2. The role of insects

2.1 BENEFICIAL ROLE OF INSECTS FOR NATURE AND HUMANS

Over the past 400 million years, evolution has produced a wide variety of arthropod species adapted to their environments. About 1 million of the 1.4 million described animal species on earth are insects, and millions more are believed to exist. Contrary to popular belief, of the 1 million described insect species, only 5 000 can be considered harmful to crops, livestock or human beings (Van Lenteren, 2006).

2.1.1 Benefits for nature

Insects deliver a host of ecological services fundamental to the survival of humankind. For instance, insects play an important role in **plant reproduction**. An estimated 100 000 pollinator species have been identified and almost all of these (98 percent) are insects (Ingram, Nabhan and Buchmann, 1996). Over 90 percent of the 250 000 flowering plant species depend on pollinators. This is also true for three-quarters of the 100 crop species that generate most of the world's food (Ingram, Nabhan and Buchmann, 1996). Domesticated bees alone pollinate an estimated 15 percent of these species. The importance of this ecological service for agriculture and nature more generally is undisputed.

Insects play an equally vital role in **waste biodegradation**. Beetle larvae, flies, ants and termites clean up dead plant matter, breaking down organic matter until it is fit to be consumed by fungi and bacteria. In this way, the minerals and nutrients of dead organisms become readily available in the soil for uptake by plants. Animal carcasses, for example, are consumed by fly maggots and beetle larvae. Dung beetles – of which there are about 4 000 known species – also play a significant role in decomposing manure. They can colonize a dung heap within 24 hours, preventing flies from developing on them. If the dung remains on the soil surface, about 80 percent of the nitrogen is lost to the atmosphere; the presence of dung beetles, however, means carbon and minerals are recycled back to the soil, where they further decompose as humus for plants. When cattle were introduced to Australia in 1788, waste biodegradation became an immediate problem, as endemic dung beetles were simply insufficient to decompose the increased amounts of manure. Australian dung beetles had adapted to the dung of marsupials (e.g. kangaroos), which differs from bovine dung in various ways, including in size, texture and water content (Bornemissza, 1976). The Australian Dung Beetle Project was initiated to solve the problem, and dung beetles were introduced to the continent from South Africa, Europe and Hawaii (of 46 introduced species, 23 established).

BOX 2.1

Outbreaks of the brown planthopper

Brown planthoppers (*Nilaparvata lugens*) cause considerable damage by sucking sap from rice plants, causing them to wilt and die. They also transmit three viral diseases that stunt rice plants and prevent grain formation. When using pesticides, beneficial insects that prey on planthoppers are killed when insecticides are used injudiciously. Beneficial insects that feed on planthoppers keep pest populations below outbreak levels. However, when this balance is disrupted, planthopper outbreaks occur.

Beneficial fauna, including insects, buttress the natural resistance of agro-ecosystems. Pest insects have a large array of natural enemies, predators and parasitoids, keeping them under economic threshold levels. However, by using insecticides, vulnerable beneficial insects can be killed quicker than the targeted pest insect. One reason for this is that the target pest is often better protected (such as stem borers by the stem and mites by webs) than beneficial insects, which need to forage. Following the application of a synthetic pesticide, the population of the pest insect first decreases but then increases exponentially, because the pest insect can now develop without being constrained by attacks from beneficial insects. A notorious example of this is the outbreak of the brown planthopper in rice instigated by the use of pesticides (Box 2.1) (Heinrichs and Mochida, 1984).

Virtually all agro-ecosytems benefit from insects because they can **naturally control harmful pest species**. The number of insects that parasitize or prey on other insects is vast. Ten percent of all insects are parasitoids (Godfray, 1994). Entire orders of insects – such as Odonota (dragonflies) and Neuroptera (net-winged insects such as lacewings and antlions) – are predators. A large percentage of true bugs (Hemiptera), beetles (Coleoptera), flies (Diptera) and wasps, bees and ants (Hymenoptera) are also predators. The number of beneficial insect species in the average agro-ecosystem typically far outweighs the number of harmful insect species. For example, in a study carried out in a single agro-ecosystem in rice fields in Indonesia, Settle *et al.* (1996) recorded 500 beneficial insect species and 130 pest species. Another 150 insect species were deemed "neutral" since they do no attack rice, although they served a very important role in the survival of predators when rice was lacking. Beetles have also been used to control water hyacinth invasions. Snout beetles (*Neochetina* spp.), imported from Australia, successfully controlled the water hyacinth in Lake Victoria (Wilson *et al.*, 2007).

BOX 2.2

Common insect products and services

- Cochineal (carmine dye): scale insects
- Honey: bees
- Shellac (polish): various Hemiptera
- Pollination: various insects
- Propolis (natural medicine): bees
- Resilin protein (for artery repair): human flea
- Royal jelly (beauty products): bees
- Silk: silkworms
- Termite hills (architectural models): termites
- Venom (treatment for inflammatory diseases): bees
- Beeswax (cosmetics and candles): bees

2.1.2 Beneficial roles of insects for humans

Besides serving as sources of food, insects provide humans with a variety of other **valuable products** (Box 2.2). Honey and silk are the most commonly known insect products. Bees deliver about 1.2 million tonnes of commercial honey per year (FAO, 2009b), while silkworms produce more than 90 000 tonnes of silk (Yong-woo, 1999). Carmine, a red dye produced by scale insects (order Hemiptera), is used to colour foods, textiles and pharmaceuticals. Resilin, a rubber-like protein that enables insects to jump, has been used in medicine to repair arteries because of its elastic properties (Elvin *et al.*, 2005). Other medical applications include maggot therapy and the use of bee products – such as honey, propolis, royal jelly and venom – in treating traumatic and infected wounds and burns (van Huis, 2003a).

Insects have also inspired **technology and engineering** methods. The silk proteins of arthropods (e.g. spiders) are strong and elastic and have been used as biomaterials (Lewis, 1992). The unique structure of silk, its biocompatibility with living systems, its function as a tool for new materials engineering and its thermal stability are only a few of the features that make it a promising material for many clinical functions (Vepari and Kaplan, 2007). For example, researchers inserted a spider's dragline silk gene into goat DNA in such a way that the goats would make the silk protein in their milk. This "silk milk" could then be used to manufacture a weblike material. Chitosan, a material derived from chitin that makes up the exoskeleton of insects, has also been considered as a potential intelligent and biodegradable biobased polymer for food packaging. Such natural packaging using the "skin" of insects can acclimatize the internal environment, protecting the product from food spoilers and micro-organisms. In particular, chitosan can store antioxidants and exhibits antimicrobial activity against bacteria, moulds and yeasts (Cutter, 2006; Portes *et al.*, 2009). However, the chitosan polymer is sensitive to moisture and could therefore be impractical in its 100 percent natural form (Cutter, 2006). Termite hills and their complicated network of tunnels and ventilation systems serve as useful models for constructing buildings in which air quality, temperature and humidity can be regulated efficiently (Turner and Soar, 2008). Drawing on nature – or rather imitating it – to solve human problems is called **biomimicry**.

The branch of entomology – or the scientific study of insects – that explores the influence of insects on culture (e.g. language, literature, art and religion) is known as **cultural entomology** (Box 2.3) (Hogue, 1987). Contributions from this field have helped highlight the distinct role that insects have assumed in literature (in particular children's books), movies and visual art, as well as their place as collection items, ornaments and more generally as inspiration for creative expression.

BOX 2.3

Examples of cultural entomology[2]

1. Ornamental insects

Insects are fascinating creatures that can easily be prepared and stored for extended periods. Given that some species and genera, mainly beetles and butterflies, are often large and extremely colourful, it is unsurprising that insects have become collectors' items. Species of commercial interest mostly belong to a few butterfly and beetle families. While the majority of insects are still collected in the wild, a number of butterfly farms rear and sell the pupae of common butterfly species. The rearing of insects by hobbyists is a recent trend (a few decades at best). The market for dead specimens and the number of insect collectors, however, seem to be in decline.

The public sector (e.g. zoological gardens and butterfly parks) is interested mainly in large and eye-catching butterfly species. These species are farmed or ranched in butterfly farms in tropical countries and the pupae shipped internationally.[3] Prices per pupae are low, ranging from a few cents up to a few United States dollars per pupa. These farms employ labour and provide income for local people. In Papua New Guinea, host to the fantastic-looking genus Ornithoptera, commonly known as bird wings, the government took an active approach in promoting butterfly ranching as a source of income for local farmers.

Beetles and other insects are not commonly reared in their countries of origin, but rather by private and professional insect growers around the world. Japan and Taiwan have strong beetle-farming communities (mainly for Lucanidae, Cetoniidae and Dynastidae), with the industrial-scale production of rearing materials, several insect shops

[2] The ornamental insects part of this box was contributed by Benjamin Harink.

[3] For a list of butterfly farms, please refer to the International Association of Butterfly Exhibitors.

Continues

Box 2.3 continued

in larger cities, and a number of magazines devoted to the topic of beetle-growing. There is however, good potential for rearing these insects in their countries of origin, for example by providing suitable sites for growing them.

The main challenges for the ornamental insect sector are legal. With declining forests and several species becoming extinct daily, more and more species are banned from trade. The second problem concerns public relations: insect collectors do not have a good reputation. They are often criticized for collecting live animals and keeping exotic species encaged as pets. Furthermore, increasing fears of invasive species complicates the transport of living animals across borders. In such a political climate, it might be better to support or create in-country agencies, such as the Insect Farming and Trading Agency of Papua New Guinea, to regulate the insect trade and ensure certain levels of income for insect growers and collectors, which would also serve as an incentive to protect natural forests.

Once the conditions have been determined, it is amazing how easily many ornamental species can be reared. Ornamental insect farmers can provide ideas for good species for human consumption to add to the existing range, such as the larvae of Dynastidae, which have the potential to grow up to 200 grams (g) each. Aquatic beetles can be consumed in both immature and adult stages (Ramos Elorduy, Pino and Martinez, 2008). Some Cetoniidae species have high reproduction and growth rates and might therefore have potential as human food, particularly as their larvae contain a lot of protein. This protein is packed in a soft skin, reducing the quantity of chitin that would need to be disposed of. The biggest advantage with these ornamental species, however, is that they live off compost and decomposing plant matter, like that produced by mushroom farms. Compost material left behind after the mushroom harvest would be an ideal substrate to inoculate with larvae of beetles for protein production. Moreover, there is no competition for food resources that could be used by humans. In addition, the excrement produced by the larvae makes good fertilizer and helps soil retain moisture for plants. Close cooperation between hobbyist insect growers and those interested in using insects as food is thus desirable, in the hope that new and more suited species than those currently in use might be discovered.

2. Singing crickets

Keeping crickets and bush crickets as pets is a centuries-old tradition in Asian cultures and even in some Western societies. Insects were first cited in an epigram dating to 600 BCE found in Ancient Greece, which referred to a young girl and her dying pet cricket. Many more poems have been written since, particularly on the sounds or songs of crickets (Weidner, 1952).

In China, singing crickets became domestic pets over 2 000 years ago. During the Tang Dynasty (618–906 CE), people kept crickets in cages to listen to their song:

> Whenever the autumn arrives, the ladies of the palace catch crickets and keep them in small golden cages, which are placed near their pillows so as to hear their songs during the night. This custom was also mirrored by common people. (Kai Yuan Tian Boa Yi Shi, *Affairs of the Period of Tian Bao*, 742–759 CE)

3. Cricket fighting

Cricket fighting flourished as a popular sport in China under the Song Dynasty (960–1278 CE). The practice was forbidden during the Qing Dynasty (1644–1911 CE), and cricket fighting became clandestine. Today, cricket fighting is again widespread, although mainly in large cities like Shanghai, Beijing, Tianjin, Guangzhou and Hong Kong, where cricket-fighting clubs and societies thrive. With the migration of Chinese people to other parts of the world, cricket fighting can now be found in places like New York and Philadelphia (Xing-Bao and Kai-Ling, 1994).

