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Insects as Food

– Something for the Future?

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Preface

For much of the world's population, insects are an important source of nutrients and an appreciated food, but from our Western perspective eating insects is a new and thrilling area. There are several reasons to learn more about insect farming and processing insects for food. For those of us working in *Future Agriculture – Livestock, Crops and Land Use*, a cross-disciplinary research platform at the Swedish University of Agricultural Sciences (SLU), entomophagy (the practice of eating insects) has emerged as a hot topic for resource-efficient food production in our part of the world.

We asked Anna Jansson and Åsa Berggren, both researchers at SLU, to write a report on current knowledge about insects for human consumption. This report is a result of literature reviews and personal communications with experts in the field. It is suitable as reading material for students and everyone interested in future food production and alternative food sources.

Anna Jansson is a professor at the Department of Animal Nutrition and Management, SLU, and Åsa Berggren is a professor at the Department of Ecology, SLU. They are currently supervising a PhD project in Cambodia about cricket farming for human consumption. The project focuses on the development of a rearing system based on endogenous cricket species and the use of local food waste products and weeds as feed for crickets.

In *Future Agriculture*, researchers together with the agricultural sector, authorities and non-government organisations are developing knowledge to address the sustainable use of natural resources with emphasis on agricultural production, including farm animals, and land use. We hope that this report will stimulate further discussions about sustainable food production and consumption in the Nordic countries.

Uppsala, June 2015

Lotta Rydhmer
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Summary

Increased world population, greater pressure on the environment, increased use of land resources globally and increased demand for nutrients and non-renewable energy are predicted for coming decades. Livestock production accounts for 70% of all agricultural land use and, as the global demand for livestock products is expected to almost double by 2050, innovative production solutions are needed. Insect farming has been suggested as a good alternative to conventional livestock farming for future food production.

Land clearing for agriculture is a major contributor to global warming and efficient use of land is therefore important. Insects have a high feed conversion rate, which in a rearing system limits the demand for land for feed production. Moreover, insects emit less greenhouse gases than conventional livestock. It has also been suggested that the volume of water required to produce edible insects is low compared with that needed in conventional livestock production, although empirical data on this are currently lacking. Most edible insects are herbivores and therefore feed of limited value to humans may be harvested and fed to insects. By-products from the food and forest industry are also alternatives. As insects are rich in high quality protein, fatty acids, vitamins and minerals, insect consumption reduces malnutrition in developing countries. Moreover, intake of insect products instead of traditional livestock products may have positive health effects in Western societies.

Insects are part of the diet of at least two billion people in the world and more than 1900 insect species are currently used as food. The most common insects consumed world-wide are different species of beetles (31% of all insects species consumed), caterpillars (18%) and bees, wasps and ants (14%). In many countries, but not (yet) in Europe and North America, insects are considered a delicacy. In Western societies, eating insects is instead commonly regarded with disgust and as primitive behaviour. In order to promote entomophagy – the practice of eating insects – in Western societies, the disgust factor must be addressed. Much can be learned from the Netherlands, where entomophagy has been successfully promoted since the late 1990s.

Today, most edible insects are harvested in the wild and it is only recently that farming of insects for direct human consumption has begun, mainly in Thailand, Laos and Vietnam. Farmed insects can also be found in the USA and the Netherlands, but mainly for purposes other than human consumption. If insects are to become a profitable commodity in Western countries, there is a need for development of safe and efficient mass-rearing systems. Many insects reproduce rapidly and have large numbers of offspring, which can be an advantage for the development of successful rearing systems. However, through their diversity in terms of types, numbers, life cycles and habitat, insects are exposed to a wide range of pathologies. Different parasites and diseases can regulate wild populations of insects, but can

also have a major impact on farmed species. However, the risk of zoonotic infections can be expected to be low.

Possible candidates for food insect production in Sweden are the house cricket (*Acheta domesticus*), mealworms, the larvae of the beetle *Tenebrio molitor,* and honeybees (*Apis mellifera*). When planning food insect production systems in Sweden, the focus should be on species that are either native or have a long history in the country, in order to minimise the impacts arising from unintentional release of insects from farming systems. For feed production aimed at insects the same rule should be applied. New plant or crop types for food insects should not be introduced on Swedish land.

Properly managed, however, insect production systems can contribute to biodiversity and land conservation. Loss of natural habitat within the agricultural landscape and increased use of pesticides and fertilisers have negative effects on biodiversity and biological control. Possible actions to mitigate biodiversity decline are management of unfertilised meadows and wet grazing areas, increased small-scale heterogeneity in monoculture landscapes and, on a smaller scale, establishment of densely vegetated strips around crop fields. Harvesting vegetation from these areas would provide farmed insects with feed, while the plant material would be sustainably grown and enhance native biodiversity even within large-scale feed production for insects.

Due to this resource use efficiency and the good nutritional value of insects, insect rearing for entomophagy has the potential to become a modern and sustainable food production system.

Why eat insects?

The world population is estimated to reach 9 billion people by 2050. This will demand increased output from available agro-ecosystems (FAO, 2015). Greater pressure on the environment, agricultural land, water resources, forests, fish supply and biodiversity, as well as an increased need for nutrients and non-renewable energy, is predicted (FAO, 2015). There is therefore an urgent need for innovative solutions.

Insects are included in the human diet in most parts of the world, with Europe and parts of North America being two exceptions (FAO, 2013). Edible insects contain high quality protein, fat, vitamins and minerals (Rumpold and Schlüter, 2013; Makkar *et al.*, 2014) and are also considered tasty and even delicious by those accustomed to eating them (De Foliart, 1999; FAO, 2013).

Insects have a comparatively efficient feed conversion, which in a rearing system limits the demand for land for feed production. There is also evidence that insects emit less greenhouse gases and ammonia compared with conventional livestock (Oonincx *et al.*, 2010). Due to these benefits, rearing of insects has been suggested as a good alternative to conventional livestock production even in Western societies (van Huis, 2013).

