Sciences institutions, (HZ Hogeschool Zeeland) and MBO Life Sciences in Oenkerk. Research in the field is conduct by the Aquaculture & Fishery group of WUR and Wageningen Bioveterinary Research, providing knowledge to public and private entities. (Appendix 6.4.)

The compliance of fishery and aquaculture products with Dutch and European food safety, traceability, and labelling regulations. Is monitored by the Netherlands Food and Consumer Product Safety Authority (NVWA), an independent agency from the Ministry of Agriculture, Nature and Food Quality. (Appendix 6.5.)

7.3. Environmental drivers

This chapter covers the environmental drives influencing the Dutch finfish aquaculture branch, see figure 10. As a result of climate change, the Netherlands will keep getting warmer and wetter (CBS, n.d.; Rijksoverheid, 2018). The rising sea level is a risk as a large part of the land, 60% of the country (Nicholls-Lee, 2019) is situated below sea level, which rises about 3mm per year (Nicholls-Lee, 2019). There is a risk that the tidal river area, which is very important for freshwater provision (Kwadijk et al., 2010) will undergo a process of salinization due to the rising sea level and reduced river discharge in the dry summer months. This will impact the ground- and surface water (Kwadijk et al., 2010), directly impacting civil society and all the businesses that are dependent on freshwater availability (including the finfish aquaculture branch).

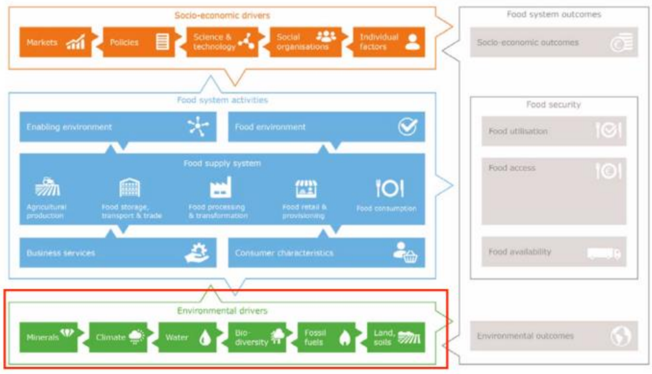


Figure 10: FSA model environmental drivers.

The water quality is at risk due to the intensive use of manure, fertilizer, crop protection chemicals, and medicines, which cannot be rinsed out and end up polluting the water. To tackle these problems, the Dutch government prepared a freshwater policy based on the availability of freshwater and water shortages in certain areas. (Ministerie van Infrastructuur en Milieu, Ministerie van Economische Zaken, 2015).

The world-wide eel populations have decreased sharply. The European eel is on the IUCN red list as 'critically endangered.' EU regulations have banned the export of European eel outside of the EU as of 2010. EU regulations limit catches and obligates to use 65% of the captured eels to be used for repopulation from June 2013. Eel farms depend on catches of wild glass eels (DUPAN, 2020).

7.4. Food system outcomes

This chapter covers the outcomes of the Dutch finfish aquaculture system, see figure 11, including the socio-economic outcomes (e.g., the income of farmers, employment, wealth generation, and the social, political, and human capital), food security (food utilization, food access, and food availability) and environmental outcomes.

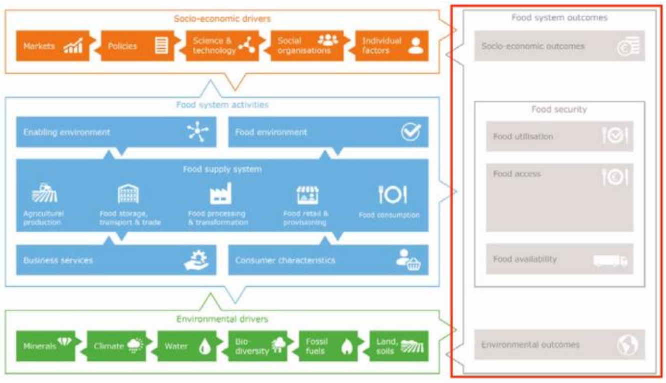


Figure 11: FSA model food system outcomes.

Socio-economic outcomes

Based on estimations (see appendix 7.1.), it can be assumed that the 50 licensed Dutch finfish aquaculture companies employ approximately 93 FTE, costing 46.000 € FTE/yearly on average.

The wealth generated by the Dutch finfish aquaculture supply chain is estimated to be: € 46.120.000,- annually (excl. retail stage). This is based upon the yearly volume and value (RSP) of the Dutch domestic fish & seafood consumption in 2017 while considering the local market share as well as exports of the Dutch finfish aquaculture branch. Elaboration on the quantification can be reviewed in appendix 7.1.

Dutch finfish farmers, predominately European eel and African catfish farmers face different difficulties pressuring their livelihoods next to the ones shared in RAS aquaculture farming. E.g., capital intensive, high risk, and small profit margins. European eel farmers face the fact that eel cannot be reproduced in captivity yet. The costs of purchasing glass-eels, therefore, having a massive impact on their production cost, which can amount up to 35% of the total expenses (Framain B.V., 2009). North African catfish farmers face the fact that cost- and sales prices are almost equal. Resulting in net-zero profits or even losses. Leading to the need for a scale-up, and constant production to be economically viable. Feed cost can amount up to 70% of the total production costs (Roosendaal, 2020). Detailed reasoning can be found in appendix 7.1.

Food Security

It is estimated that Dutch finfish aquaculture satisfies around 5% of the internal demand of fish, while approximately 50% of farmed fish come from Asian countries. This is to be put about consumer's preferences, which lean towards species not farmed in the Netherlands (such as salmon and shrimp) (Wageningen Economic Research, 2019). Only eel seems to be grown in the country mainly for internal consumption, while catfish are exported for 60 to 70 percent. Because of the country's prominent position as a hub for fish trade and processing, the availability of fish that meets consumer's preferences is guaranteed through a stable import of fish from abroad.

Road infrastructure and other means of transport are very efficient and organized in the Netherlands. Dutch logistics is well established, and it allows for the safe and timely distribution of fresh and frozen fish and fish products to the whole country. Fish and fish products are made available to retailers, fish stalls, fish stores, and catering industries, where consumers can buy them. Since more than 50% of the fish purchased is sold fresh, the importance of food safety and refrigeration along the transport is paramount. The Food Security Index shows the Netherlands as excellence regarding food safety, the ability to store food safely and the presence of agencies ensuring health and food safety of foodstuffs in the country (Food Safety Index, 2019), so, the availability of safe and fresh fish is not a concern.

Nobody in the Netherlands lives below the poverty line (Food Safety Index, 2019). Even if, on average, proteins from fish sources are more expensive than the ones derived from other animal sources and also if the price is one of the major concerns for consumers when buying fish (EUMOFA, 2018), the purchasing power of the household seems sufficient to provide for fish and fish products. The average consumption of fish is higher for men and women with higher socio-economic status (RIVM, 2016).

Fish provides less than 1% of the total caloric intake for Dutch consumers (RIVM, 2016). Around 60% of Dutch adults comply with the nutritional advice of eating fish once per week (RIVM, 2016). 23% of EPA and DHA are provided to adults by fish consumption. For adult consumers, 10% of the vitamin D introduced through the consumption of animal products is provided by fish, while for kids, the percentage is lower (4%) (RIVM, 2016). This is due to the smaller consumption of fish and fish products by young consumers.

Environmental outcomes

Finfish aquaculture contributes to various extent to environmental pollution, especially water pollution. RAS systems, thanks to their design, use relatively small water volumes compared to other systems, and the daily water exchange rate is low as well. The result is a small effluent discharges. This, combined with the capture and removal of the solids downstream, allows obtaining a concentrated sludge that can properly be disposed. The wastewater collected must be compliant with Dutch permits and licenses, which reduced any detrimental impact on the surrounding ecosystem (Badiola et al., 2015). From a comparison between RAS and intensive flow-through systems, it has been established that RAS has 26–38% less eutrophication potential[4] and 93% less dependence on the water source (Mongirdas et al., 2017). Aquaculture wastewater is often rich in potentially bioactive hormones, like cortisol and sexual hormones. It has been shown that RAS aquaculture has lower emission of hormones in the environment than a flow-through system, thanks to biological and mechanical treatment in place (Mota, 2012). In general, the adoption of a semi-closed system such as RAS allows for a reduced impact of aquaculture on the environment, and the avoidance of issues inherently connected with aquaculture, for instance, escapees and spread of diseases (Allsopp et al., 2008).

Stock overfishing and a decrease in wild fish populations are the main drivers for aquaculture (Allsopp et al., 2008). In this respect, Dutch aquaculture absolves the role of reducing the pressure on fish stocks. Nevertheless, Dutch eel farmers are still dependent on wild-caught juveniles (Nielsen, et al., 2008), therefore, proper management of wild stocks is of paramount importance if biodiversity of aquatic species must be safeguarded. The Dutch Eelplan has been established as a requirement of the European Eel Regulation (EC) No 1100/2007, aiming to sustainably recovery the eel stocks in inland waterways.

[4] Eutrophication potential leads to an increase in aquatic plant growth attributable of nutrients left by over-fertilization of water and soil, such as nitrogen and phosphorus.

DUPAN represents more than 80% of the entire Dutch eel farmer and is involved in various projects and scientific research regarding eel (DUPAN, 2020). Furthermore, the Eel Reproduction Innovation Centre (EELRIC), initiated by DUPAN and WUR, aims to achieve successful reproduction in captivity. This could close the production cycle and lead a more sustainable future for both eel aquaculture as well as management of wild eel populations (Eelric, 2020).

The conventional feed used in finfish aquaculture includes fish meal and fish oil, which are linked with depletion of fish stocks and loss of biodiversity (Allsopp et al., 2008). As long as Dutch finfish aquaculture will use the conventional fish feed in its operation. Biodiversity loss will be one of the outcomes of the branch activities, even if the effects will not be seen in the Netherlands.

Like many other agricultural activities, the finfish aquaculture branch is responsible for GHG emissions at every step of the supply chain. A study on global aquaculture emissions sets the boundaries for the analysis from the beginning of the production of the agricultural raw materials that must be deployed for fish feed production to the production of fish at farm level. Appendix 7.2. illustrates the steps of *pre-farm* and *on-farm* activities that are responsible for GHG emissions. From other studies on GHG emissions coming from aquaculture, it emerged that general hotspots at production level are related to:

- Raw materials used in feed formulation, the production process and place of production (it could add up to 87% of total emissions in marine aquaculture) (Rasenberg et al., 2013);
- The energy needed in RAS systems to run aeration, circulation, and temperature of the water.

Key Findings

The Dutch aquaculture branch is a small branch that is not self-standing and partly operates within a more extensive food system, namely that of Dutch Fish & Seafood. In 2017 the Dutch Fish & Seafood market represented a total value of €0,95 billion Retail Selling Price (RSP), and a volume of 82.400 tons averaging for €10,87/kg of fish/seafood RSP. The Dutch market represents 1.8% of the value of the European Fish & Seafood market.

Market & Food Supply System

The Netherlands are a popular trading hub for fish & seafood products in Europe. Dutch citizen consumes around 22kg/year on fish. Only 5% of Dutch fish consumption is supplied by the Dutch finfish branch. 50% of Dutch fish consumption consists of farmed fish mainly imported from Asia. Traditional selling channels in The Netherlands are:

- Retail 35%
- Direct sales 21%
- Specialty shops 17%
- Open markets 15%
- Horeca 12%

In 2018 the total export value of the Dutch seafood market was €3.8 billion from which 81% of the total value was sold within the EU. The total import value was €2.8 billion.

Production & Food System Activities

The finfish branch is tiny with only 50 licensed fish farms registered. The production of these finfish is solely based on RAS systems. The three species which represent the largest quantities are African catfish (2.470 tons from 10 farms), European eel (2.150 tons from 12 farms), Yellowtail kingfish (500 tons from 1 farm). European eel and yellowtail kingfish are considered a premium product. African catfish is not.

System outcomes

In 2018 the total production was around 5.500 tons. Valued at around €35.500.000.

Dutch finfish farmers, predominately European eel and African catfish farmers, face different difficulties pressuring their livelihoods (capital intensive, high risk, and small profit margins). Feed cost can amount up to 70% of the total production costs.

Water quality is at risk due to the intensive use of manure, fertilizer, crop protection chemicals, and medicines. Aquaculture also contributes to water pollution. To minimalize this as much as possible, the Dutch fish farmers use RAS systems, these systems use relatively small water volumes compared to other systems, and the daily water exchange rate is low as well. It has been shown that RAS aquaculture has lower emissions of hormones in the environment than a flow-through system, thanks to biological and mechanical treatment in place.

The type of feed ingredients, the production process and the place of production could add up to 87% of total emissions in salmon marine aquaculture.

8. Comparison of insect-based feed to conventional feed.

To rear fish, a well-balanced diet is necessary. A feed includes nutrients such as proteins, fats/lipids, carbohydrates, vitamins, and minerals. To understand why these nutrients are required, see appendix 8. The nutritional profile of fish- and insect meal is found in paragraph 8.2. The requirement of these nutrients for the three most reared species in the Netherlands, as seen in paragraph 7.2., will be discussed in paragraph 8.3.

8.1. Why is there a need for insect meal?

Due to the fast-growing world population, there is a big demand for animal protein. Because of this, the aquaculture sector has grown with 527% worldwide between 1990 and 2018 to 82 million tonnes of fish produced (FAO, 2020). To be able to feed all these aquaculture animals, an alternative protein source has to be found because wild-caught fish that is used to produce fishmeal is scarce and is already food for humans. Therefore the use of it is not sustainable. Insect meal could also be used to replace soy meal in fish feed. Soy meal is also considered not sustainable because, for the production of soy, forests in South America are being cut down, which leads to the extinguishing of several animal species who live in these forests.

One of the alternatives is the use of insect protein. In the next chapter, the nutritional value of insect meal and its (dis)advantages are discussed.

8.2. Nutritional profile of fish- and insect meal

To point out the differences between fish- and insect meal, it is important to know what the nutritional profile of both fish is- and insect meal. Important to know is that not all insects are allowed to be used in animal feed. As for now (28th of May 2020) only seven insect species are approved to be used in animal feed by *the regulation on the provisions on processed animal protein EC No (142/2011*[5]*)*:

- Black soldier fly (*Hermetia illucens*)
- Common house fly (*Musca domestica*)
- Yellow mealworm (*Tenebrio molitor*)
- Lesser mealworm (*Alphitobius diaperinus*)
- House cricket (*Acheta domesticus*)
- Banded cricket (*Gryllodes sigillatus*)
- Field cricket (*Gryllus assimilis*)

At this moment, the use of insect protein is only allowed for aquaculture and pets. Whole insects can be used for laying-hens and pets. Other farmed animals are not yet allowed to be fed any kind of insect protein, as this is not yet defined in EU and national legislation. Also, feed-substrates for insect culture has specific legislation, which prevents for food safety, potential zoonotic and veterinary pathogens. This makes it hard to culture insects on low-cost leftover streams.

More information on the applicability of insects in animal feed, the substrates they can be grown on, and the European regulations behind the processing of insect meal can be found in appendix 9.

[5] COMMISSION REGULATION (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as regards the provisions on processed animal protein

8.2.1. Proteins

The protein composition is fundamental when fishmeal gets replaced with insect meal, especially the essential amino acids. Below a table is presented with the crude protein levels and amino acids of different insects that can be used in fish feeds. Besides that, also the protein and amino acid levels of fishmeal are listed.

Table 1: Amino acid profiles of the black soldier fly (BSF), yellow mealworm (YMW), and fishmeal (FM). Amino acids are given as a percentage of the total crude protein. CP: Crude Protein, ARG: Arginine, HIS: Histidine, ILE: Isoleucine, LEU: Leucine, LYS: Lysine, MET: Methionine, PHE: Phenylalanine, THR: Threonine, TYR: Tryptophan, VAL: Valine. Source: (Barroso, et al., 2013).

SPECIES	CP	ARG	HIS	ILE	LEU	LYS	MET	PHE	THR	TYR	VAL
FM	**73.0**	7.42	**7.86**	5.04	7.81	8.78	**2.93**	5.38	6.26	**3.91**	5.56
BSF	**36.2**	8.24	**5.29**	5.76	6.87	7.60	**1.50**	6.88	5.39	**6.35**	6.31
YMW	**58.4**	6.14	**3.64**	5.87	8.65	6.03	**0.64**	4.29	4.49	**4.18**	7.61

8.2.2. Lipids

Insect meal is very interesting because of its fat levels. It is possible to manage the composition of the fatty acid content of insects by the substrate on which they are fed (Vrij, 2013). The essential fatty acids for fish are omega 3 and 6. Therefore insects must contain high levels of Omega-3 and -6 fatty acids. Unfortunately, some insects do contain reasonably high amounts of Omega-6 fatty acids, like Linoleic acid (18:2n-6), but lack in the number of Omega-3 fatty acids like EPA and DHA (Trant et al., 2015). Research has shown that for instance changing a substrate from only cow manure to a 50/50 mix of cow manure with fish offal will change the omega-3 fatty acids level from black soldier fly larvae from 0.2% to 2% and the total amount of lipids from 20% to 31% (St-Hilaire et al., 2007).

Fishmeal does contain higher amounts of the essential Omega-3 fatty acids; therefore, it still is a preferable source to provide the required fatty acids, although they do not provide in the Omega-6 fatty acids.

Down below, a table is listed with the crude fat levels and fatty acids of the black soldier fly, the yellow mealworm, and fishmeal.

Table 2: Fatty acid profiles of the black soldier fly, yellow mealworm, and fishmeal. Fatty acids are given as a percentage of the total crude fat (CF). Source: (Barroso, et al., 2013).

SPECIES	CF	18:2N-6	18:3N-3	20:5N-3	22:6N-3	OMEGA-6	OMEGA-3
FM	8.2	1.1	0.2	14.1	16.1	2.7	34.7
BSF	9.3	15.2	0.7	0	0	15.2	0.7
YMW	3.5	30.4	1.1	0	0	31.5	0

8.2.3. Carbohydrates

Fishmeal does not contain any carbohydrates.

