5. Environmental opportunities for insect rearing for food and feed

Feeding a growing world population with more demanding consumers will necessarily require an increase in food production. This will inevitably place heavy pressure on already limited resources such as land, oceans, fertilizers, water and energy. If agricultural production remains in its present form, increases in GHG emissions, as well as deforestation and environmental degradation, are set to continue. These environmental problems, particularly those associated with raising livestock, need urgent attention.

Livestock and fish are important sources of protein in most countries. According to FAO (2006), livestock production accounts for 70 percent of all agricultural land use. With global demand for livestock products expected to more than double between 2000 and 2050 (from 229 million tonnes to 465 million tonnes), meeting this demand will require innovative solutions. Similarly, fish production and consumption has increased dramatically in the last five decades. As a consequence, the aquaculture sector has boomed and now accounts for nearly 50 percent of world fish production. The sustainable growth of the sector will depend largely on the supply of terrestrial and aquatic plant-based proteins for feed. The opportunity for insects to help meet rising demand in meat products and replace fishmeal and fish oil is enormous.

Large-scale livestock and fish production facilities are economically viable because of their high productivity, at least in the short term. However, these facilities incur huge environmental costs (Tilman *et al.*, 2002; Fiala, 2008). Manure, for example, contaminates surface water and groundwater with nutrients, toxins (heavy metals) and pathogens (Tilman *et al.*, 2002; Thorne, 2007). Storing and spreading manure can involve the emission of large quantities of ammonia, which has an acidifying effect on ecosystems. Any increase in animal production will, moreover, require additional feed and cropland and will likely trigger deforestation. The Amazon is a case in point: pasture now accounts for 70 percent of previously forested land, with feed crops covering a large part of the remainder (Steinfeld *et al.*, 2006).

In 2010, Sachs (2010) argued that agriculture was the leading cause of anthropogenic-induced climate change and that the world needed new agricultural technologies and patterns of food consumption based on healthier and more sustainable diets. Feeding future populations will require the development of alternative sources of protein, such as cultured meat, seaweed, beans, fungi and insects.

Consuming insects has a number of advantages:

- They have high feed-conversion efficiency (an animal's capacity to convert feed mass into increased body mass, represented as kg of feed per kg of weight gain).
- They can be reared on organic side streams, reducing environmental contamination, while adding value to waste.
- They emit relatively few GHGs and relatively little ammonia.
- They require significantly less water than cattle rearing.
- They have few animal welfare issues, although the extent to which insects experience pain is largely unknown.
- They pose a low risk of transmitting zoonotic infections.

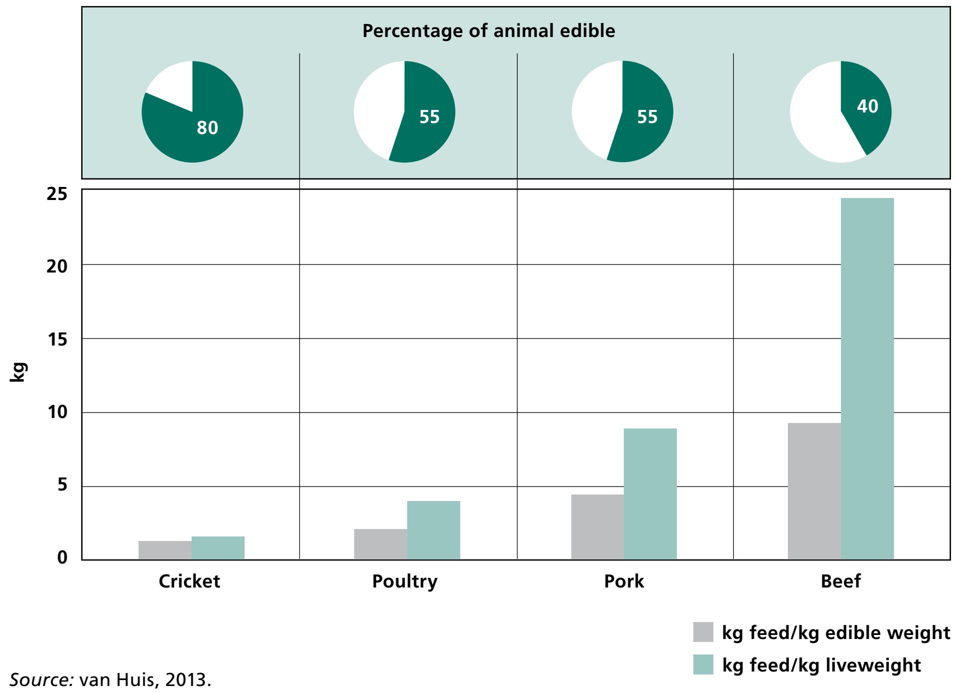
Despite these benefits, consumer acceptance remains one of the largest barriers to the adoption of insects as viable sources of protein in many Western countries. Nevertheless, history has shown that dietary patterns change quickly, particularly in a globalized world (the rapid acceptance of raw fish in the form of sushi being a good example).