Continues

Box 2.3 continued

However, there is a negative side to cricket fighting, as overcollection has caused significant problems. In Shanghai alone there are 300 000–400 000 cricket enthusiasts, and about 90 percent of them are interested in betting on cricket fights. Crickets have become less abundant in areas around large cities in China. Collectors have even reportedly caused damage to suburban vegetable plots while searching for crickets. For more information see also Ryan (1996) and Costa-Neto (2003).

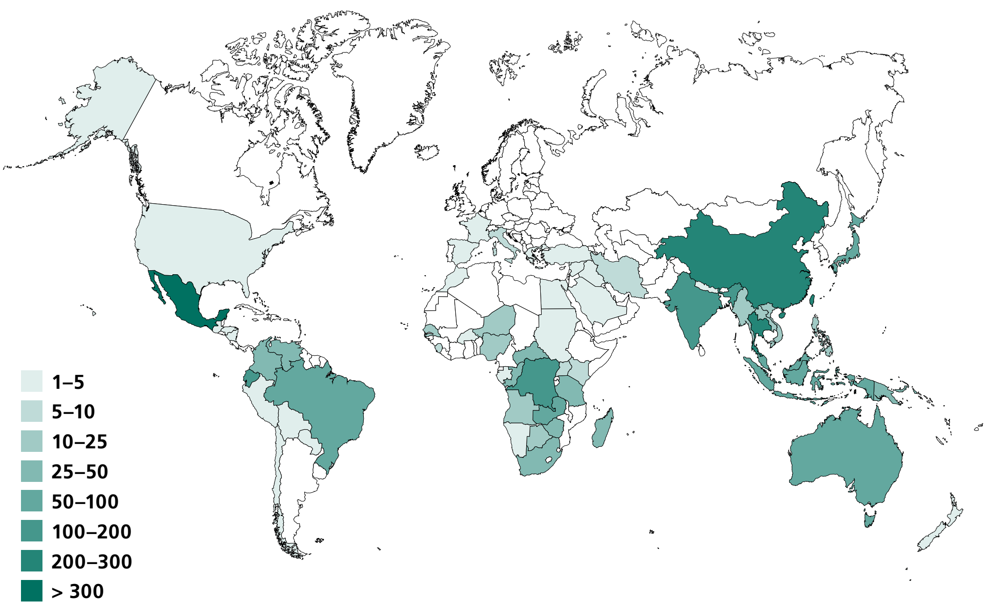
Source: Jin, 1998.

2.2 ENTOMOPHAGY AROUND THE WORLD

2.2.1 Number of edible insect species identified

Providing definitive figures on the number of edible insect species worldwide is difficult for several reasons. First, a layperson is unlikely to describe an insect by its Linnaean nomenclature, making official estimates difficult. Matters are complicated by the use in many cultures of more than one vernacular name – also called ethnospecies – for the same insect species. By using only Latin names and correcting for synonyms, Yde Jongema of WUR conducted a worldwide inventory using the literature, including from Western countries and temperate regions, and listed 1 900 edible insect species worldwide as of April 2012. Lower estimates do exist. DeFoliart (1997) counted a "low" 1 000 species, while Ramos Elorduy (2005) noted "at least" 1 681 species. Regional and national estimates have also been made: van Huis (2005) identified 250 edible species in Africa; Ramos Elorduy *et al.* (2008) listed 549 species in Mexico (although Cerritos, 2009, reported a mere 177 species in the country); in China, Chen *et al.* (2009) documented 170 species; Young-Aree and Viwatpanich (2005) reported 164 species in the Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam; and Paoletti and Dufour (2005) estimated that 428 species were consumed as food in the Amazon (Figure 2.1).

FIGURE 2.1
Recorded number of edible insect species, by country

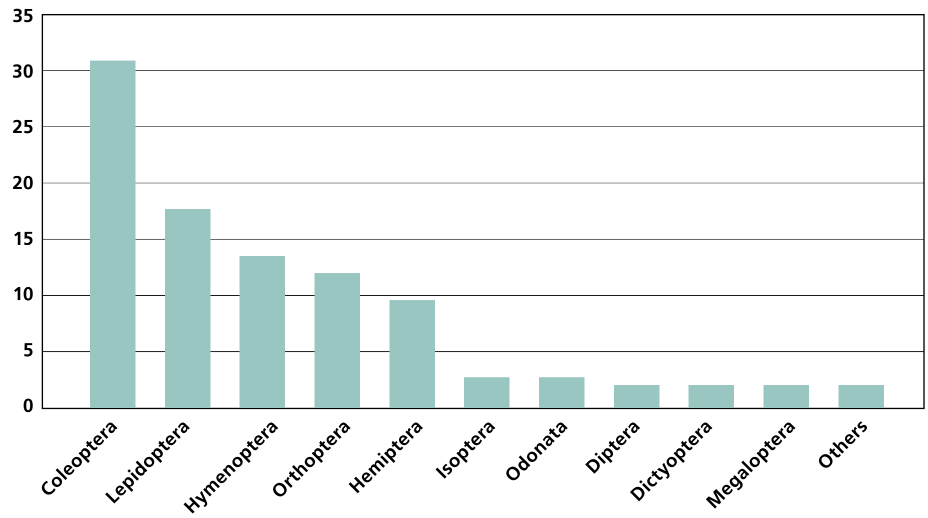


Source: Centre for Geo Information, Wageningen University, based on data compiled by Jongema, 2012.

2.2.2 Major groups of edible insects

Globally, the most common insects consumed[4] are beetles (Coleoptera) (31 percent) (see Figure 2.2). This is not surprising given that the group contains about 40 percent of all known insect species. The consumption of caterpillars (Lepidoptera), especially popular in sub-Saharan Africa (Box 2.4), is estimated at 18 percent. Bees, wasps and ants (Hymenoptera) come in third at 14 percent (these insects are especially common in Latin America). Following these are grasshoppers, locusts and crickets (Orthoptera) (13 percent); cicadas, leafhoppers, planthoppers, scale insects and true bugs (Hemiptera) (10 percent); termites (Isoptera) (3 percent); dragonflies (Odonata) (3 percent); flies (Diptera) (2 percent); and other orders (5 percent). Lepidoptera are consumed almost entirely as caterpillars and Hymenoptera are consumed mostly in their larval or pupal stages. Both adults and larvae of the Coleoptera order are eaten, while the Orthoptera, Homoptera, Isoptera and Hemiptera orders are mostly eaten in the mature stage (Cerritos, 2009).

FIGURE 2.2
Number of insect species, by order, consumed worldwide



Note: total number = 1 909.
Source: Jongema, 2012.

BOX 2.4
Example of national insect diversity: species eaten in the Central African Republic

There is considerable variation in the most consumed insect order by continent, country and community. For example, an estimated 96 insect species are eaten in the Central African Republic. Orthoptera (locusts and grasshoppers) is the most consumed class (40 percent), followed by Lepidoptera (caterpillars) (36 percent), Isoptera (termites) (10 percent), Coleoptera (beetles) (6 percent) and others such as cicadas and crickets (8 percent).

Source: Roulon-Doko, 1998.

[4] This should not be confused with the frequency at which insects are eaten in a certain group.

Coleoptera (beetles)

There are many kinds of edible beetles, including aquatic beetles, wood-boring larvae, and dung beetles (larvae and adults). Ramos Elorduy, Pino and Martinez-Camacho (2009) listed 78 edible aquatic beetle species, mainly belonging to the Dytiscidae, Gyrinidae and Hydrophilidae families. Typically, only the larvae of these species are eaten. The most popular edible beetle in the tropics, by far, is the palm weevil, *Rynchophorus*, a significant palm pest distributed throughout Africa, southern Asia and South America. The palm weevil *R. phoenicis* is found in tropical and equatorial Africa (see Box 2.5 on the use of sound in harvesting), *R. ferrugineus* in Asia (Indonesia, Japan, Malaysia, Papua New Guinea, the Philippines and Thailand) and *R. palmarum* in the tropical Americas (Central America and West Indies, Mexico and South America).

In the Netherlands, the larvae of mealworm species from the Tenebrionidae family, such as the yellow mealworm (*Tenebrio molitor*), the lesser mealworm (*Alphitobius diaperinus*) and the superworm (*Zophobas morio*), are reared as feed for reptile, fish and avian pets. They are also considered particularly fit for human consumption and are offered as human food in specialized shops.

BOX 2.5

Use of sound in harvesting larvae

In Cameroon, women are generally involved in harvesting beetle larvae. They detect the larvae in palm trees by placing their ears against the tree and listening to the sound made by nibbling larvae. This method is commonly used to determine the optimal timing for harvesting the most sought-after instar (the developmental stage of an insect or larvae) of *Rhynchophorus* larvae. In the Democratic Republic of the Congo, the same method is used to harvest edible larvae of weevil, longhorn and scarab beetles, which occur in standing or rotting *Elaeis*, *Raphia*, *Chamaerops* and *Cocos nucifera* palm trees (Ghesquière, 1947).

Source: van Huis, 2003b.

Lepidoptera (butterflies and moths)

Butterflies and moths are typically consumed during their larval stages (i.e. as caterpillars), but adult butterflies and moths are also eaten. Indigenous Australians have been reported to eat moths of the cutworm *Agrotis infusa* (the Bogong moth) (Flood, 1980) and, in the Lao People's Democratic Republic, people have been observed eating hawkmoths (*Daphnis* spp. and *Theretra* spp.) after removing the wings and legs (J. Van Itterbeeck, personal communication, 2012). Nevertheless, the practice is limited.

The mopane caterpillar (*Imbrasia belina*) is arguably the most popular and economically important caterpillar consumed. Endemic to the mopane woodlands in Angola, Botswana, Mozambique, Namibia, South Africa, Zambia and Zimbabwe, the caterpillar's habitat extends over about 384 000 km^2 of forest (FAO, 2003). An estimated 9.5 billion mopane caterpillars are harvested annually in southern Africa, a practice worth US$85 million (Ghazoul, 2006). Other caterpillars are also consumed, but to a lesser extent. Malaisse (1997) identified 38 different species of caterpillar across the Democratic Republic of the Congo, Zambia and Zimbabwe. Latham (2003) documented 23 edible species in the Bas-Congo, a western province of the Democratic Republic of the Congo.

Caterpillar harvesting is not exclusive to Africa. In Asia, the bamboo caterpillar (*Omphisa fuscidentalis*), also known as the bamboo borer or bamboo worm, is a popular food that is being promoted by the Thai Department of Forestry of the Ministry of

Agriculture and Cooperatives as an increasingly viable source of income (Yhoung-Aree and Viwatpanich, 2005). In the Chiapas region in Mexico, locals are believed to consume up to 27 caterpillar species (Box 2.6).

