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A Bug's Life

Large-scale insect rearing in relation to animal welfare

Erens, Jesse

Es van, Sam

Haverkort, Fay

Kapsomenou, Eleni

Luijben, Andy

Wageningen UR

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Andy Luijben	860105 535 120
Fay Haverkort	860306 313 100
Eleni Kapsomenou	811217 422 080
Jesse Erens	890812 228 020
Sam van Es	861125 229 120

Commissioner: Marian Peters (VENIK)

Process coach: Douwe de Goede (WUR)

Assigned expert: Stefano Pascucci (WUR)

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VENIK
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Abstract

The use of insects for human consumption is an emerging trend in the Western world. Project commissioner VENIK ('Vereniging Nederlandse insectenkwekers', the association of Dutch insect breeders) wants to anticipate this trend by up-scaling existing insect breeding facilities. The new Animal Act, implemented in Dutch Law in 2013, has therefore to be taken in account. VENIK commissioned the current project to find an answer to the question: 'How can the up-scaling of insect breeding be achieved in an insect friendly manner?'

Current knowledge available on insect breeding, both theory (scientific publications) and practice (interviews with breeders), will be assessed, which provides qualitative guidelines on insect rearing. A comparison is made between current practice and Brambell's Five Freedoms, a standard framework for animal welfare in legislation. Identified knowledge gaps will be assessed for further research.

To guarantee the freedom from hunger and thirst we advise to provide reared insects with ample quantity and quality nutrition; to guarantee the freedom to express natural behaviour and the freedom from discomfort we advise to have the breeding environment imitate the natural condition as close as possible; to guarantee the freedom from pain, injury and disease and the freedom from fear and distress, our advice is threefold: use killing techniques that ensure instant death, do not subject the insects to unnecessary stressors and (in the case of scientific experiments) sedate insects before experimentation.

Knowledge gaps still exist for the quantification of species-specific breeding standards. Future research could investigate the optimal environmental temperature range for the development of larval insects; and the correlation between environmental temperature and immuno-response for imago (adult) insects.

Since the 'Wet Dieren' (Animal Act) will be implemented in Dutch Law in 2013, potential issues for the insect breeding business were investigated, which results in the following suggestions: we advise the industry to research the legal possibilities for using insects as an ingredient in feed and to review and where necessary try for a revision of the current list of production insects in the Animal Act.

In the end all the obtained findings are combined and formed to a consult to the VENIK-associated insect breeders.

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1 Introduction

If one would consider an overview of all life on Earth, insects immediately burst out as being the most abundant group of animals on the planet. Not only do insects harbour the greatest species diversity (May, 1988), it is also expected that they are the most prevalent form of animal life in terms of sheer quantity. As predicted by Hölldobler and Wilson (1990), ants and termites alone constitute as much as 33 per cent of the total aboveground animal biomass, leaving the amount of insect biomass that is present on a global scale beyond imagination.

Within this enormous biodiversity also lies a huge potential for a wide array of human utilizations. In fact humans have exploited insects for thousands of years for various purposes. Honeybees (*Apis mellifera*) have been used for the production of honey (Dicke, pers.comm., 2012); silkworms (*Bombyx mori*) are the primary producer of raw silk (Cherry, 1993). Insects as natural enemies can play an important role in the suppression of harmful pests (IOBC Internet book of Biological control, retrieved 2012). Finally, insects can benefit humans by having multiple medical applications and as a major feed for other animals (Ramos-Elorduy, 1997).

Not surprisingly, the abundant resource of insects constitutes a significant part of the human diet throughout large parts of the world, with a vast range of around two thousand recorded edible insect species (Ramos-Elorduy, 2009). Within these regions, insects often are a valuable source of proteins, vitamins and minerals as well as being of good calorific value (van Huis, 2003). Nonetheless, insects are generally not conceived as a conventional source of food in Western society. Here, insect consumption is often regarded as being primitive and distasteful. This stigma has nevertheless been changing to some extent in recent years, and increasingly more people seem to become aware of the potential ecological, nutritional and economic benefits that insects have to offer (DeFoliart, 1999).

Due to their ectothermic or 'cold-blooded' nature, insects can operate as very efficient recyclers of organic waste into biomass of high nutritional value (Ramos-Elorduy, 1997). Furthermore, they have a higher conversion efficiency in comparison to other production animals like poultry, sheep and cattle. This means that they allocate a larger portion of their food into biomass increase. Thus their production requires a lower energy input, as they do not have to invest energy for body heat maintenance (van Huis, 2013). In addition, insect rearing has been shown to contribute less to climate change than the livestock sector. Both greenhouse gasses and ammonia emissions were observed to be lower for insect production (Oonincx *et al.*, 2010). Therefore, a shift towards insect-consumption could tackle the upcoming protein shortage as a result of a growing human population. At the same time, it could also be a more sustainable alternative to the conventional 'vertebrate-based' animal products within our society.

1.1 The Problem

At the moment there is no structured knowledge, based on scientific research, on how insects should be reared in conditions that are in accordance with their well-being. The techniques that the breeders employ in the various stages of insect production are mostly empirical and have been developed through a process of 'trial and error'. Insect rearing companies and investors are willing to proceed in an expansion of the industry. However, the lack of standardized and commonly accepted methods creates uncertainty regarding both the soundness and effectiveness of the methods themselves and the direction future investments in the sector should take. Therefore, the main problem that needs to be addressed in our project is how the up-scaling of insect rearing can be achieved whilst accounting for animal welfare in insects. Our project will also aim at defining a framework for insect welfare, collecting knowledge on the subject and specifying how this knowledge can be implemented in insect rearing.

Of particular interest for insect breeding companies in the Netherlands are the following species, which show potential for large-scale insect rearing: 1) yellow mealworm (*Tenebrio molitor*) and comparable species such as the lesser mealworm (*Alphitobius diaperinus*) and the superworm (*Zophobas morio*); 2) migratory locust (*Locusta migratoria*); 3) house cricket (*Acheta domesticus*); 4) black soldier fly (*Hermetia illucens*); 5) house fly (*Musca domestica*).

The present European (EU) legislation on animal welfare is based on the so-called Brambell's Five Freedoms (The Community Action Plan on the Protection and Welfare of Animals, 2006-2010). These Freedoms were formulated in 1965 by the UK Farm Animal Welfare Advisory Committee, chaired by F. Rogers Brambell (figure 1), with respect to intensively farmed veal calves, pigs and chicken (Brambell, 1965). They describe the standards that the animal production industry should aspire to, regarding the condition of production animals. More specifically they are:

1. The freedom from hunger and thirst.
2. The freedom from discomfort.
3. The freedom from pain, injury and disease.
4. The freedom to express normal behaviour.
5. The freedom from fear and distress.

Figure 1. F.W.R. Brambell; image courtesy of Walter Stoneman NPG, London

Should insect welfare be considered in terms of these principles, it has to be defined in what way the Five Freedoms can be used in relation to insects.

In the Netherlands, existing professional insect breeders state that the current legislation regarding insects is often unclear and the legal status of insects is poorly defined. Although insects are included in the upcoming (2013) Animal Act as production animals (Animal Act), the sections about 'accommodation and caring standards' and 'reproductive techniques' do not, for the time being, apply to insects. This makes the situation opaque as far as the admission of novel foods to the market is concerned (van Wagenberg *et al.,* 2012). At the same time, it enhances the existing uncertainty regarding future investments on insect rearing companies and the potential attitude of the public towards insect-based products.

Insects are a basic feed for fish and for other animals such as cattle and pigs, both in nature and in the relevant industry (FAO, 2012). Since 1994, as a result of the TSE (Transmissible Spongiform Encephalopathies) crisis, a feed ban was enforced in the European Union which is still in place (EC 999/2001). Based on this, the use of processed insects as food ingredients in fishmeal is allowed. However, their use as feed for other animals is prohibited. Application of this rigid regulation on insects has already had adverse consequences on insect rearing companies and the livestock industry.

Moreover, in European Law animals are now recognised as 'sentient' creatures which indicates that they are regarded as conscious beings having a value of their own (The Community Action Plan on the Protection and Welfare of Animals, 2006-2010). Although insects are evidently animals in a biological sense, it is debatable whether they possess consciousness. Besides the biological rationale, there are also ethical foundations of what an animal is. For instance, animal welfare authority Peter Singer (1975) argued that animals have a moral status based on sentience, or the ability to experience suffering. In that respect an organism might be considered an 'animal' when it indeed has the ability to suffer. But whether insects can experience pain and suffering remains unknown. So in order for any position to be taken by legislation, consumers and investors, it becomes crucial to bridge the unresolved knowledge gap concerning welfare of insects.

1.2 Stakeholders

There are various stakeholders involved in this problem. The Animal Act and the European Law on Animal Welfare will probably 'shape' to a great extent the way the industry will develop in the future. Therefore politicians and bureaucrats responsible for the writing of these regulations will have a significant impact on the problem and its solution. At the same time, insects might also be affected by both the new regulations and the possible new guidelines adopted by the companies involved in insect rearing. A solution to the problem would obviously affect both the insect breeders and the sectors in the animal feed chain that rely indirectly on insects (e.g. pet stores). Finally, surveys have demonstrated that EU citizens show an increasing appreciation for animal welfare (Eurobarometer, 2007). Therefore, the consumers' attitude towards insect products could be positively influenced if the insect rearing industry takes into account welfare issues.

1.3 Purpose and approach of the project

Within this project, our objective was to identify how the up-scaling of insect rearing can be achieved, taking into account the issue of animal welfare in insects. We used the following research question to approach the problem at hand:

> *What are the appropriate conditions to rear insects in the light of their basic needs and (Brambell's five) freedoms?*

To help us in answering this main problem, we formulated the five following questions:

1. What are the physical boundaries (qualitative and quantitative) of the techniques and methods of insect rearing?
2. How do insects experience pain and stress?
3. What is the most 'humane' way to kill insects?
4. What are the implications of European legislation and the upcoming Animal Act for insect rearing?
5. What is the current prominent political opinion regarding insects rearing?

The general methodology we use to accomplish this purpose is to compile information gathered from an elaborate literature review and from interviews with experts and insect breeding companies. Moreover, we identify knowledge gaps that merit further investigation. Finally, we provide advice on insect welfare criteria and on the legal implications of up-scaling insect rearing facilities.

More specifically, in order to address the first three questions, we carefully examined the literature on the rearing techniques of insects, their natural living conditions and their physiology. We also studied the ethical perspective on insect welfare. Finally, we delved into the relevant legislation as to answer the fourth question. Although our initial ambition regarding the first question was to define both qualitative and quantitative physical boundaries of up-scaling insect rearing facilities, we soon realized that this was not possible due to a lack of available data. So we focused on deciphering only the qualitative aspects. With respect to the main question, we used Brambell's Five Freedoms as a framework to assess insect welfare issues, because these Freedoms are at the foundation of animal welfare legislation. At the same time, we explained how and to what extent these Freedoms can be applicable to insects, whereas the insects' basic needs were defined based on the way they live in nature.

We visited four insect breeding companies (Van de Ven, Protix, Jagran and Kreca) as well as the head of the insect rearing facilities at Wageningen University, Leon Westerd. During these visits, we had the chance to discuss the methods they use to rear and kill insects. The information we collected was relevant for the first three questions. Furthermore, we interviewed three experts on Entomology: Arnold van Huis (Chair of Tropical Entomology, Wageningen University), Hans Smid (insect neurology expert, Laboratory for Entomology, Wageningen University) and Marcel Dicke (Chair of Entomology, Wageningen University), who shared their valuable knowledge on all questions. An interview with Michiel Korthals (Chair of Applied Philosophy, Wageningen University) gave us useful insights on how insects are regarded from an ethical point of view. The interview with Teun Veldkamp (senior researcher (poultry) feed Wageningen University) was enlightening with respect to the legislation issues raised in the fourth question. Finally, we allocated substantial time and effort on arranging interviews with representatives of the main political parties in the Netherlands that show concern on animal welfare issues, in particular the Party for the Animals (Partij voor de Dieren) and the Liberal Party (VVD). To our great disappointment, this was not possible.

1.4 Reader's guideline

In this final section of the introduction we will provide a brief outline of the content of the remainder of this report as a convenience to the reader. We will briefly state the contents of each chapter and the way they are addressed. Thus, the discerning reader should be able to quickly find the specific information he or she desires.

In the second chapter we provide an inventory of the current status in the field: i.e. an inventory of both the theory available on breeding techniques and an overview of the practice as employed by the insect breeders interviewed for this project. The breeding theory is addressed by way of environmental factors such as light, temperature, humidity and biotic factors such as population density (crowding) and intra-species relations (e.g. occurrence of cannibalism). The breeding theory is further assessed by addressing safety and health (i.e. disease prevention). Finally, we briefly touch upon the issues that arise regarding the nutrition of bred insects.

Aforementioned theory on insect breeding mainly covers insects in general. The latter half of the second chapter is reserved for the breeding practice of the individual species of interest. This is done by individually addressing the breeding practice per insect farmer interviewed for this project; since most interviewed breeders only breed one or a couple of the species of interest, this setup coincides with the respective species of interest.

In the third chapter we address the physiology and ecology of the insect species of interest in relation to their welfare. The framework used for this is Brambell's Five Freedoms (outlined earlier in this introductory chapter). The freedom from hunger and thirst is evaluated by assessing per species of interest their specific needs in this regard (i.e. dietary intake). The freedom from discomfort and the freedom to express natural behaviour are very much intertwined. We therefore argue that in the case of insects it is from a practical point of view assumed that the freedom to express natural behaviour leads to a freedom from discomfort. The section on the freedom from pain, injury and disease also provides physiological and neurological theory on the way insects experience 'pain' and whether they can 'suffer' like for example humans can. The killing of insects destined for (human) consumption and how this is best performed from an animal welfare point of view, is also addressed in this section. Finally we address the freedom from fear and distress and argue how insect might experience these.