Insects are a class of animals within the arthropod group. The total number of insect species on Earth is estimated to be 2-3 million and the class probably represents more than 90% of all animal species (Speight et al., 2008; FAO, 2013). Insects can be found in nearly all environments, although only a few species occur in the oceans. Spiders and scorpions, which can also be eaten by humans, are not insects but belong to the arthropods. The oceans are dominated by yet another group of arthropods, crustaceans (e.g. krill, shrimps, crabs and lobsters).

Insects are cold-blooded and their metabolism depends on the thermal conditions in the environment. Many insects occur naturally in high densities, which can be an advantage for the development of successful rearing systems and also from an animal welfare perspective.

What is an insect?

Some species reproduce rapidly and have large numbers of offspring, and most insects do not have parental care. Juvenile insects grow through nymphal or larval stages, shedding their skin as they grow. They then turn directly into an adult or enter a pupal stage that metamorphoses into the adult (Speight et al., 2008). Some species have diapause (a period during which growth or development is suspended) and thereby extend their development over one or several seasons. This is more common when climate conditions do not favour a full development cycle.

Adult insects have a three-part body (head, thorax and abdomen), three pairs of legs, usually compound eyes, two antennae and a chitinous exoskeleton. The digestive system consists of three parts: The foregut, the midgut and the hindgut. Digestion begins at the mouthparts, where salivary glands often provide enzymes and lubricants. The midgut is the principal site of digestion (Capinera, 2010). Methane originating from the hindgut (which could contribute to global warming) is only produced by cockroaches, termites and scarab beetles (FAO, 2013).

The FAO perspective

The Food and Agriculture Organization of the United Nations (FAO) has been working on edible insects since 2003, in order to:

- Generate and share knowledge in the field through publications, expert meetings and a website on edible insects (http://www.fao.org/forestry/edibleinsects/en/)
- Raise awareness of insects as food through media collaborations
- Provide support to member countries through field projects
- Support networking and multidisciplinary interactions (e.g. stakeholders working with nutrition, feed and legislation issues) with various sectors within and outside FAO.

FAO is promoting consumption of insects in the Western world too, because of the possibilities for sustainable production in these areas and because Western food culture and gastronomy tend to influence development in other parts of the world. If a food source is rejected by Western society, it is likely that other parts of the world will follow.

The way forward

To release the potential of insects as food, FAO (2013) has identified four key bottlenecks and challenges that must be addressed:

- Further documentation is needed on the nutritional value of insects, in order to efficiently promote insects as a healthy food source
- The environmental impacts of both harvesting and farming insects must be investigated, to allow comparisons with conventional livestock production
- The socio-economic benefits that insect harvesting and farming can offer, particularly in poor countries, must be clarified and communicated
- Clear and comprehensive legal frameworks at national and international level are needed to pave the way for investments, development of production and trade in insect products.

Knowledge gaps in research

In May 2014, the first international conference on insects as food, called 'Insects to Feed the World', was arranged by FAO and Wageningen University, the Netherlands. This conference was considered a milestone in the recognition of a professional insect industry and participants included food entrepreneurs, animal scientists, medical scientists, entomologists, psychologists, insect breeders, members of the feed industry, food authorities and EU officials. The conclusion from the conference was that insects are a solution for the protein deficit problem in the world. The conference formulated recommendations for academia and research agencies. The following knowledge gaps were addressed:

- Sustainable harvest from nature
- Indigenous knowledge of edible insects
- Identification of edible insects
- Standard methods for determination of nutritional value
- Mass-rearing techniques
- Trade and value chains
- Ethical issues (animal welfare)

Entomophagy – the practice of eating insects

The practice of consuming insects is called entomophagy, from the Greek *éntomon*, insect, and *phagein*, to eat. It is estimated that edible insects are part of the diet of at least two billion people and more than 1900 insect species are currently used as food (FAO, 2013) (Figure 1).

The insects most commonly consumed worldwide are beetles (Coleoptera, 31% of all insect species consumed), caterpillars (Lepidoptera, 18%) and bees, wasps and ants (Hymenoptera, 14%). Moreover, grasshoppers, crickets and locusts (Orthoptera, 13%) and cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera, 10%) are consumed. Termites (Isoptera), dragonflies (Odonata), flies (Diptera) and other insects each comprise less than 3% of insects consumed (FAO, 2013).