However, replacing a part of conventional meat with edible insects implies an end to unlimited harvesting from nature, as this would place enormous pressure on wild populations. The production of edible insects would need to shift towards rearing either at the cottage-scale level or in large industrial units.

5.1 FEED CONVERSION

As demand for meat rises, so too does the need for grain and protein feeds. This is because far more plant protein is needed for an equivalent amount of animal protein. Pimentel and Pimentel (2003) calculated that for 1 kg of high-quality animal protein, livestock are fed about 6 kg of plant protein. Feed-to-meat conversion rates (how much feed is needed to produce a 1 kg increase in weight) vary widely depending on the class of the animal and the production practices used. Typically, 1 kg of live animal weight in a typical United States production system requires the following amount of feed: 2.5 kg for chicken, 5 kg for pork and 10 kg for beef (Smil, 2002). Insects require far less feed. For example, the production of 1 kg of live animal weight of crickets requires as little as 1.7 kg of feed (Collavo *et al.*, 2005). When these figures are adjusted for edible weight (usually the entire animal cannot be eaten), the advantage of eating insects becomes even greater (van Huis, 2013). Nakagaki and DeFoliart (1991) estimated that up to 80 percent of a cricket is edible and digestible compared with 55 percent for chicken and pigs and 40 percent for cattle. This means that crickets are twice as efficient in converting feed to meat as chicken, at least four times more efficient than pigs, and 12 times more efficient than cattle (see Figure 5.1). This is likely because insects are cold-blooded and do not require feed to maintain body temperature.

FIGURE 5.1
Efficiencies of production of conventional meat and crickets



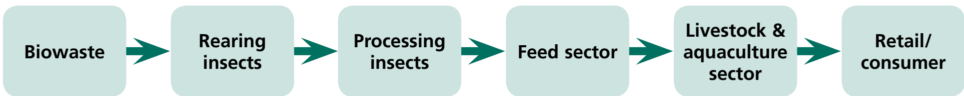
Source: van Huis, 2013.

5.2 ORGANIC SIDE STREAMS

A benefit of insects as an **alternative animal protein source** is that they can be reared sustainably on organic side streams (e.g. manure, pig slurry and compost). The use of organic side streams in insects starts by rearing the insects on biowaste. The insects are processed and fed to a specific animal (Figure 5.2), the meat of which is then sold to the consumer (Veldkamp *et al.*, 2012) (see Chapter 8).

Insect species such as the black soldier fly (*Hermetica illucens*), the common housefly (*Musca domestica*) and the yellow mealworm (*Tenebrio molitor*) are very efficient at bioconverting organic waste. For this reason, these species are receiving increasing attention, as they could collectively convert 1.3 billion tonnes of biowaste per year (Veldkamp *et al.*, 2012). Other insect species, such as crickets, are raised on insect farms and fed with high-quality feed such as chicken feed. The substitution of such feed with organic side streams can help to make insect farming more profitable (Offenberg, 2011). However, at present this is not permitted because of food and feed legislation (see Chapter 14).

FIGURE 5.2
Use of insects in the animal feed chain



Source: adapted from Veldkamp et al., 2012.

Recycling agricultural and forestry wastes into feed greatly reduces organic pollution. According to DeFoliart (1989), "Practically every substance of organic origin, including cellulose, is fed upon by one or more species of insects, so it is only a matter of time before successful recycling systems will be developed". The possibility of rearing insects on organic waste for human consumption is still being explored, given the unknown risks of pathogens and contaminants (Box 5.1).[10]

BOX 5.1
Ecodiptera project

In 2004, a project co-financed by the European programme LIFE titled Ecodiptera was launched to make better use of the huge volume of pig manure generated across Europe. The overuse of fertilizer is highly linked to a series of environmental problems including nitrification, the excessive enrichment of nutrients in soil and water, and GHGs. Additionally, the use of manure can lead to the spread of pathogens within the environment as well as between humans and animals. In this project, larval flies were used to transform manure into fertilizer and protein. In Slovakia, a pilot plant for the biodegradation of pig slurry was developed with fly larvae by adapting existing technology for chicken manure. Methods suitable for the maintenance of colonies of flies and the identification of optimal conditions were developed. The project found that when flies reach the pupal stage they can be used as protein feed in aquaculture.
The objectives of the project were to:

- demonstrate the technical and economic viability of a new pig manure management method using *Diptera* (maggots);
- obtain a balance between environmental and social concerns in order to increase community acceptance;

Continues

[10] For more information on this topic, refer to the 2012 report, *Insects as a Sustainable Feed Ingredient in Pig and Poultry Diets – A Feasibility Study*, produced by Wageningen University Livestock Research.

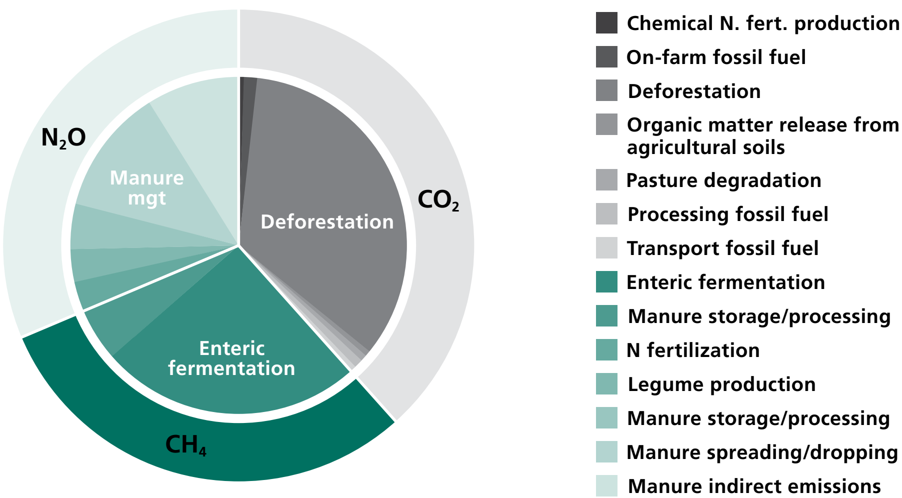
Box 5.1 continued

- encourage the progressive phasing out of the current practice of directly using pig manure as an organic fertilizer, which is not recommended due to its high nitrate content;
- prove that the obtained subproducts, such as biodegradable waste remains, pupas and flies, can be included in other processes (e.g. animal feeding and plant pollination) with the goal of obtaining a cycle that produces no waste products;
- introduce a new local juridical model;
- show that fly larvae, previously considered an environmental problem and which occur in pig manure under natural conditions, offer important degradation potential using environmentally friendly management techniques. In this case, the fly problem offers a sustainable solution to the pig manure waste problem.

Source: European Commission, 2008.

5.3.GREENHOUSE GAS AND AMMONIA EMISSIONS

FIGURE 5.3
Relative GHG contributions along the livestock food chain



Source: Bonneau, 2008

Livestock rearing is responsible for 18 percent of GHG emissions (CO_2 equivalent), a higher share than the transport sector (Steinfeld *et al.*, 2006). Methane (CH_4) and nitrous oxide (N_2O) have greater global warming potential (GWP) than CO_2: if CO_2 has a value of 1 GWP, CH_4 has a GWP of 23 and N_2O has a GWP of 289 (IPCC, 2007) (Table 5.1).

TABLE 5.1
The animal sector's contribution to GHG emissions

	Carbon dioxide (CO2)	Methane (CH4)	Nitrous oxide (N2O)
Percentage of global emissions	9	35–40	65
Caused by	Fertilizer production for feed crops, on-farm energy expenditures, feed transport, animal product processing, animal transport and land use changes	From enteric fermentation in ruminants and from farm animal manure.	From farm manure and urine