BOX 2.6

Maguey worms

Red maguey worms – larvae of the moth *Comadia redtenbacheri* – and white maguey worms – larvae of the butterfly *Aegiale hesperiaris* – are found throughout central Mexico on the leaves of *Agave salmiana*. When fully mature, the highly nutritious caterpillars are considered a delicacy by Mexican farmers. They are generally eaten deep fried or braised, seasoned with a spicy sauce and served in a tortilla. Along with the larvae of the agave weevil (*Scyphophorus acupunctatus*), red maguey worms are one of the types of *gusano* (caterpillar) found in bottles of mezcal liquor (a distilled alcoholic beverage made from the maguey plant, *Agave americana*) in the Mexican state of Oaxaca. The *gusanos* are so popular that mezcal producers send security guards into agave fields during the rainy season to stop poachers.

Source: Ramos Elorduy *et al.*, 2007.

Hymenoptera (wasps, bees and ants)

Ants are highly sought-after delicacies in many parts of the world (Rastogi, 2011; Del Toro, Ribbons and Pelini, 2012). They also render important ecological services, including nutrient cycling, and serve as predators of pests in orchards, although negative effects are also reported (Del Toro, Ribbons and Pelini, 2012). The weaver ant (*Oecophylla* spp.) is used as a biological control agent in various crops, such as mangoes (Van Mele, 2008), and the larvae and pupae of the reproductive form (queen brood), also called ant eggs, constitute a popular food in Asia (see section 4.5.1). In Thailand they are sold in cans. Shen, Li and Ren (2006) reported that the black weaver ant (*Polymachis dives*) is widely distributed in subtropical southeast China, Bangladesh, India, Malaysia and Sri Lanka. It is used as a nutritional ingredient and processed into various tonics or health foods available on the Chinese market. The State Food and Drug Administration and State Health Ministry of China have approved more than 30 ant-containing health products since 1996.

In Japan, the larvae of yellow jacket wasps (*Vespula* and *Dolichovespula* spp.), locally known as hebo, are commonly consumed. During the annual Hebo Festival, food products made from the larvae of the wasps are popular delicacies (Nonaka, Sivilay and Boulidam, 2008), so much so that the local supply is insufficient and imports from Australia and Viet Nam are necessary to keep up with demand (K. Shono, personal communication, 2012). Box 2.7 provides background information on bees.

An inventory compiled by Ramos Elorduy and Pino (2002) in Chiapas, Mexico, suggested that most (67) insect species eaten in the state belong to the Hymenoptera order, and two leafcutter ant species (*Atta mexicana* and *A. cephalotus*) are becoming increasingly commercialized there. Further south, Amerindians have also been documented eating ants of the *Atta* genus (Dufour, 1987). Colonies of *Atta* species can have more than 1 million workers, and some can have up to 7 million. Their effect on vegetation in the Neotropics is said to be comparable with that of large grazing mammals on the African savannah. Therefore, a leafcutter colony can be considered competitive with a cow (Hölldobler and Wilson, 2010).

BOX 2.7
Beekeeping around the world

The contribution of bees to nature and agriculture is well documented (Bradbear, 2009), but their enormous potential to act as a direct source of food for humans is less understood (Chen *et al.*, 1998). A limited number of studies have shown that bee brood (eggs, larvae and pupae) and adults of a number of bee families are edible, including Bombycidae, Meliponidae and Apidae (Banjo, Lawal and Songonuga, 2006; Ramos Elorduy, 2006). An extensive nutritional analysis conducted by Finke (2005) showed that bee brood (presumably of *Apis mellifera*) is an excellent source of energy, amino acids, essential minerals and B-vitamins.

Nest-building insects, such as honeybees, lend themselves easily to semi-cultivation: bees can be attracted to nest at certain spots, and their hives can be relocated nearer to home, for example. These techniques have been applied widely worldwide over a long period (DeFoliart, 1995); in Central America, they date back to the Mayan civilizations (Villanueva, Roubik and Colli-Ucan, 2005). Coletto-Silva (2005) documents an ingenious method for collecting stingless bee (*Melipona* spp.) colonies to start meliponaries, whereby the host tree is not destroyed: the tree is opened up, the colony collected and the tree closed again with natural resins.

More facts on bees:

- Along with wasps, honeybees (*Apis mellifera*) are the most important food insects in northern Thailand. Bee brood features commonly in local diets and is in high demand in markets; therefore, it is often expensive (Chen *et al.*, 1998).
- In Malawi, beekeeping is more than three times as profitable as growing maize, a staple crop (Munthali and Mughogho, 1992).
- In Australia, the hive (referred to as honeybag or sugarbag) of native stingless bees (*Trigona* spp.) is a popular source of sugar for Aborigines (Cherry, 1991; O'Dea *et al.*, 1991).

Orthoptera (locusts, grasshoppers and crickets)

About 80 grasshopper species are consumed worldwide, and the large majority of grasshopper species are edible. Locusts may occur in swarms, which makes them particulary easy to harvest. In Africa, the desert locust, the migratory locust, the red locust and the brown locust are eaten. However, due to their status as agricultural pests they may be sprayed with insecticides in governmental control programmes or by farmers. For example, relatively high concentrations of residues of organophosphorus pesticides were detected in locusts collected for food in Kuwait (Saeed, Dagga and Saraf, 1993).

Grasshoppers and locusts are generally collected in the morning when the temperature is cooler (and the insects, being cold-blooded, are relatively immobile). In Madagascar, there is a common saying: *"Comment pourriez-vous attraper les sauterelles pondeuses et faire la grasse matinée en même temps?"* ("one needs to waken early in the morning to catch grasshoppers"). In Oaxaca, the harvest of chapulines (edible grasshoppers of the genus *Sphenarium*) only takes place very early in the morning (04:00–05:00 hours) (Cerritos and Cano-Santana, 2008) because chapulines are too active and difficult to catch during the hotter part of the day (Cohen, Sanchez and Montiel-ishinoet, 2009).

In the West African nation of Niger, it is not uncommon to find grasshoppers for sale in local markets or sold as snacks on roadsides. Remarkably, researchers found that grasshoppers collected in millet fields fetched a higher price in local markets than millet (van Huis, 2003b).

The chapuline is probably the best-known edible grasshopper in Latin America. This small grasshopper has been a part of local diets for centuries and is still eaten in several parts of Mexico. The valleys of Oaxaca state are especially famous for the consumption of chapulines. Cleaned and toasted in a little oil with garlic, lemon and salt for flavour, they are a common food ingredient among not only indigenous communities but also the urban population in Oaxaca city (Cohen *et al.*, 2009). Chapulines are brachypterous, which means they have reduced, non-functional wings. *Sphenarium purpurascens* is a pest of alfalfa but also one of the most important edible insects in Mexico. Harvesters use conical nets (about 80 cm in diameter and 90 cm deep) without handles to lightly beat the alfalfa plants, allowing each local family to obtain about 50–70 kilograms (kg) of grasshoppers weekly (Cerritos and Cano-Santana, 2008). Chapulines play a significant role in local small-scale markets as well as in restaurants and export markets. Despite the nutritional and cultural value of chapulines, recent studies have shown that the grasshoppers can contain high and sometimes dangerous amounts of lead (Cohen, Sanchez and Montiel-ishinoet, 2009).

In Asia, the crickets *Gryllus bimaculatus*, *Teleogryllus occipitalis* and *T. mitratus* are harvested in the wild and commonly consumed as food. The house cricket (*Acheta domesticus*) is also reared and commonly eaten, particularly in Thailand, and is preferred over other species because of its soft body. In a study carried out in Thailand in 2002, 53 of 76 provinces had cricket farms (Yhoung-Aree and Viwatpanich, 2005). As of 2012, there were about 20 000 cricket farmers in Thailand. Additionally, the short-tail cricket (*Brachytrupes portentosus*), which has a large body and large head, is also quite popular for eating. However, this species cannot be farmed and therefore is only collected in the wild (Y. Hanboonsong, personal communication, 2012).

Despite the extensive practice of farming insects, only two species of edible cricket (*Gryllus bimaculatus* and *Acheta domesticus*) are farmed economically. Others, such as *Tarbinskiellus portentosus*, cannot be farmed due to their long life cycles. However, there are signs of change in the Lao People's Democratic Republic and Cambodia: sellers are now saying that consumers prefer farmed crickets over those collected in the wild because they taste better (P. Durst, personal communication, 2012).

Homoptera (cicadas, leafhoppers, planthoppers and scale insects), a suborder of the Hemiptera

In Malawi, several cicada species (*Ioba*, *Platypleura* and *Pycna*) are highly esteemed as food. Cicadas can be found on the trunks of trees and collected using long reeds (*Phragmites mauritianus*) or grasses (*Pennisetum purpureum*) with a glue-like residue on them, such as latex from the *Ficus natalensis* tree. The latex adheres to the cicadas' wings, which are removed before consumption. Some Homoptera yield products commonly eaten by humans, such as carmine dye (a bright red pigment also called E120) derived from the cactus cochineal bug (*Dactylopius coccus*) often used in food products. Humans also consume lerp, a crystallized, sugary secretion produced by the larvae of psyllid insects as a protective cover. In South Africa, for example, the psyllid (*Arytaina mopane*) that feeds on the phloem sap of the mopane tree (*Colophospermum mopane*) is eaten. The largest number of lerp-building psyllids is found on *Eucalyptus* species in Australia. Australian Aborigines collect lerp as a sweet food source (Yen, 2005). See section 2.4.3 for more information on lerp.

Heteroptera (true bugs), suborder of Hemiptera

Pentatomid bugs are eaten widely throughout sub-Saharan Africa, particularly in southern Africa (see section 2.4.4). In the Republic of Sudan, the pentatomid *Agonoscelis versicolor*, a pest of rainfed sorghum that causes considerable damage, is eaten roasted. Oil is also derived from these insects and is used in preparing foods and for treating scab disease in camels (van Huis, 2003a).

Most pentatomids consumed as food, however, live in water. The famous Mexican caviar, ahuahutle, is composed of the eggs of at least seven species[5] of aquatic Hemiptera (the *Corixidae* and *Notonectidae* families); these insects have formed the backbone of aquatic farming, or aquaculture, in Mexico for centuries (Box 2.8). The semi-cultivation of these species is simple and inexpensive because it can be undertaken using traditional local practices (Parsons, 2010) (see Chapter 4). The insects fetch high prices, particularly during the *Semana Santa* (the week preceding Easter). The semi-cultivation of Hemiptera is under threat, however, as a result of heavy pollution and dried-up water bodies (Ramos Elorduy, 2006).

BOX 2.8

Ahuahutle, Mexican caviar

In *Historia de las cosas de la Nueva España*, Sahugan (1557) stated that at the court of Emperor Montezuma and the Aztec kings that preceded him prior to the tenth century, the ahuahutle were prepared especially during ceremonies dedicated to the god Xiuhtecutli. Native runners brought the ahuahutle into Tenochtitlan from Texcoco so that the Emperor could have them fresh for breakfast. Sahugan called them aoauhtli or ahuauhtli and reported that the common name used by the people was *aguaucle*, which meant "seeds of the water". He also reported that they were eggs deposited by flies on the surface of stagnant waters in infinite numbers and were sold in the marketplace of Texcoco and other neighbouring villages.

Source: Bachstez and Aragon, 1945.

Isoptera (termites)

The most commonly eaten termite species are the large *Macrotermes* species. The winged termites emerge after the first rains fall at the end of the dry season, from holes near termite nests. van Huis (2003b) observed that, in Africa, locals beat the ground around termite hills (simulating heavy rain) to provoke the termites to emerge.

Syntermes species are the largest termites eaten in the Amazon. They are gathered by introducing a palm leaf rib into the galleries of the nest; the soldiers biting it are then fished out (Paoletti *et al.*, 2003; Paoletti and Dufour, 2005). More information on termites is provided in section 2.3.3.