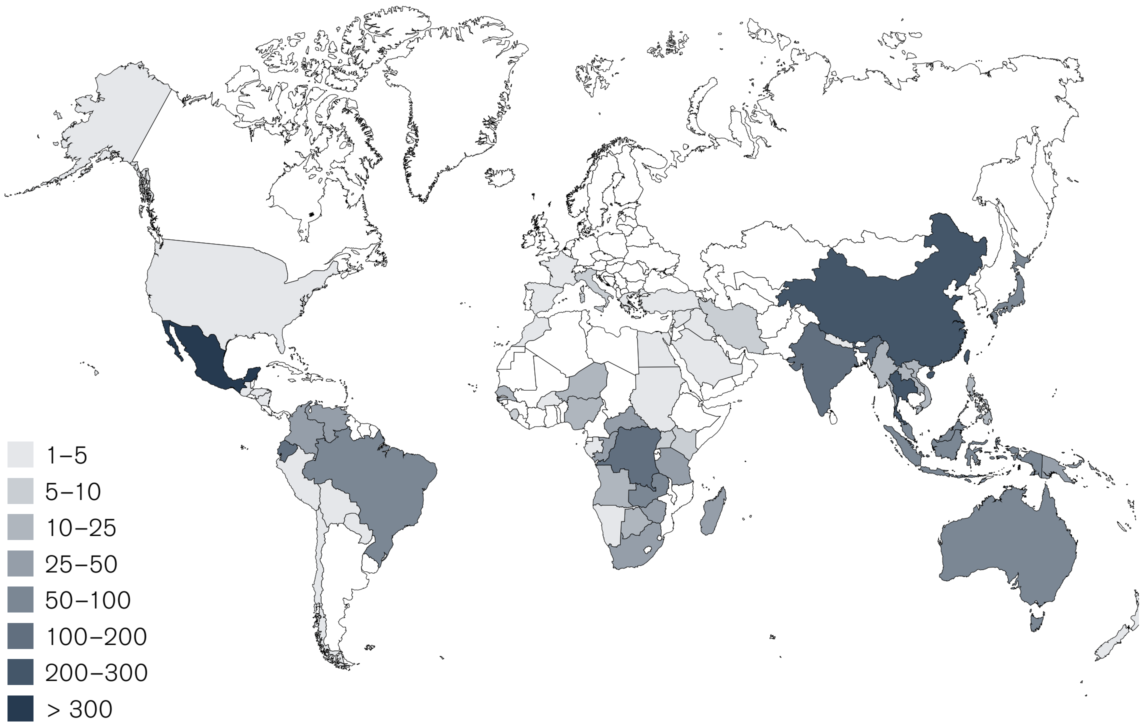

Figure 1. Recorded numbers of edible insect species, by country. (Source: Jongema, 2012; FAO, 2013).

Attitudes, market and communication

Entomophagy is influenced by culture and religion. In many countries, but not (yet) in Europe and North America, insects are considered a delicacy. For many people in Western societies, insects are regarded as pests and entomophagy is often associated with disgust and primitive behaviour (FAO, 2013). This attitude might be one reason why insect rearing has been neglected in agricultural research in this part of the world. In the Netherlands, entomophagy has been promoted since the late 1990s and today there is a wider acceptance of edible insects among the public (Dicke *et al.*, 2014). The key to success has been collaboration among the research community, the private sector, government institutions, foundations and non-profit organisations. Dicke *et al.* (2014) believe that these success factors may also be relevant for promotion of edible insects in other countries.

The disgust factor is a serious issue when promoting entomophagy. As the American psychology professor Paul Rozin has said: "the last and critical step in promoting insects as food is getting people to eat them". Rozin *et al.* (2014) predicted insect acceptance in Americans using both demographic and psychological variables. The predictions included traits such as:

- Disgust sensitivity
- Beliefs about the risk of consuming insects
- Beliefs about the benefits of consuming insects
- Desire to have new and stimulating experiences
- Risk tolerance, food neophobia (resistance to try new foods)
- Gender

It appears that people will accept eating insects if the presentation looks and smells familiar and if insects are not served intact (Dicke *et al.*, 2014). Therefore the promotion of insects cannot focus solely on communicating the functional benefits, but must also pay attention to the products so that they suit the expectations of consumers within their own cultural context (Tan *et al.*, 2014). FAO (2013) states that the disgust factor must be addressed in both communication and education in order to promote entomophagy in Western societies. However, it stresses also that communication with the media in tropical areas (where entomophagy is well established) should focus on insects as a valuable source of nutrients.

Preparation and processing of edible insects

Insects are often consumed whole, but can also be peeled and processed. Western societies might be reluctant to consume whole insects and therefore insect-based flour, granules and pastes that are included in other products can offer alternatives (FAO, 2013). It is also possible to extract protein, fats, chitin, minerals and vitamins from insects. However, these procedures can be costly and development is needed to make them applicable for industrial use (FAO, 2013). Products such as protein-enriched porridge, taco bread, muffins, protein bars and snacks have been developed. Preservation of insects and insect products is an area that needs to be further developed.

Nutrient composition and nutritional value of insects

The nutrient content of insects varies considerably between species and also between the different development phases. The crude protein and fat content is generally high (Table 1).

The amino acid profile differs between insect species, but it appears that many species may contribute well to an optimal diet for humans, even very small children (Table 2). The nutrient data available are from samples of animal feed where intact insects are likely to have been used. When consumed by humans, insects are often peeled (wings and legs are removed), which should result in an increase in the relative protein and fat contents, since wings and legs are part of the exoskeleton, which is high in carbohydrates such as chitin. In addition, further studies are needed on whether the nutrient composition is affected by other types of processing prior to consumption.

Table 1. Examples of crude protein and ether extracts of fats (% of dry matter) in house cricket, silkworm and mealworm (Source: Makkar et al., 2014)

	House cricket *(Acheta domesticus)*	**Silk worm** *(Bombyx mori)*	**Meal worm** *(Tenebrio molitor)*
Crude protein	55-67	52-71	47-60
Fats	10-22	6-37	31-43

Table 2. Amino acid content (g/16 g N) in insects produced as animal feed. (Source: Makkar et al., 2014)

	House cricket	**Mormon cricket**	**Meal worm**	**Black soldier fly**	**FAO reference protein for 2-5 year old child**
Methionine	1.4	1.4	1.5	2.1	2.5 (meth. + cyst.)
Cysteine	0.8	0.1	0.8	0.1	
Lysine	5.4	5.9	5.4	6.6	5.8

Rumpold and Schlüter (2013) list published data on the nutrient content of 236 edible insects. Compared to FAO (2013), it is clear that many of the insects listed meet the amino acid requirements of humans and are also high in mono- and poly-unsaturated fatty acids. For example, the content of unsaturated omega-3 fatty acid and six other fatty acids in mealworms is comparable to that in fish. The study by Rumpold and Schlüter (2013) also shows that many insects are rich in micro-minerals such as copper, iron, magnesium, manganese, selenium and zinc, as well as vitamins such as riboflavin, pantothenic acid and biotin and, in some cases folic acid, all of which are valuable in terms of human nutrition.

However, little is known about the digestibility and nutrient utilisation of insects by humans. Studies on animals show that dietary inclusion of insects, instead of conventional protein sources such as soybean and fish meal, does not adversely affect growth. Finke *et al.* (1989) concluded that cricket protein is equivalent or superior to soya protein as a source of amino acids for young rats. In a study with chickens, no significant differences in weight gain were found between animals fed corn-soybean meal diets and animals fed corn-cricket diets (Nakagaki *et al.*, 1987). Studies on the growth and performance of monogastric animals (e.g. laying hens and pigs and rats) on mealworm diets seem to be lacking (Makkar *et al.*, 2014), but a study with broilers showed growth rates similar to those obtained with conventional feed (Ramos-Elorduy *et al.*, 2002).

