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Supply Chain Risk Management in Entomology Farms

Case: High scale production of human food and animal feed

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This qualitative research focuses on risk management in the supply chain of industrial entomology companies that are mass rearing insects for human food or for feed for farmed animals. This research presents answers to such questions as what are the risks related especially to the entomology industry, what are the reasons behind the risks and finally how the risks can be mitigated.

The industry has started to bloom only recently in the 2010's, meaning that the industry is still lacking knowledge based on historical data and scientific coverage of the field. This research is one of the first in the world that identifies the supply chain risks associated especially with the large scale insect farming for human food and animal feed, and determines how the risk profile is formed.

The novel nature of the industry reflects to many parts of the supply chain risk management. By the time of writing this research the established networks and operators, together with standards and regulations are still in the making. Even the biggest companies in the market are still only planning their large farming facilities.

Risks like fluctuations of feed raw material prices are in common with traditional farming, but the main risks that insect farms are facing are related to the health of the animals. The knowledge of pathogens and parasites of insects is very limited. As the nature of the health risks is unknown, the mitigation must be based on precautions and preventive actions. What is alarming for the companies operating in the field is that even a well managed risk control cannot give high level of security simply because of the lack of knowledge.

The industry will continue growing globally. When the industry gets established foothold and the production and supply chain functions get standardized the risk management can reach an acceptable level.

Keywords	Supply chain, risk management, entomology, agriculture, feed, tenebrio molitor, hermetia illucens, Acheta domesticus

Contents

Definition of Concepts

FAO: Food and Agriculture Organization of the United Nations

UN: United Nations

Entomology farm: A farm where insects are reared.

Entomophagy: Human consumption of insects as food.

IFF: Insect for Food and Feed.

BSE: Bovine spongiform encephalopathy, also known as Mad Cow's disease.

Factitious prey: artificial prey

IPIFF: International Producers of Insects for Food and Feed- organization.

Entomophagous: Organism that feeds on insect based food.

Phytophagous: Organism that feeds on plant based food

Larvae: The maggot stage of an insect's metamorphosis.

Pupa: The cocoon stage of an insect's metamorphosis.

Imago: The last stage of an insect's metamorphosis where it reaches maturity.

Horizontal integration: A strategy where a company has units for outputs which are alike

Vertical integration: In Vertical Integration a company owns its supply chain.

CPFR: Collaborative Planning, Forecasting and Replenishment process (CPFR)

COGS= Cost Of Goods Sold

HACCP: Hazard analysis and critical control points

ISO: The International Organization for Standardization

GMP: Good Manufacturing Practice

1 Introduction

This research focuses on risk management in the supply chain of industrial entomology companies that are mass rearing insects for human food or for feed for farmed animals. Mass rearing can be defined as “production of insects competent to achieve program goals with an acceptable cost/benefit ratio and in numbers per generation exceeding 10000 to one million times the mean productivity of the native population female” (Morales-Ramos, Rojas and Shapiro-Ilan, 2014). Rearing insects for scientific research, pest control, or with no high commercial goals are not included in the scope of this study.

There are many things that connect the farming for human food and for animal feed. Firstly, by both ways the insects end up in the food chain of humans and for this reason they fall under the same regulatory requirements. Exceptions to this are insect based feed use for pet food and use for fur farming. Secondly, the insect species are similar and they are farmed in similar facilities. This means that the supply chains are alike as well. Thirdly, from a business perspective the two mentioned purposes are connected; to be profitable both categories require high volumes to benefit from economies of scale and they face similar challenges when entering the markets.

For clarity’s sake the widely used term “entomology farm” is not used as it refers to all kinds of insect rearing. Instead, when referring to mass rearing of insects for human food and animal feed the used abbreviation is IFF that comes from the words Insects for Food and Feed.

Three insect species stand out when looking at what are the most commonly reared species by the IFF- companies. The species are black soldier fly (*Hermetia illucens*), mealworm (*Tenebrio molitor*) and house cricket (*Acheta domesticus*) (Hubert, 2015). From the mealworm and black soldier fly the commercially interesting life stage is the Larvae stage. A larvae is the juvenile maggot stage of the insect’s life cycle before the other metamorphosis stages of the pupa- cocoon stage and finally the imago- adult stage (Encyclopedia Britannica, 2015). In the imago stage the mealworm is a beetle and black soldier fly obvious is a fly. Because these three species together make up the vast majority of the insects farmed, the research focuses mostly on the factors related to these three insect species.

The topic of insect farming for human food and animal feed is of especial interest for the author as he is working in the field and also did his internship at an IFF- company. What makes the study also scientifically relevant is that there is very little research material published in relation to the commercial insect rearing from a business perspective. It is possible that this research is one of the first in the world that connects IFF-farming and business research.

1.1 The Entomology Industry

Entomology is a branch of zoology concerned with the study of insects (Cisr.ucr.edu, 2014). The human consumption of insects is called entomophagy. There are over six million species of insects from which about 1000 are used as a food source for people around the world (FAO, 2014, 9). In figure 1 a world map is showing the recorded edible insect species in the world. From the map it can be seen that the insect consumption is mostly concentrated to the southern hemisphere.

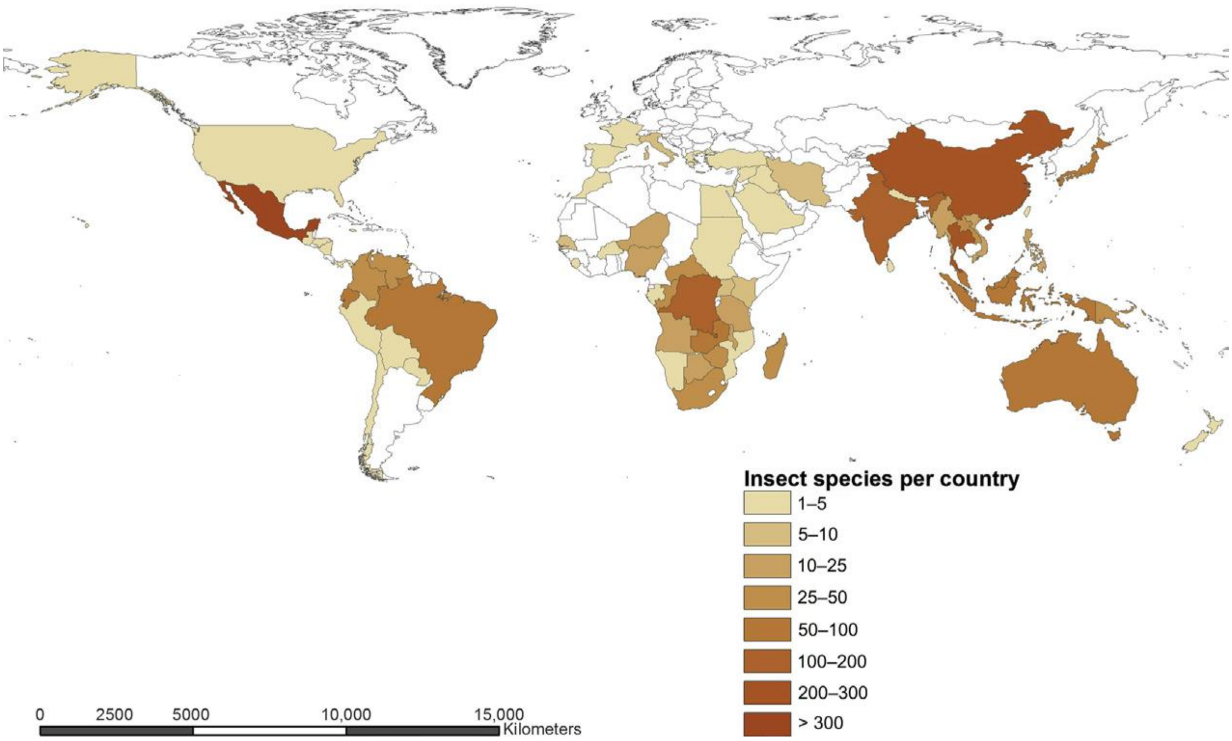

Figure 1. Recorded edible insect species in the world. Wageningen University Laboratory of Entomology, 2012. (Morales-Ramos, Rojas and Shapiro-Ilan, 2014, 617)

Traditionally the edible insects have been either collected from the wild or farmed in small scale, while all industrial farming has been focused on insect reared for crop protection. By rearing insects that are natural enemies of crop pests and releasing them at a farm, the crops are protected in a natural way. In 2011 there were at least 30 companies in the USA that employed at least 10 employees that were involved in high scale insect farming for crop protection. The study of insects like blowflies and horseflies has been essential in veterinary and medical research. Also insect research has been helpful in genetic research and improvements in crop protection methods (Morales-Ramos, Rojas and Shapiro-Ilan, 2014, 3-12).

One of the main issues slowing down the growth of insect farming for the purpose of crop protection is that even though there has been multiple studies, so far it has not been possible to farm the entomophagous insects very well with factitious prey (Morales-Ramos, Rojas and Shapiro-Ilan, 2014). This means that in order to farm natural enemy of a crop pest, the pest itself must be farmed so that the natural enemy can be reared. In other words two types of insects must be farmed, but only one can be sold. This means high production costs and complicated rearing process. This issue is not relevant in IFF- farming as explained in the chapter two.

1.2 The Importance of Entomology Farming

The world`s growing population, food insecurity and environmental challenges are forcing the human race to rethink agriculture and eating habits. A massive 70-88 percent increase is expected in the animal protein demand from the year 2012 to 2050 (Pelletier and Tyedmers, 2010) as the world population is to grow from seven to nine billion during the same time (UN, 2013). It has been calculated that from the year 2015 to 2065 people have to produce more food that they have produced in the previous 10,000 years (The Economist, 2015).