On the other hand, insects contain high levels of chitin and chitosan. Chitin is a polysaccharide which looks a lot like cellulose[6], but with an extra amine (NH_2) group (Vrij, 2013). Because this chitin also contains N atoms, it can be mistaken with protein in several feed tests, so the real protein levels are often lower (Vrij, 2020). Chitin is the main component of the exoskeleton of shrimps, crayfish, crabs, and insects. It is solid and, therefore, difficult to digest. Chitosan is produced by deacetylating chitin. In the process, a percentage of the acetyl groups (CH_3CHO-) is removed. Chitin is very hard for fish to digest, and therefore it is generally said that this is one of the factors limiting the suitability of insects in fish feeds (Trant et al., 2015). When the content of chitin is not more than 2%, it is probably no problem, and it will likely even improve the digestion of other nutrients (Vrij, 2020). On average, a black soldier fly larvae contains around 9% chitin (Caligiani et al., 2018).

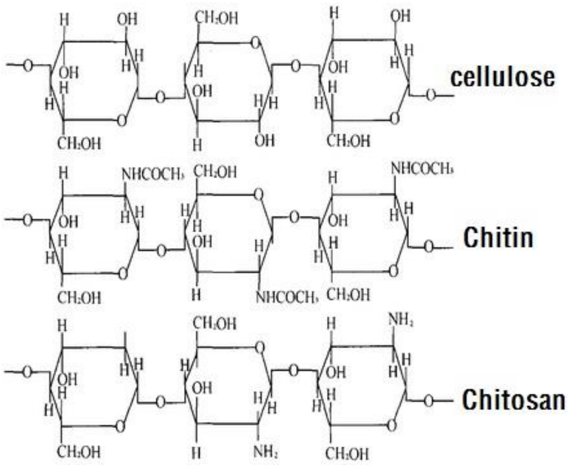


Figure 12: The difference between cellulose, chitin, and chitosan

8.2.4. Minerals & Vitamins

The mineral & vitamin content of fishmeal lies between 17% and 25% (The Fish Site, 2006). The majority of these minerals & vitamins are calcium and phosphorus. Further on, the vitamin content of fishmeal is very variable and depends on several factors, such as the origin and composition of the fish, processing method, and the freshness of the product. Vitamins that are found in moderate amounts in fishmeal are vitamins of the B-complex, niacin, choline, pantothenic acid, and riboflavin (The Fish Site, 2006).

Most insect meals have low ash content, especially when compared to fishmeal. The larvae of the black soldier fly are an exception to this. There have been reported values of > 15%. They have high contents of calcium. (Trant et al., 2015). The average calcium: phosphorus ratio of most insects varies between 0.2 and 1.2 (Trant et al., 2015) only not for the black soldier fly larvae, their rate is 8.4 (Trant et al., 2015). Fish require a minimum Ca: P ratio of 1.1-1.4.

The vitamin content of insects depends very much on the substrate on which they are grown. If this is rich in vitamins, the insects will be too (Vitamins and Minerals, 2016).

[6] Cellulose is an important structural component of the primary cell wall of green plants.

8.3. Nutritional requirements of African catfish, European eel, and yellowtail kingfish.

The nutritional requirements of the three selected species are partly understood. One of the reasons for this is that they have a small worldwide market share, so there is not much economic input for research effort. In this chapter, the main findings on subjects like proteins, fats, carbohydrates, minerals, and vitamins will be given. In the end, the average feed composition for all three species will be provided.

8.3.1. Proteins

The specific percentages on the amino acid requirement for the African catfish have been researched. They are shown in table 3, as well as the amino acid requirement for Japanese eel (a comparable species to the European eel). For the yellowtail kingfish, there is no research known on the amino acid requirement.

Table 3: Amino acid requirement of African catfish and Japanese eel as a percentage of minimum dietary protein (FAO, n.d.).

Amino acid	African catfish	Japanese eel
Arginine	-	4.5
Histidine	1.39	2.1
Isoleucine	1.56	4.0
Leucine	4.87	5.3
Lysine	4.49	5.3
Methionine	3.2	3.2
Phenylalanine	4.56	5.8
Threonine	2.04	4.0
Tryptophan	2.59	1.1
Valine	2.08	4.0

In their grow-out phase, both animal and plant proteins are well digested by the African catfish (FAO, n.d.). This makes a great opportunity to replace fishmeal in their diet. Regular catfish feeds contain a mix of animal and plant proteins, but the required amino acids can be obtained through a mix with only plant proteins (the fish site, 2006).

Research from (Satoh, 2016) had shown a decrease in the growth of European eel when the essential amino acids were taken out of their diet. Looking at figure 4 learns that when essential amino acids are taken out, the average body weight is much lower than when nonessential amino acids are taken out. On top, the normal growth with a control diet is shown.

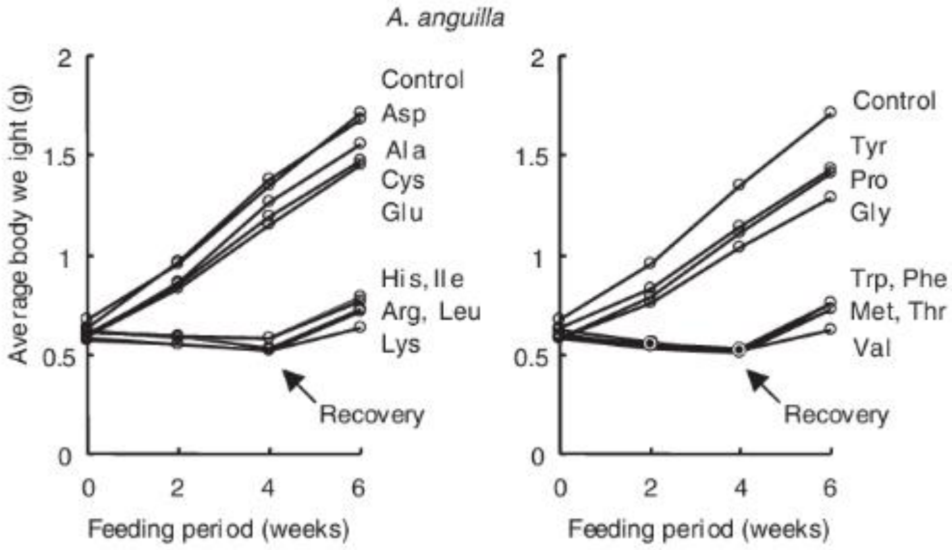


Figure 13: Growth of European eel with and without the essential amino acids (Satoh, 2016).

Looking at table 3 learns that the methionine, the requirement is 3.2% of minimum dietary protein, is not met in any of the insects, or fishmeal. This may cause a problem feeding African catfish and European eel with insect meal.

8.3.2. Lipids

In the larvae, fry, and early juvenile phase of its life, the African catfish has a demand for lipids of around 9% (FAO, n.d.). The requirements on fatty acids are unknown, except the fact that a 1:1 ratio of n-3 and n-6 fatty acids appear to be optimal for both body condition and growth (FAO, n.d.). In their grow-out phase, the African catfish need around 10-12% of dietary lipids (FAO, n.d.). Research by Ng et al., (2003) has also shown that fish oil that is used as the primary source of lipids harms their growth (FAO, n.d.).

Fats are an essential source of energy for carnivorous species like an eel. This is because they have trouble digesting carbohydrates. Research by Takeuchi et al. (1980) determined that Japanese eel need both linoleic acid and linolenic acid as 0.5% of their diet.

Because yellowtail kingfish is a marine species, it has a higher requirement of EPA and DHA (Tasbozan et al., 2017) or also known as Omega-3 fatty acids. In general, it is said that freshwater fish require linolenic acid, linoleic acid, or both, where marine fish require DHA and/or EPA (Tasbozan et al., 2017).

Freshwater fish, such as the African catfish and the European eel, require linoleic acid (18:2N-6) and linolenic acid (18:3N-3) (Tasbozan et al., 2017). Insect meal can be a good source for these fatty acids, as can be seen in table 2. For marine fish like the yellowtail kingfish, who require EPA (20:5N-3) and DHA (22:6N-3) (Tasbozan et al., 2017) insects may not be a good source of lipids because of their lack on these fatty acids.

8.3.3. Carbohydrates, Minerals & Vitamins

Research in which the requirements on carbohydrates, minerals & vitamins have been determined has not been found. Therefore, no information on this could be given.

8.3.4. Feed composition

To get an insight into the average feed composition of the selected species. The high-performance feeds from Biomar are used as an example.

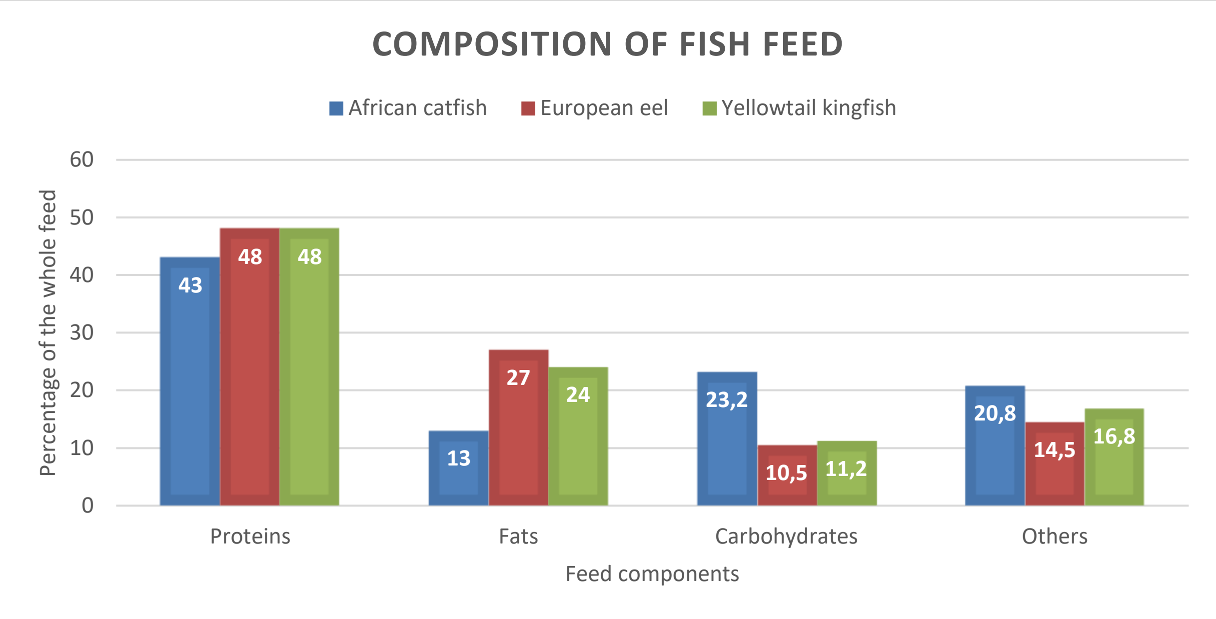


Figure 14: Feed composition (in % of total feed) of African catfish, European eel, and yellowtail kingfish (Biomar).

8.4. Price differences of fishmeal and insect meal

Prices of insect meals are very fluctuant, and the feed sources for the insects are very changeable (Katoele, 2020). Between April 2019 and April 2020, the price of fishmeal varied between 1,10-1,21 euros per kilogram (Index Mundi, 2020), and a kilogram of insect meal varies between 4-8 euros (Katoele, 2020).

The most significant contributors to the costs of an insect farmer are labour, feed, and energy. Also in that order (Katoele, 2020). To lower labour costs, automation is needed. Still, to use it, an insect farmer should grow too large quantities so automation can compete with real labour. However, most insect farmers cannot or do not dare to take this step because there is almost no demand for insects at the moment (Katoele, 2020). With feed costs being the second biggest contributor to costs, a way should be found to lower costs. For now, the reason feed costs are high is that insect farmers cannot feed their insects on 'low' cost substrates such as real waste, based on EC No (142/2011[2]). Insect meal prices are expected to drop because of the growing demand for insect-based feed. This growing demand will partly happen due to the increasing costs of fishmeal because it is also used for other animals (Gasco, 2020) , and there the need for fishmeal is rising (Gasco, 2020). In 2010 the use of fishmeal was divided into the following order: Aquaculture 56%, Pigs 20%, Poultry 12%, Ruminants <1%, Others 12% (The Fish Site, 2006). It is such a wanted feed component because of its nutrient content, high digestibility, and palatability (The Fish Site, 2006).

8.5. Case study on seabream fed with insect meal

To compare conventional feed with insect-based feed, existing research of Atsushi et, al. is used to analyse the outcomes on growth, feed conversion ratio (FCR), and the difference between the prices of fish- and insect meal.

There have been different trials in which fish meal was replaced with insect meal in varying proportions. One of these trials was the one from Atsushi et, al. In this test, they replaced fishmeal with defatted yellow mealworm larvae in varying proportions. The first diet had 65% fishmeal and no insect meal. The second diet had 40% fishmeal and 25% insect meal. The third one contained 25% fishmeal and 40% insect meal. The fourth one had 65% insect meal and no fishmeal. Apart from the results, which were surprisingly better with the insect meal instead of only using fishmeal, it is also interesting to look at what price differences these different feeds probably have.

The insect meal was added as a percentage of the fishmeal content. To simplify the price difference, it is assumed that the fish get 1kg of feed each day, which means that the inclusion levels were 250 (diet 2), 400 (diet 3), and 650 (diet 4) g/kg. Looking at the prices as given in Paragraph 8.4, the cost of fishmeal is between 1,10-1,21 euros/kg, and insect meal lies between 4,00-8,00 euros/kg. The prices of fish- and insect meal is simplified by taking their average, meaning €1,15 for fishmeal and €6,00 for insect meal.

The trial was conducted over four weeks with n = number of fish, starting from 32. To measure body weight, all the fishes were measured three times (at the beginning, after two weeks, and after four weeks). The body weight (BW) gain, total feed intake per fish, and feed conversion ratio (FCR) were calculated as follows:

BW gain (g) = BW at trial end – starting BW,
Feed intake per fish (g) = total feed intake group (g)/number of fish,
FCR = total feed intake group (g)/BW gain group.

Table 4: Results of the diets used in the trial of Atsushi et al.

Diet composition	**65% fishmeal**	**40% fishmeal / 25% insect meal**	**25% fishmeal / 40% insect meal**	**65% insect meal**
N	29	31	32	32
BW gain	7.2	10.4	11.8	12.8
Feed intake (g)	8.5	11.2	13.8	14.6
FCR	1.17	1.08	1.17	1.14
Survival rate (%)	90.6	96.9	100.0	100.0
Price of protein part / kg feed	€0,75	€1,96	€2,69	€3,90

As seen in table 4, the diets which contained insect meal scored better on several points, the more insect meal was added, the bigger they grew. Probably the feed containing insect meal tastes better, because the more insect meal was included in the feed, the more the fish ate of it. Also, the FCR is slightly better in the feeds containing 25 and 65% insect meal.

Including insect meal to the feed adds a significant amount to the price of the feed. Therefore it is understandable that fish farmers, and especially African catfish farmers who operate on minimal margins, cannot afford the feed if they do not get a premium price for their fish. Even the slightly better FCR does not outweigh the price difference.

Key findings

Proteins

Protein are an important feed component because they are made of different amino acids that are essential to create different body protein. Amino acids can be divided in essential and nonessential amino acids. Essential amino acids have to be obtained through feed. When comparing amino acids in fishmeal and insect meal the biggest differences are:

- Fishmeal contains higher levels of methionine and histidine.
- Insect meal contains higher levels of arginine and tryptophan.

Lipids

Fish require omega-3 and -6 fatty acids. These fatty acids can be obtained through different feeds. Fishmeal contains high levels of omega-3 fatty levels but lack in omega-6, for insect meal this is the opposite way, they contain high levels of omega-6 fatty acids but lack in omega-3. It is to say, though, that the fat composition of an insect depends on the substrate it is fed on.

Carbohydrates

Fish don’t need carbohydrates, the reason it is found in big proportions in their feed is because carbohydrates are a cheap energy source. When looking at fishmeal there are no carbohydrates in it. For insect meal this is different. Insect meal contains chitin, this is a hard to digest carbohydrate found in the bones of the insect. Because of this chitin, it can be questioned if insects are a good alternative for fishmeal.

Minerals & vitamins

Fish do have a need for several minerals, the two most important are calcium and phosphorus. Fishmeal and insect meal both contain calcium and phosphorus but not in high enough levels. Therefore additional minerals need to be added to the feed, this is most time done by adding a pre-mix which contains several minerals and vitamins to make sure the minimum of those minerals and vitamins are reached. The mineral and vitamin content of insect meal aren’t always the same, because these levels depend for a big part on the substrate the insects are grown on.

Price difference

Insect meal (€4,00-€8,00) is much more expensive than fishmeal (€1,10-€1,21). Reasons for this are:

- Insect farmers can’t grow their insects on ‘waste’ so they have to use more expensive alternatives. Therefore their cost price is higher, making it their second highest contributor to costs.
- Insect meal don’t yet has a constant quality. Therefore there is a low demand for it.
- The quantities insect farmers can provide to feed companies are far too small, therefore big markets can’t be supplied. Which makes it a premium.

9. Constrains limiting the utilization of insect-based feed.

Chapter 9 explores the major constraints limiting the use of insect-based feed in the Dutch finfish aquaculture branch. Through an online questionnaire distributed among Dutch finfish farmers and interviews with various (inter)national industry stakeholders, the research seeks to create a complete understanding regarding this topic.

9.1. Fish farmers' perspective

SRQ1 and SRQ2 provided the background for the formulation of the questionnaire. The main objective was to collect the constraints that Dutch fish farmers encounter in using insect-based feed and its actual retrieval, creating an understanding of possible points of improvement that could drive a wider interest from the farmers' side. A detailed elaboration on the questionnaire methodology, including sample definition, final questions formulation, and data analysis, can be found in appendix 3.

Table 5: Response to the questionnaire.