Entomophagy and human health

There is very little doubt that entomophagy can be an important solution in decreasing malnutrition in developing countries, but it may also help to improve health in Western societies. As insects are high in mono- and poly-unsaturated fatty acids, intake of insect products instead of conventional livestock products may have positive health effects.

Iron deficiency is the world's most common nutritional disorder, according to the World Health Organisation (WHO). This condition not only occurs in developing countries but also in Western societies, e.g. in Sweden, 45% of adolescent girls are at risk of iron deficiency (Sjöberg and Hulthén, 2015). Many insects have a high iron content (Bukkens, 1997; Bukkens, 2005; Oonincx *et al.*, 2011), even higher than red meat (FAO, 2013), and entomophagy could therefore be recommended from that perspective. If red meat consumption is reduced in the future, as recommended by the Swedish National Food Administration (Livsmedelsverket, 2015), iron deficiency could become even more common than it is now unless appropriate substitutes are used.

Chitin is a main component of the exoskeleton in insects and consists of a polymer of N-acetyl-glucosamine. Chitinase (the enzyme that breaks down chitin) has been found in human gastric juices (Paoletti *et al.*, 2007), but it is not clear to what extent chitin is actually digested by humans. The effects of chitin intake seem to be complex and both negative and positive impacts on the immune system have been documented (FAO, 2013). The effect of chitin consumption in humans needs further investigation.

It has been observed that consumption of locusts and grasshoppers without removing their legs can cause intestinal constipation and therefore removal of legs, and perhaps also wings, prior to consumption is recommended (FAO, 2013). A preliminary study also indicates that patients allergic to house dust mites and crustaceans may be at risk when consuming mealworm protein (Broekman *et al.*, 2014). As with all nutrient-rich food, there is a risk of contamination and growth of microbes during processing and storage of insect products. This may, of course, adversely affect product quality, but it may also cause food-borne illness.

Entomophagy and natural conservation

In countries where insects are traditionally used as food, the main way of obtaining insects is by gathering them in the wild. As a consequence, the habitats of insects and their management become important. This can result in other plants and animals inhabiting these areas being protected from exploitation (DeFoliart, 1997). Moreover, in some countries the use of pesticides has been reduced in areas where a decrease in insect populations has been noted (DeFoliart, 1997), in order to keep the insects as a food resource. As insects that are used for consumption around the world show very high species diversity, they also represent a very large diversity of natural habitats and ecosystems.

Legal obstacles

Insects are not yet fully approved as food within the EU, since risk assessments are lacking. The European Food Safety Authority (EFSA) is working on this and will deliver a report in September 2015. However, the Dutch and Belgian food authorities have already published some risk assessments (EFSA, 2014a, b, c). It is likely that insects will be approved for food use one species at a time and it is possible that some species will be accepted during 2016 (Livsmedelsverket, 2015).

Insect farming for food production

Although insects have been used by humans for different purposes for many thousands of years, only honeybees, cochineals and silkworms have been domesticated. The reason for this is probably multifactorial and includes biological, historical and cultural aspects (FAO, 2013).

Today, most edible insects are harvested in the wild and farming of insects for direct human consumption began only recently (FAO, 2013). Rearing of crickets for food now occurs in Thailand, Laos, Vietnam and Cambodia. Insect farms can also be found in the USA and the Netherlands (FAO, 2013). The cricket pet food industry in the USA is described as a multimillion dollar business, with as many as 50 million crickets produced weekly (Weissman *et al.*, 2012). In Asia, cricket farming is generally conducted with very simple means (Figure 2).

Insect farming in Western countries consists mainly of family-run enterprises with the main focus on pet and zoo animals, although some farms produce small amounts for human consumption (FAO, 2013). The species most farmed are crickets (*Gryllodes sigillatus, Gryllus bimaculatus*, *Acheta domesticus*), mealworms (*Zophobas morio*, *Alphitobius diaperinus*, *Tenebrio molitor*), locusts (*Locusta migratoria*), sun beetles (*Pachnoda marginata peregrina*), wax moths (*Galleria mellonella*), cockroaches (*Blaptica dubia*) and house fly maggots (*Musca domestica*).

If insects are to become a profitable dietary component for humans, large quantities of insects need to be produced on a continuous basis. This means that both farming and processing need to be highly automated. Accordingly, there is a need for development of efficient and safe mass-rearing systems in Western countries. Development of mass-rearing systems for some insect species is currently underway in the Netherlands (FAO, 2013).

Figure 2. A typical Asian smallholder rearing system for crickets. The crickets usually stay inside the cardboard egg boxes. Harvesting is done using a brush and a bag, or by shaking the boxes over a water trough. To prevent crickets from escaping, the tray is covered with a net and the walls may be covered with a slippery surface, e.g. tiles. (Photo: Anna Jansson).

Breeding

As already mentioned, only honey bees, cochineals and silkworms are considered to be domesticated. The fruit fly (*Drosophila melanogaster*) and other insects are often used as model animals in genetic studies, but applied research and breeding programmes for farmed insects other than honey bees and silkworms seem to be lacking. Breeding could alter e.g. insect growth rate and feed conversion, reproduction, behaviour, disease resistance and flavour.

Feeding

Most edible insects are herbivores (van Huis, 2014) and feed resources of limited value to humans therefore have potential to be used when farming insects. So far, little attention seems to have been paid to sustainable feeding of farmed insects. Mealworms are typically fed on wheat bran or flour supplemented with soybean flour, skimmed milk powder or yeast (Makkar *et al.*, 2014) and crickets are typically fed commercial chicken feed (P. Miech, pers. comm. 2014). Such strategies cannot be considered sustainable, since some of these ingredients originate from production systems that have environmental and ecological weaknesses. Moreover, many of these feed resources could be consumed directly by humans. There is therefore an urgent need to find sustainable feed resources for insect rearing systems.