Even today, before the expected high peak in human population, hunger together with protein and iron deficiency are serious problems for low-income people worldwide (Morales-Ramos, Rojas and Shapiro-Ilan, 2014, 653). In 2013 FAO, the Food and Agriculture Organization of United Nations, published a synthesis “Edible Insects, Future Prospects for Food and Feed Security” (FAO, 2014). The synthesis is considered as one of the first milestones of the industry as it was the first one on the subject by highly regarded organization. The synthesis has been downloaded over six million times that tells of high interest (Subramarian, 2014, Hubert, 2015). Since 2003, FAO has been working on the topic of entomophagy. FAO sees the development of insect farming as a tool against the earlier mentioned challenges that people are and will be facing globally (FAO, 2014).

By the nutrition values insects are similar to animal meats like beef, pork, chicken and fish, but insects have multiple advantages over the traditional protein sources. Unlike the livestock, the majority of the insects produce no greenhouse gases at all and insects need very little land for their farming. Ammonia emissions coming from insect farming are as well far lower than the livestock (FAO, 2014: 3). Pig farms are a major concern for water because of the ammonia and difficult handling of manure. Manure, that is not an issue in insect farms, has a big impact on eutrophication of waters and misbalancing of ecosystems (Brandjes, de Wit and van der Meer, 1996).

Because the insects are cold-blooded they can convert feed into protein significantly more efficiently than the traditional farm animals. For example, crickets need 12 times less feed than cattle for a similar amount of meat (FAO, 2014, 3). Insect farming could be a good choice for the poorest sections of societies as the harvesting and rearing can be done with low-technology tools and low-investments. Also, the insect farming can be carried out with a minimal piece of land and the farming can take place also in the slums or in the parts of the world where arable land is scarce (FAO, 2014, 3).

The FAO's document “Edible insects” is one of the key releases about entomophagy. However, the FAO's approach on the topic is different compared to the approach of industrial entomology farms as the industrial size farms are aiming to satisfy a different market need. FAO is concerned about the environmental and health factors, and for these issues the low-tech and low-volume farming they are promoting can have a positive effect. The work of industrial size companies is motivated by the capitalist factors and aim to the market to compete against the substitute products.

1.3 Objectives

The objective of this research is to identify the main risks the IFF-farms are facing in their supply chains and how these risks can be controlled. The research questions that thesis aims to answer are:

- What are the main risks and how they can be controlled?

- What risks are especially related to entomology farming compared to other type of farms?
- What are the reasons behind the risks?
- How the risks will change in the future?

1.4 Research methodology

This research is a qualitative research based on primary data collected by the author during his internship in the entomology field and by personal interviews. The primary data is supported by literature review on the topic. The history of industrial scale mass rearing of insects for human food and animal feed is very short (Morales-Ramos, Rojas and Shapiro-Ilan, 2014). Therefore, only a limited amount of literature is available on the topic. For this reason as addition to scientific references the interviews had to be conducted and are forming the core of this research. The interviews were rather discussions than formal, structured interviews. In the cases of Antoine Hubert and Doctor Saravanan Subramarian the interviews had a structure and a set of questions. The question template is presented in the appendix one.

Unfortunately the amount of secondary sources is limited as well. Many of the companies in the industry are protective about the technology, business approach and supply chain management. These protective policies led to multiple refusals to take part in this research.

The author did his internship at Ynsect that is a French company located in Evry near Paris. Ynsect has around 20 employees. The company was founded in 2011 and its goal is at the animal feed market as well as to production of non-feed products like chitin, derivatives, peptides and fertilizers (FAO, 2014). The internship was done in winter of 2014-2015 and involved work in logistics and production development. The experience and knowledge gathered during the internship by the author have a significant role in this research.

2 The modern IFF- farming

Small scale insect farming for human food has long roots in areas where insects are part of people’s eating culture. However, the industrial scale farming for food has started to emerge for the first time as late as in the 2010’s. There are a few reasons why the bloom has not started earlier. First of all the price of fish and meat products has increased steadily and reached a point in 2010’s where industrial companies have come to the conclusion that alternatives must be found making insect farming an interesting choice. Together with the prices of the mentioned commodities also the environmental awareness of consumers is higher than ever, making the customers interested in sustainable choices (Hubert, 2015). The FAO had an impact as well; their release “Edible Insects” in 2013 gave a boost to the industry as it was the first official article by so widely recognized organization. The major companies in the market are Agriprotein from South-Africa, Ynsect from France and Protix Biosystems from the Netherlands (Hubert, 2015). The status of these companies tells much about the novelty of the industry; all of them have announced research projects, collected noticeable amounts of investments and announced plans for large scale facilities, but by the time of writing this research none of them have been able to complete such a facility yet (Byrne, 2015). In China there are a few large producers, but they are concentrated heavily only on the national market and very little information is available on them (Vekkeli, 2015).

Some major IFF- farms are aiming to grow insects for fish feed for farms as a substitute to traditional fish feed that is largely made out of wild fish and soybean (Subramarian, 2014). One big reason to be focusing on fish feed is legislation. Insect farming for human consumption and for livestock feed is illegal for example in most countries in the EU (Anthes, 2014). However, when separated the farming and the human consumption are legal. Feeding insects to livestock is illegal with no exceptions (Evira, 2014). The legal ban comes from EU’s actions against the BSE- disease that is also known as the mad cow’s disease. The outbreak of this disease was caused by animal based feed that was given to animals which do not naturally eat other animals (Ec.europa.eu, 2014). The ban is also effective on insects, but the legislation is expected to be altered in the favor of insect feed in the coming years and one of the first industries the ban is expected to be removed from is the fish feed (Vekkeli, 2014; Hubert, 2015). In South Africa insect based meal is allowed for chicken and fish feed, but not for cows and sheep for example (Byrne, 2015).

The legal environment around the IFF- industry is very complicated simply because the interest towards the industry has emerged and increased very fast and there legislation is lagging behind. By 2015 few European Union countries have allowed the sale of insect products for human food, while the majority is waiting for the official change in the EU- level policies. In USA insect products are not banned, but importing from foreign countries is strictly controlled. Also, there are a lot of variations in the legislation regarding the insect products between different states in the USA (Vekkeli, 2015).

As already mentioned in the introduction chapter, the three main species farmed are black soldier fly, mealworm and house cricket. They are suitable for the farming because they all have the required qualities that are: Reasonably large body size, easy to cultivate, ability to feed on organic waste, high rate of reproduction, not significantly cannibalistic and high tolerance for diseases. Other insects that meet the requirements are for example house fly (*Musca domestica)*, coldling moth (*Cydia pomonella*) and the silkworm (*Bombyx mori*) When comparing to the insect farming aimed at pest control, rearing these insects require one step less as they are phytophagous meaning that they are fed either on organic waste or on plant based feed (Morales-Ramos, Rojas and Shapiro-Ilan, 2014). The factor that unites all farmed insects is synchronous development that is a desirable quality (Smith and Nordlund, 2000). Synchronous development means that the individual insects hatch and develop approximately at the same time. This helps the production planning as the time when the insects reach the slaughtering weight can be forecasted reliably.

2.1 IPIFF

One of the operators driving the interests of the industry is a non-profit organization called International Producers of Insects for Food and Feed, IPIFF. The organization presents the main companies of the industry and it was founded in 2013 (ipiff.org, 2015). According to IPIFF's webpage their goal is to help the insect industry to prosper in Europe and worldwide by composing an industry network, encouraging collaboration amongst the members, gathering the interest of members for institutional representation and support high-level research and development. A member of IPIFF's board as Ynsect- Company's presentative Antoine Hubert is referred to in this research multiple times.

2.2 The Process Flow of an Insect Farm

To understand the supply chain of an industrial entomology farm, the production process must be understood first. One of the few published researches about the actual rearing process is “Environmental Impact of the Production of Mealworms as a Protein Source for Humans – A Life Cycle Assessment” by Dennis Oonincx and Imke de Boer from the University of Wageningen, Netherlands. As the topic says the research focuses only on mealworms, but the farming of other popular insects is comparable in the high level (Subramarian, 2014).

In the figure 2 there is a simple process flow of the production process. The figure is from a mealworm- farm, but the graph presents more or less the process of black soldier fly and house cricket as well, only the inputs vary. Additionally, house cricket does not have the larvae state. In the house cricket case, the small process step “small larvae” is replaced by “small animal”.