2.2.3 Where and when are insects eaten?

The frequency of insect consumption around the world is poorly documented. The few examples found in literature are from Africa, Asia and Latin America.

Africa

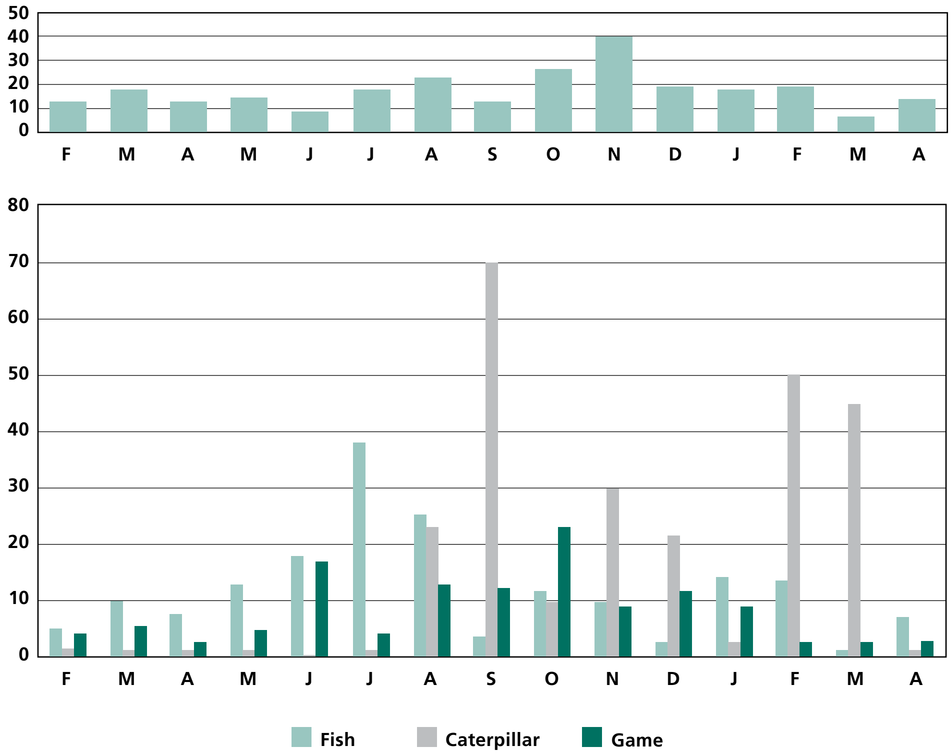
Insects can be found in abundance throughout the African continent and when staples are scarce they become important sources of food. During the rainy season – when hunting game or fish can be problematic – insects play an important role in food security. Caterpillars are especially popular during the rainy season, although their availability can vary even within the same country depending on climatic conditions (Vantomme, Gohler and N'Deckere-Ziangba, 2004); Table 2.1 shows the seasonal abundance of caterpillars in Central Africa.

The seasonal availability and correlated consumption of insects is well documented by Takeda and Sato (1993). A study carried out in tropical rainforest in the Democratic Republic of the Congo shows the remarkable resourcefulness of the Ngandu people, who obtain nourishment from what is seasonally available: cultivated and wild-gathered

[5] *Corisella mercenaria* (Say), *C. texcocana* (Jacz), *Krizousacorixa femorata* (Guér), *K. azteca* (Jacz), *Graptocorixa abdominalis* (Say), *G. bimaculata* (Guér) (Hemiptera-Corixidae) and *Notonecta* spp. (Hemiptera-Notonectidae).

plants, mushrooms, mammals, birds, fish, reptiles and insects. An earlier study carried out in the same country found that the availability of caterpillars is strongly correlated with declines of fish and game (Pagezy, 1975) (see Figure 2.3).

FIGURE 2.3
Monthly rainfall (top) and monthly occurrence of meals of fish, caterpillars and game in 15 consecutive months in the Lake Tumba region, Democratic Republic of the Congo



Source: Pagezy, 1975.

Markets in Kinshasa, the capital of the Democratic Republic of the Congo, boast an abundant year-round supply of caterpillars, and the average household in Kinshasa eats approximately 300 g of caterpillars per week. It has been estimated that 96 tonnes of caterpillars are consumed in the city annually (Kitsa, 1989). Consumption of the mopane caterpillar by far exceeds that of other caterpillars: 70 percent of Kinshasa's 8 million inhabitants are estimated to eat the caterpillars, for both their nutritional value and their taste (Vantomme, Gohler and N'Deckere-Ziangba., 2004).

Caterpillars also provide an important source of protein during the rainy season (July to October) in the Central African Republic (Bahuchet, 1975; Bahuchet and Garine, 1990), particularly for pygmies. In the rainy season, average consumption is estimated at 42 freshly harvested caterpillars per person per day. Consumption in the remainder of the year is much lower, although the insects are available year-round, either dried or smoked (see Figure 2.3). The indigenous Gbaya have been documented to consume 96 different insect species; this amounts to 15 percent of their protein intake (Roulon-Doko, 1998).

In some places, the consumption of insects is correlated with the availability of staples. In Madagascar, the consumption of rice declines at the end of the dry season and the consumption of caterpillars rises (Decary, 1937). Locals harvest caterpillars from forest trees at the end of the dry season as leaves develop just before the rain. The caterpillars can also be dried and stored for use in times of food shortage. In southern Africa, emperor moth caterpillars (Saturniidae) are widely consumed during food-deficient periods of the year.

TABLE 2.1
Abundance of caterpillars in Central Africa

Country	Province	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
CAR							■	■	■	■			
Cameroon								■	■	■	■		
DR Congo	East Kasaï						■	■					
	West Kasaï							■	■	■			
	Bandundu									■	■	■	■
	Kinshasa									■	■	■	■
Rep. du Congo	Sangha								■	■			
	Likoula								■	■			
	Brazzaville										■	■	■
	Pool	■											
	Plateaux	■											

Source: Roulon-Doko, 1998.

Asia

Between 150 and 200 species of edible insect are consumed in Southeast Asia. Red palm weevils (*Rhynchophorus ferrugineus*) from the Sago palm (*Metroxylon sagu*) are especially popular across the continent and are a highly prized delicacy in many regions (Johnson, 2010). Some insects are available year-round, including many aquatic species, while others are only available on a seasonal basis. Table 2.2 shows the annual availability of

TABLE 2.2
Availability of edible insects, Lao People's Democratic Republic, by month

Habitat	Common name (scientific name)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Aquatic	Water scorpion (*Laccotrephus* sp.) (Nepidae)	■	■	■	■	■	■	■	■	■	■	■	■
	Diving beetle (*Cybister* sp.) (Dytiscidae)	■	■	■	■	■	■	■	■	■	■	■	■
	Water scavenger (*Hydrophilus* sp.) (Hydrophilidae)	■	■	■	■	■	■	■	■	■	■	■	■
	Dragonfly larvae	■	■	■	■	■	■	■	■	■	■	■	■
	Giant water bug (*Lethocerus indicus*) (Belostomatidae)	■	■	■	■	■	■	■	■	■	■	■	■
Ground	Cricket (*Tarbinskiellus portentosus*) (=*Brachytrupes achatinus*) (Gryllidae)										■	■	■
	Scale insect (*Drosicha* sp.) [Monophlebidae = Margarodidae]	■	■	■									
	Dung beetles (Scarabaeinae)	■	■	■	■	■						■	■
Tree/ Bush/ Shrub	Cicada (Cicadidae)			■	■	■							
	Weaver ant (*Oecophylla smaragdina*) (Formicidae)			■	■	■							
	Stink bug (*Tessaratoma quadrata*) (Pentatomidae)				■	■	■						
	Scarabid beetle (*Holotrichia* sp.) (Scarabaeidae)				■	■	■						
	Grasshoppers (Orthoptera)					■	■	■	■	■			
	Bamboo caterpillar (*Omphisa fuscidentalis*) (Pyralidae)							■	■	■	■		

Source: Nonaka, 2010.

selected insect species in the Lao People's Democratic Republic. There, and in Myanmar, Thailand and Viet Nam, various insect species are collected throughout the year from a range of habitats; in this way, people can obtain a steady supply of edible insects (Yhoung-Aree and Viwatpanich, 2005) (see Table 2.3).

TABLE 2.3
Availability of edible insects in Thailand, by month

Month	Insect
January	Grasshopper, tortoise beetle, skipper
February	Adult red ant, dung beetle, scarab beetle, stink bug
March	Cicada, termites, dung beetles
April	Dung beetle, grasshopper
May	Ground cricket
June	Giant water bug, wood-boring beetle, predaceous diving beetle
July	Back swimmer, crawling water beetle, damselfly, spider
August	Bee hornet, wasp, beetle
September	Rhinoceros beetle, spider
October	Cricket
November	Long-horned beetle
December	Mole cricket, river swimmer, true water beetle, water scavenger beetle, water scorpion beetle

Source: Yhoung-Aree and Viwatpanich, 2005.

Present day entomophagy in many Asian countries is the result of migration patterns. For example, insects have long been an important part of diets in northeastern Thailand, but as a result of labour-migration to tourist areas in southern parts of the country, including Bangkok, the practice is now well established throughout the country (Yen, 2009); it is estimated that as many as 81 insect species are consumed in both rural and urban areas there. Additionally, over 50 insect species are consumed in South Asia (India, Pakistan and Sri Lanka), 39 species in Papua New Guinea and the Pacific Islands, and 150–200 species in Southeast Asia (Johnson, 2010).

Latin America

In Mexico, indigenous people possess a deep knowledge of the plant and animal species that traditionally make up their diets, including the life cycles of insects (Ramos Elorduy, 1997) (Box 2.9). Insects have been "calendarized" by species, meaning that they are believed to operate in harmony with natural phenomena such as plant life cycles, moon cycles, rainy seasons and thunder. It is widely known among indigenous people, for instance, that escamoles (larvae of the ants of the *Liometopum* genus) are ready to harvest when the jarilla plant (*Senecio salignus*) is flowering. In Oaxaca, Mexico, the harvest of chapulines begins with the onset of the rainy season and continues throughout this season. In the Amazon, insect gathering is also a seasonal affair. Maku Indians, an indigenous group of hunter-gatherers living in the tropical forest of northwestern Amazonia in Brazil, gather insects during the rainy season (from July to September) when hunting fish and game is difficult (Milton, 1984). In the Colombian Amazon, the Nukak community harvests larvae of *Rhynchophorus* species during the rainy season (Politis, 1996).