Studies on the nutrient requirements of insects are scarce, but data exist for some species (Neville *et al.*, 1961). Studies on how diet affects the nutrient composition of insects are also scarce. In one study on locusts, protein content decreased and fat content increased when wheat bran was included in a grass-based diet, but the content of retinol (a form of vitamin A) was not affected by inclusion of carrots (Oonincx and van der Poel, 2011). However, the nutrient composition of the diets offered was not analysed and the true intake of protein and energy might therefore have had a greater effect than the feed ingredients per se. Another study indicates that the fatty acid composition of insects is affected by the plants included in their diet (Bukkens, 2005). A recent study also showed that mealworms could be grown successfully on diets composed of organic by-products and that diet composition did not influence larval protein content, but did alter larval fat composition to a certain extent (van Broekhoven *et al.*, 2015). Further studies are needed to increase knowledge on the nutrient requirements of selected insect species and on how feed and nutrient intake affects mortality, growth, nutrient composition and flavour of the insects.

Feed production

Since farming of insects for direct human consumption began only recently, dedicated or commercial large-scale feed production for insects is not yet taking place. By-products from the food and forest industry are interesting alternatives and this area needs further investigation. Human food waste and animal manure have been used to rear flies for animal feed, but it is unlikely that such feed resources will be approved in the production of insects for direct human consumption. Feed preservation methods are likely to affect both nutrient availability for the insects and also the need for extra water intake. Preservation of feed for insects is a research area where there is a great lack of knowledge.

Health, disease and hygiene

Through their diversity in terms of types, numbers, life cycles and habitats, insects expose themselves to a wide range of pathologies. Different parasites and diseases can regulate wild populations of insects, but can also have a major impact on farmed species. In silkworms and honeybees there are records of diseases from the seventh century B.C. Epizootics and infectious diseases develop or are most evident at high host densities (Tanada and Kaya, 1993). This can be seen in intensive animal production and can be an animal welfare problem which causes losses of animals and production. Very little is known about these potential problems when it comes to insect farming for food purposes. However, the cricket *Acheta domesticus* is known to be affected by a densovirus and in the USA, the pet food business has been devastated by epizootic densovirus outbreaks (Weissman *et al.*, 2012). In general, FAO recommends that when starting mass rearing (irrespective of insect species), a parental line should always be preserved in case of culture crashes (FAO, 2013).

A zoonosis is an infection or infestation that is shared by humans and animals. Insect rearing for food and feed has not yet been practised long enough to determine the risk of disease transmission (FAO, 2013). However, since insects are taxonomically quite distant from humans compared with conventional livestock, the risk of zoonotic infections is expected to be low. Nevertheless, according to FAO (2013), particular attention should be paid to pathogens that initially have animals as their host, but could then shift to humans as their preferred host. The lack of studies on safety issues and hygienic handling of insects highlights the need for more research in this area.

Environmental aspects

According to FAO (2006), livestock production accounts for 70% of all agricultural land use. As the global demand for livestock products is expected to double between 2000 and 2050, innovative solutions are needed. Land clearing for agriculture is one of the largest contributors to global warming (Makkar *et al.*, 2014), and efficient use of land is therefore a high priority. Greenhouse gas emissions are a global concern. Livestock rearing accounts for 14% of global greenhouse gas emissions (as CO_2-equivalents; Gerber *et al.*, 2013). In contrast to conventional livestock, insects do not produce methane (with a few exceptions mentioned previously). However, data on greenhouse gas emission from insect rearing are scarce. A few small-scale experiments by Oonincx *et al.* (2010) indicate that greenhouse gas emissions and ammonia production from insect rearing are low (Figure 3).

Water is another element crucial for land productivity, and scarcity of water is predicted in the future (FAO, 2012). Water requirements for insect rearing have not been studied, but it has been suggested that the volume of water required to produce edible insects in equivalent amounts of conventional meat is low (FAO, 2013).

Life cycle analyses

Only a few life cycle analyses (LCA) of insect production have been carried out. Oonincx and de Boer (2012) performed LCA on data from one mealworm farm in the Netherlands. They focused on energy and land use and global warming potential and compared their results with literature data on conventional animal products. They found that energy use was numerically higher in mealworm production than in most conventional products but land use and global warming potential was lower (Figure 4). The higher energy use when producing mealworms is mainly because insects are cold-blooded and growth and reproduction are dependent on thermal conditions. For production of house crickets and