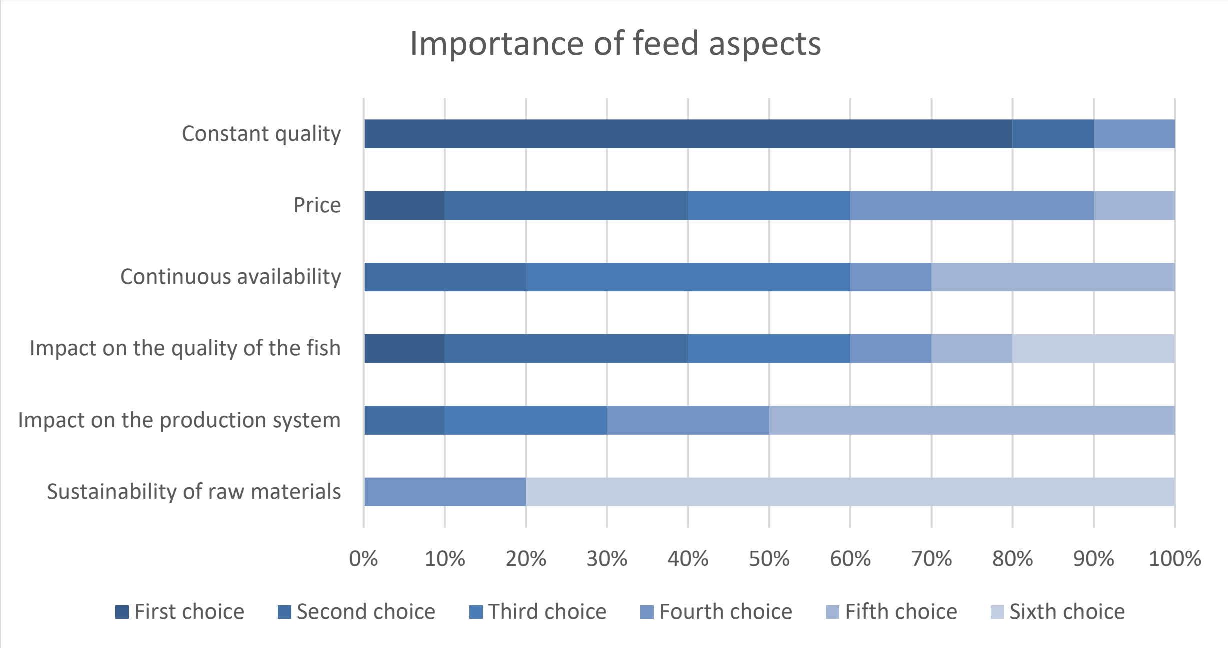
Number of questionnaires distributed	48
Fish farmers out of business	17
Total response	**11**
Respondences rate	**35%**

The majority of the respondents are male (90%), 50+ years of age (59%), and received formal education in the form of a Bachelors's degree. Most of them are a member of one or more branch organizations, e.g., NEVEVI, (81%). The respondents produce the following variety of fish species:

- European eel (Anguilla anguilla) – 6 farmers
- African catfish (Clarias gariepinus) – 2 farmers
- Sturgeon (Acipenseridae) – 1 farmer
- Rainbow trout (Oncorhynchus mykiss) – 1 farmer

As shown in table 6, most of the respondents (83%) consider the consistent quality (feed conversion & palatability) the most important aspect of their feed: Respectively price 2nd (42%) and availability 3rd (33%). Impact on the quality of their fish, on their production system, and the sustainability of the feed are ranked 4th, 5^{th,} and 6th in that order.

Table 6: Important aspects of feed, according to the respondents.



55% Of respondents indicate to be aware of the developments regarding insect meal as an alternative protein source in feed. How the respondents obtained their knowledge varies equally (33% each) between feed advisor, industry literature, and others. 44% indicate to have explored the possibility of using feed containing insect proteins to feed their fish. The respondents suggest that currently, the most significant limitation that prevents them from switching to feed based on insect proteins are:

- Price *(purchasing cost for farmers)*: 25%
- Continuous availability *(quantity on the market that can be purchased):* 25%
- Constant quality *(feed conversion ratio & palatability)*: 17%

Furthermore, 33% answered other, which entailed:

- Not proven that European eel finds it tasty
- No proof of increased performance benefit

9.2. Stakeholder's vision

To create a broader understanding of the major constraints limiting the adoption of insect-based feed, interviews have been conducted with relevant (inter)national stakeholders. Appendix 2 shows all the interviewees and gives an overview of their role in the aquaculture system, utilizing the FSA model. Summaries of the interview were coded to categorize the information provided by this expert input. The outcomes are elaborated upon here below in the form of an interpretative story. The final coding book can be found in appendix 4.

The aquaculture feed market is based on large quantities and low prices. To be able to access the feed market, insect meal (as any other feed ingredient) needs to be available in large amounts and at competitive prices. Under the current circumstances, this is not the case. Almost all the interviewees and the fish farmers that answered the questionnaire mentioned lack of volumes/availability and high prices as major issues related to the use of insect-based feed. The feed companies interviewed cited a lack of consistent quality as well. As the major reason for lack of volumes, the interviewees mentioned the lack of investments in insect production, due to the low interest that investors have for a product that at the moment has low access to market and still has many uncertainties connected with the infancy of the industry. The high price of insect meal is due to the low production volumes and the high costs of substrates currently used for insect production, which constitute the second most significant factor impacting the final price. The type of substrate used does not only affect the price of insect meal, but also the quality. Therefore their composition as a nutrient is strictly related to the quality and type of substrate. Under current legislation, the substrates allowed to feed insects follow the same limitations as animal feed ingredients. Many argue that legislation in this regard is unreasonably strict, and more substrates should be allowed. In particular, the reference is to substrates that come from actual waste streams. The restricting regulations on substrates also affect the imports of cheaper insect meal coming from outside the EU, due to the loose foreign legislation regarding the substrates allowed. Public and private research on health and safety could facilitate the necessary knowledge to draw insect-specific legislation. Research can also expand the opportunities for insect growers to use different types of substrates allowed by current legislation. Mechanization and monitoring of specific production processes could increase volumes, lower prices, and improve quality.

On the other hand, a farmer's decision on which fish feed to adopt is governed by economic considerations. Feed costs are the biggest production costs for a farmer, and his income gets severely eroded if he adopts the more expensive insect-based feed with the same selling price for his fishes. Additionally, Dutch farmers do not choose insect-based feed because they are not sure regarding the actual benefits of the addition of insects. Even if they would like to take the risk (like for farmers that sell premium products such as yellowtail kingfish and eel), there is no commercially available product for them to buy. Farmers that are selling low-value fish are dependent on the price set by the client. Dutch consumers buy the majority of their fish from retailers and value low prices and the safety of their products. Therefore, fish farmers are pressed between the global market prices set by input providers, and the customers set prices.

Key findings

- The respondents indicated that currently, the most significant limitation that prevents them from switching to feed based on insect proteins are:
  - Price: 25%
  - Availability: 25%
  - Constant quality: 17%
- The high price of insect meal is a result of the low production volumes and the high costs of substrates used for insect production.
- The quality of insect meal depents very much on the substrate the insects are grown on. Therefore the quality isn't consistent.
- The restricting regulations on substrates are the key limitation towards cheaper insect meal. Public and private research on health and safety could facilitate the necessary knowledge to draw insect-specific legislation.
- The lack of investments is the major obstacle towards insect production scale up.
- Fish farmers are pressed between global market prices and the customers set prices.

10. Creating an enabling environment

The chapter explores the dynamics at play and their interrelationship affecting the adoption of insects-based feed in the Dutch finfish aquaculture branch. Expert input provided in the previous chapter and the interpretation of the researchers led to the selection of a set of key systems variables. The relationships between the variables have been explored through the use of an Inter-relationship Diagram (appendix 10), creating the basis for the creation of the Causal Loop Diagram (CLD), allowing the identification of system Archetypes, commonly recognized in food systems. Through this, leverage points can be identified, and action can be undertaken to change the system's behaviour and, thus, its outcomes (DH, 2000). This section is concluded with a case study, which shows in practice how similar constraints present in the Dutch finfish aquaculture have been resolved.

10.1. Causal loop Diagram

A visualization of the current dynamics can be found below. The colours link back to the FSA model used in SRQ1. The polarities (+ and -) show whether a variable influences the following in the same direction or the opposite. The arrows marked by // signal a delay in the effect of a variable. The letter R identifies a reinforcing loop, the letter B a balancing loop. Reinforcing loops generate continuous growth (or collapse) at an ever-increasing rate while Balancing loops create stability in the system.

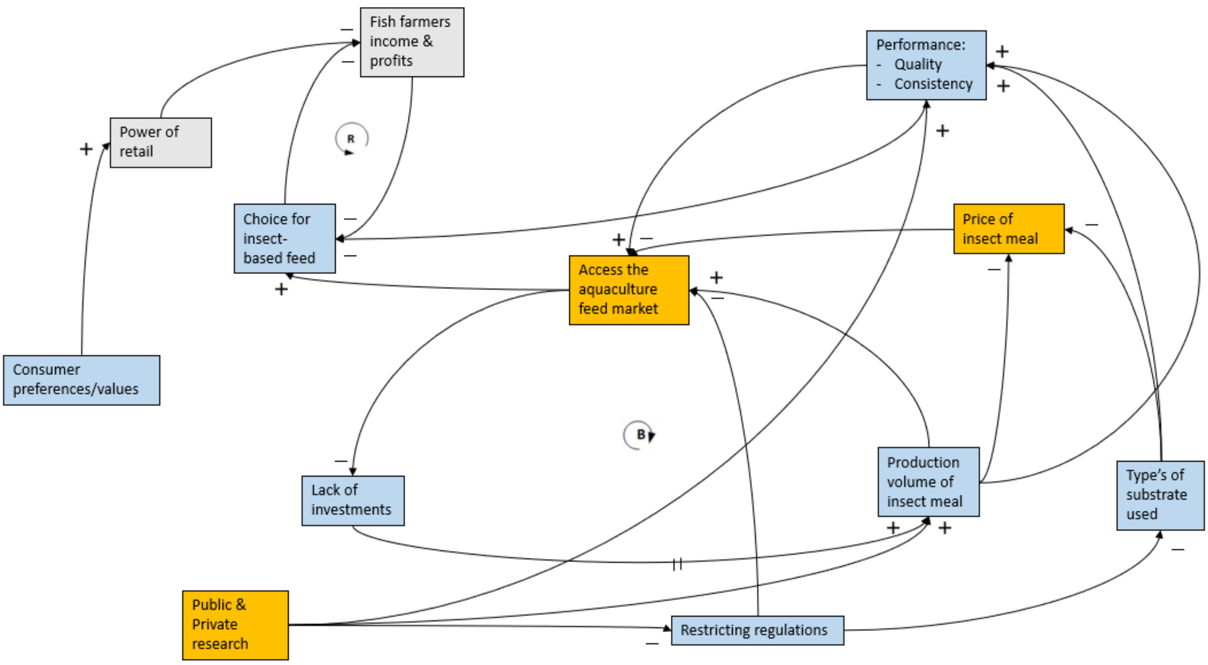


Figure 15: Causal Loop Diagram.

- **Orange**: socio-economic variables
- **Blue**: food system activities variables
- **Grey**: food system outcomes variables

10.2. Archetypes

Three archetypes[7] are identified to be present in the system analysed. Every archetype has a visualization, which is connected with the related variables present in the system.

Growth & Underinvestment

This archetype is characterized by a reinforcing loop of demand and efforts, which influence each other in a growth dynamic. The growing demand meets the current performance, which is not in line with the expectations in terms of quantity/volumes and consistency. This put a halt to the request, with a balancing loop. There is, therefore, a perceived need to invest in production capacity to meet the required performance to satisfy the demand and fuels growth anew.

The global interest for alternative protein sources from the feed producers increases the efforts of insect growing companies to satisfy this demand, which in turns result in a rising interest from feed formulators. Nevertheless, due to the limitations in the performance of current insect meal production (low production volumes and inconsistent quality and supply), the demand for insect proteins is limited. To improve current performance and bring it in line with the requested performance of feed companies, there is a need for new investments that can improve the volume and consistency of production of insect meal. But because this does not happen, the necessary improvements to correct the actual situation cannot occur, leading to a situation in which growth is balanced off by systematic underinvestment.

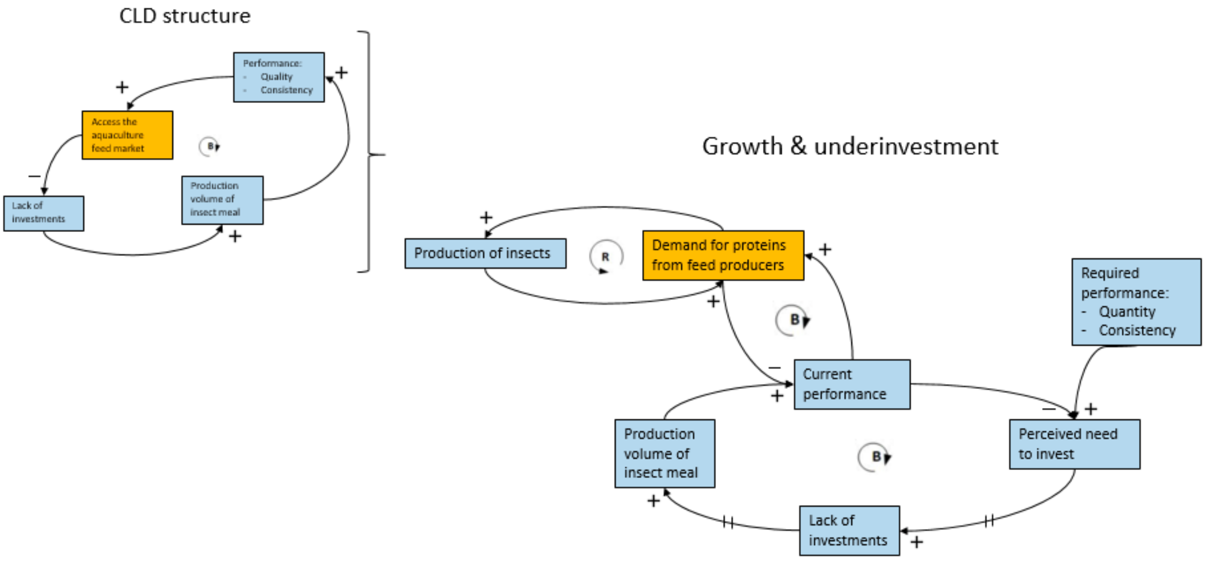


Figure 16: Growth and underinvestment archetype.

According to WUR and KIT Royal Tropical Institute (2018), leverage points for this archetype are:

- Increase investments to safeguard the quality of products and services, to prevent the demand for these from decreasing.
- Optimize capacity planning of production to be able to identify the need for investments.

[7] Archetypes: System archetypes represent generic behavioural patterns – or system dynamics – in any system.

Drifting goals

In this archetype, there is a gap between the desired goal (access the aquaculture feed market) and the actual situation (current performance). This can be solved through the adoption of corrective measures or a dimensioning of the original goal (lowering it). Access to the market is possible only if a particular performance, required by the industry actors, is met. The current insect meal is not meeting this performance standard. An option of a corrective measure would be to increase investments towards the reaching of the required performance standard to enter the market (with a delay, as it takes time to increase to improve the current performance, given the need to act upon volume and quality processes). As an alternative, the goal could be re-defined. The pressure to redefine the goal comes from the insect producers and their necessity to safeguards their income.

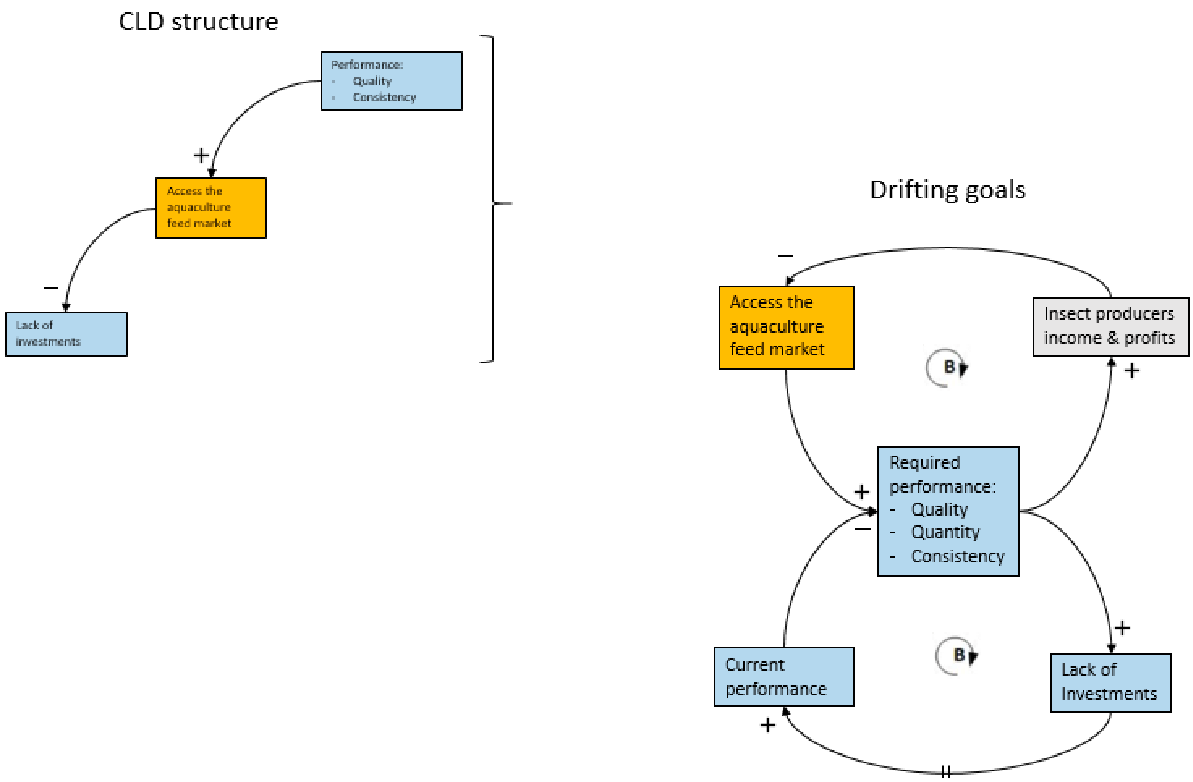


Figure 17: Drifting goals archetype.