The fourth chapter looks at animal welfare from an ethical point of view. It examines how the moral status of insects might be regarded by different schools of thought in animal ethics. Moreover, it evaluates how ethical principles in animal welfare can be applied to insects. It ends with suggestions on ethical concerns that should be considered by insect breeding companies.

The fifth chapter studies the current legislation on breeding of insects and how insects are to be implemented in the upcoming Dutch 'Animal Act'. It also investigates the consequences for the insect breeding sector that arise from legislation as well as future prospects and recommendations for insects in legislation.

The sixth chapter is the discussion, in which we summarise the most important findings and identified knowledge gaps from all the above mentioned chapters. We also provide recommendations for future research as well as recommendations for required actions so that insect welfare issues are taken into account by insect rearing companies.

The final chapter is a conclusion in the form of a factsheet highlighting the most important points from the discussion.

2 Insect rearing conditions

This chapter will provide an overview of the current insect rearing methods. The overview is a combination of literature research and interviews. By having the overview of the current situation knowledge gaps on up-scaling and welfare can be identified. The main purpose of a large-scale insect rearing facility is to produce the maximum number of qualitatively acceptable insects with minimum labour, space and costs. This, in combination with insect welfare guidelines for an insect rearing facility, will support this purpose (Pritam Singh, 1982).

Since insects are the biggest group of animals in the world, the diversity between the different species is big (May, 1988). This makes it difficult to provide guidelines for insects as a group: every species has his own specific needs and preferences.

2.1 Environmental factors

Environmental factors affect the insect during rearing. One can distinguish biotic and abiotic factors. Biotic factors include crowding, cannibalism etcetera. These factors are very species specific, therefore they will be discussed later on in this report for our species of interest. Abiotic factors contain inter alia influences of light, humidity and temperature (Schneider, 2009).

2.1.1 Light

Light has the properties of intensity, wavelength and degree of polarization. These properties can be a powerful tool of environmental influence on insects as in a physiological, behavioural and ecological way including phototaxis, circadian rhythms, diapauses and population growth.

Phototaxis is a locomotory movement, that occurs when a whole organism moves in response to the stimulus of light (Mathews and Matthews, 1978). Light can be used to influence the phototaxis of the insects in several ways. For example, attraction to light can be used to attract adults out of the mass rearing containers into the units for transporting them to oviposition containers (Robertson 1985). Most of the insects showing phototaxis are particularly sensitive to UV (300 nm – 400 nm) or green light (492 nm – 572 nm). If one wants to use light for phototaxis, those wavelengths are recommended (Burkhardt, 1964). The eyes of most insects and larvae are quite sensitive to light compared to human eyes, therefore thresholds can be very low. Hence it is recommended to use a light meter to measure the degree in darkness in which insects are exposed instead of using one's own eyes (Kitabatake *et al.*, 1983). In natural circumstances polarization is used by some insects to find directions, location of water bodies and station keeping (Waterman, 1981). The direction of movement and activity level of both adult insects and larvae is dependent on polarization of light. Under normal circumstances natural light is polarized by scattering off of small particles and is most pronounced at 90^{o} with respect of the direction of the sun. This results in spatial patterns depending on the polarization of light changing with the time of the day. One can manipulate the direction of movement for instance by rotating the polarizing filter between a light source and the insects (Wellington, 1974; Doane and Leonard, 1975).

Diapause is a natural type of dormancy in response to regularly and repeatable periods of adverse environmental conditions. The occurrence of a diapauses to insects in breeding facilities is often undesirable since it delays the development. Diapauses can be initiated by temperature and light circumstances. Day length is one of the initiators for diapauses. To avoid diapauses light (sometimes in combination with temperature) can be used, although there is still not much know about the influence of light on diapause (Tauber *et al.*, 1986). This might be a suggestion for future research.

A circadian rhythm is a biological process driven by the natural day-night cycle. The process displays an endogenous oscillation of 24 hours. Insects do have a circadian rhythm, this means that their physiological conditions and incidences of behaviour vary with time of day, this rhythm is independent of temperature (Saunders *et al.*, 2002). The circadian rhythm is expressed as a periodicity of occurrence for repeating processes such as locomotion and feeding. Processes that occur only once in a lifetime such as hatch and pupation are expressed as periodic gating. If a population has been reared in continuous darkness (DD), there is no circadian rhythm: life history events are totally random instead of programmed. This will for instance reduce the maximum rate at which individuals enter a certain developmental stage or the maximum number of insects that can be harvested. Circadian rhythms can be initiated by an exposure to a single pulse of light (Veerman, 2001). By exposure to light pulses circadian rhythms can be initiated or influenced. As with the DD reared insects you can use light as a tool to influence insects with a light-dark cycle and a continuous light cycle. By influencing the circadian rhythm certain processes as oviposition and duration of diapauses can be altered. However, this is rather species dependent therefore best results will be obtained by trial and error (Westerd, pers.comm., 2012; Veerman, 2001). For example, Jagran rears their housefly larvae in total darkness: this optimizes not only the developmental rate of the larvae, but it will also save costs on energy (Jansen, pers.comm., 2012).

2.*1.2 Temperature*

Insects are poikilotherms, a poikilotherm is an organism whose internal temperature varies considerably depending on their surroundings. Therefore the developmental and metabolic rate of an insect increases as the temperature rises and decreases when the temperature declines. As well as light, temperature can influence circadian rhythms, diapauses and population growth (Schneider 2009).

The aforementioned circadian rhythm can also be influenced by temperature. By using temperature as a tool, processes can become more efficient. In general, the warmer the environment, the faster the process of for example egg hatching and larval development, although sometimes these accelerations also have adverse effects. Fast development may for example lead to less active adults (Pritam Singh, 1982). The same goes for the diapause. By playing with temperature (and light), processes can be influenced in a good and bad manner (Saunders *et al.*, 2002). Although there has to be said again that all this is species specific.

For insect rearing four different temperature characteristics should be considered: the desired temperature set point; the temperature variation around the set point; the temperature stratification; and the range of possible desired temperatures (Saunders *et al.*, 2002). The set-point temperature is the average temperature to which the insects are exposed; generally speaking the average temperature is between 25 and 27^{o}C. The temperature variation is the amount of degrees (^{o}C) that the temperature fluctuates around the desired temperature, $\pm$ 2^{o}C is achievable in most facilities. Temperature stratification arises when warm air rises while colder settles to the bottom. This creates a temperature difference in the upper en lower parts of the facility. A difference of 0.6^{o}C is acceptable (Saunders *et al.*, 2002). The temperature is measured and monitored by thermostats in each insect room. However, there is not always need for a fixed set temperature.

2.1.3 Humidity

The relative humidity (RH) is the percentage of moisture in the air relative to the total amount it can hold at a particular temperature. The humidity is measurable by a hygrometer or psychrometer. It is important to maintain the RH with minimal variation. The desired RH set point is species dependent and also has different influences on developmental stages of the same species. To keep the humidity as constant as possible, the interviewed breeders use a thermostat. A common range in insect facilities is 40 to 80% dependent on the species and different developmental stages, a fluctuation of 5% is adequate. If the humidity is too low it may be fatal for the insects, if the humidity is too high this may result in fungal or other disease problems (Schneider, 2009; Bursell, 1974). Too high a substrate humidity might cause drowning of the larvae and asphyxiation of adults (Jansen, pers.comm., 2012).

2.1.4 Biotic factors

Besides the abiotic factors mentioned above there are biotic factors as well. When the density is too high, cannibalism can occur. A good example of cannibalism is the locust: it starts eating its conspecifics when there is a lack of space. A possible solution for this problem is to enlarge the surface for the locusts by for example adding blocks in the container (Leon Westerd pers.comm., 2012). Another biotic factor is crowding. For most species crowding is not a problem since they live together in high densities in nature as well. The adverse effect of crowding is the heat development. If it becomes too warm in a certain area diseases may occur. For instance crickets are really sensitive to diseases when reared in too high densities (Leon Westerd, pers.comm.,2012).

2.2 Safety and health

When up-scaling an insect rearing facility the occurrence of diseases and safety problems becomes a bigger risk, for both human and insects. To protect workers from health problems and insects from diseases a proper sanitation is important. Besides the sanitation the need of a HACCP certification (Hazard Analysis and Critical Control Points) and use of a HACCP checklist is compulsorily since the rearing business is involved in the production of food and feed (Van de Ven, pers.comm., 2012). "*HACCP is a systematic preventive approach to food safety that identifies physical, allergenic, chemical and biological hazards in production processes that can cause the finished product to be unsafe, and designs measurements to reduce these risks to a safe level*" (HACCP Europe, retrieved 2012). An important point on the HACCP list is the monitoring of quality control and keeping records of the feed used to feed the insects. If something went wrong with the insects it is easier to retrace for what reason it happened (Van de Ven, pers.comm., 2012). HACCP helps the breeder to deliver a safe end product. Besides the sanitation the safety of the workers has to keep in mind. To prevent accidents and injuries the use of protection equipment, as for example gloves and face masks, are considerable (Douglas Inglis *et al.*, 2009).

Microbial contaminants are a serious problem in insect breeding facilities. The definition of microbial contaminants is rather broad. Microbial contaminants can be defined as microorganisms which do not form mutualistic or parasitic relationships with insects. However, this definition does not address whether microbial contaminants are pathogens or not. A pathogen is defined as any agent that incites diseases. Microbial pathogens can be divided into different variants (Douglas Inglis *et al.*, 2009).

Most insects have various types of microorganisms living in their alimentary canal which do not harm the insect under natural conditions. However, the microorganisms can become infective pathogens: when induced by abnormal conditions, they can cause death in a large proportion of the population. For instance, if crickets are reared in too high a density a certain virus appears. This virus is always apparent in the species but it only has adverse effects if the density is too high (Westerd, pers.comm., 2012). Microorganisms that are always present but become pathogenic under abnormal conditions are called facultative pathogens. This example illustrates that a disease is not only dependent on a microorganism, but also an interaction with the environment and host (in this case the insect) (Douglas Inglis *et al.*, 2009). Therefore it is important to rear the insects in their natural conditions as much as possible. Insects are very sensitive and will react in a negative way when the artificial conditions deviate too much from their natural conditions (Arsiwalla, pers.comm., 2012). This has to be kept in mind when designing breeding facilities.

There are different sources of contamination in insect breeding facilities, such as newly introduced insects, the nutrition and its ingredients, inanimate objects (e.g. rearing containers), staff and the airflow in the facility. The two major sources are the staff people and the airflow. To reduce microbial contamination by air, air filtration is one of the most important tools to use. Clean working rooms are essential as well. The access to clean areas should only be permitted to trained staff members. Visitors should not be allowed in these areas to prevent contaminations by humans (Smith and Bruch, 1969). For example, insect breeding facility Van de Ven does not let visitors into the rearing area of their company. A few years ago an unknown contaminant pathogen killed all their morio worms (*Zophobas morio*). The breeders assume that the pathogen was brought into the company by visitors since causes were not retrievable from their rearing registrations (Van de Ven, pers.comm., 2012).

Another contamination source is through nutrition. For instance, a microbial contaminant can increase the PH of the diet to such a degree the insect is unable to obtain his diet. The microorganism influences the environment which adversely affects the insect which can cause diseases. Therefore nutrition is also an important factor to look at for restricting the cause of diseases. Many nutritional components of artificial diets contain various fungi and bacteria. These components also contain growth nutrients essential for insects but also for the microorganisms (McLaughing and Sikorowski, 1978). The same goes for nutrients as vitamins, wheat germs, caseins, tap water and gelling agents. Antibacterial agents can be a solution for artificial diets. In natural diets, for instance leaves and fruits, there will also be microorganisms, especially on their surfaces but also inside tissues. To prevent population growth of these microorganisms it is important to store feed as dry as possible. Too high humidity can cause mass population growth on many microorganisms, especially fungi (Sikorowski and Lawrence, 1991).

The primary goal of disease management is prevention. Therefore sanitation and safety checklists are necessary. Besides sanity and safety the insects are best prevent from diseases by imitating their natural environment as precise as possible (Arsiwalla, pers.comm., 2012).

2.3 Nutrition

An important step in insect rearing is proper nutrition. Knowledge of the natural conditions of an insect is necessary to be successful in developing an artificial diet. Proper nutrition has a big influence on the production. Breeder Walter Jansen (pers.comm., 2012) mentioned that his house flies cease to lay eggs when they get insufficient nutrition. Insects can be divided in zoophagous, phytophagous and saprophagous animals. Respectively feeders on animals, plants and decaying organic materials (Chaudhury, 2009). Diets differ per species, however there are some dietary components that should be part of the diet such as carbohydrates, proteins, lipids, nucleic acids, minerals, vitamins and water. Most of the diets are provided to the insects as powder. Again it is a process of trial and error to find the best diet for a specific species.). If a diet does not contain the necessary ingredients the insects do not develop the way they should which has an adversely effect on the production. One does not make the same mistake again after a large loss of production (Arsiwalla, pers.comm., 2012)

2.4 Interviews

To give a broad overview of the interviewed breeders a summary of each interview can be found in the boxes below. The knowledge about rearing techniques is quite general. The general basis for rearing techniques is trial and error. If one loses all their insects because of too high heat production, one will not let it happen again (Arsiwalla, pers.comm., 2012). Insect breeders are sceptic to share their techniques since they are afraid to be copied by other starting breeders. It takes time and money to figure out what is the best way to rear one's insect species of interest. Adjustments to obtain a higher production yield are mostly really unlaborious but not always obvious. Therefore breeders like to keep their methods and conditions to themselves (Westerd, pers.comm., 2012; Van de Ven, pers.comm, 2012; Arsiwalla, pers.comm., 2012).