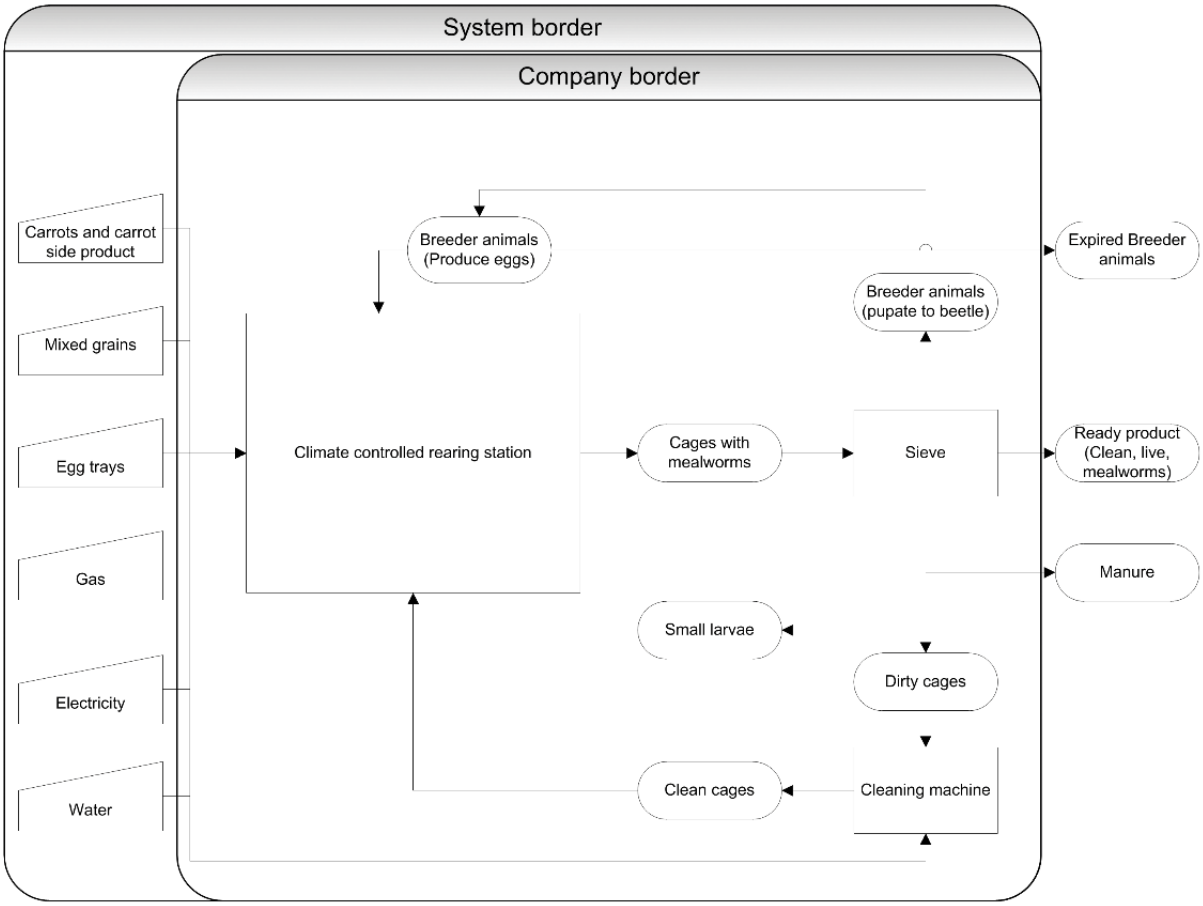

Figure 2. The mealworm production system. Flows entering the company are on the left, centrally the production steps are shown and flows exiting the system are on the right. (Oonincx and de Boer, 2012)

From the figure it can be seen that the main area of the process is the central ”Climate controlled rearing station”. The station has internal inputs (clean cages, small larvae) and external inputs (food, water and power). Output is “Cages with mealworms. The output goes to sieving station that divides the output of the rearing station to four parts:

Dirty cages that go to cleaning, manure that is also known as frass, ready products and to breeder animals- station. For closing the process loop the cleaning machine returns clean cages to the rearing station after cleaning, and the clean cages are filled with feed and small larvae that are coming from the breeder animals (Oonincx and de Boer, 2012).

In this example the animals that are being reared on the farm are coming from the process itself, from the breeder animals. It is possible that instead of the facility having its own breeders, the eggs or small animals would be brought in as an external input. When the farm is relying on its own breeder animals the production process is constant. This means that the collection of ready insects and hatching of new ones happens frequently and in repeating sequences. If the eggs are sourced from a breeder farm “all-in, all-out” method can be used in production. This means that a production cycle starts when a batch of eggs arrive to the facility that uses the whole capacity. The farm-facility grows the insects until slaughtering age and at the same time all the insects are slaughtered and the facility becomes completely empty for a new batch of eggs. This type of animal farming is used, for example, in poultry farming (yle.fi, 2015).

Of the three mentioned insects mealworm and black soldier fly are phytophagous meaning that they feed naturally on plant based food. House cricket is omnivorous meaning that it can eat both plant and animal based feeds. The mealworm eats mostly dry food, while black soldier fly and house cricket eat mostly moist food. The biggest logistics input in the process is the feed the insects need. The natural feed of the insects has low-density and the moist feed has certain storing challenges. The challenges are discussed in detail in chapter four. Several studies have been made on providing insects artificial feed. The studies have proven it very difficult as the artificial feed leads to complications, especially on entomophagous, but also with phytophagous insects (Cohen, 2004).

The insect rearing process has many issues which make it unstable and hard to forecast. The main reason is simply the lack of data; the industrial scale insect farming is emerging for the first time in history, meaning that all calculations are based on scaling from small scale production, not on actual observations. The consumption of storage items is forecasted based on expected feed consumption of the insect batches living on the farm. The fluctuations in the feed consumption are based on multiple factors. The life cycle, also known as the “from cradle to grave” cycle, of mealworm is about three months (Oonincx and de Boer, 2012). The cycle of black soldier fly and house cricket is about 60 days (Kroes, 2012; University of Florida, 2014). Average life cycle estimation can be made, but the life cycle of an insect varies depending on the living conditions. This means that the days the feed is consumed changes. Also the mortality rate of a batch of insects varies, meaning that the sheer amount of insect eating is changing. Last but not least is the factor of nutrition value of the feed. Depending on the type of feed the insects are eating the nutrient value can change. This is the case especially if the insects are fed on biological waste streams. If the nutrient values are low, the insects consume more in order to reach the harvesting body size. The unstable process leads to increased risks of overstock, running out of stock and high inventory carrying cost. The risks and their mitigation are discussed in chapter five.

3 Risk Management in Supply Chains

The word risk means a situation where the parties involved are exposed to a danger or a loss. Risk management is essential for the success of any firm in general, not only for the supply chain. Though, the supply chain manager approaches the risks from a different angle than let's say an entrepreneur. While the supply chain manager aims to mitigate and control the risks as much as possible, the entrepreneur can see a risk as an opportunity more than a danger (Schlegel and Trent, 2014; 2). Supply chain management is more than just logistics management. Supply chain management is searching for the maximum efficiency and profit for the whole chain from the logistic upstream all the way to the end customers at the end of the downstream. The goal of the supply chain management is not to aim for risk free environment, but to work as effectively as possible.

Risk management of the supply chain starts already from the high level strategy of the company. The needs that supply chain is aiming to satisfy come from the all the different departments of the company; sales, production, research and so on. When the efficiency of the supply chain is already being considered when planning new products and entering new markets, the supply chain will be able to function with high efficiency and low risk. The supply chain and its risk management part are willing to accept a certain level of risks if the risks are considered to be very unlikely or if their occurrence costs less than their mitigation. The consideration is based on different assessments such as risk tolerance-level and risk analysis; these assessment tools are explained in detail later on in this chapter four (Schlegel and Trent, 2014).

There is no such thing as a perfect supply chain; there is always something to improve on. A perfect supply chain would bring the products or services to the customer directly after placing the order with no delay whatsoever, but obviously this is impossible because there are always some tasks to be done (Modig and Åhlström, 2013). If a perfect supply chain cannot be achieved, the question is how close to perfection can the supply chain can be developed and what is the acceptable level? A good and effective supply chain can be defined in principle, even though the good and effective is based on the risk assessment of the supply chain that the members of the chain are doing themselves, meaning that the definition is based on human judgement. What can be said is that in a well-functioning supply chain the companies involved are able to forecast sales and purchases so that they will not run out of stock, but they do not need to carry too much extra stock either. Additionally, the production and deliveries are carried out in the vast majority of cases in expected quality, volume and timetable.

The design of the supply chain and its risk management are highly connected to the strategy of the whole company. Obviously the risks of running out of materials at a production plant would be lowered if the stock levels would be increased, but this would also increase the inventory carrying cost making the chain less effective. Cost cutting and just-in-time manufacturing might increase the risks, but make the chain more effective. One way of cutting cost is decreasing the level of vertical integration. The level of vertical integration tells how much control of the logistic up- and downstream the company has. High level of vertical integration means that the company has the control of most of the functions and that the risks are low, but the company has to pay a high price for it as it needs to focus its resources on multiple frontiers instead of buying the service from a specialized company (Schlegel and Trent, 2014; 42). In a modern supply chain subcontractors are widely used for example for assembly work. Using subcontractors instead of doing the assembly in-house adds a new link to the chain that is not necessary from the risk management perspective, but the added risk is in many cases worth taking as it saves a significant amount of money for the company (Grant, 2012, 1). The most important questions are how much risk can be tolerated compared to the gained cost savings and how much time and effort should be focused on the mitigation of the risk according to the law of diminishing returns.

Collaborative Planning, Forecasting and Replenishment process (CPFR) is an organizational framework that unites different departments to focus on the effectivity of the supply chain. When the production planning, inventory control and sales forecasting are working together inventory carrying cost, operations costs and logistics costs can be reduced. An example of companywide CPFR action could be a situation where the demand of a company's products is rising. The rising demand puts additional pressure on the manufacturing part of the supply chain and this raises the risk of late deliveries because the error margin is reduced. In this situation the new risk level must be analyzed and conclusions made if the risk is tolerable. The additional sales would bring more profit, but if the risk occurs and deliveries are late it will have significant impact on the image of the company and for this reason the risk cannot be taken and the additional new sales are refused. The collaboration is essential also from the supply chain risk management's point of view. When these different departments are communicating effectively, the effects of decisions will have on risks along the supply chain can be evaluated by assessment tools like Risk Tolerance, Risk Analysis, Risk Response Plan and Risk Compliance. After evaluating the risk it can be decided, if the risk can be tolerated or not (Schlegel and Trent, 2014, 47).