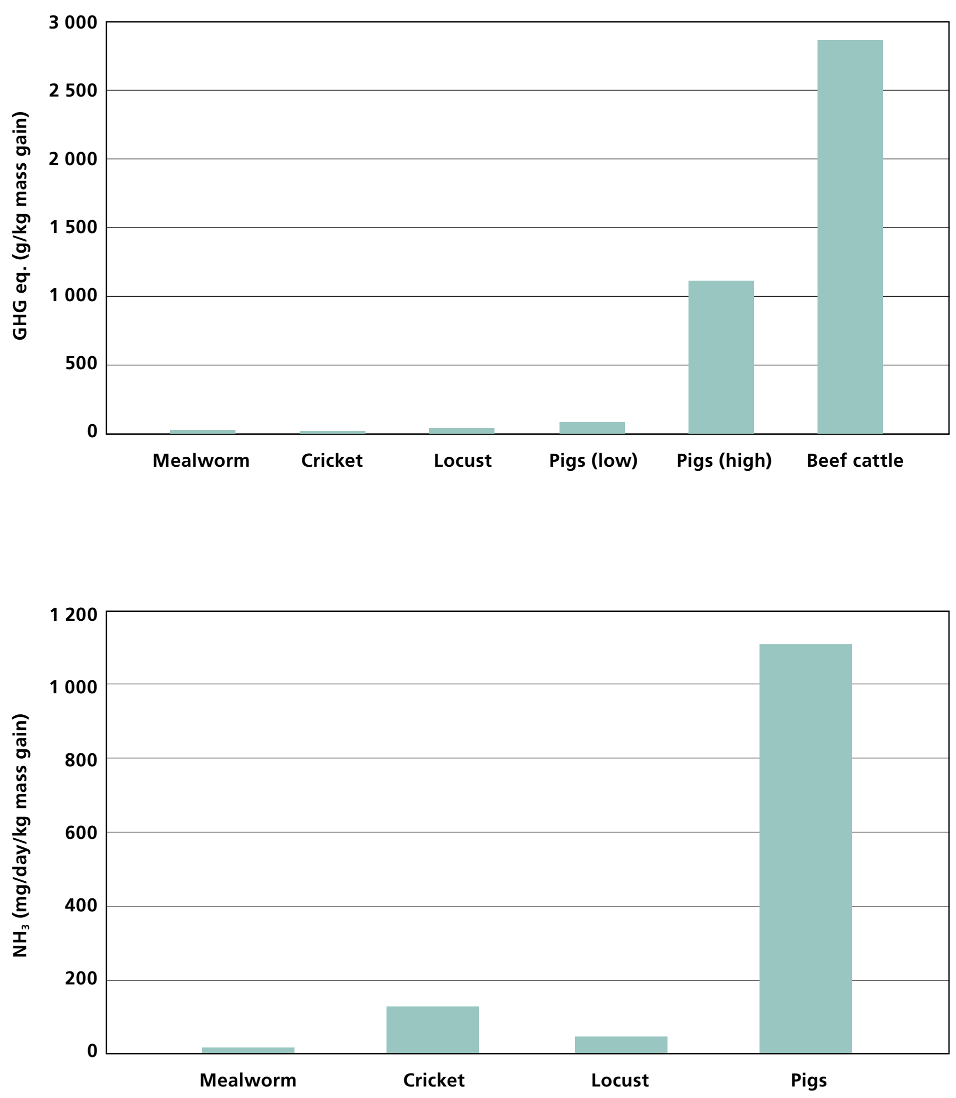
Note: This table shows how much the animal sector contributes to these emissions and why. According to Fiala (2008), 1 kg of beef causes emissions equivalent to 14.8 kg of CO_2, while emissions are lower for pigs and chickens: 3.8 kg and 1.1 kg, respectively.

Source: Steinfeld *et al.*, 2006.

Among insect species, only cockroaches, termites and scarab beetles produce CH_4 (Hackstein and Stumm, 1994), which originates from bacterial fermentation by Methanobacteriaceae in the hindgut (Egert *et al.*, 2003). Yet insects deemed viable for human consumption in the Western world include species such as mealworm larvae, crickets and locusts, which compare favourably with pigs and beef cattle in their GHG emissions (they are lower by a factor of about 100) (Oonincx *et al.*, 2010) (Figure 5.4). Livestock waste (urine and manure) also contributes to environmental pollution (e.g. ammonia) that can lead to nitrification and soil acidification (Aarnink *et al.*, 1995). Mealworm larvae, crickets and locusts also compare favourably to pigs in ammonia emissions, as shown in Figure 5.4 (about a tenfold difference) (Oonincx *et al.*, 2010). These results are taken from small-scale experiments performed in laboratories and caution should be exercised in making comparisons with large-scale pork and beef production.

FIGURE 5.4

Production of GHGs and ammonia per kg of mass gain for three insect species, pigs and beef cattle



Source: Oonincx *et al.*, 2010.