Box 1 Van de Ven

Van de Ven is an insect rearing company specialized in mealworms. Their current rearing methods are based on their own experiences. His mealworms are grown in boxes of 60 x 40 cm, after a period of 10 weeks an amount of 2 – 2.5 kilogram is produced per box. The precise amounts of worms per box is discovered by trial and error. Mr Van de Ven has a computer-steered humidity program which maintains a constant humidity of 60 – 70 %, the temperatures is also kept constant. His mealworms did not suffer from diseases yet, their only worry is fungal growth in feed. After 10 weeks of growth mealworms are ready to leave the company. Van der Ven sells his mealworms mostly alive as feed for reptiles, birds and fish. If there is a demand for death insects he uses the freeze-drying technique. The current production of mealworms is currently 1500 kilogram per week.

As an insect rearing company is a business involved in the production of food and feed, the HAPPC legislation has to take in account. Therefore Mr Van de Ven is keeping records of registration of feed for the insects and such. Proper sanitation and clean rooms is also of importance for him to prevent diseases and other health problems. Their biggest concern is the lack of knowledge of insect diseases.

Up-scaling should not be a problem for Van de Ven. They are able to expand their production by 100% with their current production methods on their current location, just by using the space more efficiently. Although they are a bit sceptical towards the upcoming animal act. He is worried that the legislation come up with some boundaries that can ruin the insect industry.

Source: Van de Ven insect rearing company, Roeland van de Ven

van de Ven
insecten kwekerij

Box 2 Protix

Protix is an insect rearing company that has developed an experimental factory to operate a scalable process that closes the nutrient cycle (proteins and fats) using insects. Their purpose is to become the world's leading insect breeder, initially for (specialty) feed applications; in a later stage also pharmaceutical and food applications. The black soldier fly is one of their main insect species. Currently their production is largely used to improve their own production process. They do not deliver products to the feed industry yet, only to pet food. Their rearing methods are based on literature, extensive experiments and some trial-and-error. According to Mr Arsiwalla the black soldier fly only do well if the rearing conditions are similar to their natural conditions. Even minor changes might affect the rearing process adversely because the black soldier fly is quite sensitive to changes in its environment. This resulted in a natural and animal friendly way of rearing the black soldier fly. He assumes this will also apply to other insects. Protix did not suffer from diseases; to prevent these, they keep their area clean and have hygiene inspections. All processes are measured and saved; every step is retrievable.

The final product is delivered as a powder. Therefore it is not necessary to kill the black soldier fly 'slowly' to keep it as a whole. Killing and powdering the insects in a mechanical way have shown to be the most efficient method and can be done in a split second, however other fast procedures are possible. Next to feed purposes, Mr Arsiwalla does not expect whole insects used in human food in Western markets soon; grinded insects may have a better chance.

The aspect of animal welfare in insect rearing facilities has not crossed the path of Protix yet. Mr Arsiwalla thinks this might have to do something with the fact that Protix is rearing for the feed industry and not for the food industry (conscious niche-buyers). Not being able to answer all questions regarding this topic should not automatically stop a new sustainable industry from developing, in particular as other animals (like fish), and nutrients, are saved.

Source: Protix Biosystems BV, Tarique Arsiwalla

PROTIX Biosystems BV

Box 3 Jagran

Jagran is in insect rearing company founded by Walter Jansen mainly specialized in houseflies. The insects as an end product are primarily directed to the feed industry, not for human consumption.

The general aim of the rearing conditions is to imitate the natural circumstances as much as possible. The housefly larvae are reared in darkness, this optimizes their developmental conditions but it will also save costs on energy. The larvae generate their own environmental temperature depending on their density. Too high or too low temperatures might affect the larvae adversely. Therefore Mr Jansen monitors the densities at which adverse effects arise and cools down the larvae to prevent this. The density of the larvae also has another point of interest concerning nutrition. The larvae collectively excrete enzymes which effectively digest the nutritional substrate; through their trachea the substrate is than taken up by the insect. This requires a densely populated area of larvae. A humidity of 60 – 70 % is mainly needed for the substrate of the larvae. If the substrate is to wet the larvae will drown, if the substrate is too dry it will not be available for the larvae. Adult flies receive a day-night rhythm (12/12) and are kept at 27 – 28^{o}C with a relative humidity of 60-70%. Adult flies will die of dehydration within two days if water is not provided If the food is of insufficient quality, the housefly will cease to lay eggs.

Jagran currently has never encountered diseases in their population. Mr Jansen mentioned the fact that the housefly has a short lifecycle: the duration of growth from larvae to harvestable insects is 3 days. If a disease shows up the costs of losing a generation is marginally. Bacteria and fungi are not a problem for the production if there is a sufficiently dense population of larvae present; the larvae excrete digestive enzymes that have sterilizing properties on the substrate which give a hygiene and germ-free end-product. Therefore an additional production step of sterilizing is unnecessary when the insects are directly used for feed.

Several killing techniques have been experimented with; such as asphyxiation, cooling, freeze-drying and boiling. They also use an insect shredder, Mr Jansen stated that this is the most animal friendly way to kill insects.

Jagran's future goal is to work with a population that is about 100% closed from the environment by using a sterilization system based on under- and overpressure to prevent the introduction of diseases.

Source: Jagran, Walter Jansen

Box 4 Kreca

Kreca is an insect rearing company that breeds a wide range of species including mealworms, wax moths, houseflies, fruit flies, cockroaches and crickets. About 95% of the insects are sold alive for consumption by pets and the fish breeding industry. The company has been founded 35 years ago and from the beginning, when literature wasn't readily available, techniques have been established by trial-and-error. All insects are grown on a flower substrate. When insects are reared for human consumption, more hygienic measures are taken: after sifting they sterilize them in hot water and then they place them in the fridge or freeze-dry them. On the contrary, when reared insects are destined to be animal feed (e.g. the fruit flies flies) they are only sifted with a sieve and then they are directly put in the fridge or are freeze-dried.

Locusts are not reared within the facility, but crickets are reared at 28-30^{o}C and require about the same conditions as mealworms. Flies are bred separately as they require lower temperatures, otherwise they become sterile.

The most common method in tackling diseases is to 'wipe everything out' and start the culture again with the more resistant insects that survive. Generally, in contrast to the livestock industry, they always keep a selling stock and a breeding stock from which they 'refuel' the former.

Ms Calis says that at the moment there are no specific regulations the insect rearing companies have to comply with regarding insect breeding. The government officials have no knowledge on the subject. There is bureaucracy only when they have to import insects or export their products. In their opinion the lack of legislation is both good and bad. On one hand, it is positive because in a way they have the freedom to do whatever they think is appropriate when they breed insects. On the other hand, it creates problems especially regarding potential up-scaling. For instance they couldn't get a permit to build a permanent construction made of concrete in order to expand their facilities, because it is unclear in legislation what an insect facility should be like. They are now collaborating with the Dutch authorities to see what rules/legislation is/are necessary for the branch. Beside that they are making a blueprint on rearing techniques: specific guidelines based on their experience, which are essential for the blooming of the branch. The authorities can use the guidelines as an example; this is expected to give more transparency to the sector. They are also interested in improving their methods.

As a concluding remark, Ms Calis thinks that there is potential in up-scaling the industry both for human consumption and for animal feed. This ultimately will demand specific legislation and more automation, so that the prices can be competitive.

Source: Kreca, Marieke Calis

3 Brambell's Five Freedoms and Insect Welfare – A checklist approach

A framework needs to be defined in order for insect welfare issues to be assessed. For this purpose, we will use Brambell's Five Freedoms as they are at the foundation of legislation. In this chapter we will evaluate each freedom separately and we will analyse how it can be applicable to insects. Furthermore, we make some suggestions on how insect welfare can be accounted for by insect rearing companies.

3.1 The freedom from hunger and thirst

This freedom is most evidently concerned with the provisioning of enough food of sufficient nutritional value, and suitable water amounts of adequate quality to the reared insect species. However, as mentioned by the interviewed experts, an additional problem arising with malnourished insects is that they are prone to resort to cannibalism whenever this occurs (van Huis, Westerd, pers.comm., 2012). As a result of this, relief from hunger might therefore play an essential role in meeting other freedom criteria. For instance, whenever cannibalism occurs, this will likely go at cost of the freedom from pain and injury as well as possibly causing an effect on fear and distress.

Besides providing sufficient food, an aspect to offering food of adequate nutrition is to provide the insects with food that is in accordance with their natural diet requirements. The larvae of *Tenebrio molitor* (yellow mealworm), *Alphitobius diaperinus* (lesser mealworm) and *Zophobas morio* (superworm) are indicated to feed rather generally on stored grain and flour products (e.g. Weaver *et al.*, 1988a; Salin *et al.*, 1999). Additionally, *A. diaperinus* is seen to thrive in poultry waste including dead chickens, eggs and manure (Salin *et al.,* 1998). It is therefore likely that the species obtain adequate nutrition through feeding on multiple plant and animal sources. Keeping them free from hunger and thirst therefore primarily seems a matter of offering enough quantities of food and water, although a specification an the specific amounts has not been found in the literature.

The *Locusta migratoria* (migratory locust) is feeding on plant material. Although it is thereby able to consume a wide variety of plant species, the species is regarded to be largely graminivorous and shows preferences for certain grass species (Centre for Overseas Pest Research, 1982). The water content of the grass needs to be appropriate to keep the locusts from dehydration (Calis, pers.comm., 2012), and thus ensure their freedom from thirst.

Acheta domesticus (house cricket) is omnivorous and is able to consume a large variety of food material, and will do so by scavenging on various plant and animal items (Kleukers *et al.,* 1997). Laboratory studies have yielded indications that crickets fed on a mixed diet show a longer life span as opposed to crickets fed on a diet containing only plant or animal tissue (Ismail, 1978). In order to meet welfare criteria surrounding the freedom from hunger and thirst, it will consequently be advisable to offer *A. domesticus* a diet containing these mixed sources.

Hermetia illucens (black soldier fly) will only feed during the larval phase. The freedom from hunger is therefore only to be taken into consideration for this life stage. As the value of their use stems primarily from their ability to consume and digest a wide variety of decomposing matter, adequately feeding the species in captivity is therefore likely only concerned with offering enough quantities of food. But as the large-scale rearing of this species is only in its beginning stages, it will probably be more clearly elucidated in the future to what extent malnutrition can occur resulting from a lack of food quality.

The adult *Musca domestica* (housefly) lacks biting mouthparts and therefore feeds by means of suction. In doing so, it will first eject digestive enzymes on its food source before ingesting it as a more liquefied substance (Malik *et al.*, 2007). It has been shown that *M. domestica* have a longer lifespan when fed on a sucrose diet. This as opposed to flies fed on a diet containing protein and or lipids (Cooper *et al.* 2004). These insights might suggest that a diet lacking protein and lipids is of optimal quality for the flies. However, effects on reproductive value have not been addressed for this diet and could prove to be undesirable for the rearing industry. An aspect with regard to water requirements was brought forward by Walter Jansen (pers.comm., 2012). Houseflies will namely die of dehydration within two days if water is not provided, indicating that careful water provisioning is important for this species to ensure their freedom from thirst. He also noted that females will cease to lay eggs if food of insufficient quality is provided, thereby showing the production value of offering sufficient quality food beyond the freedom from hunger. Although fly larvae develop most commonly in rotting vegetable matter, they will primarily feed on the microorganisms inhabiting this substrate rather than the substrate itself (Cook *et al.*, 1999). Though suitable microorganisms probably occur in multiple developmental media, in the light of their freedom from hunger and thirst, it could be interesting to see whether *M. domestica* larvae indeed are better nourished on the microorganisms residing in plant material. However, a mixture of substrates has proven to be the most effective feeding source in the breeding facility of Walter Jansen (pers.comm., 2012).

3.2 The freedom from discomfort and the freedom to express natural behaviour

A comparison to what is 'natural'

In order to assess insect welfare in the light of Brambell's five freedoms, one also needs to gain insight in aspects regarding the 'natural' behaviour of the species under consideration. This is particularly true for the 'freedom to express normal behaviour', but is also important in evaluating for example the 'freedom from discomfort' as this criterion concerns crowding and the tolerance to certain levels of rearing densities. For instance, to what extent an insect species is able to cope with high densities can – besides pragmatic observations stemming from rearing settings – largely be interpreted by the level of social interaction a species has with conspecifics when it resides under natural conditions.

More generally, in order to meet welfare criteria for insects in current practice, it becomes necessary to approach the natural living conditions of insects in the captive environment (Dicke, pers.comm., 2012). Likewise, insect breeder Tarique Arsiwalla (pers.comm., 2012) stated that approaching the natural conditions in breeding facilities is the only reliable way to ensure that the reared insect species will reside under optimal conditions, and thereby minimizing mortality and increasing productivity. Further interviews with experts provided indications that insect biodiversity is however too large to generalize upon welfare standards for insects as an entity (van Huis, Westerd, pers.comm., 2012). For each of our species of interest, specific aspects concerning their biology as available from current literature are therefore highlighted to facilitate an evaluation on keeping welfare criteria under rearing conditions.