Before any risk management actions can be taken a risk analysis must be carried out. Through the risk analysis a company aims to recognize all possible risks it is facing. The risks are assessed by the probability and the impact of the risk if occurred. There are different techniques to give a score to the recognized risks to be able to compare and understand the seriousness of the risk. The results of the risk analysis are reviewed through the risk tolerance level of the company. Risk tolerance is the level of score of the risk analysis that is accepted and which score requires mitigation actions. After evaluating the results of risk analysis through the risk tolerance level and the appropriate mitigation actions are taken, it must be understood that there is always a possibility that even the very unlikely risks might occur, for such cases a risk response plan is created. The response plan improves the company's risk resilience level meaning that the occurred risk can be taken under control as fast as possible and corrective actions are applied to minimize the negative effects the occurred risk can cause (Schlegel and Trent, 2014; 12-16). The risks are constantly changing by their quality, but also by the probability of occurrence. This is why the risk assessment must be a repetitive action. Therefore the contemporary issues should be considered in the risk analysis and so that the results of the carried out mitigation plans can be reviewed.

3.1 Supply Chain Risk Profiles

There are multiple risks that the supply chain must be aware of; natural disasters, war conflicts, employee strikes and all the way to flat tires of trucks. In 2010 the Icelandic volcano Eyjafjallajokull closed the whole airspace of Western Europe for about a week's time cancelling around 100.000 flights (Telegraph.co.uk, 2011). A volcano eruption is an example of a huge and significant event, but even just one seemingly small incident can lead to serious issues along the supply chain. In 2011 pharmaceutical company Astellas suffered a robbery of cargo. They lost a truck trailer full of products worth around 10 million US dollars. The problems did not stop there, the U.S food and Drug Administration ordered all products out from the market if they shared the same batch control code with the lost products. This was because there was a danger that the stolen and uncontrolled products might end up to the end customer. In the end Astellas suffered a loss of 47 million dollars, and all this because of a truck trailer was left unguarded at a truck stop (Schlegel and Trent, 2014; 1). These two examples randomly occurring hazard risks, but the most common risks to occur are operational risks such as late deliveries because traffic jams or overstocking. The many types of the risks that the supply chains are facing can be divided into four categories: Strategic, Hazard, Financial and Operational (Schlegel and Trent, 2014).

3.1.1 Strategic Risk

A strategic risk is a danger that has the potential to affect the whole business, not only the supply chain and endangers the company's ability to execute its operational strategy (Schlegel and Trent, 2014). An example of a strategic risk can be found from the IFF- business. The pet food industry is already legally able to use insect products as pets do not end up to the human food chain. Insects are a considerable option for example fish based feed for pet food by its nutrient values and most likely also by price when the first large-scale farms are operational (Hubert, 2015), but a strategic risk exists for the pet food manufacturers that might restrict them from using the insect based feed. Because the IFF- industry is very new and there are only few companies operating in the field, there is a risk of unexpected production difficulties, and if such difficulties occur there are very limited substitutes in the field. This situation means increased risk of late deliveries for the pet food manufacturer and as there is very limited amount of companies in the field, replacing products might be impossible to find. In the case that the risk occurs, the whole product line could be compromised meaning loss of sales, marketing efforts done in vain and a dent to the public image of the company.

3.1.2 Hazard Risk

Hazard risks are randomly occurring events such as wars or natural disasters. The hazards are also referred to as “acts of god” or “force majeure” (Schlegel and Trent, 2014). Both names underline the fact that the occurrence of these risks cannot be controlled by the company.

3.1.3 Financial Risk

The financial risks involve all the participants of the supply chain. All parties of a supply chain are concerned about the creditworthiness of the business partners. Will they pay their bills on time? If they go bankrupt what will happen to goods in their possession? In case of bankruptcy of a partner, whether it is a logistics company, subcontractor or a retailer, there is a great danger of significant losses. If the partners cannot pay their bills on time it might endanger the paying potential of the company the initial bill is owned to (Schlegel and Trent, 2014).

3.1.4 Operational Risk

Operational risks are the most common ones and individually less harming, but if occurring often they can have significant effects. Operational risks include late deliveries, quality issues and poorly handled inventory levels for example, in other words routine like a decision gone wrong. The operational risks can be further divided into four groups that are Supply Risk, Demand Risk, Process Risk and Environmental Risk (Schlegel and Trent, 2014; 128).

A supply risk is a case where the supplier is unable to deliver in agreed time, volume or quality. The reason behind why a supplier might not be able to fulfil the mentioned qualities might be because of one of the four types of risks; Strategic, Hazard, Financial or Operational, has occurred (Schlegel and Trent, 2014; 130). This means that actually a company to control its own risks; it must be also concerned about the risk management of all the companies it is involved with. A similar situation where the external factors influence the internal risk management was discussed also in the part 4.2.3, the Financial Risk.

The demand risk is related to the alternations in the demand of the company's products or services. Companies do their best to forecast the expected sales, but knowing exactly the sales levels is very difficult. The longer the supply chain is the higher the risk. The long chain might lead to bullwhip effect that means the variance of ordered goods or services is larger than the actual sales and that the variance increases as it moves towards the upstream in the supply chain (Hau et al, 1994). When there are multiple steps in the chain that are all relying on their individual data inputs when planning their operations the demand data can get significantly disoriented (Christopher, 2011). As the variance can be positive or a negative the phenomenon can be visualized with a graphic that resembles the slashing movement of a whip. That is where the name bullwhip effect comes from.

Process Risk is a risk where something goes wrong in the internal actions of a company. Examples could be poor quality control or machine breakdowns (Schlegel and Trent, 2014).

Environmental Risk comes from outside of the members of the supply chain, but from the environment the chain is operating in. Especially when operating internationally the environment changes can cause a considerable risk (Schlegel and Trent, 2014). Changing currency rates can make a big difference in the profitability of the chain as well as industry and customs regulations. An example of changing environment was seen in 2014 when the EU and Russia set import bans to each other affecting supply chains in both parts of the border significantly (BBC News, 2014). In the IFF-industry the environmental risk is the timetable of changing legislation discussed in chapter two. If the legislation changes are delayed from the expected timetable it will cause significant challenges to the companies involved.

3.2 Risk Compliance

Depending on the industry, there are certain required rules and regulations that the companies must follow. ISO 73 and ISO 31000 where the first two standard to control supply chain risks in 2009 (Schlegel and Trent, 2014; 42). The standards are protecting the customers and the good of the society. It is possible that a company would be willing to carry very high risks in hopes of very high profits, but if the high risk occurs and causes for example, lack of certain medicine from the market, the situation could lead to serious problems for the end customers.

3.3 Risk Assessment

The risk assessment tools tells to the company how exposed they are to the identified risks and whether the company is able to carry them or not. As it was noted in chapters three and 3.1 only a small part of supply chain risk management is corrective actions; the basis of risk management starts already from the very beginning from the design of products and supply chain. The example of vertical integration was already discussed earlier, but there are many other aspects to consider as well that concern the whole company and its strategy. In the core of risk mitigation is constant improvement. In this chapter 3.4 different ways are discussed how to prevent to risks from happening that were listed in the chapter 3.2.

3.3.1 Lean Philosophy as a Tool of Mitigating Operational Risks

The idea of Lean philosophy is minimizing waste to maximize value. The waste is not only physical waste, but also waste of time, space and capacity (Lean.org, 2015). The lean thinking can be put into only sentence: “aiming to walk a shorter route instead of walking faster”. Lean philosophy is a wide concept and it can be applied in manufacturing or for example to design, but all the time in the core are the concepts of minimizing waste and optimization of efficiency through rigid standardization of actions (Spear and Bowen, 1999). This means that each step of work has a purpose and it is done only in the most efficient way. The efficiency of actions is reached by simplifying the steps, constant development and high involvement of employees in the development.

The lean philosophy was briefly mentioned already in chapter three when discussing Just-in-time manufacturing, a part of Lean way of manufacturing, as a tool of cost cutting in production. A question was raised whether the extreme search for efficiency would increase the risks, but the Lean manufacturing includes few major points that look to ensure low risk exposure. As described in the earlier chapter the most common risks to occur in a supply chain is an operational error and these errors are aimed to be controlled by the highly detailed standardization; When each step has been identified and instructed, the difference between the output of individuals is minimized. This way the expected output in volume, quality and time has as little variation as possible, enabling more precise planning and inventory control, in other words better risk control.
The lean philosophy looks at the whole value stream, for example the whole supply chain, instead of only parts of it like the logistics or the production. One of the major

points of Lean is Pull- manufacturing strategy that is contrary to the traditional Push-strategy. The push and pull strategies are ways to plan actions in the supply chain and how the plan of actions is imported into the system. From risk management's point of view the Lean philosophy's Pull-strategy is more favorable as it provides a change to reduce the risk of mismanaging inventory levels. The names Push and Pull come from the direction from which the initiation of production comes into the supply chain. The Push comes from the upstream, in other words internally from the company and its forecast. Pull comes from the downstream meaning the customer (Harrison, Lee and Neale, 2003, p 16-30).

The Push strategy brings multiple risks to the supply chain. First of all the forecast is never 100 percent correct. The uncertainty of what is exactly needed leads usually to unnecessary overproduction and overstocking in order to mitigate the risk of running out of stock. The more complex and longer the production and supply chain is, the more costly the push strategy will become for the reasons presented. The Pull strategy is opposite to the Push. The production process starts from an actual, not only from the expected customer order meaning that the customer pulls the wanted product or service from supply chain towards himself. When the line is reacting only to the agreed numbers there is no need to overproduce and the production can be tailored exactly to the customer's needs. The downsides are that the delivery time to customer is longer as the products are not directly available from the warehouse, and that with the Pull-system it is more difficult for the company to benefit from economies of scale, but the cost efficiency of Pull-strategy in most cases gives a significant competitive advantage and customer is willing to wait a certain delay in delivery if the price is clearly lower. In some cases mixed pull and push strategy is the best option. For example a car manufacturer could build certain components of cars that can be used for multiple models by Push-strategy. Once the customer order has been received, the assembly is done using the ready-made component according to the wishes of the customer (Harrison, Lee and Neale, 2003, p 16-30).