5.4 WATER USE

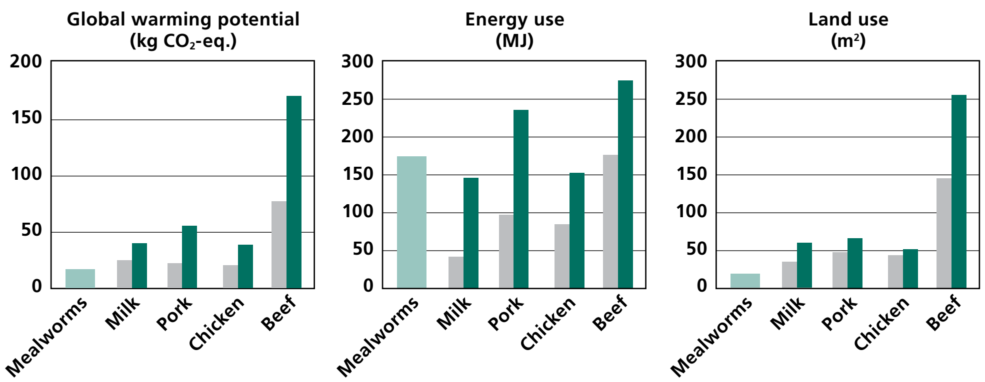
Water is a key determinant of land productivity. A growing body of evidence suggests that a lack of water is already constraining agricultural output in many parts of the world. It is estimated that, by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population will likely be under stress (FAO, 2012b). Increasing demands placed on the global water supply threaten biodiversity, food production and other vital human needs. Agriculture consumes about 70 percent of freshwater worldwide (Pimentel *et al.*, 2004). Chapagain and Hoekstra (2003) estimated that producing 1 kg of animal protein requires 5–20 times more water than generating 1 kg of grain protein. This figure approaches 100 times if the water required for forage and grain production is included in the equation (Pimentel and Pimentel, 2003). Chapagain and Hoekstra (2003) described this concept as virtual water. According to the authors, the production of 1 kg of chicken requires 2 300 litres of virtual water, 1 kg of pork requires 3 500 litres and 1 kg of beef requires 22 000 litres, with estimates for the latter reaching as high as 43 000 litres (Pimentel *et al.*, 2004). Estimates of the volume of water required to raise an equivalent weight of edible insects are unavailable but could be considerably lower. Mealworms, for example, are more drought-resistant than cattle (the growing efficiency of mealworms in the presence of sufficient water is described in section 6.1).

5.5. LIFE CYCLE ANALYSIS

Life cycle assessment is a technique to assess the environmental impacts associated with all stages of a product's life, but of the edible insects only mealworms have been assessed in this way. Oonincx and de Boer (2012) quantified GHG production (GWP), energy use and land-use area throughout the mealworm production chain and found that energy usage for the production of 1 kg of mealworm protein was lower than for beef, comparable with pork, and slightly higher than for chicken and milk. GHG emissions due to mealworm production were much lower than for the more common production animals (Figure 5.5). For every 1 ha of land required to produce mealworm protein, 2.5 ha would be required to produce a similar quantity of milk protein, 2–3.5 ha would be required to produce a similar quantity of pork or chicken protein, and 10 ha would be required to produce a similar quantity of beef protein. On the basis of this study, therefore, mealworms are a more environmentally friendly source of animal protein than milk, chicken, pork and beef.

FIGURE 5.5

Greenhouse gas production (global warming potential), energy use and land use due to the production of 1 kg of protein from mealworms, milk, pork, chicken and beef



Note: The grey bars are minimal values and the dark green bars are maximum values found in the literature.
Source: Oonincx and de Boer, 2012.

5.6. ANIMAL WELFARE

With respect to intensively farmed animals, Brambell (1965) described the standards that the animal production industry should aspire to: freedom from hunger, thirst, discomfort, pain, injury, disease, fear and distress, and the expression of normal behaviour. Concerning hunger and thirst, this means providing sufficient food of adequate nutrition to prevent, among others, cannibalism. The criteria of freedom from discomfort and the expression of natural behaviour relate to crowding and the tolerance of certain levels of rearing densities. Like many mammals under intensive cultivation, insects are typically reared in small and confined spaces. To ensure animal welfare, farmed insects should be provided with adequate space, which depends on the level of interaction a species has with conspecifics (other organisms of the same species) under natural conditions. For example, locusts reared in captivity are always gregarious and naturally occur in high densities. Mealworms also have a tendency to cluster. In rearing facilities, optimal conditions are pursued to minimize mortality and increase productivity. Little is known about the extent to which insects experience pain and discomfort (Erens *et al.*, 2012), although some research has been carried out using the fruitfly, *Drosophila melanogaster*, as a model organism. Neely *et al.* (2011) looked at nociception, defined as the "sensory perception of potentially damaging noxious stimuli" and found that the genes for nociception were the same for mammals, suggesting that nociception occurs in at least some insects. However, it is uncertain whether these are reflexes or whether higher neural systems are involved. Although there is a lack of evidence that insects possess cognitive ability to experience suffering, some invertebrates, like Cephalopoda, seem to possess advanced cognitive abilities (Crook and Walters, 2011). Until conclusive proof that insects feel pain has been gathered, Eisemann *et al.* (1984) suggested that insects, as a precaution, should be granted the benefit of the doubt. Insect-killing methods that would reduce suffering include freezing or instantaneous techniques such as shredding.