In the Ecuadorian highlands, the *Platycoelia lutescens* beetle can be found in Quito's markets from late October to early November; they are collected during winter rains. The beetles are harvested when they emerge from the soil in meadows and grasslands and are relatively easy to collect. It is believed that vibrations caused by rain and the sound of thunder trigger their emergence (Smith and Paucar, 2000). Not all insects, however, are harvested during the rainy season. For example, the larvae of the South American palm weevil (*Rhynchophorus palmarum*) and bearded weevil (*Rhinostomus barbirostris*)

BOX 2.9

Wild food consumption by the Popoloca people of Los Reyes Metzontla Puebla, Mexico

Food availability

Wild foods provide important supplements to the diet of the Popoloca people, particularly when maize and bean reserves are lean (Table 2.4). Wild plants and insect species are primarily available during the rainy season, from April to October, and before the harvest of maize and beans. The Popoloca typically gather wild foods as they go to work in their agricultural plots. In May, for example, several cacti fruits, such as chende (*Polaskia chende*), chichipe (*Polaskia chichipe*), xoconostle (*Stenocereus stellatus*), pitaya (*Stenocereus pruinosus*) and nopal de monte (*Opuntia depressa*), are harvested, along

Continued next page

TABLE 2.4

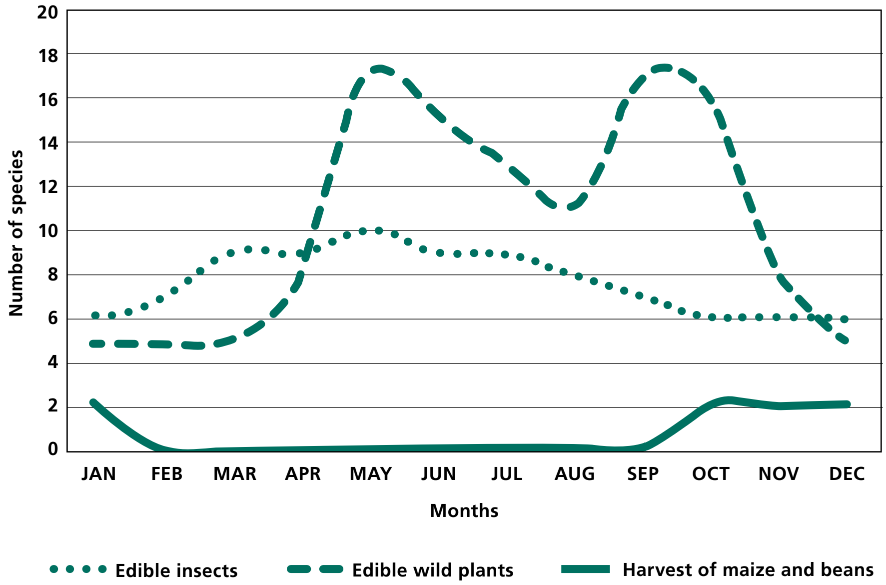
Available insect and insect products for the Popoloca people of Los Reyes Metzontla Puebla, Mexico

Month	Insect and insect products	Approximate amount of consumption
Year-round	Cazahaute worm	From ¼ to ½ litre two to three times a year per family
	Wasp nest (five species)	From 1 to 4 nests a year per family
	Apis mellifera honey	No data available
January	Year-round insects	-
February	*Comadia redtenbacheri*	Around 1 litre once or twice a year per family
March	Mormidea (Mormidea) *Notulata* and *Euschistus* sp.	From 1 to 2 litres once or twice a year per family
	Comadia redtenbacheri	Around 1 litre once or twice a year per family
	Plebeia mexica honey	Collected once a year during spring
April	Mormidea (mormidea) *Notulata* and *Euschistus* sp.	From 1 to 2 litres once or twice a year per family
	Thasus gigas	From ¼ to 2 litres one to three times a year per family
	Plebeia mexica honey	Collected once a year during spring
May	Mormidea (mormidea) *Notulata* and *Euschistus* sp.	From 1 to 2 litres once or twice a year per family
	Plebeia mexica honey	Collected once a year during spring
	Aegiale hesperiaris	Around 50 larvae each season per family
	Atta mexicana	From ¼ to 1 litre once a year per family
June	*Aegiale hesperiaris*	Around 50 larvae each season per family
	Pochocuile	Around one or two "medidas" (12 larvae) once a year per person
July	*Aegiale hesperiaris*	Around 50 larvae each season per family
	Pochocuile	Around one or two "medidas" (12 larvae) once a year per person
August	*Paradirphia fumosa*	From a couple of "medidas" (15 larvae) per person to 3 litres per family once a year
	Gusano del pirul	From ¼ to 1 litre two or three times a year per family
September	*Paradirphia fumosa*	From a couple of "medidas" (15 larvae) per person to 3 litres per family once a year
October	Year-round insects	-
November	Year-round insects	-
December	Year-round insects	-

Source: Acuña *et al.*, 2011.

Box 2.9 continued

FIGURE 2.4
Temporal availability of edible insects, wild plants and subsistence crops for the Popoloca people of Los Reyes Metzontla Puebla, Mexico



Source: Acuña *et al.*, 2011.

with insects such as chinches (stink bugs), conduchos (white agave maguey worm *Aegiale hesperiaris*) and chicatanas (the leafcutting ant *Atta mexicana*). Most of these insects (about 60 percent) are available from February to September, while about 40 percent are consumed year round (e.g. wasp nests).

Frequency and quantity
The frequency and quantity of insect consumption depend on three main factors: the consistency of climatic conditions, which can affect the quantity of insects harvested; personal choice; and chance encounters during other subsistence activities (e.g. farming) for species that are used opportunistically.

Source: Acuña *et al.*, 2011.

are collected by the Joïti people in northeastern Amazonia, Venezuela, from September to January at the end of the rainy season. Rain, in fact, keeps adult beetles away and increases the occurrence of fungal attack (Choo, Zent and Simpson, 2009).

2.3 EXAMPLES OF IMPORTANT INSECT SPECIES CONSUMED
This section describes some of the most consumed insect species but is by no means exhaustive.

2.3.1 Caterpillar
Caterpillars are among the world's most diverse groups of edible insects. They are not only valuable sources of protein and other micronutrients, they also make valuable contributions to livelihoods in many parts of the world. Among the most renowned are

the witchetty grubs[6] consumed in Australia (Meyer-Rochow, 2005) and the bamboo caterpillar (*Omphisa fuscidentalis*), which is popular in Thailand and the Lao People's Democratic Republic (Yhoung-Aree and Viwatpanich, 2005). The consumption of caterpillars is especially pervasive in sub-Saharan Africa, where 30 percent of all edible insect species are caterpillars (van Huis, 2003b). Malaisse (1997) listed 38 species of edible caterpillars on the basis of intensive studies in the region inhabited by the Bemba (Bantu-speaking people in the northeastern plateau of Zambia and neighbouring areas of the Democratic Republic of the Congo and Zimbabwe). In the Democratic Republic of the Congo, caterpillars make up 40 percent of the total animal protein consumed (Latham, 2003) (Box 2.10). The most popular and profitable caterpillar on the African continent is undoubtedly the mopane caterpillar, *Imbrasia* (=*Gonimbrasia*) *belina*.

Mopane caterpillar

The mopane woodlands are found in Botswana, Namibia, Zimbabwe and northern parts of South Africa. It is in this vast habitat that the mopane caterpillar thrives. Local knowledge of the insect's ecology and biology in some rural communities is extensive (Mbata, Chidumayo and Lwatula, 2002). Its distribution is largely correlated to that of its principal host, the mopane tree (*Colophospermum mopane*). The mopane caterpillar is bivoltine in most areas; that is, two generations are produced each year (the first between November and January, its major outbreak, and the second between March and May) (Stack *et al.*, 2003; Ghazoul, 2006).

Like many other edible insects, mopane caterpillars are not merely "famine foods", consumed in times of food shortage. Although the caterpillars are important sources of nutrition in lean times, they also form a regular part of the diet (Stack *et al.*, 2003).

BOX 2.10

Yansi sayings, Democratic Republic of the Congo

"Caterpillars and meat play the same role in the human body."

"As food, caterpillars are regulars in the village but meat is a stranger."

Source: Muyay, 1981.

Collecting, processing, trading and consuming the mopane caterpillar is an integral part of local cultures, but it is especially a livelihood strategy among marginalized groups (Illgner and Nel, 2000; Stack *et al.*, 2003). The caterpillars are collected by hand – primarily by women and children – and then degutted, boiled in salted water and sun-dried. Dried mopane caterpillars will last for several months and can be a valuable source of nutrition in times of stress. Harvesting and trading the caterpillars also provides important income for many rural families; this is often the prime incentive for harvesting (Stack *et al.*, 2003), and the income is comparable with and often higher than that generated by conventional agricultural crops (Munthali and Mughogho, 1992; Chidumayo and Mbata, 2002). The income generated by the mopane caterpillar harvest provides many families with funds to purchase household items such as clothing, school materials and basic utensils (Stack *et al.*, 2003; N'Gasse, 2004). Vast numbers of people partake in the mopane harvest: the nutritional and economic incentives are so high that many are willing to travel hundreds of kilometres across the mopane woodlands in search of the insects (Kozanayi and Frost, 2002).

[6] A term used in Australia for large, white, wood-eating larvae of the cossid moth (*Xyleutes* (=*Endoxyla*) *leucomochla*), a traditional Aboriginal delicacy.

The protein content of the mopane caterpillar is 48–61 percent and fat content is 16–20 percent, of which 40 percent is essential fatty acids. Mopane caterpillars are also a good source of calcium, zinc and iron (Glew *et al.*, 1999; Headings and Rahnema, 2002). See Chapter 6 for more information on nutrition.

2.3.2 Palm weevil

> "*Larvae assate in deliciis habentur*" [fried larvae are delicious] – Linneus on *Rynchophorous* spp. in the 1758 work *Systema Naturae*.

Larvae of the palm weevil (*Rynchophorous* spp.) are consumed in Asia (*R. ferrugineus*), Africa (*R. phoenicis*) and Latin America (*R. palmarum*). Their delicious flavour (Cerda *et al.*, 2001) is credited by some to their elevated fat content (Fasoranti and Ajiboye, 1993). In the tropics, the insects occur year-round where hosts are found. Often these hosts are trees under stress; that is, trees previously damaged by other insects, notably rhinoceros beetles (*Oryctes* spp.) or by the local traditional tapping for palm wine (Fasoranti and Ajiboye, 1993). Fallen palms can serve as breeding sites and support hundreds of larvae; for this reason, palms are often felled intentionally. Such a practice is common among Yanomamö (Chagnon, 1983) and Jöti Indians (Choo, Zent and Simpson, 2009) of the Amazon. Van Itterbeeck and van Huis (2012) noted that many indigenous people have excellent ecological knowledge of the palm weevil and can increase its availability and predictability through semi-cultivation practices. Experiments in Alto Orinoco villages have explored ways of making the production of palm weevils more sustainable than traditional palm cutting to improve the oviposition (egg-laying) of *R. palmarum* and other palm weevils (Cerda *et al.*, 2001).

Ecology

Palm weevils attack palm species, the most important of which are the coconut palm (*Cocos nucifera*), date palm (*Phoenix dactylifera*), sago palm (*Metroxylon sagu*), oil palm (*Elaeis guineensis*) and Raphia palm (*Raphia* spp.). For the African palm weevil, Fasoranti and Ajiboye (1993) noted that adult females lay a few hundred eggs on the new leaves of the plant or directly in the palm trunk. The weevil larvae burrow into the palm heart, causing its death. The total life cycle takes seven to ten weeks. A fully extended larva measures, on average, 10.5 cm in length and 5.5 cm in width and weighs 6.7 g. Extracting larvae from palms is labour-intensive and is often only carried out by young men (Fasoranti and Ajiboye, 1993).

BOX 2.11

Red palm weevil

The Red palm weevil, *Rhynchophorus ferrugineus*, is prevalent in most Asian countries and in the Middle East. It reached the Mediterranean in the 1980s as an invasive species, destroying over 13 000 date palms in Sicily by August 2009. The beetle has also spread along the Mediterranean coast and invaded mainland Italy and is killing trees as far north as Genoa. In Italy, its destruction is mainly limited to the ornamental plant *Phoenix canariensis*. The main control method in the country and throughout the Mediterranean is the systematic use of insecticides.

Source: Mormino, 2009.