3.3.2 Hazard Risk Mitigation and Risk Pooling

Hazards are very hard to predict, but this type of risks can be mitigated by risk pooling by horizontal integration. The risk pooling means that the risks are divided into multiple locations. Horizon integration again means having multiple similar operations of the same step of the supply chain. This way the weight of the risks is divided to multiple carriers and the risk exposure is lowered. For example a state of war or a volcano can take out all the factories in the affected area, but if risk pooling have been done in high enough extend the company has not placed all its operations in one country or area and only part of its operations are affected. Even though the risk pooling reduces the risk exposure, the risks are still there. The risks might not be very probable to occur, but if occurred the results can be very serious. For this reason, insurance coverage is essential against the hazard risks (Schlegel and Trent, 2014; 20).

3.3.3 Financial Risk Mitigation

Companies protect themselves against financial risks in multiple ways. Especially in cases where the transaction cost is high because the creditworthiness of a business partners is low, safety measures like a letter of credit or prepayments are used. If using for example the mentioned letter of credit, the transaction cost is increased, but the security is increased (Mann and Gillette, 2000). The means of payment play also a significant role in the profitability of the company and the supply chain. A company with low creditworthiness will suffer financially. A company that is not trusted must pay with advantage payments for its own raw materials, while it most likely must give some credit period to its clients. This leads to a situation where the company has a high capital expenditure level; it must pay its bills a lot earlier than it will receive payments from its own clients. These methods are great examples of balancing on the line how much is worth spending money and effort on the risk mitigation.

4 The Supply Chain of an IFF Farm

The following chapters four “The Supply Chain of an IFF Farm” and chapter five “The Risks of an IFF-Farm” are conclusions based on the referred sources and the author’s various discussions with the industry professional and knowledge from the field.

As it stands today, the supply chain of entomology farms is relatively simple. The only constant supply the entomology farm is reliant on is either the feed or raw materials for the feed production on site (Oonincx and de Boer, 2012). Majority of entomology farms are not willing to discuss details of their feed composition, but according to interviews conducted with major entomology farms the companies have their own mixes that they are producing on site either completely from raw materials or partly from premixes made for animal feed.

The level of feed consumption is based on Feed Conversion Rate. The rate varies depending on the nutrient values of the feed, the insect species and the development state of the animal. Feed formulation software is a big help for farms to find the balance in cost efficiency of feed raw materials. Cheap feed might tell of low a nutrient level, but to find the right choice the feed must be looked at on how much biomass can the insect gain from eating a portion of the feed. Certain high nutrient value feed raw materials might be available at cost-efficient price for insect farms if materials can be found that are highly digested by insects, but not by ruminants for example.

Other than feed, the required inputs are general utilities such as cleaning solutions, water and electricity. Additionally, egg sourcing might be outsourced, but no signs of this activity in significant level have been noted so far in the industry. The possibility of egg sourcing is discussed in chapter 4.3.

One major challenge for an IFF farm's supply chain is the large volume that is required to get started in the business, especially in the case of farming the insects for feed. The demands for raw materials in the animal feed industry can be as high as millions of tons each year (Subramarian, 2014). The demand of high volume causes a barrier of entry for the IFF-farms as the industry is still in the process to be industrialized. Mechanization, automation and formulation of Good Manufacturing Practices, GMP, will be essential for the companies to be able to reach the high production targets and the market entry is possible. By improving these three aspects the IFF-companies will be able to reach cost efficient, consistent and safe production output that uses minimal amount of the expensive human labor (Vrij and Peters, 2014). The GMP of IFF- farms is one of the topics the IPIFF-organization is working on, but the work has not been completed yet (Hubert, 2015).

4.1 Feed Sourcing

Feed is the most significant external input to the farm as explained in the chapter four. Even if the animal eggs would be sourced from outside, by the volume and cost feed is still the most important. No data is available on insect farms, but a guideline can be found in traditional livestock farms where feed costs can make up to 50 to 65 percent of the total production costs (Bergmans, 2008).

The supply chain of an IFF-farms starts from the raw material producers of insect feed, not from the insect feed producers, like claimed by Vrij and Peters in their presentation “Towards an effective insect supply chain: meeting qualitative requirements and quantitative demands” in the “Insect to Feed the World” Conference in Wageningen, the Netherlands in 2014 (Vrij and Peters, 2014). Even if the farm would be sourcing the feed, it is using ready-made feed and not making it themselves from raw materials, the company must be concerned about the origin of the raw materials of the feed for quality and risk management reasons. As mentioned in the beginning of the chapter four, there are two options for IFF- farms for feed sourcing. Either they purchase it ready-made or they mix the feed themselves. As the industrialization is still in process it is more likely that most of the companies operating in the field are mixing the feed themselves as providers of suitable feed are limited and the companies want the protect their knowledge of their feed composition.

4.1.1 Feed Composition

Mealworm needs dry, while house cricket and black soldier fly moist feed. The selection of feeds the insects are able to eat is vast, but it is a different thing what is beneficial to provide them. Naturally mealworm eats stored grain and flour products (Salin, Vernon and Varrier, 1999). House cricket is omnivorous meaning that it is able to consume a wide variety of food material. Black soldier fly consumes decomposing material. Interestingly the black soldier fly eats only in its larvae stage; the adult fly form does not even have a mouth (Erens et al., 2012).

As described, depending on the insect species the feed requirements vary, but along with their basic requirements about feed nutrient values, the feed of insects serves also as the living environment and egg-laying platform. The three insects discussed in this research all lay eggs into the feed bed. The demand of feed varies according to the stage of the animal; a tiny animal does not consume as much as an animal close to pupation age. Also to the need of certain nutrition varies according to the age. When looking at the mealworm for example in the larvae stage the fast weight gain is the main objective, while in the adult stage high egg production rate is the mail goal (Subramarian, 2014).

The safety and consistency of feed quality are very important factors for the efficiency of the production process and for that reason also for the risk management. Varying nutrient and moisture levels impact on the growth speed and feed conversion rate, while the environment and packing control of the raw material determine the probability of unwanted pathogens in the feed. This is especially the case when using biological waste where the consistency of quality can vary. When producing raw material from insect for animal feed the challenge is that the nutrient values must be high and consistent and to ensure the quality of end products, the insects must be fed with high quality and consistent feed (Subramarian, 2014). The fluctuations of production output batch quality can be evened out by mixing production batches, but this increases the production cycle that is already recognized as a major challenge. The mixing can be carried out for example in the case that a ready batch of product is noticed to contain a too low level of protein. When the low-protein batch is mixed with a high level batch a desired level is achieved.

In order to secure consistent quality and quantity of materials the companies must look for horizontal integration. For example, in case of a supplier fails to deliver or raises the prices, the buyer has the opportunity to use a different option along the horizon. In the case of waste streams, finding multiple suppliers and at the same time be able to provide consistent quality for production might be difficult. In the case of using certified animal feed producers there is an existing network of animal feed providers that have proven logistics network that provides a wide selection of sources using the quality systems and certificates that is not the case with bio waste providers.

Two major companies named by the IPIFF in chapter two, Agriprotein and Ynsect, have very different approaches to handle their feed sourcing when producing animal feed. Agriprotein is farming the black soldier fly and are feeding them with biological waste streams coming from multiple sources such as offal waste and leftovers from catering services. Even ways to use society’s waste is considered (Wired UK, 2014; Pozzebon, 2015). Ynsect again is farming both mealworm and black soldier fly (Byrne, 2015). Ynsect’s approach to feed is completely different; instead of waste streams they use certified animal feed producers to ensure law compliance, high quality and security (Levon, 2015).

4.1.2 Using Bio Waste as Feed

Using bio waste for feed is ecological and a cheap choice, but the waste based feed comes with multiple difficult issues that must be addressed. Unlike certified feed, waste can be a health risk, but also its inconsistent nature may cause difficulties in production schedule and product quality. The bio waste must be treated at least to a certain level before giving it to the animals in order to remove the health risks. The health risks are discussed in detail in chapter five.

Because of these mentioned points the approach taken by the Agriprotein- company to feed the insect by offal waste, catering leftovers and possibly even with society waste can be considered surprising and risky. Interestingly, a Canadian IFF- company Enterra is using waste streams as well, but unlike Agriprotein they are using controlled, pre-customer waste instead of waste coming from for example catering left overs used by Agriprotein. The pre-customer waste means food items that would otherwise go to landfill if not used as feed. Catering leftovers, let alone collected household wastes are inconsistent by quality, water and nutrient levels, and may include unwanted items if not very carefully controlled. Pre-customer wastes might be inconsistent as well, but together with offal waste they are traceable which is a significant benefit over the leftovers from the regulatory perspective. From these four options offal waste has one upside more that is consistent in quality. The Enterra- company writes on their homepage “Enterra does NOT accept household or institutional food waste, yard waste, garbage or manure.”(Enterra Feed Corporation, 2015). Enterra’s comprehension over the risks and traceability issues underlines the issues that are related to the different type of waste used by Agriprotein, and Enterra’s approach seems to be better from risk management’s point of view. The use of pre-customer waste does not completely clear out of the quality supply chain risks, but when farming the black soldier fly it must be accepted that some type of decomposing materials must be used because of the nature of the animal (Erens et al., 2012).