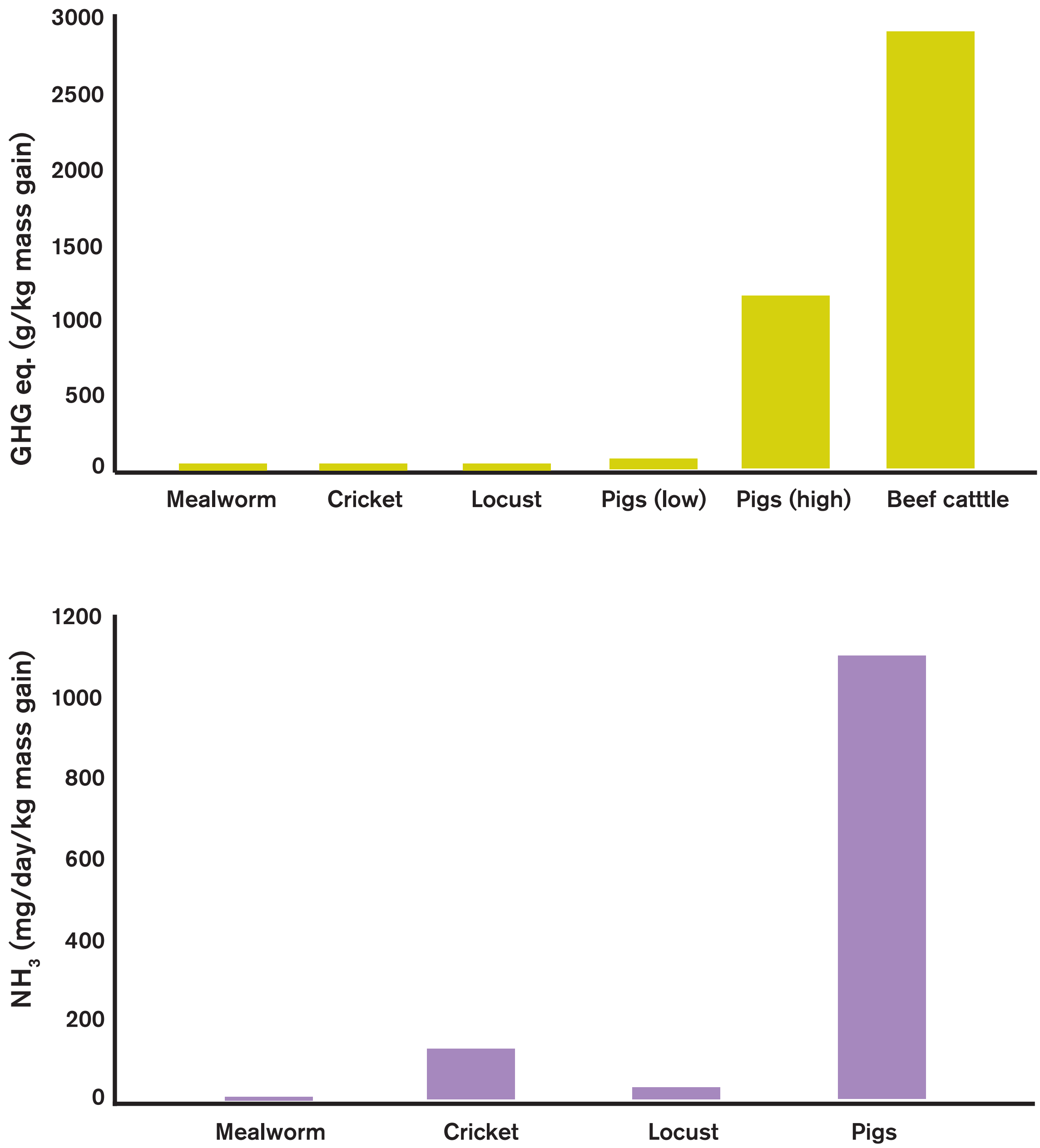

Figure 3. Production of greenhouse gases (GHG) and ammonia (NH_3) per kg of mass gain in some insect and livestock species (Source: Oonincx et al., 2010).

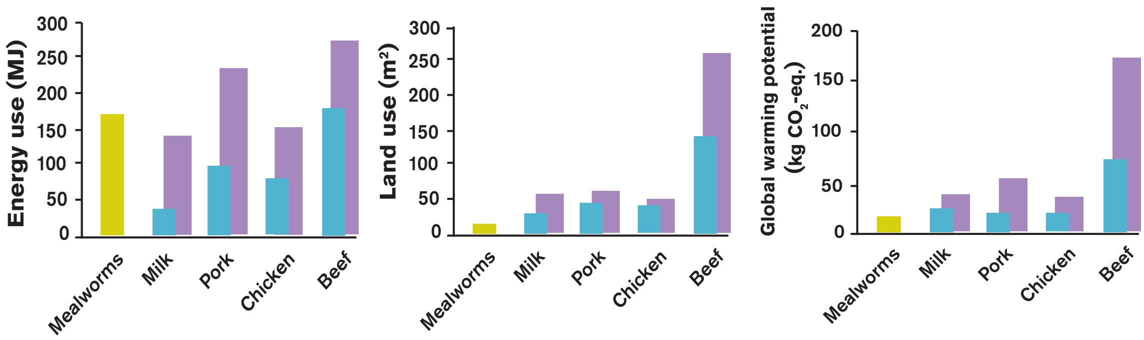

Figure 4. Environmental impact (from the production of one kg of edible protein) of mealworm production on one farm in the Netherlands compared with that of other animal products. Purple and blue bars represent maximum and minimum data from a literature survey (Oonincx and de Boer, 2012).

mealworms, for example, a temperature higher than 20°C is feasible and 25-30°C is ideal (Makkar *et al.*, 2014). For insect production to be sustainable all year around in colder climates, waste energy or renewable energy sources must therefore be used. However, this applies for all livestock production systems.

Feed conversion rates

Insects are generally considered to have a low feed conversion rate (defined as kg feed/kg growth), which corresponds to high feed efficiency (kg growth/kg feed). In the few studies carried out to date, the feed conversion rate for insects has been shown to be considerably lower than for most conventional livestock animals, chicken being one exception (see Table 3). When feed conversion figures are adjusted for edible weight (approximately 40% in cattle, 55% in chicken and pigs and 80% in crickets (Nakagaki and DeFoliart, 1991), the advantage of insects is even greater (van Huis, 2013). Crickets then are twice as efficient in converting feed to meat as chickens and more than 12 times as efficient as beef (Figure 5). When reared at optimal temperature, crickets need six times less feed than cattle, four times less than sheep and half the amount compared with pigs and broiler chickens to produce approximately the same amount of protein (FAO, 2015).

Animal welfare

Little is known about discomfort and pain experiences in insects (Erens *et al.*, 2012), but it has been suggested that welfare issues are few (FAO, 2013), probably based on that many edible insects occur naturally in crowded conditions and do not perform parental care. Erens *et al.* (2012) advise that farmed insects be provided with an ample quantity of appropriate quality nutrients, freedom to express natural behaviour, freedom from discomfort, pain, injury and disease and a breeding environment that imitates the natural conditions as closely as possible. They also suggest killing techniques that ensure instant death. Freezing or deep frying is commonly used to kill insects, but studies on the impact on animal welfare and food quality are scarce.