3.2.1 Tenebrio molitor, Alphitobius diaperinus & Zophobas morio

As for all holometabolic insects, the larvae of the above mentioned species have distinct morphological, ecological and behavioural properties with respect to the adult phase. The term 'mealworm' hereby applies to this larval stage of some of the species. *T. molitor*, *A. diaperinus* and *Z. morio* are all beetle species situated within the superfamily Tenebrionoidea, and show a wide distribution across Europe, North Africa and Asia (Löbl and Smetana, 2008). The yellow mealworm (*T. molitor*) is regarded a pest to stored human products and arises in humid and dark places on decomposing matter. The larvae will aggregate and were found to be attracted to the frass composites of other individuals of the species (Weaver *et al.*, 1988a). The larvae will frequently sample other individuals with their mouthparts to assess these chemical cues, and they have been observed to cluster in high densities in the presence of conspecific frass composites (Weaver *et al.*, 1988b). The lesser mealworm (*A. diaperinus*) shows similar 'natural' ways as it occurs in human storerooms and shows a preference for relatively dry microhabitats with high food-availability (Salin *et al.,* 1999).

As has been shown for the yellow mealworm, or the larvae of *T. molitor*, individuals will cluster together and are naturally attracted to one another. As similar clustering occurs for the remaining two species under consideration as well, it is again very unlikely that these species will suffer from discomfort as a result of direct crowding when kept in high densities in captivity. Moreover, if natural circumstances are to be allowed in rearing facilities, mealworms should be kept together and given the possibility to aggregate to ensure their freedom to express normal behaviour. Nevertheless, as insect breeder van de Ven (pers.comm., 2012) indicated, the building up of heat is the main limiting factor in keeping high mealworm numbers. Nevertheless, when too few worms were kept together, the temperature dropped to a point that is suboptimal for the species' growth. To satisfy the freedom from discomfort and preserve the worms from injury, it will be necessary to investigate the maximum densities of worms that can be kept together without resulting in detrimental heat effects. In such an investigation from Salin and associates (1999), it was shown that a temperature of 40 degrees Celsius is a critical point above which larvae of *A. diaperinus* will show strong locomotor behaviour and open their spiracles and expel water from their tracheal system. This leads to a fast drop in the larvae's water content. In turn, one might assess the density at which the temperature becomes too low for the larvae to grow optimal. A study by Rueda and Axtell (1996) showed in a comparable manner that *A. diaperinus* larvae will cease hatching and developing at temperatures below 17 degrees Celcius. As our literature review did not yield comparable data for *T. molitor* and *Z. morio*, we suggest likewise temperature assessments for these two species as well. Another aspect with regard to larvae as addressed by Arnold van Huis (pers.comm., 2012) is that they are sometimes artificially treated with juvenile hormone (JH) in rearing facilities. This will influence the moulting of the larvae which induces them to grow beyond their ordinary length. Besides the potential hazard to human health if these mealworms were to be used for human consumption, applying juvenile hormone to mealworms would therefore be in conflict with their freedom to express normal behaviour. Also to provide statements on a potential part of the freedom from injury or disease, detrimental physiological consequences of artificially applying the juvenile hormone should be assessed.

3.2.2 Locusta migratoria

Widespread throughout large parts of the World, *Locusta migratoria* inhabits a large variety of ecosystems with its distribution mainly centred around tropical regions. As its name implies, this is a migratory species. A characteristic aspect with regard to the locust's biology is thereby that it occurs in two distinct forms: a solitary phase and a gregarious phase. Between these alternative form, they differ in coloration as well as in their behavioural characteristics. Besides being triggered by unfavourable environmental circumstances, a shift from the solitary phase to the gregarious phase is elicited by an increase in population density which is mediated by pheromonal communication pathways (Benton, 2012). When in the gregarious form, individuals are more habituated to involve in intraspecific encounters. Aggregation of *L. migratoria* has by this means been recorded to comprise the movement of two million individuals per night over a kilometre wide transect (Farrow, 1990).

Since locusts are kept in the gregarious phase as they are reared (Westerd, pers.comm., 2012), and in the light of the aggregation behaviour as part of their natural behaviour, it is very unlikely that increased population density under rearing conditions will lead to significant discomfort for the species. Additionally, Wilson and colleagues (2002) showed that gregarious *L. migratoria* that that were reared under densely populated conditions are more resistant to pathogens than solitary locusts. Besides being more resistant to the prevailing entomopathogenic fungus *Metarhizium anisopliae* var. *acridum*, the species showed increased antimicrobial capability without influencing its associated behaviour and temperature preferences. Keeping the species in high densities can therefore facilitate to reach the criteria associated with the freedom from disease. However, as indicated, natural populations of *L. migratoria* are not constantly present in the gregarious form. This can be in conflict with their freedom to express normal behaviour. Therefore, we suggest more research to possible long-term welfare effects of artificially keeping of locusts in a permanent gregarious phase. Information about the long-term physiological effects that appear as a result of this is desired to assess possible detrimental aspects that arise over the entire lifespan of a locust. Furthermore, the extensive migratory and flying behaviour are largely constraint in captivity, but naturally occurring when the species is in the gregarious state. Although this expression of normal behaviour is virtually impossible to allow fully whilst in captivity, the species likely requires sufficient (vertical) space to express the basic incitement towards such movement patterns.

3.2.3 Acheta domesticus

The cricket species *Acheta domesticus* now shows a rough cosmopolitan distribution as a result of being introduced, but originates from dry areas in Northern Africa and south-west Asia. It is by this means often occurring in close association with human settlement outside its original distribution area. In northern areas they are probably able to colonize spaces in human habitation and are unable to survive the winter without doing so (Benton, 2012). This is because the species lacks a diapause stage in its lifecycle. Ovipositioning takes place in moist areas, but nymphs and adults have a preference for more dry surroundings (Singh and Moore, 1985). Being largely active at dusk and during the night, males will create sounds to attract females (Benton, 2012). Males of *A. domesticus* will also indulge in fighting behaviour (see Hack, 1997). The species has also been observed to be active during the day and have shown the capability to fly (Benton, 2012). Kleukers and associates (1997) highlighted the suggestion that the species also distributes by means of flying over some distances, although this is probably not their most predominant way of dispersing.

As *A. domesticus* occurs within colonies as part of their natural behaviour, it is not very likely that the species will suffer from substantial discomfort as a result of increased population numbers. A proper quantification of natural densities was however not found within our analysis, in addition to lacking technical details from cricket breeders. Hack (1997) showed that dominant males spend more energy in fighting compared to subordinate males. Therefore, having a high density of male individuals within a rearing colony might therefore have adverse effects on welfare criteria. Besides potentially injuring one another, prevalent fighting is likely to increase fear and distress among male individuals. The increased energy expenditure related to fighting will probably also go at cost of longevity. We therefore suggest future research to what ratio of males to females is optimal in minimalizing fighting behaviour while not going at cost of reproduction and production yield. As the species is primarily nocturnal and will only begin displaying courtship behaviour around sunset, it will probably be necessary to provide a captive colony with sheltering possibilities. These should be established to provide sufficient darkness and cover enough area to potentially shelter all individuals in the colony. This will meet the freedom to express normal behaviour as individuals will be more inclined to hide during the day. Additionally, also a day/night rhythm should be provided in the within the lighting technics. Although flying behaviour is not expected to be a big part of *A. domesticus* behaviour, for this species it will also be required to provide sufficient vertical space to allow normal behaviour whenever flying incentives occur.

3.2.4 Hermetia illucens

The dipteran species *H. illucens* is distributed throughout tropical and warm temporate regions, and it colonizes a broad range of decomposing organic matter in which the female will oviposit (Sheppard *et al.,* 2002). As also stated in section 3.1, the period of food intake of this species is limited only to the larval phase. These larvae are expected to be largely polyphagous and are in this way capable on feeding on a wide variety of decomposing matter including dead plant and animal material, manure and also human food waste. When the larvae of this species occur in such decomposing substance, they are noted to occur in very dense numbers (Zhang *et al.,* 2010). The interest of using this species in waste management systems stems from the larval property to be more efficient and quick in consuming large quantities of unprocessed waste than any other known dipteran. This is a result of their highly powerful jaw apparatus and digestive system (Kim *et al.,* 2011). Nevertheless, as noted by Tomberlin and his fellow researchers (2002), the biology of *H. illucens* remains largely unknown.

Comparable to the previously described species of interest, black soldier fly larvae will cluster together and naturally occur in very high densities. Violating the freedom from discomfort directly resulting from crowding effects is therefore not likely to ensue in *H. illucens*. However, as this species has not been studied as well, there might be other side-effect (e.g. temperature constraints) arising as density increases. Attempts to upscale the rearing of black soldier flies in high densities have, for example, provided indications that they are very sensitive to subtle environmental changes (Arsiwalla, pers.comm., 2012). Therefore it becomes indispensable to evaluate potential distorting effects of high *H. illucens* larvae densities both for maintaining production and welfare standards. As the natural behaviour of the species is poorly documented at present, it is challenging to hypothesize on the criteria that the species needs to retain its freedom to express normal behaviour. For that reason, it also becomes necessary to make exploratory observations under rearing circumstances to assess the conditions that invoke the least unusual behavioural and physiological responses in the species.

3.2.5 Musca domestica

As its common name insinuates, the housefly lives in close contact with human settlement and its surroundings. It is thereby nearly ubiquitous in its distribution around people and is often regarded a pest as it acts as a vector for pathogens and wastes human food resources. In this respect, the species also occurs throughout cattle sheds, poultry stables and other livestock farms (Malik *et al.,* 2007). The larvae will develop on a range of organic matter including human waste, deteriorating plant and animal tissue as well as the faeces of several animal species (Cook *et al.,* 1999). *M. domestica* has a relatively fast lifecycle with multiple generations during a single season. At 25 degrees Celcius, the entire development of the species is completed within 14 to 18 days. In temperate regions nevertheless, the species will show hibernation in the winter during the larval or pupae stage. But natural populations in tropical regions show the ability to lack this diapause and produce year-round (Noorman, 2001).

Although there is more knowledge available on the biology of *M. domestica* than reviewed for most of the other species of interest, our literature assessment did not yield clear indications about its crowding behaviour and natural densities. Nevertheless, as females lay batches of 90 eggs on a developmental substrate (Noorman, 2001), it becomes likely that the larvae will live in close contact upon hatching and are again not very likely to suffer from discomfort of high densities *per se* during the beginning life stages. Moreover, insights provisioned by *M. domestica* breeder Walter Jansen (Pers.comm., 2012) indicated that the larvae have a facilitating effect on each other. Higher larvae numbers will collectively more efficiently digest their feeding substrate by means of their excreted enzymes, as subsequently the pre-digested food is ingested through the species' tracheal system. This will, in turn, also facilitate to keep the species free from disease as the larval excretion have inherent anti-fungal and bacterial properties. The additional win for the breeder is that when the insects are directly used for feed it doesn't need an extra production-step of sterilizing. In a study by Ragland and Sohal (1973) it was shown that variation in population composition significantly influences aspects like wing abrasion and mortality in adult flies. Especially reproductive behaviour was linked to this. It was indicated that isolating a fly and therewith eliminating reproductive behaviour, maximized lifespan and reduced the physical motion which presumably resulted in wing damage. Isolation is evidently not realistic under rearing condition as reproduction is essential, but also to take into account the freedom to express natural (reproductive) behaviour. For this species it is therefore also fruitful to investigate which sex ratio minimizes wing abrasion associated with reproductive activity and thus considers their freedom form injury, but without going at cost of production value of *M. domestica*.

3.3 The freedom from pain, injury and disease

In the European Union, Brambell's Five Freedoms, one of which is the freedom from pain, injury and disease, are at the basis of legislation regarding animal welfare (Article 1.3 of the Animal Welfare). This implies that decisions on animal welfare also rely on judgments about animal pain and suffering. Logical questions that follow from this statement are: How do we know that an animal is in pain or suffering? What criteria can be used to measure this? More relevant to the scope of our project; do insects experience pain and suffering?

As Bateson (1991) suggested, assessments on pain and suffering may be quite straightforward for mammals and other vertebrates. However, the more phylogenetically distant an animal is from a human and the less complex it is, e.g. an insect, the more challenging it becomes to assess this.

In an article published in Theoretical Medicine in 1991, David de Grazia and Andrew Rowan make a stark distinction between nociception, which generates direct, acute pain, and chronic pain or suffering. This distinction is frequently used in research of pain in animals. Therefore, in order to answer the above mentioned questions, it is important first to clearly establish the concepts of chronic pain and nociception.

3.3.1 Definition of pain and nociception

The International Association for the Study of Pain defines pain as 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' (International Association for the Study of Pain, 2012). This definition suggests that pain is not simply a sensory experience, elicited by the nociceptor and nociceptive pathway, but it is always an emotional state of the brain. The word nociception originates from the Latin 'nocere' meaning 'to harm'. According to the International Association for the Study of pain, nociception is defined as the 'sensory perception of potentially damaging noxious stimuli' (International Association for the Study of Pain, 2012). This does not necessarily imply a pain sensation.

Eisemann and his colleagues (1984) describe direct pain, as understood in humans, as a 'variable and subjective experience'. The intensity of pain can be affected by various factors such as previous experience, information by other sensory systems like vision and hearing, focusing of attention and attributed importance to the experience. On the other hand, suffering in humans is difficult to ignore; it comprises an 'unpleasant emotional quality' combined with a strong drive to alleviate pain and escape its source. In animals suffering can be measured indirectly from changes in their physiology and behavior, e.g. hypersensitivity of flexor reflexes (flexor reflexes remove a limb from a noxious stimulus), increase in blood pressure, tachypnea (hyperventilation or rapid breathing), vocalization (production of voice sounds indicating pain) and release of stress hormones.