When looking at the feed and the costs related to it the companies must look at the total cost of ownership closely when deciding which operations are economically beneficial to do in-house, and which outsource. In the case of bio waste depending on where the waste is coming from and how well it has been controlled, there are multiple risks that must be managed before it can be used as feed. Unlike the certified feed, the bio waste might be inconsistent by unit size or the unit size is not directly usable. For example, if the waste includes animal organs, they cannot be given directly to insects because they are too big by size and this leads to two issues: First of all, if the feed unit is too big the insects are not able to consume it fast enough and long exposure to humid and warm environment at the rearing facility increases the risk of bio hazardous fungal and pathogen exposure. Secondly, the large and also the inconsistent unit size are a challenge to feed distributor machines. Additionally, the risks can be unwanted items in the waste such as stones, pieces of plastic, metal or class. These items can cause a health hazard for the insects, but also might break down machinery in the production facility. For all these reasons the bio waste must be controlled with specific machines and workforce that both increase the total cost of ownership. Purchasing of these machines requires an investment, but might be a beneficial choice in the long run. For companies using bio waste having the machines in-house would make the horizontal integration easier as the standardization of quality would be done at the site and possible variance in feed unit size could be eliminated and unwanted items removed.

Unlike the bio waste that is not designed for feed use, the certified feed producers manufacture their products to be safe and consistent so that they are ready to be used directly at a farm. Even though there are many feed producers with strong knowledge of the field, the knowledge of feed designed especially for insects is very limited. For this reason it is possible that the IFF- farm should apply certain especial treatments also on the certified feed. For example, it is possible that some feed materials contain insect eggs. The miscellaneous eggs do not cause any harm for livestock, but once placed into an IFF-farm where the perfect environment for insects are provided hatching of the unwanted insects is a possibility might lead to risk endangering the safety and functionality of production.

The mentioned companies refused to discuss how the bio waste is sourced and how they are controlling the risks. The missing knowledge directly from the companies leaves questions open and creates a need for further research. What is known about Agriprotein’s approach is their brief explanation offered online at their homepage: “Tested on arrival and then blended and processed into a formulated larval feed” (Agriprotein.com, 2015). Additionally, in Agriprotein’s social media channel a video from 2013 shows that the company has at least tested collecting kitchen waste from private citizens (YouTube, 2015). These small bits of information can be found, but how the companies manage the issues raised in this chapter remains unknown.

4.2 Feed Manufacturing Operations

Using ready feeds makes the internal actions simpler; less work is required and the only feed-related investments required are storage and distribution machines. When purchasing ready feeds the quality is ensured by a professional company that has gained a high level of expertise from the field, this is something that might be missing especially from a starting insect farmer.

If the feed is done in-house some additional investments are needed, but these investments bring multiple advantages. The investments included are of course a machine to mix the feed, but the biggest expenses are coming from the work that must be done to prepare the feed from the raw materials. The most noticeable benefit is the increased control of inventory. When purchasing raw materials instead of the ready feed, the value of the items in the storage is lower since the value of the work has not been associated with them meaning lower inventory carrying cost. Additionally the use of raw materials gives more flexibility. The same raw materials can be used to create multiple different feeds. This is a great benefit, especially for the farms that are more farming more than one insect species. The possibility to alter the mix is also a way to lower the risk of overstocking. It is possible that when using ready mixes the requirements of the feed change, for example, because the demand between different species changes or simply because a better feed mix is being discovered. In such a situation the ready-made mix that has been purchased has no use and a new one must be sourced. Also the changing prices of the used raw materials must be noted.

Price fluctuations are a major risk for the profitability of all farming activities, not only for IFF-farming (Bergmans, 2008). Comparably high fluctuations are common in raw materials of feed such as corn, soybean and grains that are considerable options for insect feed. The high fluctuation is caused by the seasonal nature of the crops and yearly changes in the yield that is depending for example on the weather (Bergmans, 2008, Hunt, 2012, Lappalainen, 2011). Feed formulation-software can help the farms to find substitutes for the most expensive raw materials without compromising the desired nutrient levels.

4.3 Egg Sourcing

As mentioned in this chapter egg sourcing is done in very low volume, meaning that farms are mostly breeding their own eggs. In chapter 2.2 it was suggested that egg sourcing could be used in a way that a certain farm would focus only on egg production, while others only on rearing of the hatched eggs. Specialization could be a way to find cost savings in the supply chain. Egg sourcing is an important tool for stabilization of the production process and risk management. If a farm is relying only on internal egg production it means that its horizontal integration level is minimal; the supply is reliant only on one source. The risks of the one source failing to produce can be mitigated by having a ready network of egg suppliers.

As it was noted in chapter 2.2 the production process is unstable meaning that the output has a large standard deviation. This will mean in some cases unnecessary large amount of eggs, in such a case in order to avoid the risks of overproduction or waste of materials the eggs should be sold to another farm. On the contrary, in case of low output of eggs because of the large deviation or because of occurred risk in the breeding process, eggs must be sourced so that the future outputs are not compromised. If all these mitigation actions are taken an IFF farm is an egg producer, but also an egg purchaser and an egg seller.

4.4 Transporting Live Insects

In the traditional farming the transporting of live animals is part of the normal routines. The transportation starts from farms that only aim for reproduction of animals and goes to farms that are specialized to rear the animals (Ljunberg, Gebresenbet and Aradom, 2006). The reasons for the animal transportation in the IFF-industry are similar to other animal farming; the upkeep of the healthy genetic pool, expanding of operations and sale of animals or eggs (Levon, 2015).

Quality control is also important during the storage and shipment processes of insects. Entomophagous insects for biocontrol are recommended to be transported in immature state and cool temperature in order to maximize the yield percentage of live insect at the destination. Similar recommendations are missing from the IFF-insects (Morales-Ramos, Rojas and Shapiro-Ilan, 2014). Humidity and temperature control are very important for the safe transportation of insects. The used materials for packing of insects could be for example phase change materials that can absorb or release energy to balance the humidity and temperature changes. The packages used for insect transportation must not be airtight, but unlike mammals, insects can survive days without water and food that makes the transportation easier (Morales-Ramos, J., Rojas, M. and Shapiro-Ilan, D. 2014, 128-129). Though, it is possible that the transportation environment might affect their growing potential after the transportation (Subramarian, 2014).

4.5 Risk Compliance and Regulatory Matters in IFF- Farming

One major question for the industry when looking for growth is how to earn the trust from the customers in order to lower the transaction cost. As the historical data is missing the customer relationship must be built from the beginning. Standardization of operations and the use of quality systems based on known standards like ISO that are used by other farms play an important role (Vrij and Peters, 2014). International Organization of Standardization (ISO) defines a standard as "a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose." The need for standards is explained by the ISO organization in the following way: "Specifications are essential characteristics and tolerances, limiting values and other definitions for materials, products, services, processes, systems, or persons contained within the provisions of a standard" (Juran et al. 1979).

One of the major standards is GMP, the Good Manufacturing Practice, but in the core of food safety control is Hazard Analysis and Critical Control Points (HACCP) system. The first version of HACCP was published by Codex Alinmentarius in 1960 and since then step by step it has been included as part of legislation of farms and food manufacturing plants. To EU-legislation HACCP was included in 1993. HACCP sets standards and procedures on how to recognize health risks and how they can be controlled (Evira, 2013). HACCP is not a way to guarantee safety at the end of the process, but a tool to prevent risks along the production process (Fao.org, 1997).

The standards and regulations that IFF farms should use are not clear as the legislation is still under development, but the situation is not much better in the rearing of predatory insects for biocontrol. What is known from other fields of insect farming is that for insect reared for biocontrol there are standard developed by The American Society for Testing and Materials International (astm.org). Also, it is known that at least one company located in the Middle-East uses ISO 9001-standard (Morales-Ramos, Rojas and Shapiro-Ilan, 2014; p. 280). The latest scientific release on the topic is not very new; Mass Production, Storage, Shipment and release of natural Enemies by J.C van Lenteren and M.G Tommasini, was published in 2003 and according to it quality control standards were available on for species called *Cryptolaemus montrouzieri* (Morales-Ramos, Rojas and Shapiro-Ilan, 2014; p. 44).

5 The Risks of an IFF-Farm

The main risk associated especially with the IFF farming is that there is no historical data. The lack of knowledge increases all risks in every department and function of an IFF- farm, not only in the supply chain. As mentioned in chapter two by the time of writing this study there are no functional large-scale facilities operating yet, only plans exists. Even though the companies will do their best to predict upcoming challenges, it is likely that there will be surprises that the companies are not able to predict. There is not much scientific research on the industry so a lot of the data and knowledge companies have is gathered through their own research and development projects and based on the experiences of the individuals. As the data is private and essential for the company`s success the knowledge is carefully protected and out of reach of the public. As mentioned already in the opening chapter other than IFF- insect farming has related history, however the knowledge from the field of for example farming of entomophagous insects cannot be directly used to help the risk control in IFF- farming .This is because the insect species feed on different nutrition and the scale is significantly bigger. Relevant knowledge can be found in relation to risk mitigation by how to control the environment and how to safely transfer live animals (Charlton et al., 2015).

Demand risk is obvious, especially in the first years of the industry as the growing rate might be even explosive. The demand rate is really hard to forecast because of the lack of historical data. The rate might explosive, but does that happen in each market and does it include all types of insect products? It is likely that there will be a lot of variance, meaning that while some producers are running out of stock, others might be left with overstock. What makes the reacting difficult for producers is the long production process that is explained in chapter 2.2.

There has been a few studies on the safety of the insect for human and animal consumption (Belluco et al., 2013; Van der Spiegel et al., 2013; Awoniyiet al., 2004) but still the available data is limited for example in terms of from where are the possible safety risks originate from. What makes the limited information even scarcer is that the safety considerations must be insect species specific. For example, it is even possible that some insect species contain unknown venoms (Charlton et al., 2015).