Detecting the larvae

In the Democratic Republic of the Congo it is customary for women to detect the most opportune moment to harvest weevil larvae and longhorn and scarab beetles – which occur in standing or rotting *Elaeis*, *Raphia*, *Chamaerops* and *Cocos nucifera* palm trees (Ghesquière, 1947) – by putting their ears against the trees and listening to the sound made by the chewing and burrowing beetle larvae. This method is also used in Cameroon to harvest the palm weevil larvae (*Rhynchophorus phoenicis*) in its most appropriate instar (developmental stage) for consumption (van Huis, 2003b). The same practice has been documented in the Central African Republic (Roulon-Doko, 1998) and the Americas (Ghesquière, 1947; Wolcott, 1933). In Italy, forest inspectors have been known to use electronic listening devices to detect early infestations of the red palm weevil, given that when symptoms of the damage become apparent the palm tree will die (Box 2.11).

Consumption

Palm weevil larvae are typically collected, washed and fried for consumption (Fasoranti and Ajiboye, 1993). It is unusual to add oil because the larvae are high in fat and exude oil during the frying process. Common condiments include onion, pepper and salt. Barbecuing the larvae is also common practice.

In Nigeria, adults discourage children from eating palm weevil larvae. It is thought that this is done to prevent children from felling palm trees, which can increase breeding sites for the available stock of number of larvae to be harvested in the short term but would cause irrevocable long-term damage to host trees (Fasoranti and Ajiboye, 1993). Protecting palm trees is considered essential to communities, who depend on them for other key products, including palm oil, palm kernels and palm wine.

2.3.3 Termites

In the Western world, termites are generally synonymous with pests and are renowned for their capacity to devour wood. Damage from termites is said to cost over half a billion dollars per year in the United States of America alone. Yet termites are considered a delicacy in many parts of the world. They are consumed both as main and side dishes, or simply eaten as snack foods after they have been de-winged, fried and sun-dried (Kinyuru, Kenji and Njoroge, 2009).

Although they are often erroneously referred to as ants or white ants, termites occupy a different order to ants, viz. Isoptera. Edible termites, which typically belong to a family of macrotermites (Macrotermitinae), generally consist of the winged form that swarm from termite hills shortly after the first rains begin at the end of the dry season (often called the nuptial flight). These winged termites are the future queens and kings. They can be eaten, as can soldier termites. Termites are known to have large and elaborate nests; some species have nests as tall as 8 m, and a single nest may house as many as 1 million individuals consisting of workers, soldiers, a queen and a king. The global biomass of termite individuals is believed to exceed that of all human beings combined.

Termites cannot digest cellulose and lignin, so their digestive systems contain symbiotic protozoa and bacteria that digest the cellulose in wood. Termites live on the byproducts of this digestion and on the bodies of the symbionts themselves. For example, species of macrotermites use fungi in their nest, which aid in breaking down cellulose and lignin into a more nutritious source of food. The fungi are part of an extracorporeal digestive system that converts undigested woody material in plants into higher-quality oligosaccharides and more easily digestible complex sugars. In turn, termites "outsource" cellulose digestion. This digestion is responsible for about 4 percent of global GHG emissions from methane (Sanderson, 1996).

Queen and soldiers

Queen termites are considered particularly important delicacies, often reserved for special occasions (van Huis, 2003b). Their nutritional value is so high that in Uganda and Zambia they are fed to undernourished children. However, digging queens – which are capable of laying 2 000 eggs per day and measure up to 10 cm in diameter – is laborious, and their removal causes the death of entire colonies.

The consumption of soldiers of larger termite species has been documented in the Central African Republic, the Democratic Republic of the Congo, the Bolivarian Republic of Venezuela and Zimbabwe (Bequaert, 1921; Bergier, 1941; Owen, 1973; Chavanduka, 1976; Roulon-Doko, 1998; Paoletti *et al.*, 2003). They are often fried or pounded into cakes. Sometimes, for example in Uganda, only the heads are eaten (van Huis, 2003b). Termite soldiers can only be collected in small quantities, and generally collection is by women and children (Roulon-Doko, 1998). Unlike the winged forms, the soldiers can be gathered at any time of the year.

Collecting termites

Winged termites can be collected in a number of ways. In urban areas, they are trapped in receptacles with water near light sources, to which they are attracted. In rural areas, winged termites are typically caught at the termite mound itself. When they emerge – attracted by the light of a bundle of grass set on fire – they are swept into a hole dug for the purpose. In parts of the Democratic Republic of the Congo, people place baskets upside down over the holes so that the termites, which cling to the bottom of the baskets, fall into the holes when the baskets are shaken (Bergier, 1941). Instead of baskets, structures made of sticks or elephant grass covered with banana or maranta leaves or a blanket are also used to cover the holes (Bergier, 1941; Osmaston, 1951; Roulon-Doko, 1998). All escape routes are fenced off so that the termites are forced to emerge through a single opening on one side of the structure, to which the flying termites are attracted because of light from the sun, moon, torch or fire. A receptacle is placed near this opening to collect the termites (Harris, 1940; Bergier, 1941; Ogutu, 1986). Osmaston (1951) described how, in Uganda, intricate networks of clay pipes were assembled over the emergence holes, leading to a receptacle. It has also been reported that continuous beating and drumming on the ground (resembling rain) around termite hills triggers certain termite species to emerge (Owen, 1973; Ogutu, 1986; Roulon-Doko, 1998). Recently, Ayieko *et al.* (2011) combined modern technology with a indigenous practice for collecting termites (Box 2.12).

BOX 2.12

Merging traditional knowledge and new technologies for termite harvesting in Kenya

In Kenya, a study carried out in cooperation with Kenya Industrial Development found that constructing a simple light trap and receptor would facilitate the mass collection of *Macrotermes subhyalinus*, known in the Lake Victoria region as agoro, and lead to increased food security among those communities practising entomophagy.

The study proposed teaching communities in the region to construct traps using local and readily available materials in order to maximize collection and stressed the need to develop local familiarity with the various species of termites. For example, understanding the emergence pattern of the agoro termite – in short, identifying potential active mounds – would maximize collection. It would be equally important to take stock of changing environmental contexts. Merging modern science with indigenous practice shows promise, but further research is necessary to understand why there is so much variation in current yields, among other issues.

Source: Ayieko *et al.*, 2011.

Eating termites and nutritional value

Termites are rich in protein, fatty acids and other micronutrients. Fried or dried termites contain 32–38 percent proteins (Tihon, 1946; Santos Oliveira *et al.*, 1976; Nkouka, 1987). Essential fatty acids such as linoleic acid are particularly high in the African above-ground hill termite species, *Macrotermes bellicosus* (34 percent) and *M. subhyalinus* (43 percent) (Santos Oliveira *et al.*, 1976). In the Bolivarian Republic of Venezuela, soldiers of *Syntermes* species (e.g. *Syntermes aculeosus*) are renowned for their high nutritional value. The protein content of this species is a remarkable 64 percent; the genus is also rich in essential amino acids such as tryptophan, iron, calcium and other micronutrients.

Termites are generally consumed fried, sun-dried or smoked, although they are steamed in banana leaves in Uganda. To sun-dry or smoke termites they must first be killed by boiling or roasting for a few minutes (Silow, 1983). Sometimes they are crushed into powder form with a pestle and mortar and eaten with honey (Ogutu, 1986). The Azande people and pygmies in the Democratic Republic of the Congo fry meats in the fat residue of these termites (Bequaert, 1921; Bergier, 1941). The pygmies also use the oil to treat their body and hair. Termite oil is extracted by pressing dried termites in a tube (Costermans, 1955). In many East African towns and villages, sun-dried termites can be bought at local markets (Osmaston, 1951; Owen, 1973). Sun-dried termites can be ground into powder and mixed with other food ingredients (Pearce, 1997) by baking, boiling, steaming or processing them into crackers, muffins, sausages or meat loaves (Kinyuru, Kenji and Njoroge, 2009; Ayieko, Oriamo and Nyambuga, 2010). In Botswana, San women collect the winged termites *Hodotermes mossambicus* and roast them in hot ash and sand (Nonaka, 1996).

Termites as feed for pigs, poultry and fish

The use of termites as feed is documented in several countries. In Burkina Faso, termites are harvested using small calabashes, which are ingeniously filled with moist old dung, mango pits and other organic material and placed under the ground (van Huis, 1996). Three to four weeks later, the calabashes are unearthed and the contents – filled with termites – are fed to poultry. Such methods are particularly important at the end of the dry season when food is scarce (Iroko, 1982). Farina, Demey and Hardouin (1991) have shown how termites are fed to guinea fowls and chickens in villages in Togo using a technique comparable to that used in Burkina Faso. Swarming alates have been used to feed jungle fowl chicks in India and also ostriches in farms across Africa (Pearce, 1997).

Mushrooms from termite nests

In addition to termites, mushroom species found growing on termite nests are consumed regularly in many tropical countries. Wild mushrooms constitute important food supplements for local populations and also have a role in cultural traditions. In many parts of Africa, mushrooms are commonly found in markets, and are also stored for use during the cold dry season (Parent and Thoen, 1977). In Nigeria, Yoruba traditional doctors use a number of *Termitomyces* species (Lyophyllaceae) as medicines or charms. These mushrooms also have a place in mythical folklore (Oso, 1977).

Mushrooms belonging to the *Termitomyces* genus arise directly from the fungal combs in termite nests (Zoberi, 1973). The local names for these mushrooms are often derived from the local names for the termites. In Uganda, for example, the Nyoro tribe uses the term obunyanaka for mushrooms that grow on mounds of termite species known as enaka, while obunyantaike mushrooms grow on hills of the termite species entaike. Species of *Termitomyces* are large (up to 80 cm in diameter), with the exception of *T. microcarpus*, which is 0.5–2 cm in diameter (Parent and Thoen, 1977); this latter species is found across West Africa and in southern Africa (Skelton and Matanganyidze, 1981).

2.3.4 Stink bugs

Throughout Mexico (Ramos Elorduy and Pino, 2003), southern Africa and Southeast Asia, it is not uncommon to find people eating stink bug (Hemiptera: Pentatomidae) nymphs and adults (DeFoliart, 2002). In southern Africa, *Encosternum* (=*Natalicola*) *delegorguei* are considered delicacies. Stink bugs are consumed in Malawi, South Africa and Zimbabwe (Faure, 1944; van Huis, 2003b; Morris, 2004), while *Tessaratoma* species, *T. papillosa* (litchi stink bug), *T. javanica* (longan stink bug) and *T. quadrata* ("mien kieng", a local name in the Lao People's Democratic Republic) are widely sought-after in China, the Lao People's Democratic Republic and Thailand (Nonaka, 2007; Chen, Feng and Chen, 2009).

Ecology

Encosternum delegorguei, commonly known as the edible stink bug (thongolifha in the Venda language, xipembele in the Tsonga language and podile in the Northern Sotho language, southern Africa) are large, herbivorous, pale-green bugs with piercing and sucking mouthparts that they use to feed on plant juices (Triplehorn and Johnson, 2004). The name stink bug derives from the smell the insects release when they are disturbed (Aldrich, 1988). Stink bugs are collected from May to August, the period in which they occur in large numbers (Faure, 1944; Dzerefos, Witkowski and Toms, 2009). In Southeast Asia, aggregations of *Tessaratoma* species occur in a variety of trees during the dry season (peaking in March and April) (J. Van Itterbeeck, personal communication, 2012). Stink bugs also feed on crops and for this reason are considered agricultural pests (Panizzi, 1997).