3.3.2 Nociception and pain sensation: a comparison between vertebrates and insects

Pain is a complex phenomenon. Based on Bateson's review, Sneddon (2004) formulates specific criteria in order to measure whether animals are capable of experiencing pain. These criteria include, among others, the presence of nociceptors, brain structures and pathways leading to brain structures, as well as the lack of behavioral responses to harmful stimuli, which in vertebrates would be indicative of pain.

In the following paragraphs, three aspects of pain detection will be assessed in insects: the neurobiological basis of nociception, the behavioral responses of insects to noxious stimuli and the adaptive value of pain. At the same time an analogy with vertebrates will be made. It has to be noted that although a plethora of information is available with respect to nociception and pain in vertebrates (especially mammals, amphibians and birds), very little is known about lower vertebrates as well as invertebrates, such as insects.

3.3.3 Neurobiological basis of nociception

Nociceptors are important components of the nociception mechanism. In vertebrates, nociceptors are neurons whose free endings expand to epithelial tissues, such as the skin, oral mucosa or gut; there they can detect stimuli like heat, cold, mechanical pressure, and damaging chemicals. The cell bodies of nociceptors are located in the trigeminal and dorsal root ganglia (Im and Galko, 2012). Their architecture enables the quick perception of stimuli which exceed a certain threshold and which therefore are regarded as capable of producing tissue injury. Moreover, the sensitivity of nociceptors to the detection of stimuli can be increased as a result of inflammation or injury (Lumpkin and Caterina, 2007). The presence of nociceptors can be identified by molecular marks, such as the proteins that belong in the transient receptor potential cation channel family (i.e. ion channels which mediate the response of a cell to external stimuli and are specific for pain receptor neurons) (Andrews, 2011).

Nowadays, there is consensus that nociception occurs in insects. The first evidence was provided in 1994, when Kernan and his team carried out an experiment in fruit flies. They found out that *Drosophila* larvae which were subjected to noxious mechanical or heating stimuli exhibited a characteristic withdrawal behavior different from their typical movements. Nine years later, in 2003, Tracey *et al.* used this behavioral response to search for *Drosophila* mutants insensitive to noxious heat. They discovered that the gene *painless* is required for perception of noxious heat. Interestingly, *painless* codes for a transient receptor potential (TRP) channel, which, as mentioned previously, is characteristic element of nociceptors.

With the aid of *Drosophila melanogaster* as a model organism, recent research has shed more light on the underlying mechanisms of nociception in insects. Using a newly developed high-throughput screening method, Neely and his colleagues screened the genome of adult *Drosophila* for putative genes that regulate nociception and identified hundreds of them. Furthermore, they provided evidence that Trp1 (Transient receptor potential 1) plays a role in thermal perception in Drosophila (Neely *et al.*, 2011). TRP1 has been shown to be involved in chemical nociception (Kang *et al.*, 2010). The fact that the same gene has also been found in mammals suggests that the basic mechanism of nociception is conserved among species.

3.3.4 Avoidance of normal behavior in response to noxious stimuli

There is no evidence of insects exhibiting protective behavior towards a damaged body part, which is a common feature in vertebrates. Eisemann *et al.* (1984) mention various observations: a locust which went on feeding while it was being eaten by a praying mantis; male praying mantes which continue mating while being eaten by their female partner; caterpillars which go on feeding while being eaten by parasitoids growing inside them; a tsetse fly which sought food even though a large part of it had been removed by dissection. Consequently, the observation that insects continue normal behavior, like feeding, even after substantial damage has been done to them, including body part removal, has been regarded as evidence that insects do not feel pain in contrary to vertebrates.

3.3.5 Adaptive value of pain in mammals and insects

Eisemann *et al.* (1984) argue that, from an evolutionary perspective, pain confers obvious benefits to the survival of mammals. Firstly, it acts as an 'alarm device' leading to immediate withdrawal reflexes and protection of the injured body part, which can prevent further damage. Secondly, mammals show significant behavioral plasticity and have a high capacity to learn. Consequently, they can learn from the pain responses of their conspecifics as well as from their own pain experiences, so that they can avoid potentially painful stimuli.

It would be interesting to consider the adaptive advantage of pain sensation in insects. Investing on 'expensive' brain tissue does not seem to be advantageous for insects. Eisemann *et al.* (1984) claim that 'insect behavior patterns are to large extent pre-programmed'. This implies that their learning ability is limited. At the same time, acute pain sensation, based on nociception, is more important for protection from harmful stimuli, without requiring more elaborate pain sensation. This is thought to be especially true for animals with a short-life cycle like insects.

On the other hand, an 'emotional brain', which is required for the sensation of pain, would demand complex neural networks and subsequently a large brain size. In an insect brain no center for pain and suffering has been described yet. The lack of closed blood circulation also sets constraints to the size of the brain of insects, its complexity and putative functions, since there is no direct energy and oxygen supply.

3.3.6 Disease

Besides the freedom from pain and suffering the third of Brambell's five freedoms also considers welfare through absence of disease. We specifically make a distinction towards the freedom from disease as this criterion concerns a less fundamental discussion as is the case with the whole of insects in relation to pain sensation. Insect will namely show species specific diseases which therefore need to be more explicitly addressed within the framework of Brambell's freedoms. To preserve the freedom from disease, one needs to gain insight in the specific prevalent diseases and possible aspects involved in the transmission of the associated pathogens. For each of our species of interest, a short review about this knowledge is provided.

In *Locusta migratoria*, the available literature on this subject is mostly revolved around the fungal pathogen *Metarhizium anisopliae* var. *acridum*. For instance, as described before, rearing high densities off *L. migratoria* will induce more resistance to this pathogen (Wilson *et. al.,* 2002). Another aspect with regard to this phenomenon has been addressed by Elliot and associates (2003). They namely showed that a transgenerational shift from gregarious to solitary more likely occurred in the offspring when a parent had been infected with the fungus. Therefore, the pathogen can also have undesirable effects for the long-term production efficiency of the species under rearing conditions. It has also been shown that through active thermoregulation, the species shows the potential to increase its survival after being infected with the fungus *Metarhizium anisopliae* var. *acridum* (Ouedraogo *et al.,* 2004). Under rearing conditions, it will therefore be advisable to provide a heat gradient in order to allow active thermoregulation in the species and subsequently limit the infection potential of fungal pathogens.

Instead of evidently being in conflict with the freedom from discomfort, keeping high densities of *Acheta domesticus* can however induce the occurrence of disease (L. Westerd, personal communication). A pathogen that frequently infests European commercial rearing facilities is the *A. domesticus* densovirus (AdDNV). The cricket species is highly susceptible to this virus, which spreads rapidly and causes high mortality rates. The disease is especially prevalent in late larval stages and within newly emerged adults. Infected individuals become less active, remain smaller and are not able to jump as high as uninfected individuals. The increased mortality lets lifespan rarely exceed two weeks (Szelei *et al.,* 2011). In contrast to *L. migratoria*, *A. domesticus* thus seems to show an opposite correlation between population density and disease resistance. To effectively tackle AdDNV, it therefore becomes critical to assess the underlying disease transmission mechanisms that arise when *A. domesticus* kept under high densities. This also accounts for the potential physiological background in increased susceptibility of the crickets.

Although a myriad of literature sources address the pathogens that can be transmitted by the three species of *Tenebrio molitor, Alphitobius diaperinus* and *Zophobas morio* to which these act as a vector or reservoir species, empirical information on the diseases that are detrimental to the insects themselves is not readily available. This was also mentioned by insect breeder R. van de Ven, who himself experienced massive mortality among his stock of *Z. morio*. Although the disease seemed to be highly infectious and eventually caused elimination of the total population in the breeding facility, no information could be provided on which disease it was or how it could be treated. A very recent study by Catalán and colleagues (2012) showed an interaction between behavioural thermoregulation and immune response in *T. molitor* similar to as was seen in locusts. By regulating its body temperature, the species was able to enhance its antibacterial response. As mealworms will create heat themselves in captivity, it will be hard to realize conditions that facilitate active behavioural thermoregulation in the species. So in addition to assessing the density at which *T. molitor* larvae will produce too much heat as described before, it can be worth looking into the density of mealworms that can be kept together to optimize immune response.

Perhaps even more unknown are the pathogens that can be harmful for *Hermetia illucens*. First attempts to breed the species on a large-scale in the Netherlands resulted in mortality waves that were initially thought to be a result of a pathogenic infection. However, this was later rejected and probably was more due to other unfavourable basic environmental circumstances (T. Arsiwalla, personal communication). Therefore, the first impression is that pathogens are currently not a significant threat to rearing *H. illucens* on large-scale, both in terms of safeguarding production as well as meeting welfare requirements for the freedom from disease.

Besides the information available on vector-borne pathogens being transmitted by *Musca domestica*, the most well-known disease to the species itself is the *Musca domestica* salivary gland hypertrophy virus (MdSGHV). This virus is present throughout the World and exclusively infects adult individuals of the species. When a female fly is infected, the virus will induce a signalling pathway that will shut down female receptivity and egg production. The virus seems however not sexually or vertically transmittable (Lietze *et al.,* 2007). As the pathogen replicates within the salivary glands, it is transferred to healthy individuals through mouth contact with oral secretion upon feeding sources (Lietze *et al.,* 2009). An interesting aspect with regard to this disease under rearing conditions is that when *M. domestica* are treated with a MdSGHV inoculum 24 hours after adult eclusion, they become significantly more resistant to the disease (Prompiboon *et al.*, 2010). Therefore, in case of an outbreak of the disease, there could be potential in treating artificial feeding substrates with homogenized MdSGHV in an attempt to retaliate the virus and ensure the flies' freedom from disease. The feasibility of such a solution needs however to be investigated to see whether this will be effective in tackling the disease in the long-term in breeding facilities. Practical implications in tackling diseases also arise from the short generation time of the species (Walter Jansen, personal communication). As the duration of development from egg to harvestable larva is completed in three days, sterilizing the entire facility will be possible without causing too much costs in losing several generations of breeding time.

3.3.7 Conclusion

Considering the studies mentioned in the previous paragraphs, it can be concluded that insects demonstrate the capacity for nociception, as shown by behavioral responses and by the presence of nociceptors. However, pain sensation, or suffering, is very unlikely to occur. The perception of injury is related to the perception of pain. If, based on existing scientific research, insects are not likely to experience chronic pain and go about with their normal behavior even after, for instance, a body part has been removed, then 'injury' is probably not of fundamental importance to insect welfare. Cooper (2012) mentions that some insects can replace all or part of a lost limb, especially if they have not matured yet. At the same time, many gaps in knowledge with respect to pain perception in insects still remain to be elucidated. Further research is therefore required to provide more insights on these issues.

Invertebrates comprise over 30 phyla of extremely diverse organisms, ranging from honey bees to octopuses, and encompass 95% of all animal species on the planet. Similarly, the class Insecta consists of over one million different species. It is evident, therefore, that generalizing upon the total spectrum of invertebrates and insects with regard to pain sensation, suffering and injury is both impossible and inaccurate (deGrazia and Rowan, 1993). Indeed there is evidence that some invertebrates, like cephalopoda, possess advanced cognitive abilities (Crook and Walters, 2011). Already the legislation of some countries, e.g. Canada, has taken this into account. The same is also likely to happen in the European Union over the next two years (Andrews, 2011).

Sherwin (2001) claims that *'… we should either be more cautious when using the argument-by-analogy (i.e. assessing the ability of an animal to experience suffering based on the similarity of its responses to those of higher animals) or be open-minded to the possibility that invertebrates are capable of suffering in a similar way to vertebrates.'* Until conclusive proof that insects feel pain has been gathered, Eisemann and his colleagues (1984) suggest that insects, as a precaution, should be granted the benefit of doubt. In other words, they should be anesthetized prior to being subjected to traumatizing procedures. In accordance to this, leading experts in entomology at Wageningen University, including Marcel Dicke and Hans Smid (pers.comm., 2012), confirmed that they are trying to minimize suffering of insects used in their experiments. For instance, they always freeze insects first before performing dissections so as not to inflict to them unnecessary pain or harm. When they have to put them down, they do it as quickly and painlessly as possible. There is need, though, for a general consensus on guidelines for the manipulation and anesthesia used in laboratories and insect breeding companies. Insect breeders should also keep this in mind. In practice, they should try and take good care of insects and keep them in conditions that mimic as much as possible their natural environment. As Marieke Calis of Kreca (pers.comm., 2012) mentions 'this is not only a fair treatment for insects themselves, but also improves the quality of the final product.'

3.4 Freedom from fear and distress

Andrews (2011) argues that, although the perception of pain is perhaps the main focus of animal welfare, the effect of stressors should also be considered when assessing animal welfare issues. Fear and distress are elements of the fifth Freedom of Brambell as well. But what does this mean for animals? Are fear and distress applicable to insects?

DeGrazia and Rowan (1993) note that anxiety is an important component of suffering, whose significance has not been properly evaluated. They propose the following definition of anxiety: *"Anxiety is an emotional response -typically unpleasant, typically involving heightened arousal and attentiveness to the environment, and typically inhibiting action- to the perception of a threat to one's well-being or to one's ego (sense of self)."* Anxiety seems to be of a more general nature and often requires a 'sense of future' in contrast to fear which is usually pointing towards a clear object. Korte *et al.* in their article 'A new animal welfare based on allostasis' (2007) claim that fear has fitness value and is essential for the survival of animals. So, freedom from fear should be 'freedom of fear in the absence of obvious threat', in other words no unnecessary fear.