Table 3. Examples of feed conversion rate (FCR) in insects and conventional livestock

	FCR (kg feed/kg growth)	**Reference**
Cricket	1.7	Collavo *et al.*, 2005
Chicken	1.8	Sheppard *et al.*, 2009; Patricio *et al.*, 2012
Mealworm	2.2	Oonincx and de Boer, 2012
Pigs (conventional crossbred pigs)	2.6	Smit *et al.*, 2014
Pigs (Moo Lath breed, Laos)	4.5	Chittavong *et al.*, 2013
Beef	> 4.5	NRC, 2000

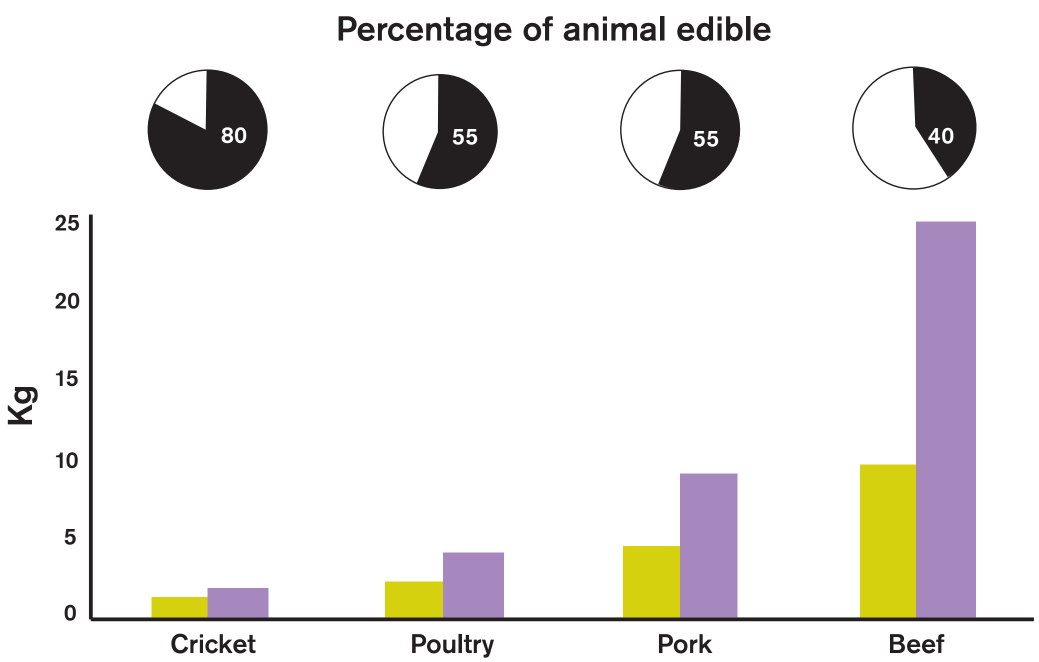

Figure 5. Efficiency in converting feed into live weight and edible weight (green bars = kg feed/kg live weight and purple bars = kg feed/kg edible weight) for crickets and some conventional livestock species. The edible proportion of cricket and of poultry, pork and beef animals is 80, 55, 55 and 40 %, respectively (A. van Huis, pers. comm. 2014; FAO, 2013).

Interest from society

Interest from entrepreneurs

Some companies in the USA manufacture insect products for human consumption, for example Exo (https://www.exoprotein.com/) and Chapul (http://chapul.com/) produce bars including cricket flour. In the Nordic countries, an Icelandic company is working to produce energy bars with cricket flour (Crowbar, http://www.crowbarprotein.com/) and a few restaurants serve insects (e.g. Noma in Copenhagen, http://noma.dk/). Nordic Food Lab, a non-profit organisation working on the development of gastronomy, supports entomophagy (http://nordicfoodlab.org/). At least one Swedish company sells imported insect products intended for human consumption (www.hakunamat.se). There is also a Swedish blog (www.bugburger.se) where entomophagy is promoted and the writer (A. Engström) is playing with the idea of starting a burger chain named 'Bug Burger' where the 'meat' comes from insects. The Open Bug Farm (www.openbugfarm.com) is a web forum that describes itself as "An innovation platform to stimulate interaction between farmers, researchers and hobbyists who want to change the world with edible insects". A Swedish architect's firm (Belatchew architects) recently won an international prize for its concept BuzzBuilding, which integrates building of flats with rearing of crickets and bees in and around the building (BuzzBuilding, 2015a, 2015b).

Interest from media and the public

The magazine Fast Company has put the Brooklyn-based company Exo on its list of the world's top 10 most innovative companies of 2015 for its protein bars that include cricket flour, and Time Magazine sees insect bars as a trend for 2015. The Swedish media has also shown interest in insects as food. Information from SLU about entomophagy and cooking of insects has appeared in different types of media during the past year (*Nyhetsmorgon, Vetenskapsradion, Uppsala nya tidning*). This has sparked huge interest and positive responses from other branches of the media and the public.

In 2014, students at SLU carried out a project on marketing of edible insects within a course at the Department of Economics (reported as: Edible insects – Marketing strategies for Western markets, by P. Bechter, I. Bodén, S. Hakkarainen and M. Nilsson). The interest in entomophagy is in accordance with observations in another small Swedish study (BSc thesis) including 15 young people, where 13 volunteers consumed insects in bars and intact with spices (Aspholmer and Gellerbrandt, 2014). When asked about important factors that could decide whether entomophagy is accepted, these participants suggested properties such as familiar taste, visually appealing, competitively priced, low environmental impact and good for health. Food where insect inclusion was not visibly apparent was asked for especially. In that study, the negative influence of TV shows such as Fear Factor (where consumption of insects is used to create disgust) on people's attitude to entomophagy was also discussed.