Livelihoods

Inflated stink bugs or tessaratomids make an important contribution to rural diets in many parts of the world. In Zimbabwe, stink bugs are a valuable source of income for the Norumedzo community and are essential for buying household items and covering school fees (Makuku, 1993). Stink bugs are exported to neighbouring countries due to high demand, and collectors are known to travel up to 200 km to areas rich in stink bugs (Teffo, 2006).

Data on the nutritional value of stink bugs, however, are scarce, although some accounts do exist. According to Teffo (2006), *E. delegorguei* has a protein and fat content of 35.5 g per 100 g and 50.6 g per 100 g of edible weight, and consuming 100 g of *E. delegorguei* provides 2 599 kilojoules of energy. This species was also found to be high in minerals such as iron, potassium and phosphorus. In Southeast Asia, stink bugs of the *Tessaratoma* genus are especially esteemed. In the Vientiane Municipality, the Lao People's Democratic Republic, they are collected, consumed and sold *en masse* (J. Van Itterbeeck, personal communication, 2012).

Stink bugs are collected by hand throughout southern Africa, as well as in Southeast Asia. Collecting often results in yellow or orange staining from defensive secretions (Faure, 1944), which is why collectors tend to cover their hands with plastic bags (J. Van Itterbeeck, personal communication, 2012), and long sticks with nets attached to one end are also used. The insects are dislodged from trees by throwing small sticks or by shaking branches (J. Van Itterbeeck, personal communication, 2012). Collectors take special care to protect their eyes, as they believe secretions cause infections of the cornea and even blindness (Faure, 1944; Siripanthong *et al.*, 1991). It is easiest to collect the bugs when temperatures are cool – in the early morning, at sundown and especially after rain showers (Faure, 1944).

In both southern Africa and Southeast Asia, stink bugs are eaten both raw and cooked (Faure, 1944; J. Van Itterbeeck, personal communication, 2012). The heads of live or dead bugs are removed by squeezing (from back to front), which discards their "poison" (Faure, 1944; Toms and Thagwana, 2003). In the Lao People's Democratic Republic, only the scutellum (neckpiece) is removed after frying; it is said to be the source of its bitter taste (J. Van Itterbeeck, personal communication, 2012). Soaking the bugs in water, as well as immersing them in tepid water, also causes the insects to release their secretions; they can then be sun-dried for consumption (Toms and Thagwana, 2003). The water in which *Nezara robusta*, the green shield stink bug, leaves its secretions is used as a pesticide to protect houses and gardens from termites (Morris, 2004).

Ecological implications

Stink bugs face similar threats to many other highly sought-after edible insects. Because they have become a significant source of income and nutrition, over-harvesting and mismanagement of their habitats are increasing concerns. One reason for this is that many amateur collectors fell entire trees prior to harvest, with dangerous consequences for the sustainability of the practice (Faure, 1944; J. Van Itterbeeck, personal communication, 2012). In addition, overharvesting can and eventually will undermine stink bug populations, threatening subsequent copulation periods (beginning in mid October). Another issue has consequences for both the environment and food safety – stink bugs of the *Tessaratoma* genus are considered agricultural pests and may be subject to chemical treatment (e.g. the lychee stink bug, *Tessaratoma papillosa*, which is found on *Litchi chinensis*) (Menzel, 2002), which is a public health concern. The harvesting of stink bugs could protect crops and provide additional income and nutrition; eradication of the pest would likewise eradicate an important source of livelihoods, which should be avoided (Cerritos, 2009).

In some parts of the world, the benefits of insect gathering to lives and livelihoods are incentives for proper management. The Norumedzo community in Zimbabwe, for example, has designated stink bug habitats as community-protected areas. These forests are continually monitored and tree-felling is kept to a minimum (Makuku, 1993).

Some agricultural fields where stink bugs occur are subject to mechanical harvesting. In these cases, stink bugs are collected by hand to preserve the crop and earn income from the sale of the bugs. This method is becoming increasingly common in cultures where agricultural pests are also valuable sources of nutrition and income.

2.3.5 The edible grasshopper, *Ruspolia differens*

Development and collection

The edible grasshopper (*Ruspolia differens*), formally known as *Homorocoryphus nitidulus vicinus*, is a long-horned grasshopper of the Tettigoniidae family. It is a common food source in many parts of eastern and southern Africa. In the Lake Victoria region of East Africa, where the grasshoppers are known as nsenene, they form a major part of food culture (Kinyuru, Kenji and Muhoho, 2010). The Bahaya ethnic group in Tanzania's Bukoba district considers grasshoppers a delicacy. In Uganda, nsenene are traditionally collected by women and children.

Grasshopper eggs – which are laid in batches in the haulms of grasses – do not develop under dry conditions. Rainfall triggers development, which takes about four weeks (McCrae, 1982). Larvae and adults feed off grass anthers or grains such as rice, millet, sorghum and maize. Traditionally, grasshoppers are gathered during the day from these grasses (Mors, 1958).

"Okulinga ensenene" means that the Bahaya peoples (in Tanzania) step out of their huts in the early morning to look for nsenene in the fields. When they find them, they cry loudly to announce to the village where the nsenene have alighted – in banana groves or open fields, or on the hills. The young and old, especially women and children, go out to catch them. The grasshoppers may be gathered anywhere they fall, and owners of banana groves, for example, cannot expel as trespassers those who come to collect the ensenene. In collection times, the land is considered communal.

Today, expanding access to artificial light sources has made it possible to collect grasshoppers at night with relative ease. Professional collectors can be seen using potent artificial light sources to harvest grasshoppers, although women and children also participate, making use of street illumination (van Huis, 2003b). Some collectors are even charged by electricity companies (US$170 per month) for the provision of constant night-time electricity (Agea *et al.*, 2008). A loss of electricity supply can play havoc on the income earned from harvesting edible grasshoppers (Box 2.13).

BOX 2.13

Power cuts harm Uganda's edible grasshopper business

Power rationing is a common feature in Uganda, with some Kampala households experiencing blackouts lasting more than 48 hours. This has made life difficult for many Ugandan grasshopper catchers and traders.

Julius Kafeero, a grasshopper catcher from the Ugandan capital, Kampala, says electric light is vital for his business. The unreliability of the power supply has forced him and several other collectors to rely on alternative sources of power such as fuel generators.

Despite rising prices, fried grasshoppers remain a delicacy in Uganda. Juliet Nakalyango, a saleswoman at Nakasero market, says customers still buy her grasshoppers, even though prices have doubled. A spoonful of grasshoppers now costs about €0.40 (US$0.50). Last season, the same amount would have bought a whole plastic cupful.

Source: Gitta, 2012.

Commerce

In Uganda, a market study of *Ruspolia nitidula* in Kampala and Makaka districts found that, being a delicacy, 1 kg of grasshoppers fetched prices at local markets that were 40 percent higher than 1 kg of beef (Agea *et al.*, 2008). The study, which interviewed 70 traders and 70 consumers, revealed that retailers bought three-quarters of their supply from wholesalers, and the remainder was derived directly from collectors. The majority of the traders, moreover, indicated that the trade in *R. nitidula* was concentrated along roadsides and/or in service areas along highways. Although men were dominant actors in the trade, women also contributed to collecting. The wholesale price of the grasshoppers was about US$0.56 per kg, while the retail price was about five times higher (US$2.80). On average, traders generated revenues of more than US$200 per season from the sale of *R. nitidula*. One of the issues hindering the sale of *R. nitidula*, however, is that the insect is only seasonally available and shelf life is short.

Other grasshopper species

In Japan, grasshopper harvesting (mainly *Oxya yezoensis*) is connected to the rice harvest. Collection occurs in the morning, when the grasshoppers are wet from the morning dew. The grasshoppers are kept alive for one night after they are collected to allow time for the faeces to be expelled. The next day they are fried or boiled and the legs are removed, as these are not suitable for eating. After being sun-dried, the grasshoppers are cooked in soy sauce and sugar. They are eaten in the autumn as a side dish or snack. Some people store them for up to a year. However, the harvesting and consumption of grasshoppers in Japan has declined in recent years (Nonaka, 2009).

Rice-field grasshoppers are eaten in most Asian countries. In Korea, they were commonly eaten as a side dish, as a lunch-box ingredient and as a snack. The use of rice-field grasshoppers declined during the 1960s and 1970s due to increased insecticide use. In 1981, the rules mandating insecticide use loosened and farmers started using less, which allowed grasshopper populations to increase. The decline in insecticide use and the desire of some Koreans to eat pesticide-free rice led to the development of organic rice farming in Chahwang Myun. This was economically viable because the yields of rice were the same in unsprayed fields as in sprayed fields, and organic rice sold for higher prices. In 1989, the Chahwang Agricultural Cooperative, which functions primarily to buy, mill and sell rice, began to buy dried grasshoppers from farmer-collectors. Three species were present. *Oxya velox* was the most common species (yellow-green and 27–37 mm in length, found in Japan and China and on the Korean Peninsula and the island of Taiwan), comprising 84.5 percent of the total, followed by *Oxya sinuosa* with 14.8 percent and *Acrida lata* with less than 1 percent. In 1991 and 1992, the Chahwang Myun Cooperative continued to buy and sell large numbers of grasshoppers and many people came to buy directly from farmers (Pemberton, 1994).

Forty years ago in Thailand there was an outbreak of the patanga locust (*Patanga succincta*) in maize. Aerial spraying of insecticide did not succeed and a campaign to promote the eating of the patanga locust was initiated between 1978 and 1981. The grasshoppers were deep-fried, used as a cracker ingredient and fermented to make a cooking sauce. Today, the grasshopper (deep-fried) is one of the best-known and most popular edible insects in Thailand, and this species is no longer a major agricultural pest. Some farmers even grow maize crops to feed the insect, rather than harvesting the maize for sale (Hanboonsong, 2010).

The commercialization of grasshoppers is highly dependent on the region. In the Lao People's Democratic Republic, grasshoppers (*Caelifera* spp.) consume weaver ants, the second-best-selling insect on the market (Boulidam, 2010). A number of grasshopper species are collected for family consumption when clearing fields for paddy planting. Cooking is simple: the grasshoppers are salted lightly, boiled in a little water and simmered until dry. Sometimes they are stir-fried, while the bigger ones are deep-fried until crisp, like fried prawns. They can be roasted as well. Usually grasshoppers are served as a single dish and not mixed with vegetables or meat (Chung, 2010).

In Mexico, grasshoppers (*Sphenarium purpurascens*), commonly known as chapulines, are a popular form of street food. Although generally available at informal street stands and small-town restaurants, grasshoppers, among other insects, are now also found on the menus of more expensive restaurants, and dried packaged grasshoppers can be purchased in up-market shops (Ramos Elorduy, 2009).

2.4 IMPORTANT INSECT PRODUCTS

A wealth of bee products – including honey, propolis and beeswax, among others – are well known among the public and are documented extensively by Bradbear (2009). The fact that silk fabric is obtained from silkworms is common knowledge. Yet the general public is less aware of a host of other insect products, many of which are found in most kitchen cabinets, medicines and other household products. Carmine, for example, also called cochineal, is a red dye produced by scale insects, and is typically used to colour food products and as a dye in textiles and pharmaceuticals. Despite its widespread use and approval by the United States Food and Drug Administration, carmine has recently been the subject of controversy, outraging consumers of a popular American coffee chain company because of its use in its beverages (Box 2.14). Silkworm pupae are considered a delicacy in Asia (see section 2.4.2). Lerp (see section 2.4.3) and a host of edible oils derived from pentatomid bugs (see section 2.4.4) are other insect products in common use.