Arnold van Huis (van Huis, person. comm., 2012) mentioned a simple observation he has made: when you put insects into a jar with some chemical substance, they run around looking very stressed. A recent study by Mendl and his team (2011) revealed that the decisions honeybees make in ambiguous conditions depend on whether they have previously been subjected to the negative experience of a dangerous event, simulated in the experiment by vigorous shaking. This is regarded as a 'pessimistic' cognitive prejudice also typical of anxious and depressed humans and other vertebrates in possible negative emotional states. However, it is debatable whether honeybees are consciously aware of these emotional states. Data on the impact of stressors on insect survival and on how insects perceive negative experiences such as fear and stress is generally very scarce. Further research is required to shed light on this issue. More specifically, it could be investigated whether particular procedures used in insect rearing facilities are a source of stress for insects, e.g. sifting insects to separate them from their feeding substrate, and whether there are alternatives to these.

3.5 Insect killing techniques

As Sherwin (2001) notes, empathy on invertebrates is relatively low in comparison to vertebrates. In particular insects are regarded as pests by many people. A search for articles on insect killing techniques reveals that they mainly revolve around insecticides and methods of controlling harmful insects such as mosquitoes. In the context of insect welfare, however, the aim should be to kill insects in a humane way.

According to the UFAW 'Handbook on the care and management of laboratory and other research animals' a killing method should fulfil several criteria in order to be characterised as humane. The handbook distinguishes, inter alia, the following standards:

- death must occur without producing pain.
- the time required to produce loss of consciousness must be as short as possible.
- the time required to produce death must be as short as possible.
- the method must be reliable and non – reversible.
- there must be minimal psychological stress on the animal.
- the method should be economically acceptable.

Moreover, Cooper (2012) argues that ascertaining the death of an insect is often a difficult task as some species of insects can recover fully from treatments that would be considered lethal for other animals, e.g. administration of toxic agents. He suggests that the best approach to tackle this problem would be to 'await signs of autolysis/rigor mortis or to destroy the animal physically'.

For this report five insect breeders were interviewed. The main killing technique currently employed by insect rearing companies is freezing and dry-freezing (i.e. primarily a dehydration process which allows water to be extracted from the frozen insect when the surrounding pressure is reduced).

Van der Ven was among the interviewed insect breeders. Mr. van der Ven produces mealworms which he then sells, mostly alive, as feed for reptiles, birds and fish. When necessary he 'boils' the insects or uses the dry-freezing method to kill them. According to the breeder this is a natural way for insects to die; insects are simply put a sort of hibernation.

Leon Westerd, head of the insect rearing facilities of Wageningen University, was also interviewed. He mentioned that small insects are killed by being sprayed with hot water, after having been subdued first with CO2. He regards this to be an efficient and painless method. Larger insects are killed by dry-freezing.

Tarique Arsiwalla, representative of Protix Biosystems, was the third interviewee. He disclosed the information that in this company black soldier flies are mechanically crashed, e.g. with centrifugation, because in their final product insects are not required as a whole. Mr Arsiwalla believes that in this manner insects die instantly.

At Jagran, the main killing techniques they use are shredding and freezing. In Walter Jansen's opinion shredding is the most insect friendly killing method, because insects die very quickly. They are also experimenting with what they consider to be a very promising and painless new technique: asphyxiation with a high nitrogen/low oxygen mixture.

Finally, at Kreca, they freeze or freeze-dry the insects when they want to kill them, although 95% of the insects they produce are sold alive.

To our knowledge, there are no studies on the effect of these techniques on insects. The entomologists we questioned (personal communication with Arnold van Huis, Marcel Dicke and Hans Smid, 2012) agreed that hypothermia (chilling/cooling) is a humane way to euthanize insects. Insects are poikilotherms, which means that their body temperature is not constant but varies depending on the temperature of their environment. When placed into a freezer the insects' metabolism slows down until they freeze solid. Arnold van Huis mentioned that in Africa locusts are harvested by locals early in the morning, when the temperatures are lower and consequently the animals are immobile and easier to collect. Another advantage of this method is that the use of potentially harmful chemicals is avoided. However, this method is regarded by some insect breeders as relatively costly.

In conclusion, little reference to invertebrates has been made in official texts on euthanasia of experimental animals, but the number of scientific publications that touch upon this issue is increasing, especially with respect to mollusks and crustaceans (Cooper, 2011). Nonetheless, methods of euthanasia of insects have been poorly investigated and this topic demands more attention, especially in relation to insect welfare.

4 Ethical considerations

A concluding remark on the matter of pain perception in insects (chapter 3) is that though there is an absence of proof, this does not imply proof of absence. What can be done in the absence of proof? Consider that when it comes to animal welfare, there is often much fundamental disagreement; on both sides common assumptions are questioned for their adequacy. Untutored 'common sense' therefore is insufficient to solve the issues at hand (DeGrazia, 1996). We therefore encourage an ethical approach, with the hope to come to an authoritative conclusion based on reason and not emotion.

Although humanity has cultivated insects for thousands of years (e.g. honey bees and silk worms; and more recently e.g. parasitic wasps as biological pest controls), public interest in animal welfare in insects only appeared when insects were first bred for (human) consumption (Dicke, pers.comm., 2012). This because the public then started to associate insect breeding with factory farming (Dutch: 'bioindustrie') and its associated animal welfare and public health issues.

This chapter however will *not* focus on consumer ethics (the general public's perception of an ethical issue). The aim of this project is after all to investigate animal welfare in insects. By doing so, the insect breeders can explain the consumer how the insects' welfare is guaranteed and anticipate and prevent a negative opinion on the consumer's part. In other words: the aim is to help form the general public's perception, not investigate what it might be: consumer ethics will only be mentioned in passing.

4.1 Schools of thought in ethics

When it comes to animal ethics, we can distinguish four schools of thought, each using a different basis for reaching right ethical conduct: animal welfare advocacy, a utilitarian position, i.e. based on the aim to reduce overall suffering (consequences); animal rights advocacy, a deontological position, i.e. based on ethical rules for the rightness or wrongness of a behaviour itself, rather than its outcome; and pragmatic ethics, which is based on social context.

Both animal welfare advocates and animal rights advocates are abolitionists when it comes to the issue of animal welfare: they want to altogether abolish human management of animals (Korthals, pers.comm., 2012). Since this basically boils down to questioning the entire premise of insect breeding, we will not consider the abolitionist point of view much further here. Note however that both schools have mainly used the case of vertebrates in general and of mammals in specific as a basis for their reasoning. It remains to be seen if either school would grant insects moral status (i.e. a being towards which humans have moral obligations, instead of treating it in just any way we please – Warren, 1997). Let us consider that animal welfare advocates use the capacity for suffering as a basis for granting moral status and that animal rights advocates use the presence of certain cognitive abilities (having a plan-of-life; being goal-oriented; possessing a memory) as a basis for granting moral status. In other words, to be considered for moral status by abolitionists, insects should possess sentience: the ability to feel, perceive, be conscious or to have subjective experiences. Given the lack of proof for insects' cognitive abilities to experience e.g. suffering (refer to chapter 6.1), it is to be expected that both animal welfare advocates and animal rights advocates[1] would have less of a problem with insect farming than say for instance, cattle farming. Animal welfare advocacy authority Peter Singer once stated that: *"(…) I'm not as concerned about insects as I am about vertebrates who I'm sure can suffer*" (Utilitarian Philosophers, retrieved 2012), though he postulated to give them the 'benefit of the doubt' where one can.

(Note by the way that although animal welfare advocacy is a utilitarian position and animal rights advocacy is a deontological position, not all utilitarians are animal welfare advocates, nor are all deontologists animal rights advocates. E.g. other utilitarian schools of thought want to reduce overall *human* suffering and don't acknowledge or don't take into account the suffering of non-human agents.)

Pragmatists are *not* abolitionists: they acknowledge human management of animals and the fact that humans and animals share the same sphere of cohabitation. Although not entirely inconsiderate of the welfare or rights of animals, pragmatists mainly consider the social context: what is the current practice and what is the public's acceptance of said practice? (Korthals, pers.comm., 2012) In light of the issue of animal welfare (in insects), this social context could be defined as they way humans interact with animals/insects. Out of a historical context, in Western society insects and all manner of bugs have been considered with a feeling of disgust: vermin – except for maybe butterflies. For this relatively new interaction of insect farming, pragmatists would therefore refer to the public's opinion and consumer ethics. Note however that pragmatists are not totally unconcerned with the animal position: rather, pragmatists can be said to consider the position of *all* stakeholders involved: humans (consumers) and animals (insects) in this case.

Box 4.1 On animal welfare and animal rights

This report is concerned with animal welfare, which should not be confused with animal rights. Animal welfare, coming from the utilitarian school of thought, is concerned with the (potential) suffering of animals, but not necessarily respecting an individual animal's intrinsic rights. The animal rights movement, based on the deontology school of thought, *does* concern itself with individual animals' rights. Point in case: an animal welfare advocate (a utilitarian position) would find no problem in knocking out a chick's nerve system to prevent it from suffering anymore; an animal rights advocate (a deontological position) would argue that this goes against the rights and integrity of the individual animal. It should come as no surprise then that animal rights advocates are set against the killing of animals, while animal welfare advocates are not set against the killing per se, provided it happens without suffering – in a quick and painless manner.

Since: 1) this project's assignment was concerned with animal welfare, and 2) since the issue of animal rights is against killing of animals, therefore questioning the whole premise of insect farming, this report will keep to animal welfare.

[1] Note that eusocial insects (e.g. honey bees) show a clear goal-directedness and possess the cognitive abilities for memory (Smid, pers.comm., 2012), so the animal rights school might be expected to make an exception for them (Korthals, pers.comm., 2012).

4.2 Ethical principles in animal welfare in insects

The question then becomes how much (if at all) inconvenience insects experience from stressors as thirst, hunger etcetera. An important notion in light of this discussion is the concept of *nociception*: pain signals without the mental state of pain – because of the lack of higher brain functions required for sentience. Given the uncertainties regarding insect sentience showcased in the previous chapters, we propose a reticent approach: 'better safe than sorry'.

One principle that does *not* generally apply to insects in our society, is the Transivity of Respect Principle ('(…) *moral agents should respect one another's attributions of moral status*') (Warren, 1997): in our culture, insects are mostly just considered pests or vermin. Note however that this attitude is not universal and at least to an extent culturally motivated: consider e.g. the non-violent teachings of the Indian religion Jainism.

What likely *does* apply however is the Anti-Cruelty Principle ('[sentient] *beings are not to be killed or subjected to pain or suffering, unless there is no other feasible way of furthering goals that ar*e (…) *important to human beings,* (…)'). The fact that these particular insects likely owe their existence to the breeder, does not exempt him/her from the Anti-Cruelty Principle. On the contrary: compare parents, who are not exempt from the Anti-Cruelty Principle with regards to their child(ren), despite (or rather, *because*) the parents' responsibility for its creation (Warren, 1997).

The Anti-Cruelty Principle is accounted for in Dutch Law by inclusion of Brambell's Five Freedoms (though not explicitly called such): an animal (insect) should be free from: thirst, hunger and inappropriate feed; physical and physiological inconvenience; pain, injury, and disease; fear and chronic stress; limitations on natural behaviour (within reason). Note that Brambell's Five Freedoms are not specific: experience and careful observation are needed to learn what members of a particular species need in order to live well in captivity/domestication (Warren, 1997). Though Brambell's Five Freedoms were postulated with vertebrates in mind (Brambell, 1965), lacking a more appropriated model and given the general acceptance of Brambell as a framework for animal welfare, we propose using it as a framework for the insect case. This again leaves the question how much inconvenience insects experience from stressors as thirst and hunger (if at all).

4.3 Concluding remarks

Current practice in insect breeding shows that most cultivated insect species are very sensitive to e.g. temperature, humidity etcetera. Regardless whether insects can experience suffering (absence of proof, but this is not proof of absence), it therefore pays insect breeders to optimize such conditions as precise as possible (Van de Ven, pers.comm., 2012; Arsiwalla, pers.comm., 2012; Jansen, pers.comm., 2012). A conflict might arise in case of insect species not as sensitive to environmental conditions: i.e. insect species being bred in an environment they would shy away from under natural conditions, but in which they still stay alive and reproduce. It would therefore be prudent to investigate which (if any) insect species currently being bred shows this resilience, thus being proactive of any animal welfare issues that might arise. E.g. insect population density is naturally regulated by negative feedback: at too high densities the heat generated by the collective insects' body temperature becomes detrimental to the individual insects (due denaturating proteins). In breeding facilities populations can be kept at artificially high densities by using a cooling system to prevent the detrimental effect of too high a population density (Jansen, pers.comm., 2012). The question than rises what other detrimental effects the insects experience at these artificially high population densities. Not to say that they that this is necessarily the case, rather a topic worth investigation in the light of animal welfare in insects.

Optimized practice and animal welfare in insects also go together when it comes to the killing methods used in breeding facilities: optimized practice should kill as much insects as possible in as short a time as possible and *in a reliable manner*. Since the animal welfare point of view is that killing should be quick and (relatively) painless (i.e. 'instant death') (Korthals, pers.comm., 2012), killing insects as fast and reliable as possible is preferable to both the breeder and the insects. A conflict could arise when other incentives (e.g. financial issues) might prompt an insect breeder to use inefficient or antiquated killing techniques.

Given: 1) the absence of proof of the capacity of insects for suffering; 2) the synchronicity between optimized practice and animal welfare in insects; 3) moral objections from any of the major schools of thoughts in ethics are unlikely to arise in the future, we foresee no major ethical problems in the future with regards to animal welfare in insects, *provided* the general public is well informed about animal welfare in insects and how this is applied.