According to WUR and KIT Royal Tropical Institute (2018), leverage points for this archetype are:

- Define realistic goals.
- Increase corrective actions to close the gap between actual performance and the required performance.
- Be more explicit in the defining steps required to achieve the desired goal.

Limit to success

In this scenario, two loops face each other. One is reinforcing and the other balancing. Efforts that are undertaken will lead to a certain performance overtime decrease in their effectiveness because of an opposite balancing loop containing a factor that causes the initial growth to level off. In the current case, the initial R&D efforts performed by public and private actors increased insect meal performance (quality, quantity, and supply), which in turn increased these efforts. Over time, the betterment of insect meal performance reached a point in which investments became the limiting factor. The lack of investments that affect the current system is to be re-conducted to the lack of access to the feed market, which reduces the investors' interest in financing the insect industry.

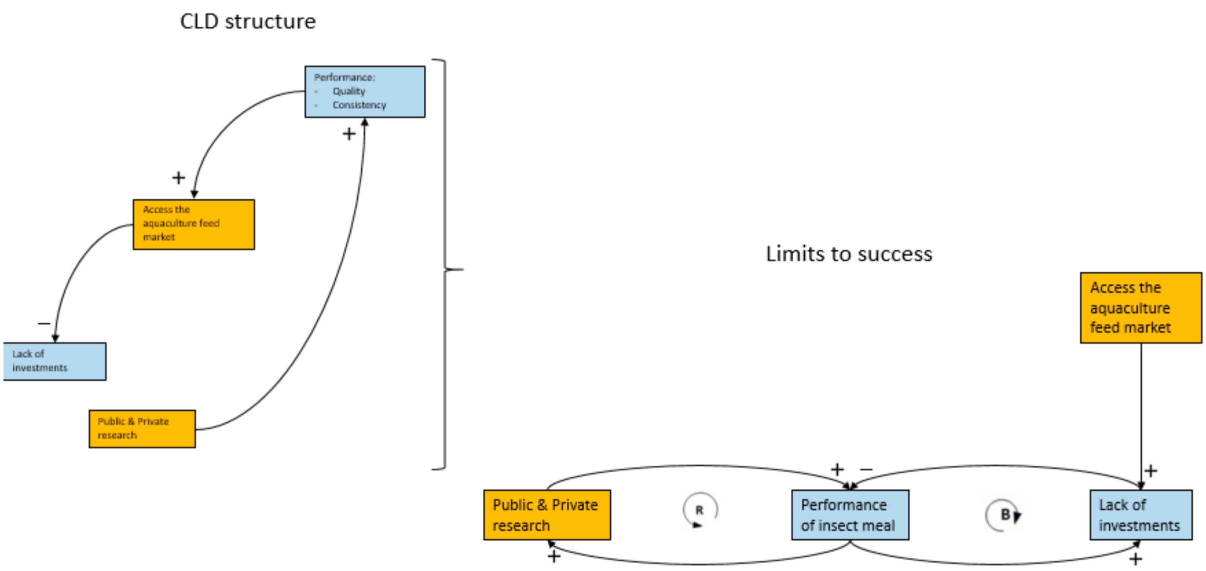


Figure 18: Limit to success archetype.

According to WUR and KIT Royal Tropical Institute (2018), leverage points for this archetype are:

- Identify the limiting conditions that slow down the achievement of the desired result.
- Weaken or eliminate the limiting condition.
- If not possible, seek to identify additional efforts that can be undertaken to stimulate the achievement of the desired result.

To sum up, investments constitute a leverage point common to all the archetypes identified. Acting on the investments (mainly increasing them) would allow volume and quality to improve, bringing the current overall performance of insect meal closer to the required one. Re-defining the goal (access the feed market) into a smaller more realistic (e.g., target a particular kind of fish or introduce a specific benefit in feed) could also constitute a point of intervention to introduce change in the system, without a significant injection of capital.

10.3. Case study

The insect industry in Europe is in an infant stage, and many constraints and dynamics that are pointed out for the Dutch situation are typical to all the stakeholders at the European level. Through the research, it was possible to identify a successful case of the implementation of insect-based feed within the French aquaculture feed market, which led to the commercialization of insect-fed fish.

This case study involves the French insect producer Innova feed, the retailer chain Auchan, the trout grower Truite Service and the feed formulator Skretting. For Innova Feed, governmental support was very relevant in the first R&D phases, and the company could access some European grants to finance the initiation of the business. European subsidies for innovative start-ups can be accessed by all the Member States in an equal manner.

The French finfish aquaculture market is almost five times bigger in value than the Dutch market, and it is dominated by the production of salmonids (predominantly trout) (France AgriMer, 2019).

The French consumer is quite different in comparison to the Dutch consumer. With an average of 34kg per capita, French consumers are consuming more fish than the Dutch ones. Looking at household expenses for fish, the preferred products are fresh fish (32%) and chilled delicatessen (36%). The preferred sales channel for both are supermarkets: 68% of fresh fish and 75% of chilled delicatessen are bought there. Fishmongers and markets are not as popular as in the Netherlands (France AgriMer, 2019).

Using insect-based feed to produce fish

In 2016 Innova Feed approached the French retailer chain Auchan. Auchan was already interested in diminishing its impact on oceans. In fact, during the Mediterranean bluefin tuna overfishing crisis in 2008, the chain was between the first who decided not to sell the fish anymore in its shops, so the Innova Feed project resonated very well with Auchan values.

The first step was to establish a **commercial trial**. The third partner to come on board was the fish farmer Truite Service, already supplying Auchan. Lastly, a feed provider was included in the partnership: Skretting. The chosen fish specie was trout: a traditional, widely produced fish in France. Another important aspect that was considered as the life cycle of the fish: trout has much faster growth than other salmonids (e.g., salmon could take up to 2-3 years before reaching the market, while trout can be of a marketable size already in 3 months).

The second step was to **solve a wide array of challenges**, ranging from technical to commercial. In this step, the individual competencies of each partner were used. It took 1.5-2 years to be able to have the first 30 tons of insect-fed trout on Auchan shelves, and it was a success.

The last step was to **establish a steady value chain**, which happened in December 2018. In February 2020, it was announced the addition of a new partner, the microalgae producer Veramaris. Algae oil has been introduced as a substitute for fish oil, which is in line not only with the sustainability target but also it will increase the amount of omega-3 present in the final product, contributing to consumer's health.

Challenges and solutions

As mentioned earlier on, Innova Feed alone and the partnership as a whole, had to overcome some challenges. The solutions that have been found are the result of the skills and knowledge of all the actors.

Table 7: Challenges and solutions in the French case study.

Challenge	Solution
Establish good and stable quality insect feed	**Use of agriculture by-products (starch co-products) from companies nearby.** The new production plant is co-located with a starch factory. **This allows for a constant stream of quality-stable feed for insects** and savings for the starch company.
Insect meal quantity	**The first plant, opened in 2017 had sufficient capacity to satisfy the needs of the partnership,** which was initiated in 2016. The pilot plant can produce around 300-tons of insect meal/year. A new plant will be active soon and will be able to produce 10 000 tons of insect meal/year.
Creation of a market/ demand for insect-fed fish	Innova Feed **worked with a supermarket chain that showed interest in fish sustainability topics.** The interest of Auchan was backed-up by consumer studies. Test panels were also set up.
Insect meal inclusion level	**The inclusion levels of insect meal have been worked out together with Skretting and the fish farmer**. Fish formulators are well prepared to conduct applied research and elaborate on a new product. The target became substituting 50% of the fish meal in trout feed. Such an amount was set for communication and marketing purposes. Not all the fish meal is unsustainable, so the focus is not to fully substitute fish meal but to increase the sustainability of trout in general.
Communication with consumers	**A logo has been created together with Auchan**. The logo resonates with the traditional image of trout fly fishing. It is immediate and straightforward. Few posters in the shops and a QR code that communicates the vision behind the project.
Production costs and price competitiveness with fish meal	The interviewee from Innova Feed claimed that the objective is to be competitive with fish meal. This might suggest that the company might not be there yet. **The insect-fed trout is sold for a premium in Auchan shops.** The substitution of soy meal is not in the plans; because, the price difference is still too big. **The company does not see a real bottleneck in being competitive with fish meal, once established economy of scale.**
Legislation	Innova Feed did not perceive legislation as an obstacle to its development, but in fact, saw it as a warranty that all the European players will work on a level playing field and as an assurance of quality for feed formulators. Of course, the time has been spent to adjust the business practices to respect the legislation in place. The use of food waste as a substrate is a topic currently lobbied in the EU. **The interviewee questioned the use of food waste:** ***"there will not be a stable influx of substrate (due to quantity and seasonality), so there will not be a stable output."***

Feasibility in the Dutch aquaculture branch

As seen in the case study, the partnership focused its efforts on a locally produced and consumed fish, trout. In the Dutch situation, the fish specie that would be similar to the trout in this regard is eel. The consumption of trout in France in comparison to eel in the Netherlands is 28 000 tons against 2150 tons. The production life-cycle (PLC) is very different between the two species: for trout three months are sufficient to have a marketable product, for eel 18 months are needed. The eating behaviour is also different: trout eat a variety of different feed, eel is more selective.

In the French case, the partnership included a large retailer, which had a relatively large amount of power and was the party that introduced the fish grower. In the Netherlands, it is prohibited to sell eel in the supermarkets due to historical sustainability issues. Nowadays the only points of sale are speciality shops, fishmongers and foodservice.

A fillet of smoked trout is 17 euros/kg, while smoked eel sells for 38 euros/kg. Eel is a premium product compared to trout, which potentially could offer more margin for the adoption of a more expensive feed and the retrieval of a premium on the consumer's side. Furthermore, Dutch consumers are already familiar with the sustainability topic about eel, due to the endangered past of the specie. A step forward into a more sustainable future for this fish could play well in the eyes of the consumers.

The sustainability efforts could be harder to communicate to the consumers in the Netherlands due to the fragmentation of the sales points in comparison to the French case: supermarket chains are more consolidated than fishmongers and speciality shops. Dutch foodservice could be an excellent alternative to partner up.

The creation of a logo to communicate the natural aspect of insect-fed trout plays with the traditional fly fishing image, an established picture in the consumer's mind. The same strategy could not work for Dutch consumers and eel, as it is not possible to fish them for decades, and there is not a particular traditional image associated with eel catching.

Finally, the eel sector is not as big as the Salmonids sector, and traditionally it is not the first mover in pursuing and introducing innovations. It could be challenging to work with more conservative actors, without the right incentives in place to take risks.

Key variables

Table 8: Key variables feasibility of French case study in the Netherlands.

France (trout)	**Netherlands (eel)**
28.000 tons/y	2.150 tons/y
3 months (PLC)	18 months (PLC)
17 euros/kg	38 euros/kg
Supermarkets	Speciality shops, fishmongers and foodservice
Consumer awareness through sport fishing	Consumer awareness through sustainability issues
Salmonids sector are first-movers	Smaller more conservative sector

11. Discussion

Some limitations of this research can be read in this chapter.

SRQ1: *How is the Dutch finfish aquaculture branch organized?*

The FSA is a newly conceptualized model that does not have many practical applications. The researchers applied the model on the base of reports suggested by Mr. van Berkum, one of the authors, and on the base of additional consultation of a HAS researchers in Future Food Systems. The socio-economic outcomes of the system were based on relatively old and uncompleted data, and some assumptions had to be made on the base of the retrieved information. One of the most significant impacts on the environment is connected with the type of fish feed used, which can add up to 87% of the carbon footprint in the context of salmon aquaculture, due to the origin of source materials (e.g., soy from Brazil) and their production. Dutch aquaculture does not engage in salmon farming, so it is possible that these results do not reflect the Dutch branch situation.

Nevertheless, these results are relevant as they exemplify the enormous environmental impact that aquaculture fish feed could have, and establish a strong case to start a protein transition in the industry. A comparison with insects could not be made as it was out of the scope of the current research. Still, it is possible to make the hypothesis that they could have a reduced environmental impact due to the local substrates used and the local production process.

SRQ2: *How does insect-based feed compare to conventional feed in relation to nutritional needs and economic performance of selected fish species?*

In addition to this, limitations have been encountered in retrieving specifics nutritional needs related to the species investigated due to the high variability of the reported data. The variability has been tackled by establishing an average of the data reported. Retrieving the actual composition of fish feed resulted in a big challenge, which led to restructuring SRQ2 as a comparison between insect meal and fish meal, with an evaluation of the benefits from the introduction of insects in relation to their higher price.

SRQ3: *What are the major constraints limiting the utilization of insect-based feed in the Dutch aquaculture?*

Another limitation can be seen in the questionnaire results due to the low response rate. The response rate was low (35%), and the results are, therefore, not representative of the opinions of all the fish farmers in the Netherlands. Nevertheless, they could be used in a qualitative way to have an idea of the issues encountered by fish farmers. Another limitation in SRQ3 is the lack of interviewees representing the retailer category. The information reported regarding retailers come from desk research and interviews with the other stakeholders.

An interesting result emerged from the interviews and the coded summaries. Besides some generally shared constraints within the branch in regards to insect-based feed, there seems to be an unclear or delayed communication between the insect-related topics researched and experimented and the farmers. Fish farmers mention more than once that there are no apparent benefits for the fish in introducing insects in the feed. At the same time, researchers seem confident in reporting gut health benefits and a possible reduction of the use of antibiotics during the rearing of the fishes. In addition to this, fish farmers mention the absence of a business case that shows the actual implementation of insects in fish. Even if there is not an abundance of companies active in the insect industry that have established a value chain, including insects in fish feed, there are few successful examples in Europe. Still, it seems that they are not very well known by fish farmers in the Netherlands.

SRQ4: *How to create an enabling environment for the utilization of insect-based feed in aquaculture?*
At the beginning of this research, the Backcasting methodology was thought to be the most suitable way to approach the last of the sub-questions. It would have indicated the stakeholders of which steps to take to achieve the desired future. The advantage of this model is that the solutions are the result of a creative and un-prejudiced process/dialogue between stakeholders. During the research, though, the researchers discovered the existence of the Decision Support Tool, which is connected with the FSA, and it has been used to identify and initiate change within food systems. The Tool represented an optimal way to analyse the current system and the dynamics that are preventing the adoption of insects. Therefore the researchers decided to apply it instead of the Backdating methodology. The researchers acknowledge the possibility that with the original planning, the results of the research could have been different. Nevertheless, the two methods could be seen as complementary: with the Decision Support Tool the current dynamics are analysed, and suggestions are made on the best way to initiate change on the base of a successful business case. At the same time, the backcasting methodology could be used in future research to engage different stakeholders in imagining and building a future for insects in aquaculture.

The Decision Support Tool can be applied, according to time and resource availability, in three ways: a Light, Advanced and Comprehensive Package. Due to time constraints, the researchers used a “Light Package” of the Decision Support Tool. This does not diminish the results obtained, but it highlights the possible need for in-depth analysis with more resources and time available. An example of this limitation is the following: the Causal Loop Diagram should start with a discussion between stakeholders to identify the dynamics in the system. Due to time and resource limitations, this step could not be followed according to the manual. Instead, as a baseline, the summaries of the interviews have been coded and used to identify the main variables at play and their relationships. Through a stakeholder dialogue, possibly more links would have emerged, or different variables would be considered. The researchers did their utmost to adhere to the information retrieved through the interviews and to interpret the variables in light of the objective knowledge acquired through desk research. Nevertheless, they acknowledge the possibility that the system dynamics identified could be tainted by their subjective interpretation.

12. Conclusions

It can be concluded that the Dutch finfish aquaculture branch is relatively small, producing predominately European eel and African catfish. Production is solely based on RAS systems. The branch is well organized in terms of associations and dedicated communication channels. As in other agricultural supply chains, farmers' bargaining power is limited, pressured by the high cost of inputs and the low ex-farm sales prices. RAS system reduces the impact of aquaculture on the environment. Up to 87% of the total GHG emissions in the context of salmon aquaculture relates to the ingredients used in feed formulation.

Insect meal contains the necessary essential amino acids. The inclusion of insect meal in the protein fraction improves the FCR and increase the survival rate in sea bass (Atsushi, et al. 2019), but it raises the price of the feed almost two-fold (with insect meal inclusion of 25%). The substrate used to feed insects affects both the composition of insects (quality) and the cost price. The use of actual waste streams (e.g., municipal waste, manure) can reduce the cost price and make insect meal cheaper. Still, it is unclear if the use of these waste streams is safe and if the variability in quality would negatively affect the quality of the insect meal. Therefore, more research regarding this topic is needed. The restricting regulations on substrates also affect the imports of cheaper insect meal coming from outside the EU, due to the loose foreign legislation regarding the substrates allowed.

The major constraints limiting the utilization of insect-based feed are the high price of insect meal, the low volume that is currently produced, and the varying quality. These constraints prohibit it from accessing the aquaculture feed market, as this is based on large quantities at competitive prices. The lack of market access reduces the economic incentive for insect producers and private investors to inject the capital needed to achieve the required performance standard. The adoption of a more expensive fish feed is not interesting for fish farmers unless there are proven benefits that motivate the switch (e.g., better FCR, health benefits for the fish, higher palatability). Adoption under the current conditions requires the willingness of consumers to pay a premium to make the increased cost justifiable for the actors in the food system.

The gap between current and required performance is explained by the difference in the maturity of insect industry and feed industry. The French case study proves that targeting a specific fish species and consumer base offers the opportunity to verify the potential of the use of insect-based feed in aquaculture. Though, the strategy applied (focusing on a locally grown and eaten species and partnering with a supermarket chain) is challenging to replicate in the Dutch context. In the Netherlands, the locally produced and consumed species is eel. Still, many issues (endangered species, regulations, longer production cycle, small market, sold at many and little sales points) could make it not feasible.