5.7 RISK OF ZOONOTIC INFECTIONS

Intensive animal production with high densities of animals is a starting place for many significant health issues and has been known to trigger the emergence of antimicrobial resistance. Diseases are the cause of large-scale losses of animals, either through high mortality or because of culling policies. Some of these diseases are zoonotic (e.g. H5N1, the highly pathogenic avian influenza, foot and mouth disease, bovine spongiform encephalopathy and Q-fever).

A **zoonosis** is an infection or infestation shared in nature by humans and wild or domestic animals. Recently there seems to have been a serious increase in zoonotic diseases due to the intensification of animal production and climate change. In recent years, the emergence of severe acute respiratory syndrome coronavirus (known as SARS) and influenza A viruses (H5N1 and H7N7) has caused global concern about the potential for pandemics. Many past zoonoses have remained within confined populations; however, in a globalized world the likelihood of such pandemics is increasing. A number of examples exist from various parts of the world, including cutaneous zoonotic leishmaniasis in Manaus, Brazil; ebola, monkeypox and Rift Valley fever in Africa and the Arabic Peninsula; Crimea Congo haemorrhagic fever in the Middle East; bovine spongiform encephalopathy (BSE) in Europe and elsewhere; West Nile fever in Canada and the United States; and paramyxoviruses in Australasia. These demonstrate that a wide variety of animal species, both domesticated and wild, act as reservoirs for pathogens, which may take the form of viruses, bacteria or parasites (Meslin and Formenty, 2004).

In the livestock sector, pathogens that carry infectious diseases are subjected to pressures resulting from the production, processing and retail environment. Taken together, these alter host contact rates, population size and/or microbial traffic flows in the food chain. Insects for food and feed have not been tested sufficiently to determine the risk that they will transmit diseases to humans. Intensive insect-rearing facilities will also be subject to the same pressures exhibited in animal production and, at present, it is not fully understood whether they could be a source of harmful emerging pathogens. Particular attention should be paid to pathogens that initially have animals as hosts but may shift to humans as their preferred hosts. Some well-known diseases (e.g. HIV-related diseases) have been introduced by animals in this way. Pathogen transmission occurs first by the adaptation of the pathogens to the new host population and second by spreading inside the host population. The adaptation of the pathogen to the new host is dependent on the genetic difference between the two species and the nature of the pathogen itself (Slingenbergh *et al.*, 2004).

Because insects are taxonomically much more distant from humans than conventional livestock, the risk of zoonotic infections is expected to be low. Nevertheless, insects are potential vectors of medically relevant pathogens, including the eggs of gastrointestinal helminths found in human faeces. The risk of zoonotic infections (transmitting diseases from humans to animals and back) could rise with the careless use of waste products, the unhygienic handling of insects, and direct contact between farmed insects and insects outside the farm due to weak biosecurity. More research in this area is needed. Safety issues and the hygienic handling of insects are discussed in Chapter 10.

5.8 THE ONE HEALTH CONCEPT

FAO, the World Health Organization (WHO) and the World Organisation for Animal Health use the following informal definition of One Health: "the collaborative efforts of multiple disciplines working locally, nationally and globally to attain optimal health for people, animals and our environment". One Health is a means of managing the threats posed by the interface between human, animal and environmental health. This view of health acknowledges the strong linkages and interconnectedness between the animal–human–environmental health nexus. The health approach is coupled with the biosecurity approach: "Biosecurity is a strategic and integrated approach to analysing and managing relevant risks to human, animal and plant life and health and associated risks to the environment" (WHO/FAO, 2010). Entomophagy, as well as the use of insects for feed, is an area in which the application of the One Health concept would be appropriate, although it requires more research.