Since we were issued to look into animal welfare aspects, this chapter mainly focused on the ethical aspects *for the insects*, but ethical aspects of other actors also play a role: e.g. consumers (Van Itterbeeck, 2008) and ecology (Dierenbescherming, 2010). For a recent overview of the consumer ethics involved in insect breeding for human consumption, we would like to refer the reader to an extensive thesis by Van Itterbeeck on the matter (Van Itterbeeck, 2008).

5 Legislation

An important issue when talking about the up-scaling possibilities of the insect rearing industry is the accompanying legislation. Up to today there is a lack of legislation in this field. The planning is that there will be a new law on animals implemented in Dutch legislation in 2013, the exact date is unknown. This law; the 'Animal Act', is based on the 'European Animal Health Law'. The European Animal Health Law is a basis, the Dutch Animal Act will be more extensive as a whole and more strict on some points.

The implementation regulations from the Animal Act are clustered into six general measures of general directive; this is done in order to make the legislation accessible for the general public (commentary on law, act of animal keepers, chapter1, §1). The six acts are: the act of animal keepers, the act veterinarians, the act animal products, the act veterinary medicines, the act animal feed and the act enforcement and miscellaneous affairs Animal Act. These acts find there basis in European legislation which is applied to Dutch law. This means that for instance the TSE-legislation (EC 999/2001) is admitted in the act animal products.

Box 5.1 Terminology

- Animal Act:	a comprehensive legal framework that was introduced for the rules governing the behavior of people towards animals and the rules to control the risks of animals or animal products which may entail for humans and other animals. The 'Animal act' provides rules which mainly relate to livestock.
- Accompanying acts:	In order to make the law and accompanying legislation accessible for the general public; six general administrative measures (Act) were constructed. Each act is related to a certain field with relevant legislation. (E.g. Act keepers of animals)
- TSE legislation:	TSE = Transmissible Spongiform Encephalopathy – A group of rare degenerative brain disorders characterized by tiny holes that give the brain a "spongy" appearance. Since July 1994, there has been an EU ban on the use of Processed Animal Protein in cattle feed due to an outbreak of BSE (Bovine Spongiform Encephalopathy). A total EU suspension on the use of processed animal protein in feed for any animals farmed for the production of food has been in place since 2001. This is referred to as the TSE legislation EC 999/2001.

5.1 Current legislation on breeding of insects

The act of animal keepers is of special interest in this case, mainly on the subject of animal welfare. In this act of animal keepers an update of the production animals is made. Among other animals, twenty-nine insects are listed as production animals (table 2). All species on the list of production animals (ranging from several species of mammals to a list of bivalves) fall under the legislation concerning production animals. In Dutch legislation this comes in the form of the Animal Act and accompanying acts.

Currently no legislation is in place specifically for insects. In fact the most basic legislation on the ‘accommodation and caring standards’ as well as the ‘reproductive techniques’ does not apply for insects. Insects are also excepted in the act veterinarians. This means that insects are the only group of animals where someone without the proper education can perform medicine on. The reason that is given is because, as is currently stated in the Animal Act, their wellbeing is not measurable.

The Animal Act states that the intrinsic value of an animal needs to be recognized (chapter 1, §1, article 1.3) as a consequence animals should be held free from the following five points:

Animal Act	Brambell
a. thirst, hunger and inappropriate feed	1. Freedom from Hunger and Thirst
b. Physic and physiological inconvenience	2. Freedom from Discomfort
c. pain injury and disease	3. Freedom from Pain, Injury or Disease
d. fear and chronic stress	5. Freedom from Fear and Distress
e. limitations of their natural behaviour	4. Freedom to Express Normal Behaviour

Table 1 table comparing brambell’s five freedoms and the points of which animals should be held free from.

The five points mentioned here (table 1) are derived from Brambell’s five freedoms (noted in the five points following the points a-e) and are fully integrated in Dutch legislation. An explanation of Brambell’s five freedoms can be found in the introduction. This last point (e.) has the sentence ‘as far as it can reasonably be desired’ added. This points to another issue in legislation (commentary on law, act of animal keepers, §2, 2.2.1) which states that the economic value is something to be taken into account.

The five species of special interest in our project are the Mealworm beetle (*Tenebrio molitor*) and comparable species (two species of Darkling beetle, *Alphitobius diaperinus* and *Zophobas morio*), House cricket (*Acheta domesticus*), Migratory locust (*Locusta migratoria*), Black soldier fly (*Hermetia illuscens*) and the Housefly (*Musca domestica*). The Black Soldier fly (BSF) is not implemented in the list of production animals. Presumably as there is currently only one company involved in rearing these species. Whether this has implications for breeders rearing Black soldier flies remains a question. According to an expert in the field Dr.ing. Veldkamp (Wageningen UR Livestock Research, personal communication) this will not be an issue. However, according to article 2.2 of the Animal Act (chapter 2, §1), it is prohibited to keep animals unless stated otherwise (this is referring to the list of production animals).

Whether insects are exempted from that rule is so far unclear. The legal provision laid down in article 2.2 is the no, unless principle. This to recognize the intrinsic value of animals, intended to prevent the breeding of animals for production purposes if for that species it has not been established that the use for production purposes at a (relative of the animal) acceptable way may take place.

On the point of feeding insects (or insect-derived protein) to other animals there is a lot unclear. In 1994 the animal feed-ban was put in place as a consequence of the TSE-crisis. This has resulted in the following actions: since July 1994, there has been an EU ban on the use of Processed Animal Protein in cattle feed. A total EU suspension on the use of processed animal protein in feed for any animals farmed for the production of food has been in place since 2001. Limited amendments to the feed ban were adopted since 2005. The basis of the TSE-legislation which still is in place is law EC 999/2001.

The main rule of the TSE-legislation is the ban on the use of animal-derived protein in to feed of ruminants, expanded to a general ban on the use of animal-derived protein to livestock.

As of March 2011, the law EC 1069/2009 has been in place. This law concerns animal and public health rules for animal by-products and products derived thereof. This law specifies under which conditions animal by-products may be used for applications in animal feed and for various purposes, such as in cosmetics, medicinal products and technical applications. Animal products are divided in three categories. It is stated that only category 3-material can be used for feed for production animals other than fur-animals. Category 3 material is: carcasses and parts of slaughtered animals that can be used for human consumption, but for commercial reasons will not be used for human consumption.

Latin Name	**Dutch Name**	**English Name**
Blaberus craniifer	Doodskopkakkerlak	Death's head cockroach
Blaptica dubia	Argentijnse boskakkerlak	Dubia Cockroach
Periplaneta americana	Amerikaanse kakkerlak	American cockroach
Acheta domesticus	**Huiskrekel**	**House cricket**
Gryllus bimaculatus	Tweevlek krekel	Field cricket
Locusta migratoria	**Treksprinkhaan**	**Migratory locust**
Schistocerca gregaria	Woestijn sprinkhaan	Desert locust
Caruasius morosus	Indische wandelende tak	Indian stick insect
Baculum extradentatum	Annam-wandelende tak	Vietnamese walking stick
Pachnoda butana	Gouden tor	Scarab beetle
Pachnoda aemole	Gouden tor	Scarab beetle
Pachnoda marginata	Gouden tor	Scarab beetle
Alphitobius diaperinus	**Buffalokever**	**Darkling beetle**
Zophobas morio	**Reuzenmeeltor**	**Darkling beetle**
Sitophilus ganarius	Graanklander	Wheat weevil
Sitophilus oryzae	Rijstklander	Rice weevil
Drosophila hydei	Fruitvlieg	Fruit fly
Drosophila melanogaster	Fruitvlieg	Common fruit fly
Musca dom. var.	**Krulvleugelvlieg**	**Housefly**
Galleria mellonella	Grote wasmot	Greater Wax Moth
Achroea grisella	Kleine wasmot	Lesser Wax Moth
Sitotroga cerealella	Graanmot	Angoumois Grain Moth
Plodia interpunctella	Zadenmot, Indische meelmot	Indian Meal Moth
Pyralis farinalis	Meelmot	Meal Moth
Calliphoridae	Vleesvlieg	Blow-fly
Apis mellifica	Honingbij	European honey bee
Tenebrio molitor	**Meeltor**	**Mealworm beetle**
Chironomidae	Vedermug	Non-biting midges
Vespidiae	Wesp	Wasps

Table 2 The list that states which insects are classified according to the Animal Act (List of Production animals). In bold are the insects that are of special interest for our project.

This is a complicated issue, as insects are not reared for human consumption they technically do not fall under the category 3 material however this is an 'entrance' so to speak for insects to enter the feed production system. Therefore can be concluded that with the current legislation one is not allowed to use insects or insect-derived proteins for the production of animal feed, this is also one of the conclusion of the feasibility study performed by the Wageningen UR Livestock research. They conclude that with the combined articles 1069/2009 and 142/2011 (on the implementation of 1069/2009) insects fall under the same category as aquatic animals (article 10, §1, 1069/2009) however still defined as processed animal protein (appendix 1, point 5, 142/2011). This leads under the current TSE-legislation that it is not allowed for use in the food production chain.

However these same rules might be an entrance for insects to enter the feed production system as fishmeal. It is a start; ultimately insects should be used in all kinds of feed and food but this will take time. By current legislation one is allowed to use insects as a basis for fishmeal.

Table 3 gives an overview of the current (2010) legislation on animal proteins and other animal-derived products for animal feed. Concluding from this insects-derived hydrolysed protein (broken down to component amino acids) can be used as a basis for feed destined for non-ruminants. A recent report from the Wageningen UR Livestock research concluded contrastingly that insect protein is still banned as a feed-ingredient due to the current TSE legislation. This might be due to the costly hydrolysing process.

Products	Ruminants	Non-Ruminants	Fish	Fur animals and pets
Products derived from ruminants	NA	NA	NA	A
Hydrolysed proteins from ruminants	NA	NA	NA	
Blood meal from non-ruminants	NA	NA	A	A
Fishmeal	NA	A	A	A
Hydrolysed proteins from non-ruminants	A	A	A	A
Non-ruminant gelatine	A	A	A	A
Egg, egg products, milk, milk products and Colostrum	A	A	A	A

Table 3 Legislation in 2010 on the use of animal products in animal feed. A = authorized; NA = not authorized. Authorization of ingredients finds it legal bases in TSE-legislation. Figure is adapted after: (A Strategy paper on Transmissible Spongiform Encephalopathies for 2010-2015).

The legislation on killing animals when using them for feed- or food production is at the moment not directly applicable for insects. The legislation on the killing of animals does not mention insects in particular but does exclude fishes for instance. The importance of food, which is partly inspired by the desire to consume animal products, and the economic interests of those involved in the production of animal products, weighs in this respect heavier than the intrinsic value of the animal. Legislation about killing animals for production-purposes is regulated in EC 1099/2009.

At present, these rules are continued in the act keepers of animals (articles 1.12 to 1.14). These include the requirement that mammals, reptiles, amphibians, birds or fish at killing and related operations are to ensure any avoidable pain, distress or suffering (article 1.12). In addition, it applies to mammals, reptiles, amphibians and birds, that the killing is conducted in a manner that ensures that death immediately or as soon as possible occurs (article 1.13) and that whoever conducts the killing operation possesses the required knowledge (article 1.14). The articles 1.13 and 1.14 exclude fish, it can be expected that also insects will be excluded from these rules.

5.2 Implications for insect breeders

When looking into the legislation as stated in the Animal Act and accompanying acts, there will be no significant changes for current insect breeders. Mainly for breeders of insects on the list of production animals the impact of this will be negligible. The reason for this is that the 'accommodation and caring standards' as well as the 'reproductive techniques' does not apply for insects. It must be pointed out however that the five freedoms from Brambell is now something inset breeders should take into account.

A point of interest is the fact that insects are used for laboratory research, with old regulation no ethical issues were involved when performing tests on them. This will be a point of concern, when a number of insects are noted as production animals the legislation concerning animal testing might also be applicable no them. Although as stated in the Animal Act is that the Law on Animal Testing is not changed by the Animal Act; whether this also applies to animals added to the list of production animals is unclear.

A point of concern is the possible prohibition of the breeding of animals that are not on the list of production animals. This will be treated in the next chapter on 'future prospects and recommendations'.

5.3 Future prospects and recommendations

At this moment there are no significant changes for insect breeders when looking into the Animal Act and accompanying acts. However, because the prospects of insects as a base for animal feed in the near future and in the further future as base for human food there will be made some changes in legislation to make this possible. As said earlier, by current legislation one is not allowed to use insects for food or feed with the possible exception of fishmeal. There will be changes in this topic, the prospects of using insects is both sustainable and economically interesting. Legislation will have to change in order to make this possible, changing legislation will have quite some effects on the branch.

For now, breeders don't have to take into account the 'accommodation and caring standards' as well as the 'reproductive techniques'. This will change when insects will be used in the food-chain, people will start asking question on the welfare issues of insects. By being a step ahead insects and insect welfare can be implemented in the law. For instance by using Brambell's five freedoms as a framework for welfare and creating breeding standards based on current techniques and physiological needs of the insects.

Currently VENIK is trying to get the Dutch government to cooperate on the issue of legislation in insect breeding and the up-scaling thereof. The Dutch government will make the effort, if and when possible, to remove the unnecessary limitations in law and legislation, brought to their attention by VENIK. This is the outcome of the Green Deal on food, feed and pharma. It basically means that the government is willing to aid VENIK in their effort in the up-scaling of insect farms and to explore the possibilities for the use of insect-derived proteins for feed, food and pharmaceutical products.