The main risk for humans and animals eating the insects are accumulated chemicals, pathogens and heavy metals. In a recent study by Charlton and others in 2015 the toxic heavy metal cadmium was found to be present in all tested samples of fly larvae that are planned to be fed on farm animals. Also, some veterinarian medicine and minor pest were found but most likely they are not serious. Further studies must be made to understand how the accumulation varies between species, how the accumulation continues when the insect is fed to farm animals and what is the most interesting from the supply chain's point of view from where are the residues originating from (Charlton et al., 2015)

5.1 Pathogens and Parasites

Pathogens and parasites are the biggest concern for all entomology farms; they can wipe out entire facilities endangering the production output for a very long time. What makes the risk even more serious and the mitigation more difficult is that there is a very limited amount of knowledge available on the subject on commercial level farming. The insect pathogens include viruses, bacteria, fungi, protists and nematodes (Eilenberg et al.). An example of a problematic pathogen is densovirus that can cause serious damage to cricket farms that can wipe out entire colonies (Szelei et al., 2011). For controlling the risk of contaminations by pathogens and parasites high hygienic conditions are required, similar to other food production (Klunder et al., 2012). It is very likely that several species of grain beetles like the mealworm can carry the notorious Salmonella pathogen, but all in all, very little is known about the danger of Salmonella and other pathogens in general and how they are associated with edible insects (A. van Huis et al., 2015).

Pathogens and parasites cannot be controlled completely as they are in some cases originated from the insects themselves (Eilenberg, 2015). At times the pathogens will outbreak and cause problems for the production. An example of a minor case could be a loss of a few percentages of insects, or maybe only a slowed down growth rate. In the worst case scenario the whole colony dies. Losing a colony can be a catastrophe for an insect farm because risk residence resilience level is low due to the lack of egg supply in the market (chapter 4.3).

In the case that a large rearing facility loses its animals the rearing of a new colony must be started with a small amount of insects that needs multiple generations to grow and reach the capacity that is required as there is a very limited amount of eggs available for purchase. Let's imagine a company that has a large mealworm colony which is able to upkeep its own size by internal egg production and which additionally gives one ton of output product per week, just like the example company in chapter 2.2. If the colony is lost, it is very likely that in this novelty state of the industry the company is able to source only a few percent of eggs it would need for the full capacity. The few percent must be reared for multiple generations that take multiple months before the same capacity is reached. Additionally to the loss of the animals, it is also possible that all feed must be destroyed if it has been identified as a possible source of the pathogen or parasite that caused the death of the colony.

Also, in the case that the company has sold eggs or transferred adult animals from the same colony to other locations precautions must be taken to ensure that the transferred animal do not spread the risk in their body. All these issues mean that not only the future sales are compromised, but also the storage materials are possibly lost. Regardless of the amount of infected insects still similar actions must be taken to get the situation under control.

As identified in the chapter 5.1 the most serious risk for an IFF farm is a disease outbreak. Managing the risk of pathogens and parasites is done by focusing on the prevention. In the long run diseases cannot be avoided, but their occurrence rate can be significantly lowered and the effect of the occurred disease can be mitigated by appropriate risk management planning. In the book Mass Production of Beneficial Organisms (2014) the rearing of entomophagous insects for biocontrol is discussed. It is recommended that in order to minimize pathogen and parasite risks “feeder insects should be obtained from qualified suppliers, fed an appropriate diet, and maintained under hygienic conditions to minimize the risk of transmitting pathogenic bacteria” (Morales-Ramos, J., Rojas, M. and Shapiro-Ilan, D. 2014, 607). There are no scientific recommendations for phytophagous insects, but these guidelines can be used for them as well before more detailed information is available.

Pathogen and parasite outbreak can be considered as a hazard risk because of the lack of knowledge and low control level caused by it. The lack of knowledge leads to a situation where the companies do not have complete understanding of the dangers. What are the pathogens and parasites, where they can come into the process and what are the circumstances that favor the unwanted visitors? When the risks or their cause are not known, they cannot be mitigated. Other hazard risks are for example natural disasters as discussed in chapter 3.2.2. These risks cannot be controlled completely, but a company can be prepared for them.

Unlike in the case of hazards like natural disaster, insurance protection against pathogen and parasite outbreak might be impossible to arrange. Because it is unlikely that no money in the world could purchase the required amount of eggs or animals to restart production in a reasonable time because of lack of supply in the market, no insurance can be offered to cover the actual losses or the insurance price would be extremely high. Additionally, because of the lack of knowledge related to insects and their diseases, it is a difficult to make a judgement what was the cause for the outbreak? Was it a lack of quality control or something that could not be prevented by the actions of the company?

In the traditional livestock farms the pathogen and parasite problem is mitigated partly by high hygienic conditions (Klunder et al., 2012) and with different forms of medication (Whittaker, 2014, FDA, 2013). For example the use of antibiotics is extensive; from all the antibiotics used in the USA about 70 percent is given to farm animals (Pewtrusts.org, 2015). Unlike mammals, insects cannot be vaccinated or medicated for a few reasons; one of the reasons is that the vaccination is based on affecting an acquired immune system that for example birds and mammals have. In the majority of cases insects have an inner immune system that excludes the vaccination technique. Even if vaccinations would be possible to give to insects, their small size makes the traditional injections impossible or at least very difficult and expensive (Eilenberg et al, 2015). Medication for insect is not an obvious solution, but it is possible in theory. One of the reasons why there is no existing medicine for insects is that the insects are not looked by the health of an individual, but the colony. Medicating individuals that form only small portion of the colony is not efficient economically (Eilenberg, 2015).

In order to prevent pathogens and parasites a tight quality control of the environment, feed and water have an important role, but it requires also providing the best possible living environment to the insects. The risk of disease outbreak is decreased when the animal is provided with natural and stress-free environment. The best possible living environment for an insect depends on the species that are being reared. The level of the population density is one of the examples that are varying a lot depending on the insect species, but with each species the environment specification must be considered carefully. Too tight environment can lead to too much heat and stress for the insects, but too open is expensive and ineffective (Eilenberg, 2015).

For example the mealworm can improve its antibacterial response by controlling its body temperature. The mealworm must be given the opportunity to apply its natural antibacterial actions to ensure healthy colony. The environment must be controlled, but it is difficult to notice the conditions that facilitate active behavioral thermoregulation (Catalán et al., 2012). What makes the environment control even more complex from the health perspective is that the worm colony itself creates heat; this means that too few worms cannot keep the optimal temperature level high enough, but in the other end of the scale it is a the large colony that creates too much heat.

In the article “A Bug’s life” published in 2012 a case of pathogens related to black soldier fly rearing is presented. Just like in the case of mealworms, also the pathogens of black soldier fly are largely unknown. In the presented case a large scale farm suffered mortality waves that were first thought to be caused by pathogenic infection. However, this conclusion was later rejected and the most probable cause accepted was unfavorable environmental circumstances. The article gives a preliminary conclusion based on this case that the pathogens are not actually the main threat to black soldier fly in large scale farming (Erens et al., 2012, p. 32-33). The conclusion made tells of the low level of knowledge in the field of insect pathogens. Was it the environment that made them stressed and that killed them, or was it so that the unfavorable environment exposed them to pathogens that were the cause of the mortality wave?

The farming of honey bees encounter surprising production problems time to time, even though there are multiple research laboratories focused only on them. Keeping this in mind it is no surprise that rearing species like black soldier fly that was been introduced to farming quite recently is suffering from lack of knowledge, when even the case of traditionally farmed honey bees are not known well (Eilenberg, 2015).

The best way to mitigate this hazard risk of pathogen and parasite outbreak is risk pooling by horizontal integration. When the rearing facility and the egg production are both divided into multiple locations the possible outbreak will not affect all of the insects in the facilities. The integration can be done even in a same building if the farm is divided into multiple departments that are clearly separated from each other not only by a wall barrier, but by the process inputs as well. The appropriate level of segregation must be standardized by the industry players and the IPIFF- organization.

5.2 Production Planning and Mitigation of Demand Risks in IFF-Farms

The solution for mitigation of the demand risk that can lead to mismanagement of stock levels could be the mixed “push and pull”- production method. What is especially challenging regarding the production planning is the long production process that increases the order-to-delivery time when using the pull- strategy. When using only the push-strategy the exposure to demand risks is higher and can significantly increase the production costs. The pros and cons of these strategies were discussed in detail in chapter 3.4.1. No matter how much of the final product processing will be done after the rearing process, the vast majority of the production time is related to the rearing of the insects. The cycle varies depending on many things, but even the fastest cycles are months. Examples of insect cradle-to-grave cycle were given in chapter 2.2. Because the rearing process is so time consuming, even the high investments to fast packing and product processing, for example to slaughtering machinery, cannot cut down the order-to-delivery time so much that the investments could be easily reasoned by the lead time cutting.

One option for the demand risk management is alternation of the slaughtering date. Each IFF-farm must calculate the optimal slaughtering average weight of the insects, meaning the point when the slaughtering is the most beneficial to do. The point is the date when along the growth rate curve the feed conversion rate is about to drop so that the value of the sellable biomass grows less than the value of the feed and the upkeep of the environment that must be given in order to continue the growth. The optimal slaughtering day is not a definite age of the insects because of the natural variation there is some level of standard deviation. By moving the date earlier from the optimal date the production cost is increased as the feed conversion rate is decreased leading to higher production cost, but the benefit is shorter order-to-delivery time.

The moving of the slaughtering date earlier from the optimal point leads also to an unwanted effect on the demand on egg production. When an individual insect weights less on the slaughtering moment, the need of hatching eggs increases as well. When combining the loss of growth potential, increased egg demand and decreased feed conversion rate increase the production price significantly and it is likely that the customer is willing to pay the increased price for the order-to-delivery rate is shorter.

5.3 Quality Control

At the moment there are no quality control standards for IFF farms, but in the future the quality control will be based on standards and regulations like HACCP and ISO as described in chapter 4.5. The standards for biocontrol insect farming cannot be used for IFF-farming as they focus on things like the age, weight, motility and level of parasitism of the insect (Smith, 1996). These characteristics are not relevant for insect farmed for food and feed. Instead, important aspects are consistent quality and the safety of use. The IPIFF- organization, presented in chapter 2.1, is aiming to standardize the quality control in the IFF- industry in the near future (Hubert, 2015).