13. Recommendations

The recommendations given here below are listed in order of priority, from present to future.

The knowledge among stakeholders active in the branch regarding the applicability and potential of insect-based feed varies widely. The lectureship can play an important role in reducing the **knowledge gap** through active knowledge dissemination, pursuing the affiliation of all relevant stakeholders: fish farmers, feed producers, research institutions, government, financial institutions, NGOs, insect growers and retailers. For example, creating a LinkedIn page can increase the outreach of the lectureship and can help to connect with stakeholders.

The lectureship, as a public stakeholder, can provide a neutral ground to facilitate the process of **value chain development**, promoting the adoption of insect-based feed to secure a more sustainable future for the branch. The methods applied in this research can be used as the first step to inspire multi-stakeholder discussion. The **Food System Decision-Support Tool** can be used to create a shared understanding of the current situation among the stakeholders affiliated to the lectureship. It is recommended to apply the following steps:

- Determine systems boundaries,
- Develop an Interrelationship Digraph
- Identify seed structure
- Build a Causal Loop Diagram
- Identify Archetypes and leverage point

In addition to the Tool, **Backcasting** can be explored as a way to involve stakeholders in the definition of a participatory future, by setting creative actions to achieve it.

The results presented by this research recommend to **re-define the goal** (to promote the branch-wide adoption of insect-based feed) into a smaller and more **realistic one**. This can constitute a point of intervention to initiate the transition, requiring a smaller amount of capital investments. For instance, similar to the French case study, a **specific fish species** or **consumer base** can be targeted. Some of the interviewees mentioned the improved gut health when fishes are fed with insect meal. This may reduce the need for antibiotics, which can be used as Unique Selling Point to appeal to a specific consumer base, justifying the payment of a premium. This creates a market that can attract investors' interest and investments to develop further production capacity to access the feed market. In partnership with feed producers, fish farmers, insect growers and retailers, the lectureship can assist with the following supportive research:

- Trial to investigate the possible improvement of FCR, gut health and survival rate resulting from the inclusion of insect meal in feed, in relation to the potential production output and the additional feed costs.
- Consumer study to verify the interest of consumers for fish grown with reduced antibiotics and the willingness to pay a premium for it.

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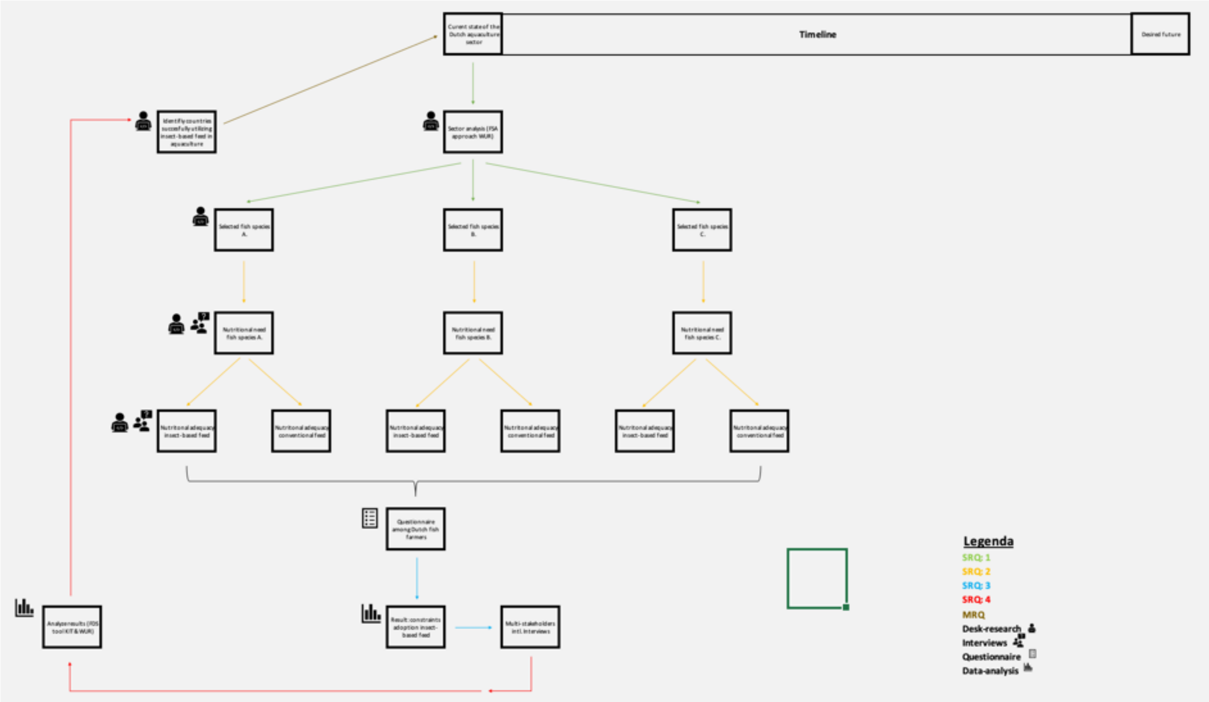
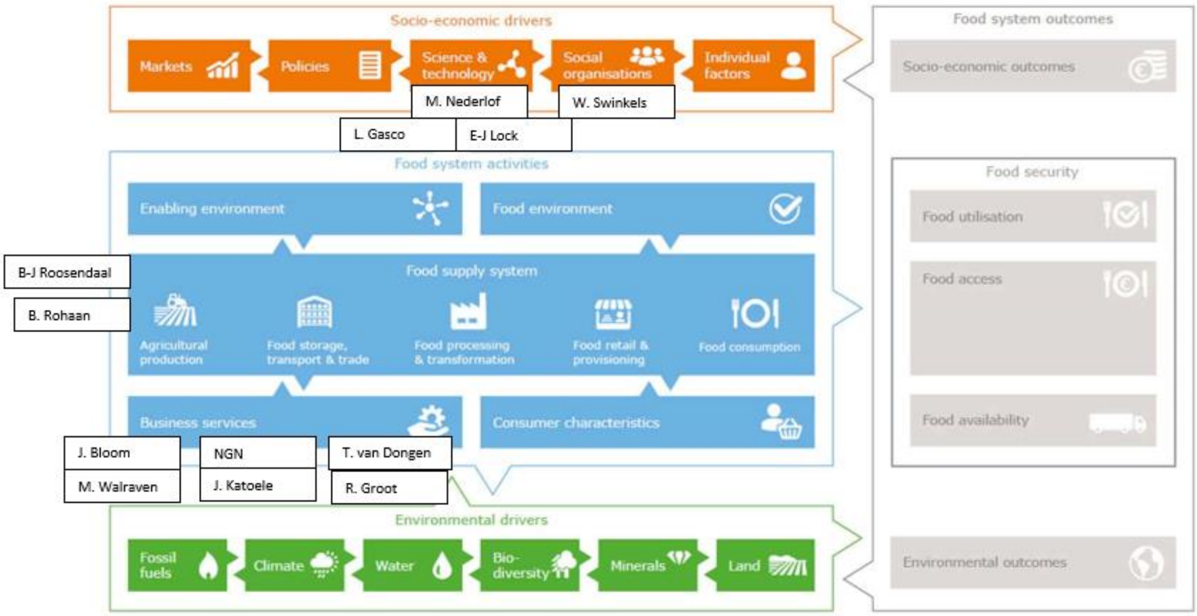
Appendix 1 – Research activities



Appendix 1.1.: Research activities figure.

Appendix 2 – List of interviewees



Appendix 2.1.: Interviewees, according to the FSA model.

Appendix 3 - Questionnaire

Key Hypothesis

The questionnaire is formulated considering mainly interviews with experts, within the background provided by SRQ1 and SRQ2.

The demographic questions (numbers 1 to 7) will give an overview of the average age and education of commercial fish farmers in the Netherlands. These aspects could result in high or low awareness of insect-feed related developments. The education level could be used in a later stage to define appropriate communication channels to disseminate research results. Up to this moment, the researchers have the supposition that fish farmers in the Netherlands have a formal aquaculture education of different sorts, ranging from vocational training up to a master's degree. In fact, in the Netherlands, various aquaculture-related courses can be accessed at a different level of education. The questions will also investigate the species grown and quantities produced per year. This will allow characterizing better the aquaculture branch in the Netherlands. Additionally, a specific question has been designed to investigate farmers' affiliation with sector organization, an aspect that could bring up the awareness of alternatives for fish meal.

The questions from 7 to 15 aim to confirm the knowledge acquired by the researchers. From interviews with selected farmers prior the elaboration of the questionnaire, it emerged that there is a vast difference in farmers margins according to the fish species grown and the impact of a higher feed cost could quickly bankrupt the business, if not balanced by proven market demand and higher customer willingness to pay more. To confirm this hypothesis, questions will first investigate the most important feed qualities in the farmer's eyes. The researchers expect the cost to be the first most chosen feed quality, regardless of the fish quantities produced. There might be some differences for farmers producing premium fish species. After a small introduction of novel protein sources and insects as a sustainable alternative, questions will investigate farmers' awareness of insect meal existence and the source of information. Researchers expect farmers to be aware of the existence of insect meal, due to communication with feed companies' representatives and sector magazines. Additionally, the questionnaire will investigate if farmers concretely tried to pursue insect meal for their business, and why it did not work for them. The answers are expected to be in line with interviews that highlighted as significant constraints to the widespread adoption of insects in feed the high cost of insect meal and its scarce availability.

Finally, some interviewees highlighted "market pull" as the main area to influence to achieve a change in the branch, so the questionnaire will investigate farmers' vision of insect-based feed as a way to add value to their product and their motivation (or willingness) to adopt insects as feed in the presence of a higher customer's willingness to pay more.

Sample definition

The selection of the sample group has been made based on an old excel list of fish businesses in the Netherlands provided by the client. Such a list has been used as a guideline and contacts, and company status has been verified through search engines and discussed with the client. The scope of the current research focuses on the Dutch finfish aquaculture branch; therefore, the selection of the contacts does not include farmers outside the Netherlands. Farmer's perspective on insect meal introduction in fish feed is relevant for the research, as it can confirm the information provided by expert interviews and highlight leverage points for the broader adoption of insects in fish feed. Hobby fish farmers have been left out of the sample group, as they are targeting a different market (angling), and feed is not such a fundamental factor in their business.

The last contacts list has been created in three steps:

1- Outdated excel list of fish companies in the Netherlands provided by the client
2- Verification of contact information from online search
3- Validation of such contacts from clients' side
4- Code-colour classification according to the relevance for the stated objectives (green= high relevance for the research, yellow= possible relevance for the research, red=no relevance for the research or bankrupted)

Questions and aim

The group discussed the questions and drew up the questionnaire. The clients and an external professor have been invited to fill it in and express their suggestions on the changes to implement and the efficacy of questions formulation. The final version of the questions and the reason behind them can be found below.

Appendix 3.1.: The questions of the questionnaire and their aim.

Question:	Aim:
1. Wat is uw leeftijd?	Demographic questions inform on human and social capital (part of the FSA model) e.g. - ability to understand, develop and implement an organization's strategy - loyalties and motivations for improving processes, goods, and services, including the ability to lead, manage and collaborate
2. Wat is uw geslacht?	
3. Heeft u een formele opleiding afgerond in het vakgebied van aquacultuur?	
4. Wat is het niveau van uw hoogst genoten opleiding?	
5. Bent u lid van één andere of meerdere branche organisaties?	
6. Welke vissoort(en) houdt u?	
7. Hoeveel produceert u per jaar?	
8. Wat is voor u als viskweker het belangrijkste aspect omtrent voer? Zet de opties in volgorde van 1 = meest belangrijkst tot 6 = minst belangrijk	To see the relative importance of various feed factors among farmers and to see if the insect-based feed can meet these factors.
9. Heeft uw klant ooit navraag bij u gedaan omtrent de duurzaamheid van het voer dat u gebruikt?	To see if costumers of fish farmers care about the descent of the feed the farmers use.
Er wordt momenteel onderzoek gedaan naar het gebruik van duurzamere eiwitbronnen in de formule van voer ter vervanging van vis/sojameel.	
10. Er wordt momenteel onderzoek gedaan naar het gebruik van duurzamere eiwitbronnen in de formulatie van voer ter vervanging van vis/sojameel.	Investigate farmer's knowledge of alternative proteins
11. Wat is voor u de voornaamste bron van informatie hierover?	Investigate the source of information for farmers
12. Heeft u de mogelijkheden onderzocht om voer met insect-eiwitten te gebruiken in uw onderneming?	Test the willingness of farmers to change. Relation with education.
13. Heeft u het gebruik van andere eiwit alternatieven onderzocht? Zo ja, welke?	Test the willingness of farmers to change. Relation with education.

14. Wat is momenteel de grootste beperking die u ervan weerhouden over te schakelen op voer op basis van insect-eiwitten?	What are the major constraints that farmers encounter in adopting insect-based alternatives
15. U heeft op de vorige vraag "anders" geantwoord. Wat vormt voor u de grootste beperking m.b.t. het overschakelen op voeding op basis van insect-eiwitten?	What are the major constraints that farmers encounter in adopting insect-based alternatives
16. Vindt u het goed als wij n.a.v. uw antwoorden contact met u opnemen voor eventuele andere vragen?	In the eventuality, the researchers would want to contact them with more specific questions.

Data analysis:

Microsoft Office package software (e.g., Excel), was used to organize and save information, and social media and collaboration tools were used to share the questionnaire, collaborate, and work on data analysis. Office Forms was the selected choice to place the questionnaire online. The study of the data collected follow the steps below:

1- collection of answers
2- visualization through Microsoft Excel
3- if relevant, other visuals could be utilized
4- confirmation (or disproval) of hypothesis

Appendix 4 – Codebook

Appendix 4.1.: Codebook.

	CODE	EXAMPLES
SOCIO-ECONOMIC	Market price: the high cost of insect meal	
	Market price insect meal: could be increased due to health benefits	
	Market price fish meal: growing	
	Rising demand fishmeal	
	The market price of raw materials: drive feed industry	
	Market price catfish: seasonal price fluctuation	
	Market demand plant proteins: rising	
	Market: insect meal alternative to plant proteins	
	Insect substrate cheaper for BSF	
	Insect meal price competitiveness with plant proteins and fishmeal	
	Sci&tech: Not enough knowledge on production (insect producers' side)	ex. some companies do not deliver constant quality and quantity
	Sci& tech: lack of knowledge (farmer's side)	ex. Insect benefits for fish, feed formulation
	Sci&tech: health benefits of insects meal	
	Sci&Tech: production problem during summer	
	Sci & Tech: general lack of knowledge on specific topics	ex. Safety of waste streams as feed
	Insect farmer can' t scale up if there is no market	
	Sci&tech: research gap on insects benefits in feed	
	Sci&tech: lack of trials	
	Sci&tech: farmer's perceived lack of research on insect feed quality	quality= healthy fish, performance
	Policy on health and safety	produce restrictive regulations for trade and production
	Lack of Policy on insect welfare	doubts on slaughtering and rearing conditions
	Policy make expensive labour	
	Individual acceptance of insects for fish feed	
	Individual preferences for cheap fish drive down retailer prices	
SYSTEM ACTIVITIES	Inputs: low quantity/availability of insect meal produced	
	Input supply: small EU insect market vs large global feed market	
	Input reduction when used insect meal	
	Input supply: consistency will drive down prices	

	Input quality: insects are a natural diet for fish	
	Input quality inconsistent from restaurant waste and household waste	
	Insect industry infant stage	
	Legislation: limitation to waste substrate use as insect feed	issues with USP; competition with other uses of high- quality substrates
	Trade regulation on the import of insect meal	
	Immature regulation for insect sector	
	Consumer values of end products justify the use of high-cost insect meal	ex. Veterinary food, premium fish
	Consumer's perception of premium product and willingness to pay	
	Consumer's willingness to pay more for a considered premium product	
	Consumer's value: product safety	
	Lack of consumer knowledge on fish feed and fish production	
	Consumer knowledge of product origin is lacking	
	consumer's preferences for naturally fed fish	
	High Share of feed cost price in production cost for fish farmers	connected with consumer's preferences- sales price;
	Share cost price for insect farmers	ex. Electricity costs, labour costs, substrate costs
	Supply chain organization: the farmer is far from the consumer	
	Farmer's lack of knowledge on insect feed applications	
	Certification fail in giving higher revenues to farmers	
ENVIRONMENTAL	ambient temperature not suited for insect rearing in NL	
SOCIO-ECO OUTCOMES	avoid bad publicity feed industry	need for communication with the consumer
	Retail power can enforce insect meal use	
	Retail power can define prices	
	Retail power can introduce new products	
	Farmer's endangered livelihood	due to lack of bargaining power, bring risk avoidance
	Farmer's risk avoidance	
	Decisions are made by major feed companies	
	Ingredients Market is led by the biggest company (power distribution)	
	Farmer-feed company relation based on price and performance of feed	
	insect grower's risk avoidance	
ENVIRONMENTAL OUTCOMES	GHG emissions from fish feed up to 83% of fish footprint	

	local supply chain (with insects) can reduce GHG emissions

Appendix 5 – Dutch consumer characteristics

Persons aged 40+ eat more fish than children, and consumption increases with age (RIVM, 2016). There is a small difference between eating patterns in rural and urban areas, with little or no difference according to the formal education received (RIVM, 2016). The ethnical background seems to be a more substantial influential factor in fish consumption, with Surinamese background positively influencing fish consumption (RIVM, 2016).