The implications of the Green Deal are yet unclear, our recommendation would be to come up with alternatives for legislation on the TSE-legislation as this is the main hurdle in legislation to be overcome. Proper research is needed on this part to find out whether the risks of using insect-derived proteins are in any way a risk for public and animal health. Additionally a thorough list of required actions is to be put up by VENIK and other insect breeders in order to create an overview of changes in legislation that are needed.

A point of further research in legislation is the implication on the Law on Animal Testing. The main question is whether the inclusion of insects in the Animal Act has any legal implications on this matter. In the Animal Act is stated that the law has no implications for the Law on Animal Testing, however whether this also covers the new list of production animals is definitely of interest for entomologists in the Netherlands.

For all current production animals (pigs, meat-cows, dairy-cows and such) specific legislation is in place per species. This should be followed by legislation on insect rearing, for instance the amount of space an animal need (e.g. broiler chickens in the act of animal keepers chapter2, §6) should be applied to a certain species of insect according to its biological needs. We recommend the use of Brambell's five freedoms as a framework for this.

Erroneous spelling in list of production animals	Correct spelling
Caruasius morosus	*Carausius morosus*
Pachnoda aemole	*Pachnoda aemula*
Sitophilus ganarius	*Sitophilus granarius*
Achroea grisella	*Achroia grisella*
Vespidiae	*Vespidae*

Table 4. Overview of Latin spelling in the list of production animals (the erroneous ones) followed by the correct spelling (underlined).

The current list of production animals, especially insects, should be open for debate and possible changes. For instance on the matter of the Black soldier fly, it is currently not on the list but there are breeders that are using the insects as they can be used as a very promising alternative for fishmeal.

We would therefore recommend to include the Black soldier fly to the list of production animals. The fact that the Black soldier fly is currently known to be missing from the list of production list does not mean that it is the only species of insects that missing; a thorough revision of the list is therefore recommended. It is also highly recommendable to check the list on the matter of spelling (Latin names in particular) there are some erroneous names on the list (table 4), this could pose a threat to the feasibility of the law.

6 Discussion

The use of insects as a staple for the food and feed industries has been brought forward as a more sustainable alternative to conventional meat production respectively the use of e.g. soy beans. To be at all competitive in either field (though especially so in the feed industry) a consistently large supply of insects or insect-derived protein is needed. Large-scale insect breeding facilities are the only realistic option to ensure this consistent supply.

The most pressing matter that needs to be addressed to allow for such large-scale insect breeding facilities is ensuring that legislation provides a workable framework. Keeping animals for the purpose of producing meat or other products derived from them is in principle illegal by law, except for animals specifically designated as production animals. Though in current legislation insects are not incorporated in the list of production animals, this is about to change. The Animal Act will be in place in 2013 and it incorporates a number of insect species as production animals. 29 Insect species will be implemented which are then legal to be bred.

However, due to the relatively recent outbreaks of the mad cow disease, it is prohibited to use animal proteins as an ingredient in animal feed according to current TSE-legislation (on transmissible spongiform encephalopathies). This has proven to be a significant legislative barrier for the rearing industry. VENIK is currently working together with the Dutch government to make the necessary changes in legislation by cooperating in a so-called Green Deal. We recommend the participants to make an inventory of the required changes in legislation.

Presently the only way to circumvent the legal impediment is to come up with alternative ways for insects (and insect derived proteins) to enter the feed-production chain. A possibility is to use insect as fishmeal or to use live insects as feed, both legal by law. Using insects as ingredient for feed other than fishmeal ought to be pursued if a large-scale rearing industry is to be established.

Upon implementing insect rearing conditions in legislation, it would be convenient to come with general guidelines for insects as a whole. However, all interviewed experts and breeders suggested that, due to the sheer size and variety of the group of Insecta, generalizing is not feasible. Additionally, when applying legislation to ensure insects' proper breeding conditions, one must take into account that for every production animal distinct standards are specified by the law. Therefore, our suggestion is to define species-specific guidelines on animal welfare in insect breeding.

As the list of production animals counts 29 species at the writing of this report, this is a significant undertaking and the question is whether this is possible. Given the general lack of literature and specific knowledge on breeding insects, one might ask whether the current list of species is appropriate: is there enough specific and publicly accessible knowledge available on how to breed every species mentioned on the list? If there would for example be a single Dutch breeder for a species, they could prove reluctant to share their current techniques due to the commercial value. Even if sharing were not a problem, this one breeder might be inclined to specify the breeding standards to their own preference or advantage.

This example shows that creating species-specific breeding standards in legislation is potentially problematic. However as said before, generalizing is not an option either. In order to resolve this problem we propose several possible solutions.

Firstly independent research is needed in order to come up with species specific breeding conditions. We found that breeders prove reluctant in sharing information on their techniques. We surmise that for this independent research to work, a change in mind-set is needed among insect breeders. Given the sensitivity of the information for the competitiveness of their business, we realise such a change can only takes place over a long time span. A way to overcome this is to ensure the confidentiality of the provided information.

Secondly we also recommend to take a closer look at the insects currently listed as production animals. There are some species with erroneous nomenclature in the list. Furthermore the question rises whether the list is either too elaborate or missing specific species, such as the already bred black soldier fly.

Both the lack of literature as well as the reluctance of breeders to share (quantitative) breeding details proved a challenge. This has forced us to focus on the qualitative aspects of insect welfare instead of quantifying specific breeding details, as was first intended.

To create qualitative breeding standards that are both feasible by law and respected by the general public, guidelines on welfare standards are required. We used Brambell's Five Freedoms as a framework: they not only form the basis for animal welfare in both current *and* upcoming legislation, but they can also be considered a 'standard' in animal ethics.

To reiterate what was mentioned in chapter 2, the Brambell's five freedoms are: freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury and disease; freedom to express normal behaviour; and the freedom from fear and distress. Our research showed Brambell's five freedoms are intertwined: i.e. they are not mutually exclusive. For instance in migratory locusts (*Locusta migratoria*) one needs to meet the freedom from hunger in order to prevent the occurrence of cannibalism which would go at cost of ensuring the freedom from pain, *injury* and disease.

Let us first consider the freedom to express normal behaviour and the freedom from discomfort. The freedom from discomfort is conventionally ensured by providing enough living area for the individual animal (i.e. in vertebrates). For insects however, this does not seem to be an issue: as insects often aggregate under natural conditions, they are not likely to suffer from discomfort by crowding. Additionally, clustering behaviour facilitates the freedom to express normal behaviour. The yellow mealworm (*Tenebrio molitor*) for example exhibits attraction to conspecifics; and larval houseflies (*Musca domestica*) facilitate one another in collectively digesting their feeding substrate. Note however that these population densities are regulated through negative feedback: at too high densities the heat generated by the collective insects' body temperature becomes detrimental to the individual insect. In order to ensure welfare standards regarding this specific issue, we recommend to infer both the minimum rearing temperature for each species' larvae above which development is possible as well as the maximum temperature above which detrimental heat effects will occur.

High population densities are also to be taken into account when assessing the freedom from disease: some species seem to be more susceptible to disease with increasing densities (e.g. *A. domesticus*) while some show more resistance to disease (e.g. *L. migratoria* in their gregarious state).

In disease prevention, species like the mealworm (*T. molitor*) and the migratory locust (*L. migratoria*) show potential in enhancing immune response through active thermoregulation. Providing a heat gradient under captive conditions could therefore prove beneficial in preventing disease outbreak. For the larval stage however, it is advisable to infer the rearing temperature that optimizes immune response, and apply this in breeding facilities in case of an outbreak.

For the insects to be able to fulfil their potential in expressing normal behaviour, the freedom form hunger and thirst should first be met. A breeder should ensure feed of proper quality and quantity readily available for the insects. As mentioned in the example on cannibalism mentioned above, this will then also help guarantee the freedom from pain, injury and disease.

Most of the abovementioned examples clearly illustrate how optimized breeding practice should mirror the natural condition as closely as possible: the health and survival rate of insect populations is very sensitive to environmental factors. By providing a breeding environment that mirrors the natural condition, an insect breeder not only optimizes the quality and consistency of their output, but also ensures the freedom from discomfort and the freedom to express normal behaviour.

The ability to express normal behaviour is not always desirable as some species show the possibility to injure one another as a result of reproductive behaviour. It is advisable to investigate the sex ratios that minimize injuries related to this behaviour, but without going at cost of production efficiency.

To further ensure not only the freedom from pain, injury and disease, but also the freedom from discomfort, we need to ask ourselves to what extent the subjective concepts of pain and discomfort are applicable to insects (if at all). Since it is not actually self-evident that insects can experience pain and discomfort, let us review what is known about insects and pain perception.

On the one hand the capacity for nociception has been demonstrated in e.g. fruit flies (*Drosophila melanogaster*): they possess nociceptors and exhibit behavioural responses such as withdrawal from a injurious stimulus. On the other hand insects do not show protective behaviour towards damaged body parts. It remains an open question whether they are aware of emotional states, though their behaviour when subjected to stressors (e.g. toxic chemical substances) could be interpreted as 'stressed'.

A concluding remark on this matter is that though there is an absence of proof, this does not imply proof of absence. What can be done in the absence of proof? Consider that when it comes to animal welfare, there is often much fundamental disagreement. Therefore we encourage an ethical approach, with the aim to come to an authoritative conclusion based on reason and not emotion.

The three most prominent schools of thought in animal ethics are the animal welfare advocates, the animal rights advocates and the pragmatists. Although both animal welfare advocates and animal rights advocates are abolitionists, it remains to be seen whether they would extend their abolitionist approach towards insects or grant them moral status. Animal welfare advocates grant moral status on the basis of the capacity for suffering, while animal rights advocates would grant moral status on the basis of certain cognitive abilities (having a plan-of-life; being goal-oriented; possessing a memory): i.e. insects should be sentient to be considered for moral status by abolitionists – as stated before, there is no current proof for this.

Pragmatists stress the position of *all* stakeholders involved (insects, breeders and consumers in our case) and the relationship between them: although pragmatists also take animal welfare and animal rights into account, they stress the importance of consumer ethics. A negative public perception of the animal welfare (however erroneous) would be detrimental to the image of insect breeders and their business - no matter their good intentions. We therefore give the advice to inform the public of how animal welfare is ensured in the insect breeding branch. Also the difference in welfare standards comparing vertebrates and in this case insects is something that needs to be addressed in the matter on public opinion.

We propose a cautious approach: ‘better safe than sorry’. Ensure quick and painless death by providing instant killing techniques. Try to sedate insects before experimenting on them. Abstain from any unnecessary stressors in insect breeding facilities. This cautious approach stems from a combination of the biological knowledge that is available *and* right ethical conduct.

A change is glooming on the horizon of the insect breeding branch. Changes in legislation will force the branch to take a closer look at insect welfare; the prospect of using insects as ingredient for feed and food will mean large-scale rearing. Given the multitude of changes that in that case will happen in the branch, we foresee a major issue. Current breeders face the explicit choice: continue business as is (focusing on pet shops and novelty food) *or* shift to bulk production as large-scale suppliers of the feed and food industries. The former option doesn’t imply neglecting the feed and food industries altogether, but the latter option is required to make full use of the business potential these industries have to offer.

7 Conclusion

Breeding standards

1. Lack of scientific literature and the reluctance of breeders to share detailed information makes it impossible to quantify breeding standards.
2. To safeguard welfare standards and optimize production, natural conditions should be mirrored as closely as possible.
3. Provide food of sufficient quality and quantity to prevent cannibalism from occurring.
4. Discomfort stemming from crowding is not of fundamental importance in insects, and can even be seen as part of their normal behaviour. However, too high densities should be avoided in:
   - Rearing larvae, as this induces detrimental heat accumulation.
   - Species in which it increases disease outbreak (e.g. *Acheta domestica*).
5. Regarding pain sensation, detection of harmful stimuli has been shown but pain experiencing and suffering are unlikely to occur. However, absence of proof is not proof of absence:
   - Ensure instant death
   - No subjection to unnecessary stressors
   - (anaesthesia for experiments)

Further research & knowledge gaps

1. Quantification of species specific breeding standards.
2. Infer the species-specific larvae densities that keep rearing temperatures in a range that optimizes development and prevents detrimental heat effects.
3. The prevention and treatment of insect diseases are largely unknown. In need of further review is:
   - The allowing of active behavioural thermoregulation (e.g. by providing a heat gradient in captivity).
   - Potential inoculation for prevalent diseases (e.g. MdSGHV).
4. Investigate the sex ratios under rearing conditions that minimize injuries related to reproductive behaviour, but without going at cost of production efficiency.
5. Shed light on mechanisms underlying pain sensation, fear and distress in insects. Furthermore, it should be investigated whether current breeding and killing techniques could be a source of pain, fear and distress.

Consumer ethics

1. Inform public how welfare standards for insects are:
   - Fundamentally different from vertebrate welfare standards (e.g. discomfort from crowding)
   - Guaranteed in rearing facilities and upheld in the law.

Legislation

1. Investigate the possibilities to use insects in feed other than fishmeal
2. Review the list of production animals including the 29 species of insects:
   - Revise mistakes in nomenclature.
   - Pursue the inclusion of the black soldier fly (*Hermetia illucens*).
3. Species specific welfare guidelines per production insect are required as insect biodiversity is too hard to generalize upon for insect rearing standards.

8 Literature

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Act of animal keepers - **Besluit van ... houdende regels met betrekking tot houders van dieren** (Besluit houders van dieren)

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