Use of insects in a wide perspective

Although the present report focuses on the use of insects as food, it should be mentioned that the human use of insects is wider and is an ancient practice. Honey and silk are the most commonly known insect products. A common dye (carmine) used to colour food and textile red is also by insects. A rubber-like protein called resilin that enables insects to jump has been suggested to have both industrial and biomedical applications (Elvin *et al.*, 2005) and chitosan, a material derived from chitin in the exoskeleton, has been considered as a potential polymer for food packaging (FAO, 2013). Fats from insects can be extracted for mechanical use, since these fats may possess valuable properties like extremely low freezing points. Some insects are used in biological pest control and bees are used for pollination of crops. Rearing of crickets and mealworms for the pet and zoo market has been carried out for quite some time. Insect production for inclusion in feed for conventional livestock is an alternative use of reared insects (Makkar *et al.*, 2014). Systems using organic waste and rearing of black soldier fly and house fly are currently being developed and American patents are pending.

Mealworms

Ice lollies containing insects

Insect farming for food in Sweden – risks and possibilities

Ecological aspects

Importance of using native species for mass rearing

There is a potential for Swedish native insects to be used as 'mini-livestock' for food production. Intended or unintended introduction of new species is one of the greatest threats to natural systems and production systems today. Invasive species are estimated to reduce food production by 14% globally, while 30-45% of the pests in agricultural and forest systems are non-native (Pimentel, 2007; Kenis and Branco, 2010). New species are being introduced to ecosystems as a result of increased transport and travel and imports of goods. The success of establishment of non-native species is expected to increase due to changes in land use and climate, factors that can increase the competitiveness of new species. There are around 2200 non-native species in Sweden today, of which 376 are regarded as invasive and 82 as potentially invasive, while for 990 species there are currently no estimates (Nobanis, European Network on Invasive Alien Species). World-wide, the monetary costs of non-native species that have become invasive are enormous. At a conservative estimate, these costs amount to around 5 billion Swedish crowns per year in Sweden (Gren *et al.*, 2009). It is very important not to contribute further to this existing problem with non-native species. Insect species that do not exist in Sweden should not be used in production systems. The focus should instead be on species that are either native or have a long history in the country and where no negative impacts have been observed, in order to minimise the impacts if farmed insects are unintentionally released from holding areas. For feed production for insects the same rule should be applied. New plant or crop types should not be introduced on Swedish land for use in the system.

Sustainable use of the agricultural landscape

The loss of natural habitats within the agricultural landscape is believed to be the main driver of biodiversity declines on arable land (Senapathi *et al.*, 2015). Increased use of pesticides and fertilisers has negative effects on biodiversity and biological control (Rundlöf *et al.*, 2015). Possible actions to mitigate biodiversity decline based on landscape composition and management can be: managing unfertilised meadows and wet grazing areas; increasing small-scale heterogeneity in monoculture landscapes; and, on a smaller scale, establishing densely vegetated strips (buffer strips) around crop fields (Samways, 2005; Josefsson *et al.*, 2013). Harvested vegetation from these areas could be used as feed in insect production according to what is suitable for the species. This approach would provide feed for farmed insects and the plant material would also be sustainably grown and enhance native biodiversity. It is likely that large-scale feed production for insects could also contribute to biodiversity.

A meadow in the Swedish countryside

Potential insect species for farming

House cricket

The house cricket (*Acheta domesticus*) has been part of the Swedish fauna for several hundred years and can today be considered native. Crickets are considered easy to farm (FAO, 2013) and that is probably one important reason why there are very large numbers of cricket farmers in countries such as Thailand (20 000 farmers; FAO, 2013). Crickets can eat a large range of organic material, can be reared in crowded conditions (2000 insects/m^2) and prefer temperatures above 20°C (Makkar *et al.*, 2014). Crickets contain many nutrients that are essential to humans and have been proposed as a commercially feasible source of food for humans (Collavo *et al.*, 2005). There are some studies on the nutrient requirements, feeding and rearing of this insect (e.g. Neville *et al.*, 1961; Parajulee *et al.*, 1993). Unfortunately, large populations of the house cricket farmed today seem to be affected by a virus (Liu *et al.*, 2011), which may have devastating effects on populations (Weissman *et al.*, 2012).

Mealworm

Mealworms, the larvae of the beetle *Tenebrio molitor,* can be a promising option for mass rearing in Western countries as this insect is endemic in temperate climates, has a short life cycle, is easy to farm and farming expertise is already available in the pet feed industry (FAO, 2013). There are also some studies on the nutrient requirements, feeding and rearing of this insect. Moisture in the feed seems to be critical to the mealworm and may affect productivity and fat content (Urs and Hopkins 1973; Makkar *et al.*, 2014). Mealworms are omnivores but are typically fed on wheat bran or flour supplemented with soybean flour, skimmed milk powder or yeast (Makkar *et al.*, 2014). Rearing mealworms on wheat flour, soya and skimmed milk cannot be considered sustainable, since these products could be considered more suitable for direct consumption by humans. However, according to Makkar *et al.* (2014), mealworms have the ability to recycle plant waste material of low quality into high quality feed.

Honey bee

Honey bees (*Apis mellifera*) can be a potential species for breeding. There is a vast amount of knowledge on honey bee ecology, breeding and population health. Varroa mites (*Varroa destructor*) have major impacts on bee health and the survival of bee colonies. Varroa is more often found in drone broods and one method to reduce varroa mites is to make the queen lay the drone larvae in special combs that are later harvested (Calderone, 2005). This reduces the amount of varroa mites in the population without adversely affecting the worker population or honey production. In a method currently being tested in Denmark, the drone larvae that are harvested from the hives are used in cooking (E. Forsgren, pers. comm. 2015).

Insects as food – something for the future?

It is well known that many current food production systems are not sustainable in a global perspective. The struggle to mitigate the effects of land clearing for agricultural use, loss of natural habitats, global warming, use of pesticides and health and welfare issues in animal production systems will continue unless major changes are made. Due to the high resource efficiency and good nutritional value of insects, insect rearing for entomophagy seems to fit perfectly with a modern food production system.

Fried silk worms

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The report *Insects as Food – Something for the Future?* is a result of literature reviews and personal communications with experts in the field of insect biology, ecology and rearing. It is suitable as reading material for students and everyone interested in future food production and alternative food sources.

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