The amount of money that Dutch consumers are willing to spend on fish and shellfish is slowly increasing, due to eating trends such as sushi and exotic cuisine. In 2017, the average Dutch consumer spent € 73, - on fish and € 21, - on shellfish. In 2018 this increased to € 86, - and € 26, - respectively (Wageningen Economic Research, 2019). Consumption takes place mainly during dinner time and in out-of-home establishments (e.g., restaurants and canteens). Furthermore, Dutch people seem to eat fish, mostly during the weekend (Geurts, et al., 2016). The most consumed seafood products in the Netherlands are salmon, herring, canned tuna, fried kibbling and fish stick, mussels, cod, and shrimps. They are mostly purchased fresh (55%), frozen (28%), and canned (17%). Consumers generally consider fresh produce to be of higher quality. Reflected by freshness being the highest-ranked factor determining purchasing decisions (56%), followed cost (52%) (European Market Observatory for Fisheries and Aquaculture Products, 2018; MarketLine, 2018; U.S. Department of Agriculture's Foreign Agricultural Service, 2019).

Dutch consumers are increasingly referencing fish as a healthy alternative to red meat and poultry products. People who value health as one of the main attributes of food are buying more fish, vegetables, and fruits (M. Geurts, 2016). According to Eurobaromer, 84% of the interviewees indicated health to be the main factor in buying fish, followed by good taste (78%), easy digestibility (23%), and low-fat content (21%) (Eurobarometer, 2018). A significant development is the increased focus on sustainably caught and responsibly farmed fish & seafood. The Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council (ASC) are among the most popular sustainability labels in the Netherlands to both retailers and consumers. They are mostly a mandatory requirement to be included in a supermarket's assortment (MarketLine, 2018). According to EUROBAROMETER, 30% of the Dutch consumers value a product's sustainability level, and it ranked the 3rd most critical factor influencing the purchasing decision. Twice as high in comparison to the EU average.

Appendix 6 – Production & food systems activities

6.1. - Social organizations

NeViVi has about 37 finfish farmers affiliated with the association. The main goal of NeViVi is to strengthen the business activities of the members and stimulate the growth of the branch. The Dutch Society for Aquaculture (NGvA) is a more branch over-arching association with approximately 300 members consisting of fish farmers, knowledge institutions, suppliers, etc. The NGvA aims to promote knowledge and practice regarding aquaculture in the Netherlands and abroad. Four times a year, the NGvA publishes the magazine "AQUAcultuur" and organizes events like; theme evenings and days to create opportunities for their members to the network (Het Nederlands Genootschap voor Aquacultuur, 2020).

The foundation DUPAN (Stichting Duurzame Palingsector Nederland) was founded in 2010 by the associations of inland fishermen and small-scale coastal fishermen (netVISwerk), fish farmers (NeVeVi), and eel traders (NeVePaling). In reaction to the Dutch Eelplan that has been established as a requirement of the European Eel Regulation (EC) No 1100/2007, aiming to sustainably recovery the eel stocks in inland waterways. DUPAN represents more than 80% of the entire Dutch eel farmer and is involved in various projects and scientific research regarding eel (DUPAN, 2020).

NeVeVi is affiliated with the Dutch Society for Aquaculture, and the chairman of NeViVi is a board member of DUPAN foundation (Sustainable Eel Sector, the Netherlands) (NeVeVi, 2018).

The Eel Stewardship Association (ESA) founded in 2015 by organizations from the eel sector in the Netherlands, Germany, and England. To accelerate the recovery of European eel stocks by focusing on transparency in catch and trade, for the sustainable use of the eel populations. The ESA is the holder of the Eel Stewardship Fund and owner of the ESF logo. (Eel Stewardship Association, 2016).

6.2. - Business services

Fingerlings & broodstock

Dutch fish farmers predominantly rely on the purchasing of fingerlings to grow out. Companies specialized in fingerlings, and broodstock is Til-Aqua, specialized in tilapia broodstock and production of nurseries and hatcheries equipment, and Aquaculture ID, specialized in African catfish broodstock, fingerlings and hatchery equipment (Dutch Aquaculture Experts, n.d.). Eel aquaculture has a different setting since there are no possibilities to grow glass eel in captivity: the juveniles (called glass eel) come from wild catch. The glass eels used for aquaculture in the Netherlands come mainly from France, followed by Spain and the UK (de Graaf, et al., 2017).

Feed & agro-inputs

Fish feed producers/mills located in the Netherlands or with international branches specialized in aquaculture are Nutreco (Skretting is the company brand for fish and shrimp feed), De Heus Animal Nutrition, Alltech Coppens, Provimi and Biomar.

Access to agrochemicals inputs is not a concern for the Dutch aquaculture branch, as there is the opportunity to buy them through retailers or online. Agro-chemicals are distributed by companies specialized in aquaculture (e.g., Aquaculture ID). Other companies are directly located in the Netherlands, such as MSD in Boxmeer, which is specialized in the production of vaccines and other medicines. Some examples of chemicals used in aquaculture branches are cleaning and sanitizing products, ovulating/spermiating agents, antibiotics, vaccines, and other medicines, other chemicals, such as fish sedatives, water conditioning agents, and egg treatments.

Financial services

Rijksdienst voor Ondernemend (RVO) – Netherlands Enterprise agency shows grant opportunities and subsidies for fishery and aquaculture projects, aimed at strengthening the sector, sharing knowledge, and stimulate innovation. Allowances are made available to the Netherlands through the European Maritime and Fisheries Fund. The Dutch government in cooperation with FMO- Entrepreneurial Development Bank are also providing funds to Dutch businesses in during their start-up phase that engages with developing markets in the sector of food, energy, education, such as Partnership Development Facility (PDF) and Development Accelerator (DA) (FMO, n.d.). Dutch aquaculture farmers can also access a range of financial services provided by banks in the form of loans.

6.3. - Policies

The most recent policy framework at hand is the Rijksoverheid "Nationaal Strategisch Plan Aquacultuur 2014-2020," an attachment to The Dutch Operational Programme which had to be formulated by the Dutch government to receive funding from the European Maritime and Fisheries Fund 2014-2020, for the sustainable development of aquaculture. Considering the EU's Common Fisheries Policy, active from 2014 onwards. The Dutch "Nationaal Strategisch Plan Aquacultuur 2014-2020" describes the perspective of the Dutch aquaculture sector and future market opportunities considering global trends and development, elaborated upon in appendix 8.2. The next term of the EMFF fund (2021-2027) is currently under proposal. The Commission proposed a total budget of €6.14 billion to continue to support the European fisheries sector towards more sustainable practices (European Commission, 2018).

The main trends outline a future with a significant increase in global demand for seafood that cannot be met by the forecasted increase in production. Due to the tiny share of global output, the Dutch aquaculture sector cannot make a significant contribution to meeting increasing global demand by focusing on higher production. Dutch seafood products are mainly sold to neighbouring countries, and opportunities to tap into new markets outside of the EU are limited due to low distinctiveness and the availability of cheaper alternatives.

Though the Dutch aquaculture sector can make a significant contribution to the growth of global seafood production though the export of high-quality knowledge available at Dutch companies and research institutes. In, e.g., production systems, feed, breeding, medicine, logistics, and cultivation techniques.

Regarding aquaculture specifically, this is translated in the following two main policy objectives:

1. Fostering an environmentally sustainable, resource-efficient, innovative, competitive, and knowledge-based aquaculture sector.

The objective is to increase the value of aquaculture production via niche and high-value products. Promote active participation and cooperation within the sector and the chain through common goals. Further focus on the development and innovation of fish and aquaculture products and associated knowledge and services and dissemination of available expertise in foreign markets. The budget allocated for realization: EMFF € 4.920.000, National contribution €.1.640.000.

2. Fostering marketing and processing.

To strengthen the important function of the Dutch fish-processing and wholesaling industry as a trading hub for other EU countries. Promotion of the integration of processing with trading activities. Improvement of the market organization for aquaculture products, leading to higher sales values. The budget allocated for realization: EMFF € 3.423.730, National contribution € 820.000. (Rijksoverheid, 2014; European Commission, 2014).

6.4. - Science & technology

Wageningen University is the most renowned agriculture university in the Netherlands and perhaps in the world. Research regarding aquaculture is done by the Aquaculture and Fisheries Group, part of the Animal Sciences Group of Wageningen University & Research, led by prof.dr.ir. GF (Geert) Wiegertjes (NARCIS, 2020). The Aquaculture and Fisheries Group is active in research, projects, education on various levels from BSc, MSc, Ph.D., and gives training and workshops. Predominantly focused on the following fields of expertise: Nutrition and health, Recirculating Aquaculture Systems (RAS), an adaptation of fishes and fishery to changes in the environment (Wageningen University & Research, 2020). Next to the previous, Wageningen Bioveterinary Research-WBVR has a specialized fish and shellfish disease laboratory for the diagnostics of infectious diseases, which serves as knowledge and advisory centre for Dutch Ministry of Agriculture, Nature and Food Quality (LNV) and on request for private entities (WBVR, n.d.). It is also possible to have courses regarding aquaculture on an Applied Science level, for instance, at HZ Hogeschool Zeeland (HZ, 2020). Short courses and training are also provided by colleges, like MBO Life Sciences in Oenkerk (MBO Life sciences, n.d.). Consultancies provide education and knowledge to private companies along the supply chain. The kind of expertise and training necessary depends on the needs. Still, some examples of educational topics for producers are the following: technical documentation, operation manuals, design courses with Recirculation Aquaculture Systems (RAS) technology, fish processing, biological water treatment, management, quality management (e.g., ISO 9001:2015, ISO 2200, HACCP or Beter leven).

Furthermore, the Eel Reproduction Innovation Centre (EELRIC), initiated by Stichting Duurzame Palingsector Nederland (DUPAN) and Wageningen University and Research Centre (Wageningen UR). Aims to function as an international platform for the reproduction of eel in captivity to support sustainable aquaculture. Eel farms depend on the catches of wild eels, which they can then grow to market size, of which only a restricted number is available. The objective is to achieve successful reproduction in captivity. This could close the production cycle and lead a more sustainable future for both eel aquaculture as well as management of wild eel populations (Eelric, 2020).

6.5. - Regulations

Minimum regulations for treatment, processing, preparation and marketing of fish products come from the European Union: Regulation (EC) No 178/2002 laying down the general principles and rules of food law, Regulation (EC) No 852/2004 which states the obligation of a HACCP based system for companies processing food, Regulation (EC) No 853/2004, Regulation (EC) No 854/2004, which ensure the safety production of food. These European laws, Part of the General Food law, are translated into the Commodities Act and Animal Act by the Dutch Government. The authority in charge to monitor the application of the previous regulations is de Nederlandse Voedsel- en Warenautoriteit (NVWA)- the Dutch Food Safety Authority, an independent agency from the Ministry of Agriculture, Nature and Food Quality.

Food labelling rules that apply to all the foodstuffs sold in the Netherlands are contained in Regulation (EU) No 575/2013. Additional requirements are included in other European and Dutch regulations.

Fishery and aquaculture products that are placed on the European market need to comply with traceability obligations that apply to all market participants (from catch and production to trade, processing, distribution, and retail chain). Traceability means that a series of information should be included, for instance, on the commercial designation, the production method, the catch area (NWVA, n.d.).

Regulation (EU) No 1169/2011 on Food Information to consumers specifies the need for a nutritional declaration on the food package, intending to stimulate healthy eating as highlighted by national guidelines. Are provisions in the regulations (such as clarity and readability of the font) are set in place to help consumers for taking conscious choices for their nutrition (European Commission, 2011), and possibly, influencing food preferences over time.

The exploitation of fish farms

The necessary permits that need to be obtained to set up for fish farms in the Netherlands are often not explicitly tailored to this purpose, as the sector in the Netherlands is too small to create separate rules and regulations. The necessary permits and legislation that must be complied with can be divided into two topics: Construction and Environment, and Animals.

Construction and Environment:

- *Environmental permit (Omgevingsvergunning)* www.omgevingsloket.nl
- *Destination plan (Bestemmingsplan)* http://www.bestemmingsplan.nl
- *Building Regulations, 2012 Building Decree (Bouwregeling, Bouwbesluit 2012)* http://vrom.bouwbesluit.com/Inhoud/docs/wet/bb2012
- *Environmental permit, Environmental Management Act (Milieuvergunning, Wet milieubeheer)* www.omgevingsloket.nl
- *Water permit - Extracting groundwater, Water Act (Watervergunning - Onttrekken van grondwater, Waterwet)* www.omgevingsloket.nl
- Water permit - Regulations for discharges, Water Act *(Watervergunning - Regelgeving lozingen, Waterwet)* www.omgevingsloket.nl
- *Fertilizers Act (Meststoffenwet)* www.omgevingsloket.nl
- Soil Protection Act (Wet bodembescherming) http://www.infomil.nl/onderwerpen/klimaat-lucht/handboek-water/wetgeving/wet-bodembescherming/

The last two do not apply when wastewater is discharged into the sewer system. They only apply when waste is used as land manure.

Animals:

- *NVWA license (NVWA vergunning)*
- *Animals law (Wet dieren)* The fish species to be produced must be on the list of production animals mentioned within this law. http://wetten.overheid.nl/BWBR0035217/BijlageII/geldigheidsdatum_19-01-2016
- *Certificate of professional competence, decision Keepers of Animals (Certificaat voor vakbekwaamheid, besluit Houders van Dieren)*

- *The Flora & Fauna Act (De Flora & Faunawet)* http://www.ondernemersplein.nl/regel/ontheffing-flora-fauna/
- The Flora and Fauna Act regulates the protection of wild animals living in the Netherlands. If the fish species to be produced falls under this Act, an exemption must be requested from RVO.
- *Veterinary prescriptions (Veterinaire voorschriften)* Animal health conditions are laid down in European regulations in 2006/88 / EC, implemented via 1251/2008 / EC. These European regulations are implemented in the Netherlands via the Aquaculture Regulations *(Regeling Aquacultuur), included in the Animals Law.* https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/dieren/dierenwelzijn/welzijnseisen-voor-dieren/wet-dieren
- *Transport permit (Transportvergunning)* https://www.nvwa.nl/onderwerpen/dieren-dierlijke-producten/dossier/vervoer-levende-dieren
- *Hygiene regulations (Hygiënevoorschriften)*

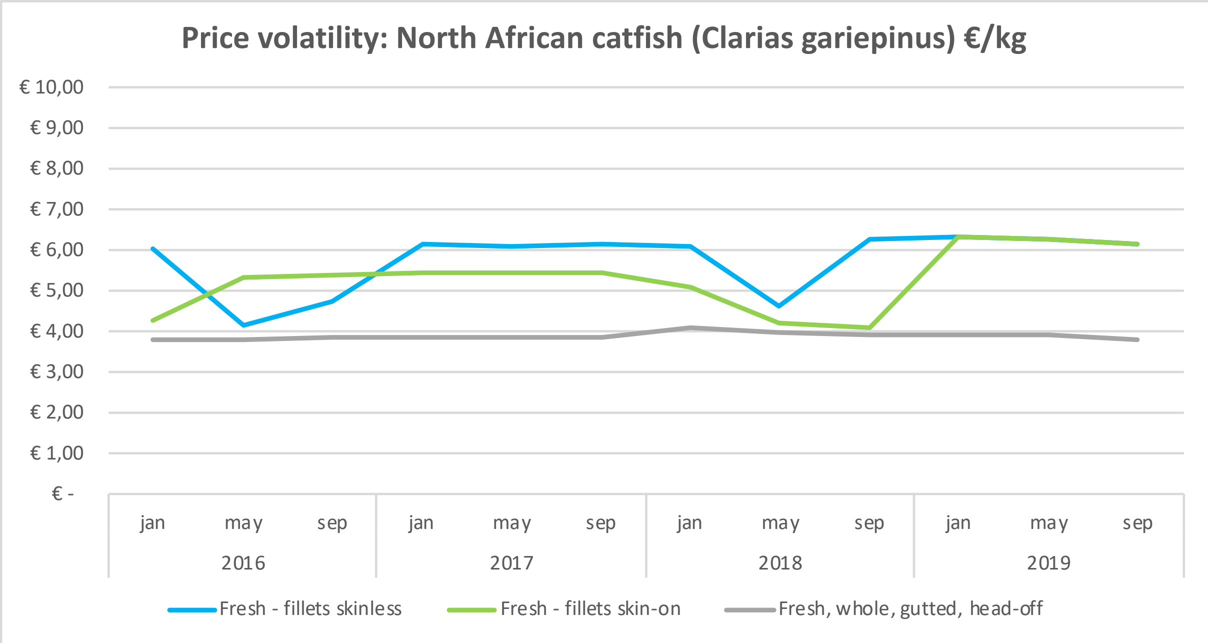
6.6. - Price volatility of main produced fish species

A STECF Economic Report of the EU Aquaculture sector from 2018, stated the average first-sale price for European eel to be €8,4/kg and €1,7/kg for North African catfish. The relatively high cost of European eel can be explained through the fact that world-wide eel populations have decreased strongly. The European eel is on the IUCN red list as 'critically endangered.' EU regulations have banned the export of European eel outside of the EU as of 2010. EU regulations limit catches and obligates to use 65% of the captured eels to be used for repopulation from June 2013. Eel farms depend on catches of wild glass eels (DUPAN, 2020).