2.4.1 Cochineal

Cochineal (carmine) is a red dye obtained primarily from *Dactylopius coccus* and is used in the food, textile and pharmaceutical industries. The insects live on the cactus *Opuntia ficus-indica*, which is cultivated for its fruits known as prickly pears. The Canary Islands, Chile, Ecuador, Peru and the Plurinational State of Bolivia are the largest

BOX 2.14
Controversial use of cochineal

In early 2012, controversy developed over the Starbucks Coffee Company's strawberry Frappuccino®, after the popular international coffee conglomerate stated that the pink colour of the beverage originated from cochineal extract made from dehydrated and cochineal beetles.

Prior to using cochineal extract, Starbucks had used artificial additives and chose to switch to a more natural means of colouring (Leung, 2012). When this was brought to the attention of a group of vegan[7] consumers in the United States, the story went viral through blogs and web forums and was widely reported in North American media.

In a comment to consumers, the President of Starbucks United States noted that in response to consumer reactions to the use of cochineal extract in some of its products, the company would now use a tomato-based colouring (Burrows, 2012). Within the United States and Canada, the use of the conchineal extract is permitted by their respective food and drug administrations (Health Canada, 2006; USFDA, 2009).

[7] The vegan diet excludes the consumption of animal and animal products, including insects.

producers of cochineal. Between 2000 and 2006, world production increased more than 2.5 times because of increased demand due to growing interest in natural dyes in the food industry (for such products as Campari and Danone strawberry yogurt). In 2006, national production in Peru amounted to 2 300 tonnes (85 percent of global production), with an export value of US$39.6 million. The biggest importers of carmine are Brazil, Denmark, France, Germany and the United States. Other carmine products in Peru include carmine lacquer (US $12.9 million), dried cochineal (US$3.65 million) and carmine acid (US$2.03 million) (Torres, 2008).

In addition to its uses in the food industry, cochineal production has provided a host of social benefits for Peruvians, not least employment. Moreover, production has been hailed for its environmental benefits, as the planting of its host plant, *Opuntia ficus-indica*, protects open spaces from erosion, develops fertile soil for farming, and captures a significant amount of atmospheric carbon.

2.4.2 Silkworm products

Silkworm production is an ancient practice in many parts of Asia, as well as in Europe since its introduction after the crusades. In China, evidence of mulberry production dates back 5 000 years. The famous trade route known as the Silk Road stretched from eastern China to the Mediterranean Sea, making trade in silk, among other products, an international affair as far back as 139 BCE. Silkworm production also has considerable economic relevance, particularly in China and India, where annual production reaches 115 000 and 20 410 tonnes, respectively. More recently, Brazil, Thailand and Uzbekistan have also produced significant quantities.

Aside from mulberry silkworms, significant silk production is obtained from, in decreasing relevance, the Chinese (oak) tussah moth (*Antheraea pernyi*), the camphor silkworm (*Eriogyna pyretorum*), the Thai (or eri) silkworm (*Philosamia* (=*Samia*) *cynthia ricini*) and the Japanese oak silkmoth (*Antheraea yamamai*). Chinese tussah silkworm cocoons production yielded 60 000 tonnes in 2005. Male moths are also used to produce health food products and health wines. In addition, pupae are traditionally eaten and sold in many markets and by vegetable grocers in northeastern China (Zhang, Tang and Chen, 2008). Silkworm pupae are commonly eaten in other Asian countries, including Japan and Thailand and on the Korean Peninsula.

The Thai silkworm is a traditional product that is now distributed on a global scale. The worm is considered a commercially viable product, not only because it produces considerable quantities of silk, but also because its pupae – considered delicacies in China, Japan, Thailand and Viet Nam – are high in protein, making them extremely valid sources of nutrition. About 137 000 households raise silkworms in Thailand, contributing to 80 percent of the country's total silkworm production and to incomes in poor rural households throughout the country. About US$50.8 million was generated from production in 2004 (Sirimungkararat *et al.*, 2010). Pupae of the silkworm are sold processed, packaged and labelled. As such, Thai silkworm pupae can be considered one of the first – if not *the* first – insect product on the global market.

Interest in the possibilities of using silkworms and mulberries for non-textile purposes by making use of silkworm waste was highlighted at the 22nd Conference of the International Sericulture Commission (ISC, 2011). The possibility of silkworm and mulberry production for pharmaceutical and nutritional ends was also explored at the Conference on Sericulture for Multi Products – New Prospects for Development, organized by the Black, Caspian Seas and Central Asia Silk Association (BACSA, 2011). In India, research at the Department of Sericulture at the Tamil Nadul Agricultural University is exploring the possibility of using the high waste streams of the silkworm industry as feed in broiler production (ISC, 2011). In the Republic of Korea, silkworm powder is being produced as a medicine for diabetics because of its blood glucose-lowering effect (Ryu *et al.*, 2012).

2.4.3 Lerp

Lerp is a crystallized sugary secretion produced by the larvae of psyllid insects (belonging to the Hemiptera order) as a protective cover. Psyllids excrete an array of substances because the phloem sap on which they feed is rich in carbohydrates and low in essential nutrients, such as nitrogen; thus, they must suck large amounts of phloem sap to obtain sufficient nutrients and the remainder is excreted as honeydew. The cones of psyllids consist of the insect itself, the secretion and the five exoskeletons the insect sheds when it moults. The conical structures adhere firmly to leaves. Normally the entire insect "cone" is eaten.

Several hundred species of lerp-producing psyllids are found on *Eucalyptus* species in Australia (Yen, 2002). There are also lerp-forming species in Africa and Japan (although possibly only one species in each of these locations). Lerps may have evolved to reduce desiccation in arid environments, and they are an important food source for many birds and mammals. In Australia, for example, the bell miner bird (*Manorina melanophrys*) "farms" psyllid nymphs by removing lerps as a food source but leaving the nymphs, which then construct new lerps (Austin *et al.*, 2004).

The word lerp is derived from the Australian Aboriginal word "larp" for the thick encrustations that form on the insects, which are traditionally collected for food

BOX 2.15

Using scale insects to enhance honey production

The scale insect *Marchalina hellenica* has been introduced in some Mediterranean areas, mainly Greece and Turkey, to increase honey production. The insect sucks the sap of pine trees such as *Pinus brutia*, *P. halepensis*, *P. sylvestris*, *P. nigra* and *P. pinea*. The honeydew the insect produces is an important source of food for honeybees, which produce pine honey. Artificial infestation by beekeepers has resulted in a loss of ecological balance between the insects and their natural predators. As a result, surrounding pine trees are stressed and dying (Gounari, 2006).

(Yen, 2005). Manna, a broader term cited in the Bible and Qu'ran as a "gift of God" that "came from heaven", is believed to denote the same substance, which was found on forest floors, trees and shrubs. While manna has also been used to describe sugary exudations from plants and entire organisms like lichen or fungi (Harrison, 1950), it is also used to refer to manna of animal origin produced indirectly on host plants, including excretions from aphids or coccids, which are insects that feed by sucking up plant juices.

One such "manna" product is mopane bread, which is produced by the psyllid *Arytaina mopane*. These insects feed on the phloem sap of the mopane tree (*Colophospermum mopane*), a common tree species in southern Africa (Sekhwela, 1988). The mopane caterpillar (*Imbrasia belina*) can leave large areas of host trees leafless, and as such is a competitor for lerp production (Hrabar *et al.*, 2009). In nature, animal species often share and compete for food resources. The mopane caterpillar shares its primary food source, the mopane tree, with elephants. Elephants often break stems and branches of mopane trees when feeding and also destroy the plant species preferred by mopane moths for oviposition. Not surprisingly, this elephant activity has been documented to have a negative effect on the abundance of mopane caterpillars (Hrabar *et al.*, 2009). This demonstrates the interdependency of a vertebrate species – the elephant – and two invertebrates – the psyllid and the mopane caterpillar.

Mopane bread delivers 250 calories per 100 g. It has a high percentage of monosaccharides and water-insoluble carbohydrates, low protein content and a high concentration of potassium and phosphorous (Ernst and Sekhwela, 1987), making it a valuable source of nutrition. Mopane bread is only available, however, during the dry season, as rain washes the product from the leaves of trees, although it can be sun-dried and stored. Mopane bread is said to make a delicious meal when mixed with milk (Sekhwela, 1988).

Lerp was particularly popular among Australian Aborigines (Bourne, 1953). Affected leaves were collected and soaked to dissolve the sugar, which acted as a dietary supplement. Yen (2002) described how, in the Australian state of Victoria, lerps were either eaten raw or as a mixture with gum from *Acacia* trees. In arid areas, affected *Eucalyptus* branches were collected and put in the sun and the dried lerps were shaped into balls to be eaten at leisure.

2.4.4 Edible oils from the melon bug and the sorghum bug in the Republic of Sudan

The melon bug (*Coridius* (=*Aspongopus*) *vidutus*) is widely distributed throughout the Republic of Sudan, mainly in the western areas of Kordofan and Darfur states, where field watermelons are considered one of the most important crops in traditional rainfed agriculture. Small farmers in these states consider watermelons a strategic crop because of their role as a main source of drinking water during summer and the use of their crop residues as fodder for animals. For this reason, the melon bug is still very much considered a pest – in fact, it is considered the primary pest of watermelons because of the damage it inflicts on watermelon crops. Both nymphs and adults of the bug pierce leaves, stems and young fruits and suck their sap, resulting in wilting, fruit drop and ultimately the death of the plant.

Although the melon bug is considered a pest, its culinary uses are appreciated throughout the country. Melon bugs are generally cooked in their last nymph stage, when they are relatively soft. In Namibia, locals collect the adults and use them as a relish or spice (in powder form). In the western Kordofan state of the Republic of Sudan, the oil extracted from the bugs (after soaking in hot water), known locally as um-buga, is an important source of nutrition. It is also used in cooking in remote areas of the former Sudan and is particularly important when food is scarce. Melon bug oil is used in medicine, for example to cure skin lesions (Mariod, Matthäus and Eichner, 2004).

Besides the nutritional benefits of melon bugs – specifically their oil – the insects boast antibacterial properties. Mustafa, Mariod and Matthäus (2008) tested the oil against seven bacterial isolates and found high antibacterial activity. They concluded that the oil could potentially be used as a preservative in meat and meat products to control gram-positive bacteria (most pathogens in humans are gram-positive). Research has also shown that only very slight chemical changes take place in melon bug oil preserved at temperatures below 30 °C for two years. Furthermore, it was demonstrated that the oxidative stability of sunflower kernel oil was improved by blending it with the highly stable edible oils of the melon bug (as well as the sorghum bug) (Mariod *et al.*, 2005).

The sorghum bug (*Agonoscelis pubescens*) is consumed in Sudan and is known locally as dura (the main pest of sorghum) in both rainfed and irrigated areas. The bugs hibernate from September to December, when they can be found on trees in clusters or in crevices between rocks (van Huis, 2003b). People in the Nuba Mountains in Kurdufan can often be found collecting the insects from these crevices. In western parts of the former Sudan, sorghum bug adults are collected and eaten after frying, and in some areas oil is extracted from the bugs and used for cooking and in medicine. In the Botana area of the former Sudan, nomads use the tar obtained from the bugs after they have been heated to treat their camels for dermatological infections (Mariod, Matthäus and Eichner, 2004). The potential use of these bug oils as biodiesel has been explored, opening insect-related research to an entirely new field (Mariod *et al.*, 2006).