Quality control can be an expensive task, but it is a must for the production security and food safety. A supply chain can look for cost saving by eliminating possible unnecessary double check points. For example, if a feed provider checks the quality of the shipment when it is leaving and there is no regulatory requirement or no risks identified in the transportation, there is no need to check the same things again at arrival. Second example could be a situation where the incoming feed material is treated against pathogens. In such a situation regular quality checks are not needed at the feed provider's end nor at the arrival because the possible risk will be eliminated, present or not, at the treatment point. The check in this example must be done after the treatment. Certain quality checks require laboratory tests that are considerably expensive. In order to avoid the costs related to regular testing, the supply chain management could consider investing in machinery and procedures for risk elimination. According to GMP, these types of arrangements do not take out the need for basic entry control for example for correct documentary, color, structure, moisture and odor of the feed shipment (Ovocom.be, 2015).

As noted already multiple times, the use of organic waste in insect production encloses multiple risks. According to FAO prevention, detection, identification and mitigation of microbial contaminants are crucial for successful and safe insect production (FAO, 2014). When a high quality standard is expected in the production phase, the same level of standard must be expected also in the beginning of the supply chain (Kramer and Langner, 2004). The low-level of knowledge of the topic means that additional care must be paid to the safety and quality control in order to cover also the areas that are currently unknown.

There are few basic technologies that can be used to improve the safety and quality of insect feed. These methods are the use of impact milling- machinery and fermentation. Fermentation is used widely in the production of feeds for poultry and pigs. By fermenting the digestibility and nutrient values of the feed can be improved as it alters the pH-level and changes to bio-organism base, reducing the threat of pathogenic microorganisms like Salmonella (Niba et al., 2009; Heres et al., 2002). Acknowledging this, the fermentation process is an essential treatment for bio waste based feed. The earlier mentioned companies which use bio waste do not share information whether they use fermentation or not. Fermentation makes the feed wet if the raw materials are not wet already before starting the process. This narrows down the option out from certain insects like the mealworm that requires dry feed. Fermenting has also a positive effect on the storing age of bio waste and it stabilizes the quality (Subramarian, 2014).

The impact milling- machine is also known as Entoleter –machine. Entoleter is actually a name of a company that has become a standard name for a type of machine made for “disinfestation in flour processing in which insect eggs remaining in sifted flour are destroyed on impact as the flour is thrown against the lugs and case of a rotor revolving at a high rate of speed” (Merriam-webster.com, 2015; Entoleter.com, 2015). As mentioned earlier, unwanted insects might enter the insect farm through the feed as eggs. The eggs might not be filtered out as they do not pose a risk when in traditional use for livestock, but in an insect farm the case might be different. The impact milling destroys any possible insect eggs inside dry flour or grains.

6 Conclusions

The IFF-industry is in its novelty and the lack of historical data is reflected to all aspects of the business area increasing uncertainty and raised exposure to risks. The small size of the industry and the small number of companies in the field restricts the opportunities of vertical and horizontal integration moderations that mean higher production costs and fewer tools for risk management.

The lack of knowledge and historic data are the main issues of the industry and the companies must address this together with help of public research facilities such as universities, but unfortunately this view is not shared widely in the industry. As it was described in in the chapters 1.4 and 4.1.2 multiple companies refused to take part of this study that is not only increasing the knowledge of the topic for the wide audience, but also increasing the image of the industry that can be considered as safe and reliable in the same level as any other farm businesses. Only few of the refusals were reasoned, but a conclusion can be made that a large portion of the industry in general does not consider the scientific studies important.

The standard- and legislation environment and the market demand are under constant changes and this builds up the challenges how the companies are trying to find a way produce in a profitable way and control the risks in the same time. Together with the market and the environment also the technology and scientific knowledge are developing fast. The companies must be able to be agile so that they will be able to compete in the markets by taking advantage of the new research results. Improvements especially to risk management are needed.

The risks that the supply chains of IFF-companies are facing are somewhat similar to traditional farms, but the knowledge around insects and the risks related to them are very limited. Because of the limited knowledge IFF-farms face more hazard and demand risks than traditional farms. What is in common with the traditional agriculture is the price fluctuations of the main input, the feed raw materials, are comparably high. According to the present knowledge the IFF farms have a wider selection of raw material selection compared to other farmed animals that makes the mitigation of risk of prices of certain commodities easier.

The main risk is a serious outbreak of a pathogen as it endangers the whole functionality of the company and since the mitigation tools against the risk are limited due to the undeveloped ecosystem of the industry. Because the level of horizontal integration is low due to the low number of producers and their low capacities, the IFF-farms must look into risk management through risk pooling. It is known that the pathogen risk is evident and not enough knowledge is available so that the mitigation could be done in high enough extent only by high hygienic control.

IFF- farming has been going through very high speed development in the 2010’s. The pace of changes will not be slowing down in the future; it is even possible that the speed even increases. It will be left to see what the exact direction is and how the cost efficiency will be found, but increasing population of the planet and their raised concern over the unsustainable nature of the traditional farming are reasons why insect farming has a bright future. The factor affecting the near future the most is upcoming legislation changes in the EU area that are expected during the year 2015. It is expected that the changes will favor the opening of the market for insect products (Hubert, 2015). When the market opens it will attract more companies to the field as well as investors making more efficient research and development efforts possible and increasing the public's knowledge on the subject.

In order to become profitable the IFF- farming must grow significantly. The growth is first of all needed to overcome the entry barrier of large quantities needed by the customers who produce pet food, animal feed and food products for large markets. The growth enables also the benefitting of economies of scale. The economies of scale do not only satisfy the large demand of the market, but also enables the IFF- companies to produce with reasonable price compared to the substitutes.

How the supply chain network and production technologies will develop is hard to forecast. It is unknown how the market will behave and what will be the used technology and what are the species that have the most demand? If the most efficient production is reached by high-technology, it is possible that the industry develops to be more like modern technology instead of traditional agriculture. If the insect farming will move towards traditional farming it will mean that the supply chain will resemble other animal farming so that there will be certain farms concentrated on egg production, while others just do the rearing and a third group of companies that do the product development. Vertical integrations through specialization into egg and rearing farms bring cost efficiency but increases the risks. The higher risk is mitigated as external horizontal integration is made possible.

The other mentioned business model was the one comparable to modern technology. There are few leading companies in the industry at the moment that are developing their own technologies and keeping it away from each other. Depends how the technology will advance in the coming years and how the different risks can be handled the most efficient way, it is possible that the farming activities are left in the hands of a few, but very large, companies that do their insect rearing with their own high- technology concepts and control the markets like mobile phone manufacturers.

Once the technology has reached a high enough level so that the production process is secure and risks can be managed the question of breeding can be discussed. For now the IFF- farms must concentrate on the safe management of the species and focus on avoiding inbreeding, more than looking at developing the species to desired direction. As there are so many challenges based on the simple management of the pathogen control, feed composition and rearing technology, the research efforts of IFF- companies should focus on these first before dreaming of developing better breeds of insects (Eilenberg, 2015).

Further studies are required considering the risks and risk management of IFF farming. This research gives a general view on the subject, but due to the low number of co-operating industry operators high level of detail is missing. Especially important questions needing an answer are what are the origins of pathogens in IFF- farms and how to improve the controllability of the production.

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Appendix. Questionnaire used for interviews:

No	Topic	Question
1	Company	What are the insects farmed?
2	Company	What are the final products?
3	Company	What type of organizations are customers? End user?
4	Company	Where is the farm located?
5	Company	How many employees?
6	Company	What is the annual turnover?
7	Company	What are the future plans? E.g Investements.
8	Company	How is your company different from the competition?
9	Company	Do you produce with principle make to stock or make to order?
10	General	How big percentage of COGS does the feed take? Rest is on just upkeep and work?
11	General	what you think about the FAO edible insects?
12	General	What started the current bloom?
13	General	The amounts of insects that are raised for pest control are they comparable for feed industry?
14	General	What is the difference between growing insects for human food, for feed, and for pest control?
15	General	In the book mass production of beneficial organisms (2014) there is a lot studies and information about pest controlling insects, but very little about insects grown for food. Why is that?
16	General	Are farmers using antibiotics and other medication? If not, do you think farmers will start using antibiotics in the future?
17	General	What does IPIFF do?
18	General	Does IPIFF present the majority of the industry?
19	Feed	Is the breeding done in-house?
20	Feed	What is the feed?
21	Feed	How and where is the feed made?
22	Feed	How is the feed stored?
23	Feed	Do you ferment the feed?
24	Feed	Is the claim correct that core of the feed is always some grain type?
25	Supply chain	What are the challenges of the supply chain?
26	Supply chain	Do you have logistics professional in disposal?
27	Risks	What are the risks in the supply chain?
28	Risks	How do you mitigate the risks?
29	Risks	how do you see the risks if operating in higher scale?
30	Quality control	Do you have quality professional in disposal?
31	Business	What are the risks in the supply chain in the entire industry?
32	Business	Do you think it's likely that there will be companies that produce feed made for insects?
33	Business	Do you think an egg-hatchery would be a business in the future?
34	Business	What are the main differences with insect and livestock farming?

35	Claim	Is the fair to say that BSF, Tenebrio and house cricket form vast majority of insect farmed for food?
36	Claim	Industrial scale and traditional serve different cause?
37	Claim	Do you agree that lack of competition is hurting the growth of the industry?
38	Claim	EU and other western countries will open their markets for insect products before 2020
39	Claim	The attached picture is showing an example how mealworm can be farmed. Is it fair to say that farming or house cricket and BSF is farmed in similar farm?