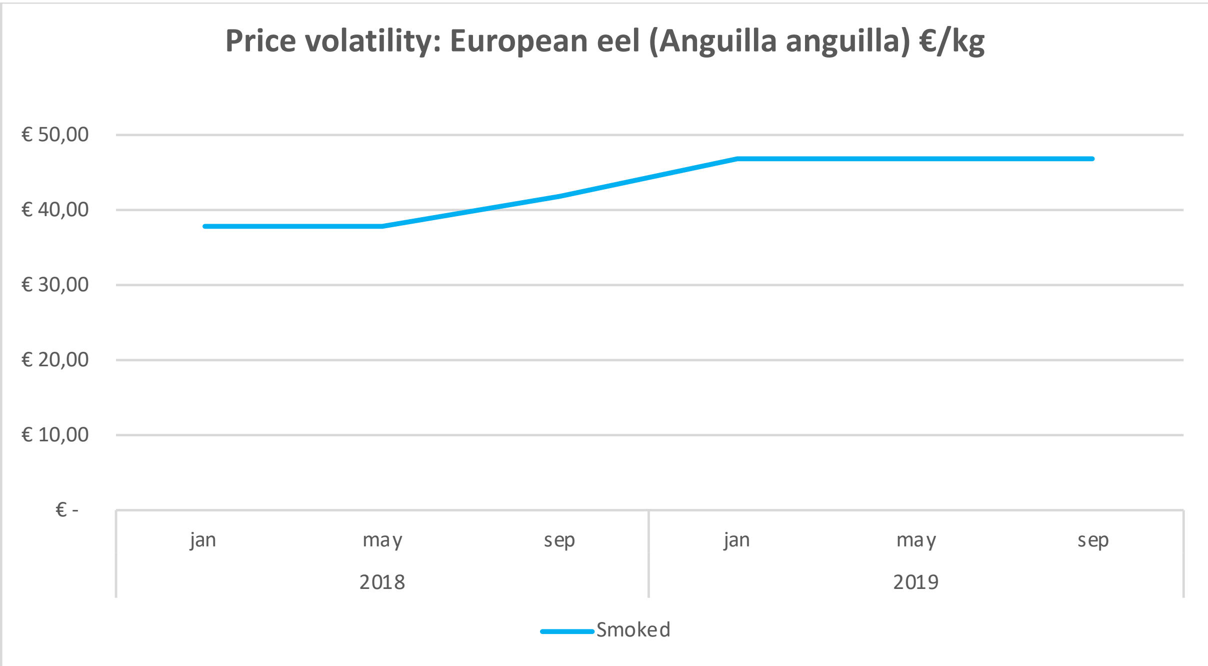
As indicated in appendix 6.1. North African catfish prices vary according to a yearly cycle. High season is around Christmas and Easter, while the low season is around summertime (Roosendaal, 2020). Furthermore, it shows the relatively high added value of processing activities to the average first sales price mentioned here above (Joint Research Centre, 2018).

The graphs displayed here below show the price volatility of the fish species discussed in chapter 7.2. Based on "The European Fish Price Report," a monthly publication by GLOBEFISH from the FAO. Unfortunately, data on prices of European eel only go back as far as January 2018. Furthermore, it is essential to note that the reference price used by this report for European eel is the "France wholesale price." The reference price of North African catfish is the "ex-farm price" from Hungary. The ex-farm price is the price received by the farmer. Often referred to as the farm-gate price, this price is excluding (VAT) (Department of Agriculture, Food and the Marine, 2008).

Though not reflected in the graphs, world fish prices were exceptionally volatile in 2019, for both wild and farmed species. Predominantly due to variability in supply and trade uncertainty imposed by the trade war between China and the United States of America and the process of Brexit, which saw business confidence suffering and slow down growth in many large economies. The worldwide seafood market is highly sensitive to broader economic implications. The forecast for 2020 is uncertain. It is expected that for the most important traded commodities, supply will slightly slow or remain steady. Though, implications resulting from the precise terms of the Brexit negations are still not clear. The China-US trade conflict is far from resolved, and the economic impact of the COVID-19 outbreak could be significant (GLOBEFISH, 2020).



Appendix 6.6.1.: Price volatility of North African catfish (FAO, sd).



Appendix 6.6.2.: Price volatility of European eel (FAO, sd).

Appendix 7 – Food system outcomes

7.1. - Socio-economic outcomes

Employment

As mentioned in chapter 1.2, there are currently 50 licensed fish farms in the Netherlands, producing approximately 5.500 tones (NVWA, 2017; NeVeVi, 2018). A source from the FAO estimated that there were around 155 people (FTE) employed by the Dutch finfish aquaculture branch (FAO, n.d.), but this source seems to be dated. A review of the EU's aquaculture sector conducted by Framain B.V. shows a similar result indicating 160 (FTE) to be employed by 92 fish farms in 2006, while production levels at that time were 9.500 tons (Framain B.V., 2009). Which seems to be co-responding.

Unfortunately, there is no up to date data available from that 2006 onwards regarding topics such as industry structure, employment, and economic performance for the Dutch finfish aquaculture branch. According to a (STECF) - Economic Report of the EU Aquaculture sector in 2018. None of the farmers provided detailed information for the research (0% of the 36 companies active). The reason for this, according to the report, being that "Land-based aquaculture in the Netherlands is a relatively small, reluctant, fragmented, highly competitive and dynamic." (Joint Research Centre, 2018)

Assuming the amount of labour needed in 2006 to produce 9.500 tons is translated to today's need for labour. It can be estimated that current employment represents 93 (FTE). Advances in production technologies and breeding not considered. (The personnel cost per FTE in this sector was equal to 46,000 Euros.)

Wealth

To quantify the wealth generated by the Dutch finfish aquaculture branch, the following approach has been taken. As mentioned in chapter 1.1, Dutch domestic fish & seafood consumption represented a volume of 82.400 tons and a value of € 0,95 billion (RSP) in 2017. It is estimated that 5% of this market is supplied by Dutch finfish aquaculture, which would correspond with a volume of approximately 4.000 tons. This seems to be legit looking at the total production of Dutch finfish aquaculture in 2018 (5.500 tons) minus the export of African catfish, 60-70% of the total production volume, which is (1.500 tons) (MarketLine, 2018; NeVeVi, 2018).

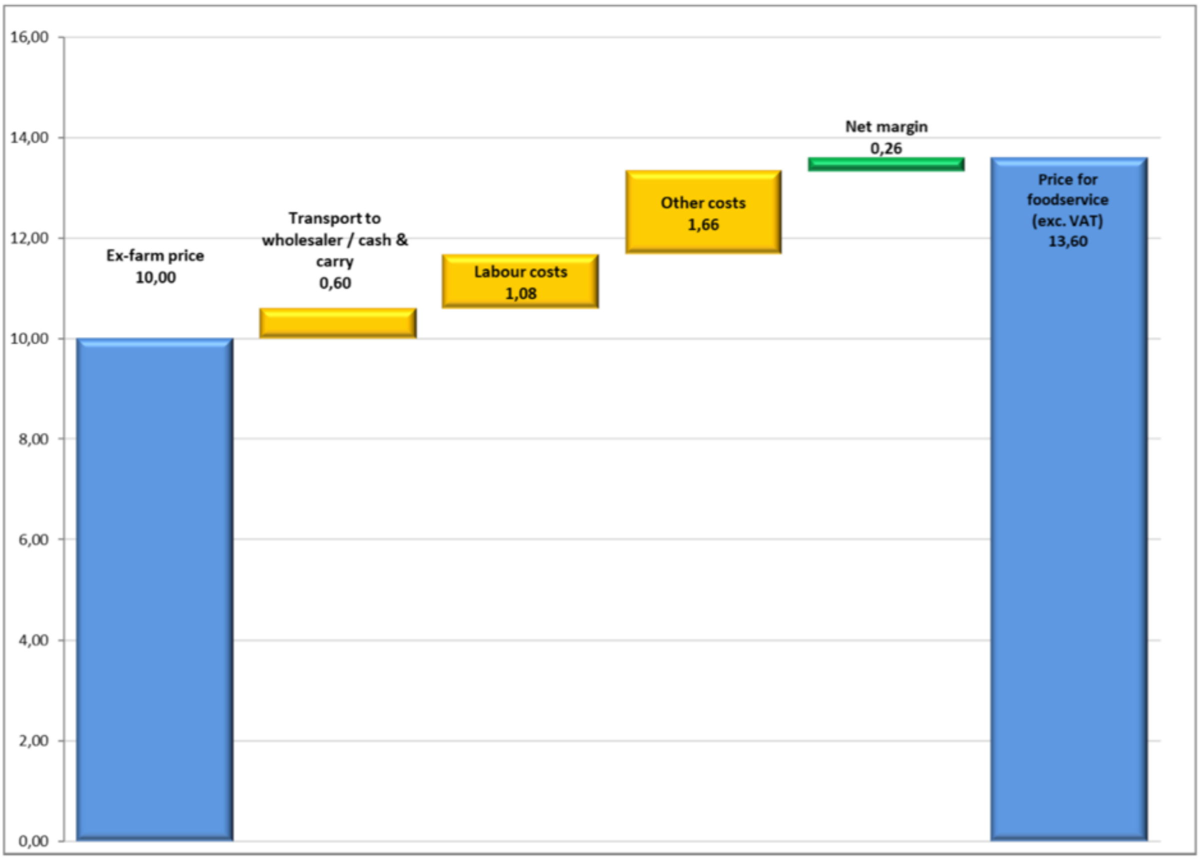
By calculating the average ex-farm price (€ 6,45/kg) and deducting this price from the average retail price RSP (€ 11,53/kg), value creation along the supply chain can assume to be (€ 5,07/kg) on average. Including the primary production stage, the value creation of the Dutch finfish aquaculture supply chain for the domestic market is estimated to be: € 46.120.000, - annually (MarketLine, 2018; NeVeVi, 2018).

Unfortunately, there is no data available regarding the price structure along the supply chain of European eel and African catfish in the Netherlands or other EU member states to verify this. Though data has been found regarding this topic on Turbot in the Netherlands. Turbot farming in the Netherlands is relatively old, but production levels have remained low. As of today, there is just one company active in turbot farming, Seafarm BV, located in the province of Zeeland. All their production is sold whole to supply Asian restaurants, directly or through specialized Dutch wholesalers.

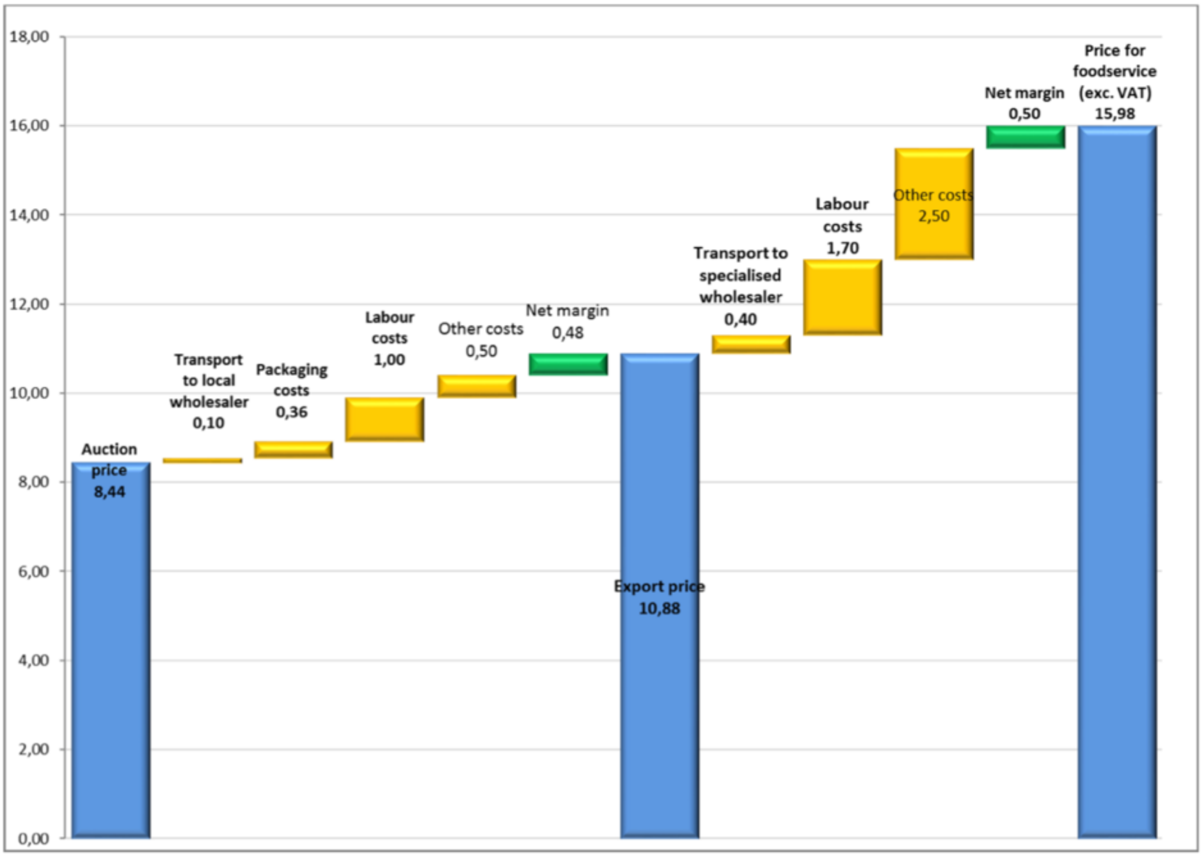
According to a case study by EUMOFA, the ex-farm price for Dutch farmed Turbot in 2017 was € 10,00 (whole/1,2kg) with the price for foodservice (ex. VAT) being € 13,60. The value-added along the supply chain was € 3,60. Added through the following activities:

- Transport (€ 0,60)
- Labour (€ 1,08)
- Other (€ 1,66)
- Net margin (€0,26)

This excludes, for example, packaging, additional transportation, and net margins costs that are included in the export of wild turbot from the Netherlands to France, as shown in the same EUMOFA report. Through which the price for foodservice (ex. VAT) rose from € 8,44 (auction price) to € 15,98. Though price structure along the supply chain varies widely depending on fish species, manner and origin of production, product type (fillets/whole cuts), and export destination (EUMOFA, 2018).



Appendix 7.1.1.: Food system outcomes (EUMOFA, 2018)



Appendix 7.1.2.: Food system outcomes (EUMOFA, 2018)

Income & livelihoods

The availability of information regarding the economic performance of Dutch finfish farmers is somewhat limited. Though a few sources exist regarding the species selected for more in-depth analysis by this research, unfortunately containing information only up to approximately 2009. It must be noted that the sources used to mention that not all farmers contacted for data collection were willing to corporate. Information gathered via an interview with Mr. Roosendaal (Managing Director Fleuren & Nooijen B.V.) will be used as an additional information source.

In 2006, European eel farmers performed quite poorly as it costs out weight revenues. Predominantly due to increased energy and interest costs. Another important aspect is the high price of glass-eels, which must be purchased as European eel cannot be reproduced in captivity yet. Thus, having a large impact on the production cost of European eel. The costs of glass-eel can amount up to 35% of the total costs (Framain B.V., 2009). According to Mr. Roosendaal, the cost price of European eel (€ 6/ Kg), is high, among others, because they live in a fancy system with added oxygen. The limited-time window in which glass-eels can be purchased (December to March) and the high price, which can be range from € 0,35 to € 0,40 per glass-eel. Farming an eel up to harvest weight takes relatively long (18 months). Therefore, eel is usually a full-time occupation (Roosendaal, 2020).

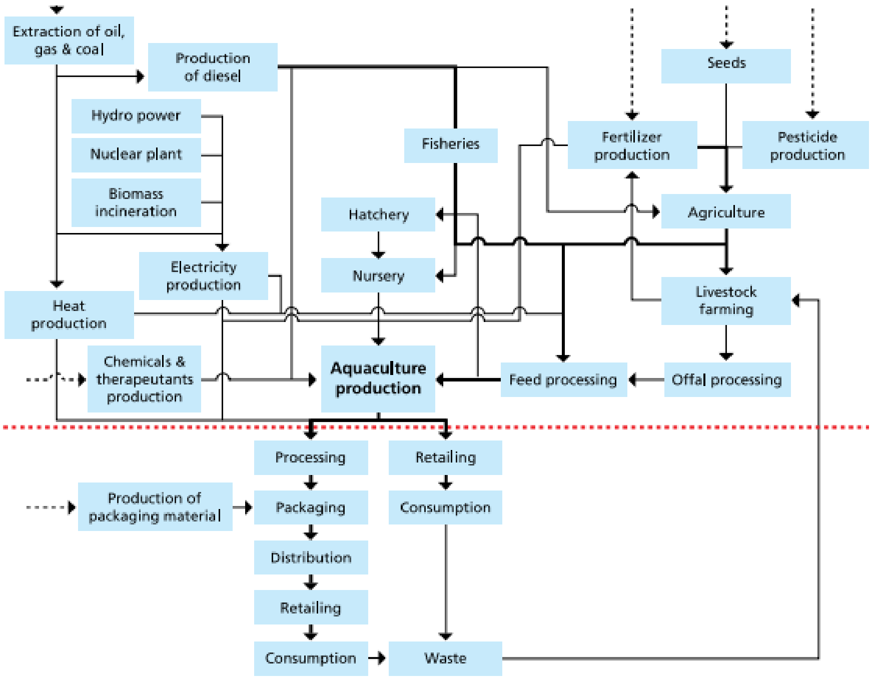
The economic performance of the catfish sector is rather weak. The average cost price and sales price are almost equal. Resulting in net-zero profits or even losses. The primary cause of this is the weak marketing efforts in the upcoming years of the catfish sector (Framain B.V., 2009). According to Mr. Roosendaal, the production cost of African catfish is € 1,40/kg, depending on farm size, with a maximum sales price of € 1,60/kg and a minimum of €1,50/kg, or even less. So, farmers operate on a minimal margin while taking huge risks. To become economically viable, market-ready fish must be produced every week. This results in much parallel production, requiring a large amount of fish to be in the system called "standing stock." For African catfish production in RAS systems, usually, this means that for 100 tons production, there is a standing stock of 20 tons. Next to this, a certain amount of feed must be in stock as well to be able to continually feed the fish, resulting in a lot of capital and risk being on the farm (Roosendaal, 2020).

Mr. Roosendaal provided a breakdown of the production cost for African catfish. 70% feed, 5% energy, 5% labour, 5% maintenance, and 15% depreciation of the RAS system. Furthermore, the prices of fish feed increase every year. In 2010, e.g., with 12%, which means an 8% increase in cost price in the case of Mr. Roosendaal, his African catfish production. While on the other hand, consumer prices in supermarkets stay the same or are even going down, putting pressure on the viability of fish farmers (Roosendaal, 2020).

7.2. - Environmental outcomes

The findings highlighted where and what the major GHG gases emitted by the aquaculture branch are:

- N_2O (nitrous oxide): arising from the microbial transformation of N from applied fertilizers in soils during the cultivation of feed crops.
- CO_2 (carbon dioxide): from *pre-farm* energy use associated with feed and fertilizer production, *on-farm* energy use (e.g., water pumping, electricity), and during *post-farm* distribution and processing. Changes in carbon stocks above and below the ground due to land-use change can cause a rise of CO_2 emissions (e.g., increased demand for feed crops can lead to the conversion of forest and grassland into arable land).
- CH_4 (methane): can arise during fish farm waste management
- F-gases (fluorinated gases): very potent GHG gases, small amounts can leak from cooling systems *on-farm* and *post-farm* (MacLeod, 2019).



Appendix 7.2.1.: System boundaries GHG emissions.

Appendix 8 – Fish nutritional needs

Proteins

Proteins are the most important feed component in fish feed. They are needed for several things but especially for the growth of the fish. On average, a fish requires 30% to 55% (Francoise et al., 2009) in its diet. Proteins are made of various amino acids. These amino acids are essential for creating body proteins such as enzymes, hormones, and immunoglobulins (Delbert et al., 2010). The amino acids can be divided into two groups: the "essential" and "nonessential" amino acids. Essential amino acids must be obtained through their diet. The nonessential amino acids the body can synthesize from other sources. There have been determined ten essential amino acids for several fish species. Appendix 8.1. shows the essential and nonessential amino acids.

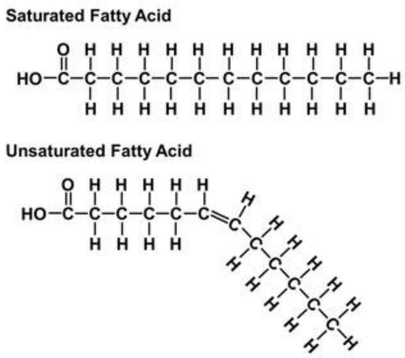
Appendix 8.1.: Amino acids needed for fish (Delbert & Gatlin, 2010).

Essential	Nonessential
Arginine	Alanine
Histidine	Asparagine
Isoleucine	Aspartic acid
Leucine	Cystine
Lysine	Glutamic acid
Methionine	Glutamine
Phenylalanine	Glycine
Threonine	Proline
Tryptophan	Serine
Valine	Tyrosine

The requirement of proteins changes throughout the life stage of a fish. Tests have shown that fries need a diet, of which nearly half of the ingredients must consist of proteins (FAO, n.d.). As the fish grows, the demand for protein decreases.

Lipids

Fats or lipids are a high-energy feed component that provides about twice the energy compared to proteins and carbohydrates (Craig et al., 2017). On average, lipids make up 7%-15% (Craig et al., 2017) of a fish's diet. Lipids consist of different compounds. At first, there are neutral lipids. This are fats and oils in the form of triglycerides. Triglycerides are a type of fat that is used as a source and store of energy in the body (FAO, n.d.). They are produced by the liver, but also enter through certain feeds (Becel, n.d.). Lipids are involved in different metabolic functions and help absorb fat-soluble vitamins (the fish site, 2006). Fats also provide certain fatty acids that cannot be synthesized by the organism itself. The most essential fatty acids for fish are linolenic acid (n-3) and linoleic acid (n-6).



Appendix 8.2.: Difference between saturated and unsaturated fatty acids. Upper fatty acid is 12:0, the lower is 12:1n-6

The n- or "omega" nomenclature describes fatty acids by the general formula X:Ynz. X stands for the carbon length. Y tells the number of double bonds, and n-z tells the position of the first double bond. Fatty acids without double bonds are called saturated fatty acids; those with one or more double bonds are called unsaturated fatty acids (Hamelink, 2019). So, for example, 12:0 is a saturated fatty acid with 12 carbons and no double bonds, 12:1n-6 is a monounsaturated fatty acid with 12 carbons and one double bond that is six carbon atoms from the methyl end (MVO, n.d.).

Most of the freshwater fish can desaturate long carbon chains like 18-carbon linolenic acid (18:3n-6) with three double bonds or up to longer chains of **H**ighly **U**nsaturated **F**atty **A**cids (**HUFA**s) with five or six double bonds (Delbert, et al., 2010). Marine fish cannot (Delbert et al., 2010). They need to have HUFA in their diet. HUFAs are an essential component of cell membranes (Delbert et al., 2010), especially within the neural tissue of the brain and eye (Delbert et al., 2010). The most important HUFAs are eicosapentaenoic acid (**EPA**, 20:5n-3) and hexanoic acid (**DHA**, 22:6n-3). Also, there is a big difference in fatty acid requirement between warm- and cold-water fish. The main reason for this is the melting point of the lipids. Where cold-water fish have higher nutritional needs for n-3 fatty acids, warm water fish are satisfied with a mixture of n-3 & n-6 (FAO, n.d.). The chemical explanation behind this is that the longer the chain is, the higher the melting point. So, for fatty acids with several double bonds, the melting point is much lower because these can be divided on the double carbon bonds (MVO, n.d.).

In general, it is said that freshwater fish require linolenic acid, linoleic acid, or both, where marine fish require DHA and/or EPA (Tasbozan et al., 2017).

Carbohydrates

Carbohydrates are not a specific dietary requirement. The reason carbohydrates are included in fish diets is because they are an inexpensive source of energy. The ability to utilize the carbohydrates depends mainly on if they are carnivores, omnivores, or herbivores. It is known that many carnivores are less efficient in using carbohydrates than omnivores, and herbivores are. Feed for carnivore species does often contain less than 20 percent carbohydrates (Delbert et al., 2010), while feed for omnivores and herbivores species contain 25 to 45 percent carbohydrates (Delbert et al., 2010). Besides being a source of energy, carbohydrates also give structure and stability to the feed pallet, so they are less dense.

Minerals

Within the aquaculture, minerals have an important role. Minerals are essential for cellular metabolism (Paul et al., 2001). Minerals are divided into two groups. Macro- and microminerals (Delbert et al., 2010). Based on the amount needed in the diet and stored in the body. Fish can get these minerals both from their diet as well as from ambient water (Takeshi et al., 1997). Macrominerals that are essential for the body functions of fish are calcium, phosphorus, potassium, sodium, magnesium, etc. (Paul et al., 2001). The most important mineral in fish is calcium (Hossain et al., 2014).

Calcium is important for the skeletal system of fish, as well as for some physiological processes (Hossain et al., 2014). Almost 99% of the calcium present in fish bodies is used in bones and scales (Hossain et al., 2014). It also is an important factor in forming a blood clot, the transmission of nerve impulses, the contraction of muscles, activates several important enzymes, and for managing the acid-base equilibrium (Hossain et al., 2014). Phosphorus is known to be the most critical macromineral in a fish diet because there is only a little phosphorus in the water (Delbert et al., 2010). The ratio in which calcium and phosphorus are present in the fish body is very important. This is because calcium is important for phosphorus utilization. The bone matrix is an organic component that consists mainly of collagen, with inorganic minerals deposited during the process of mineralization as hydroxylated polymers of phosphate and calcium (Hossain et al., 2014). The calcium and phosphorus ratio needs to be kept at a constant level because most fish keep a constant level of calcium/phosphorus in their bones and plasma (Hossai, et al., 2014). The desired ratio for fish lies between 1.1 and 1.4 (Trant et al., 2015).

The most important minerals present in micro quantities (trace level) are iron, manganese, zinc, copper, cobalt, selenium, chromium, and iodine (Takeshi et al., 1997; Paul et al., 2001). These minerals are responsible for the skeletal formation, maintenance of colloidal systems, regulation of acid-base equilibrium, and for the establishment of some physiologically relevant compounds like hormones and enzymes (Takeshi et al., 1997; Paul et al., 2001). Appendix 8.3. shows the trace minerals and some of their prominent functions.

Appendix 8.3.: Trace minerals and some of their prominent functions (Delbert & Gatlin, 2010).

Trace mineral	Function
Copper	Metalloenzymes
Cobalt	Vitamin B_{12}
Chromium	Carbohydrate metabolism
Iodine	Thyroid hormones
Iron	Haemoglobin
Manganese	The organic matrix of bone
Selenium	Glutathione peroxidase
Zinc	Metalloenzymes

Vitamins

There are determined fifteen vitamins that are essential for several fish species, known to date. Vitamins are needed for specific structural or metabolic functions (Delbert et al., 2010). Vitamins can be divided into two groups based on their solubility. There is water- and fat-soluble vitamins. Fat-soluble vitamins are metabolized and deposited in combination with body lipids. In this way, fish can go for long periods without these vitamins before showing signs of deficiency. Water-soluble vitamins are not stored in significant amounts in the body; therefore, symptoms of deficiency usually appear within a few weeks. Most of the water-soluble vitamins are components of coenzymes that have specific metabolic functions (Delbert et al., 2010). Appendix 8.4. shows the fifteen essential vitamins with their major functions as established in fish. In feed formulations, vitamins are most of the time added as a premix, containing more than enough of the required vitamins.

Appendix 8.4.: Vitamins and their major functions (Delbert et al., 2010).

Fat-soluble vitamins	Function
Vitamin A, retinol	Epithelial tissue maintenance, vision
Vitamin D, cholecalciferol	Bone calcification, parathyroid hormone
Vitamin E, tocopherol	Biological antioxidant
Vitamin K	Blood clotting
Water-soluble vitamins	
Thiamine, B_1	Carbohydrate metabolism
Riboflavin, B_2	Hydrogen transfer
Pyridoxine, B_6	Protein metabolism
Pantothenic acid	Lipid & carbohydrate metabolism
Niacin	Hydrogen transfer
Biotin	Carboxylation & decarboxylation
Choline	Lipotropic factor, component of cell membranes
Folic acid	Single-carbon metabolism
Cyanocobalamin, B_{12}	Red blood cell formation
Ascorbic acid, vitamin C	Blood clotting, collagen synthesis
Inositol	Component of cell membranes

Appendix 9 - European law on insects in feed

Introduction

To get to a more sustainable future for aquaculture, it is essential to minimalize the use of fishmeal in the feed as much as possible, because fishmeal is partly made of wild-caught fish. The FAO report "State of the World Fisheries and Aquaculture," which is released in 2014, stated that 20% (Turner, 2014) of total fish catch is directly used for producing fishmeal or fish oil. That is more than 20 million tonnes (Turner, 2014). Because the capture of wild fish does much environmental damage, it is highly necessary to have a more sustainable source, for example, insects to feed aquaculture fish with.

Feed for insects

Some possible feed sources for insects are bio-waste, by-products such as restaurant/catering/household waste, slaughterhouse by-products, animal manure, and intestinal content, gardening waste, and even human manure or sewage sludge (Lähteenmäki-Uutela et al., 2016). These are all low-value sources with significant nutritional value. Because insects are very good at processing low-value nutritious sources into high-quality proteins and fats (Kourimská et al., 2016) these feed sources make that they are a sustainable solution.

However, the regulation on animal by-products EC No (1069/2009[8]) and EC No (1774/2002) state that farmed insects are, in definition, farmed animals. Because of this, the rules applied to insects are the same as the ones applied to any other farmed animal. Therefore, animal by-products or derived products cannot be used to feed insects.

These are:

- Faeces and separated digestive tract content.
- Restaurant/catering/household waste.
- Food products, if they contain meat or fish.

To allow these sources, a change to the regulations must be made.

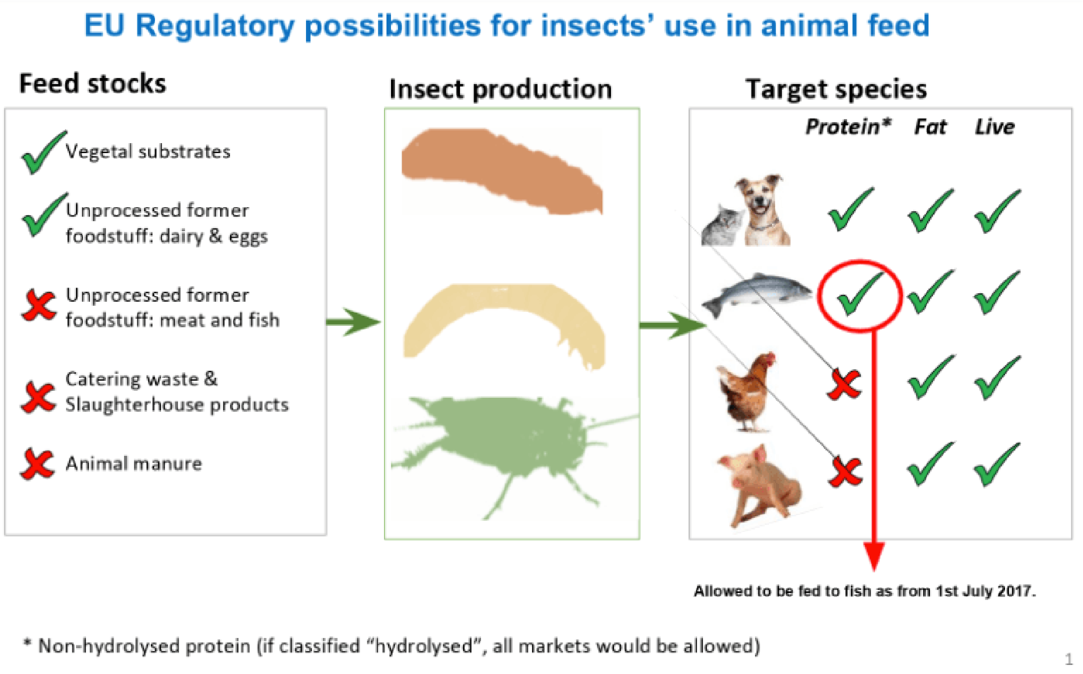
[8] Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation)

Insects as feed

There is much interest in using insects as a feed source for different agriculture and aquaculture animals. Because of their high protein and fatty acids content, they are considered a good alternative for a variety of protein sources. Looking at the current legislation, the use of insect proteins is limited. According to the provisions on processed animal protein (142/2011[9]), the species that are considered safe to use for feed use are:

- Black soldier fly (*Hermetia illucens*)
- Common house fly (*Musca domestica*)
- Yellow mealworm (*Tenebrio molitor*)
- Lesser mealworm (*Alphitobius diaperinus*)
- House cricket (*Acheta domesticus*)
- Banded cricket (*Gryllodes sigillatus*)
- Field cricket (*Gryllus assimilis*)

Even though these seven insect species can be used as a feed source, not every component of the insects can be used in every specie's feed. As seen in Appendix 9.1., insects can only be reared on specific feedstocks; on the other side, these insects have only limited use in feed for pets, aquaculture, poultry, and pigs. For now, processed animal proteins (except ruminants) can be used only for aquaculture and within pet feed (Lähteenmäki-Uutela et al., 2016) according to EC No (2017/893[2]). Fishmeal, on the other hand, can be used in any feed except in feeds for ruminants according to EC No (999/2001[2])



Appendix 9.1.: Possibilities for insects' use in animal feed (IPIFF, n.d.).

[9] COMMISSION REGULATION (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as regards the provisions on processed animal protein

Insect welfare

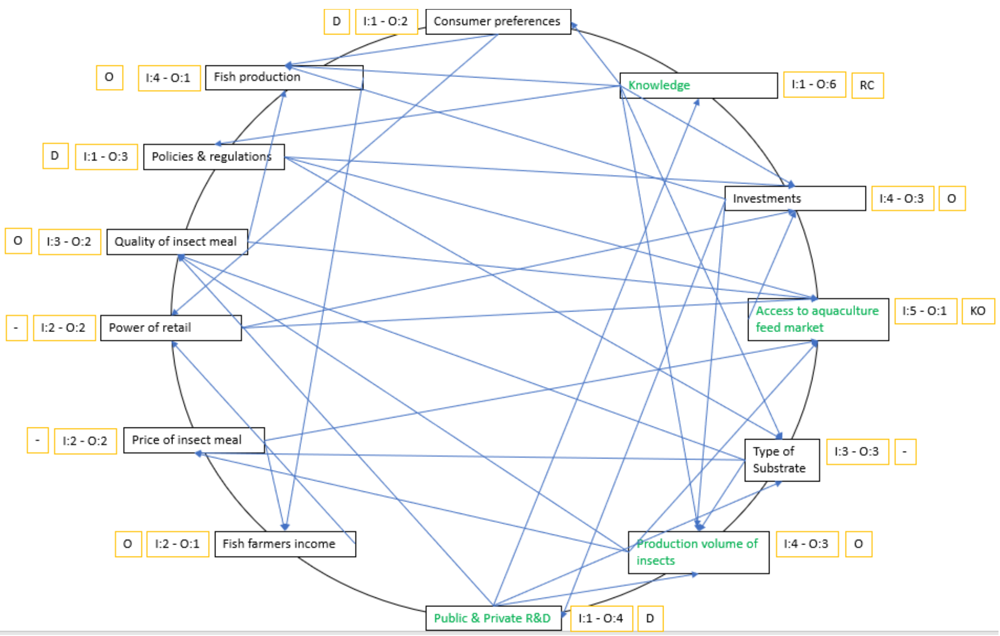
While talking about animals, their welfare is always a big topic. There are a lot of European and National welfare laws that state how to treat an animal. For example, the European animal welfare directive (98/58/EC) for farmed animals[10] and The Regulation (1/2005[11]) on transport and the Regulation (1099/2009[12]) on slaughtering tell a lot about how to farm, transport and slaughter farmed animals. However, those regulations do not apply to insects. For the future, it is, therefore, necessary that such conditions will be regulated.

Also, farming animals means that the animals must be given the five freedoms. These five freedoms were first introduced by the Brambell commission in 1965, later the British Farm Animal Welfare Council (FAWC) took over and elaborated into the following list of five freedoms:

1. Free from thirst, hunger, and improper nutrition.
2. Free from physical and thermal discomfort.
3. Free from pain, injury, and illness.
4. Free from anxiety and chronic stress.
5. Free to display its natural behaviour.

For insects, some of these freedoms are still not or hardly understood, and therefore more research must be done (Lähteenmäki-Uutela et al., 2016).

Appendix 10 – Inter-relationship Diagram



Appendix 10.1.: Inter-relationship Diagram

[10] Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes
[11] Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97
[12] COUNCIL REGULATION (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing