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Insects as food and feed in the Asia Pacific region: current perspectives and future directions

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REVIEW ARTICLE

Abstract

Western cultures currently struggle to have insects accepted as a human food. This barrier is not as high in many parts of the Asia Pacific region because entomophagy is (or was until recent times) a part of their accepted diets. The region is comprised of many different cultural groups and the degree to which they embraced entomophagy has been determined by dietary needs, cultural considerations, and the availability of insects. While entomophagy has decreased in westernised societies, the demand for edible insects has increased in parts of Asia in association with rising standards of living. An assessment of the use of insects as food and feed in the Asia Pacific region is provided and important knowledge gaps are identified. Edible insects are sourced by three main strategies: wild harvesting, semi-domestication of insects in the wild, and farming. Semi-domestication and farming have the potential to provide a more sustainable food supply, but globally 92% of species are wild harvested. The harvested insects come from all trophic levels, although most of the terrestrial edible insect species are herbivores and most species of edible aquatic species are predators. The increased demand for edible insects puts pressure on the source populations because new technologies are now used to harvest insects more efficiently and to store them safely for longer periods, facilitating the harvesting of greater amounts of insects. This, in combination with either loss of natural habitats or changes to the environment, puts even more pressure on insect populations. The over harvesting of edible insects from different trophic levels could have long term adverse implications for ecosystem processes in Asia Pacific and other regions.

Keywords: Asia Pacific, entomophagy, sustainable harvesting

1. Introduction

With the increased demand for animal-based food to feed the exponentially growing global population, insects have been advocated as a source of food because of their diversity, apparent abundance, and the lower ecological footprint required for their production (FAO, 2013; Van Huis *et al.*, 2013). Attitudes towards accepting insects as food vary geographically, and are determined by cultural and human health issues (Van Huis *et al.*, 2013). Currently the highly industrialised continents are the ones where human entomophagy is not readily accepted. However, this lack of acceptance may not be such a barrier in continents where entomophagy was or is still part of the normal diet.

The Asia Pacific region has had a long history in the use of insects as human food or as animal feed. According to Yi *et al.* (2010), insects were consumed in China 3,200 years ago. This includes the wild harvesting of insects as food, insect farming, and the use of insects in small village level animal production systems involving fish or poultry. This paper will briefly review the use of insects as food or feed in the Asia Pacific region, then assess one of the main questions facing increased insect consumption: how sustainable is wild harvesting, what are the ecological implications of over-harvesting, and can semi-domestication of insects or insect farming be solutions? While the main subject in this paper is insects, the use of spiders and non-marine molluscs as food and medicinal insects are referred to when they are relevant to issues associated with food insects.

2. Insects as food and feed in the Asia Pacific region

The Asia Pacific region is defined as Northern Asia, Southeast Asia, Southern Asia, and Oceania and does not include the islands and continents on the eastern side of the Pacific Ocean. It is environmentally and culturally diverse, and each country has had different histories of settlement. The Asian nations maintain much of their cultural identities, while Australia and New Zealand have been changed considerably by European settlement. One of the consequences of this geographical and cultural diversity is that the ways that insects have been used as food or feed are also quite diverse, both in the degree in which they are used, in the species used, and how they are used. Many Asian and Pacific nations do not have the negative attitude of insect food found in the west (De Foliart, 1999). As a consequence, trying to gain acceptance of food insects may not be such a problem. There are still barriers to success that include the lack of baseline information (what is eaten, how different cultures use or used them), the reluctance to eat insects due to increasing Western influence and the globalisation of fast foods, health and safety issues, and legislative requirements.

The extent of entomophagy in the Asia Pacific nations is based on available published information and summarised in Table 1. Each country is assessed in terms of whether insects are wild harvested, semi-domesticated (habitat manipulation to increase production) or farmed, and whether they are used for subsistence or commercial purposes. A positive indication in the columns does not reflect the degree or importance of the use of insects in each country and no entry indicates that it has not been recorded there. It is difficult to quantify the information any further because of the lack of reliable information from each country. What is apparent is that the wild harvesting of food insects is widespread across the region for both subsistence and commercial purposes. Where semi-domestication is the mode of production, it is predominantly for subsistence use although some is sold at domestic markets. Farming involves mainly crickets and silkworms, the latter as a by-product of silk production.

Increasing commercialisation: the Thai experience

One train of thought is that insects are only eaten by 'primitive' people or only as a last resort in times of famine. This is definitely not true in many cultures and, insects are often a food of choice (along with other types of foods) (Ramos-Elorduy, 2009). The main evidence for this is that the demand for insects as food has increased along with rising standards of living and increasing globalisation

Table 1. Insects as human food in the different Asia Pacific nations according to the mode of production.[1]

Country	Wild harvesting		Semi-domestication		Farming	
	Subsistence	Commercial	Subsistence	Commercial	Subsistence	Commercial
Australia	x	x	x			x
Cambodia	x	x			x	
China	x	x	x		x	x
Fiji	x					
India	x	x	x		x	x
Indonesia	x	x	x			
Japan	x	x	x	x		
Laos	x	x	x		x	
Malaysia	x		x			
Myanmar	x	x				
New Caledonia	x	x				
New Zealand	x					
North Korea	x					
Pakistan	x					
Papua New Guinea	x		x			
Philippines	x					
Samoa	x					
Solomon Islands	x					
South Korea	x	x			x	x
Sri Lanka	x					
Taiwan	x					
Thailand	x	x	x	x	x	x
Timor Leste	x					
Tonga	x					
Vietnam	x				x	x

[1] The information for each nation is based on the following sources: Australia (Yen, 2010; Yen *et al.*, 2012); Cambodia (Münke *et al.*, 2014); China (Chen *et al.*, 2009, 2010; Demick, 2013; Feng *et al.*, 2010; Jäch, 2003; Yi *et al.*, 2010; Zhang *et al.*, 2008); India (Ao and Singh, 2004; Chakravorty *et al.*, 2013; Doley and Kalita, 2012; Imtinaro *et al.*, 2012; Meyer-Rochow, 2005; Meyer-Rochow and Chakravorty,, 2013; Sarmah, 2011); Fiji (Pond, 1994); Indonesia (Césard, 2004, 2006; Edwards, 1998; Lukiwati, 2010; Rana, 2014; Shugart, 2010); Japan (Mitsuhashi, 2005; Nonaka, 2009b, 2010; Pemberton, 2003); Laos (Boulidam, 2010; Hanboonsong and Durst, 2014; Nonaka, 2009a; Nonaka *et al.*, 2008; Van Itterbeek *et al.*, 2014); Malaysia (Chung, 2010); Myanmar (De Foliart, 2002); Nepal (De Foliart, 2002); New Caledonia (Bresica *et al.*, 2008); New Zealand (Hayward and Brook, 1981; Pond, 1994); North Korea (Meyer-Rochow, 2013); Pakistan (De Foliart, 2002); Papua New Guinea (Dwyer, 1985; Dwyer and Minnegal, 1991, 1992; Meyer-Rochow, 1973, 2005; Duffels and Van Mastrigt, 1991; Mercer, 1992, 1997; Ramandey and Van Mastrigt, 2010; Schiefenhövel and Blum, 2007; Tommaseo-Ponzetta and Paoletti, 2005); Philippines (Adalla and Cervancia, 2010; Anonymous, 1993); Samoa (Pond, 1994); Solomon Islands (Pond, 1994); Sri Lanka (De Foliart, 2002; Tennent, 1861); South Korea (Pemberton, 1994, 2003); Taiwan (various people, personal communications); Thailand (Boongird, 2010; Hanboonsong, 2010; Hanboonsong *et al.*, 2013; Leksawasdi, 2010; Prachaiyo, 2000; Sirimungkararat *et al.*, 2010; Yhoung-Aree, 2010); Tonga (Pond, 1994); and Vietnam (De Foliart, 2002).

(westernisation) of foods in parts of Africa, Asia and Latin America, where the cost of insects can exceed the cost of more conventional animal meats.

Thailand is an example of a nation where the standard of living is rising and the country is becoming more westernised. Insects have been part of the normal diet in parts of Thailand (Bristowe, 1932), but the practice has become more widespread over the last few years. This is partly due to demographic changes within Thailand, such as the internal movement of Isaan people from the north east throughout Thailand to seek employment. While some insects are sold to be used as ingredients in dishes, a lot of the insects are consumed as snacks that appeal to both Thais and foreign tourists (Yen *et al.*, 2012). This has resulted in increased demand for insects, and in the establishment of new market supply chains. Instead of a simple supply chain of insects collected by people as a subsistence diet or to be traded or sold at local markets, the chain involves traders who sell to wholesalers that distribute insects to small retailers or to larger supermarkets (Figure 1). This increased commercialisation is accompanied by more effective collecting techniques, improved transport networks, storage of insects in freezers so that out of season demand can be met, and there is also an export industry for insects as food (Hanboonsong *et al.*, 2013). A similar scenario exists in parts of China (Yi *et al.*, 2010). This has put more pressure on wild populations of edible insects, but also has led to the establishment of more productive methods to obtain insects, namely semi-domestication and insect farms. This raises the important questions whether there are enough insects to meet increasing demand, and whether the modes of production are sustainable.

3. Insect diversity and abundance: are they an infinite resource?

Insect diversity and abundance

Insects are considered the most species rich group of animals, comprising anywhere from 70-95% of all animal species (Chapman, 2009) and their biomass can be very high in some ecosystems (Fittkau and Klinger, 1973). There are several generalisations about insects that are associated with their diversity: small size, short generation times, high reproductive rates, and large population sizes. Consequently they are viewed as a potential unlimited resource. There are many exceptions, and while many species of insects fulfil these criteria, many do not.

Just how many species of insects are suitable for human food or animal feed is not known. Currently around 2,000 species of insects are known to be consumed by people (Jongema, 2014). There are about 1.1 million described species of insects globally, and there could be a total of more than 6 million species globally (Hamilton *et al.*, 2010). The number of known edible species is only a fraction of the estimated number of species, but we have no idea of just how many species are suitable as food or feed. The relatively small number of insect species consumed is probably dependent upon availability and personal dietary preferences but a larger number of species could be utilised in the future if we consider using insects as feed or as a food additive. This could reduce reliance on too few species for food (as is the current situation with many conventional species of plants and animals).

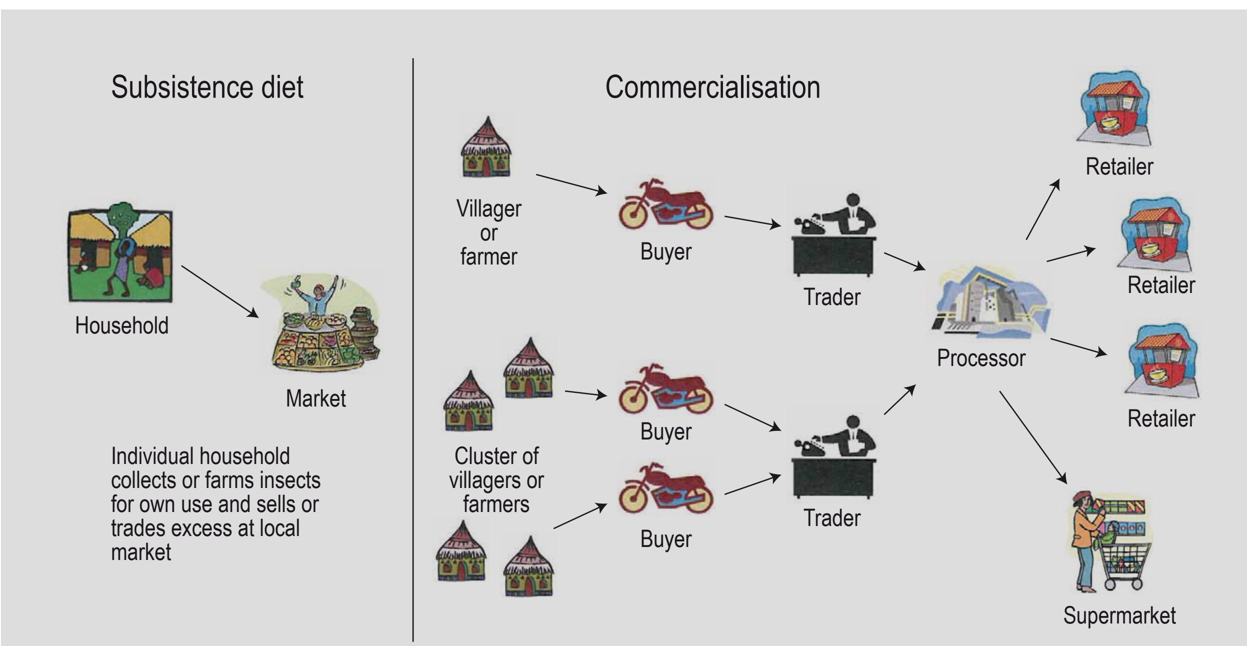

Figure 1. Market chain of edible insects in Thailand for subsistence use and for the retail sector.

One of the important questions is simply how many individuals of a species can be harvested without threatening the long term survival of the species? Bodenheimer (1951) provides some figures about the annual amount of insects sold as food. These range from 0.1-8 tons of caterpillars (Africa), 3-5 tons Hemiptera (Mexico), 16 tons aquatic insects (Zaire), 30 tons ants (Mexico), 183 tons silkworms (India), an unknown but large amount of termites, and 5-170 tons Orthoptera (Algeria, Mexico, Thailand) (Bodenheimer, 1951; Kunckel d'Herculais, 1891). Parsons (2010) estimated that Lake Texcoco in Mexico may have provided 3,900 metric tons of aquatic insects (including eggs) annually as both food and agricultural fertiliser in pre-Hispanic Mesoamerica. Although these are only snap shot figures, the annual figures are in the range of 0.1-200 tons, and this is most probably at the lower end of the range. The figures are very low compared to the potential biomass available.

Insect production methods

Edible insects can be obtained in three ways: (1) wild harvesting; (2) semi-domestication (habitat manipulation to increase production); or (3) farming (which can range from the single small cage scale through to a large factory). The range for wild harvesting is 0.1-200 tons annually (Bodemheimer, 1951), semi-domestication can produce 2-43 tons annually (higher for aquatic Hemipteran eggs in Mexico) (Hanboonsong *et al.*, 2013; Parsons, 2010), while farms in Thailand can currently produce 7,500 tons of crickets annually (Hanboonsong *et al.*, 2013), and China produces over 250,000 tons of silkworm pupae annually (http://www.fao.org/economic/ess/en/#.U9eHe8scRYU). These three modes of production are not sequential steps in a technological pathway. Farmed insects were initially wild harvested, but some wild insects cannot be domesticated. There is no doubt that farming insects can produce much greater volumes of insects with fewer adverse impacts on the natural environment compared to wild harvesting the same volume of insects. However when the global list of known edible insects (Jongema, 2014) is assessed as to whether they are wild harvested, semi-domesticated, or farmed, the vast majority of species are wild harvested (Figure 2). The results indicate that 92% of known edible insect species are wild harvested, 6% are semi-domesticated and only 2% are farmed. The figure for wild harvesting is likely to increase as more information about the extent of entomophagy is collected. Egan (2013) summarises the importance of wild harvesting: (1) insects are a traditional food; (2) they taste good; and (3) importantly, they are free. In most cases, wild harvesting is conducted because the people do not have the knowledge or the infrastructure to farm insects.

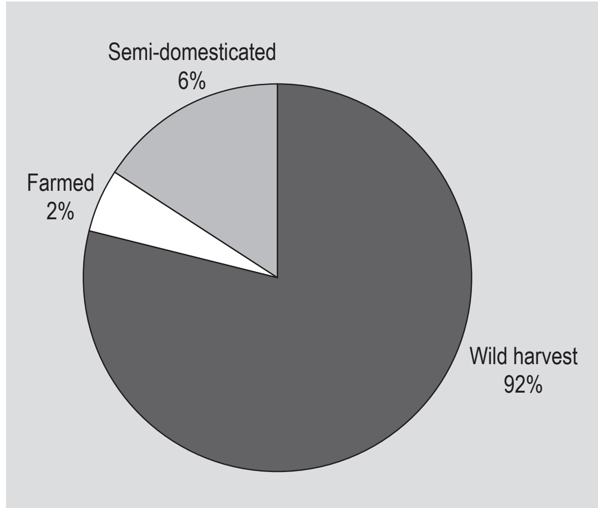

Figure 2. Percentages of the known edible insects that are wild harvested, semi-domesticated, or farmed (data from Jongema, 2014).

Harvesting agricultural pests

A common suggestion about eating insects is that it could be a way to reduce pests. Bodenheimer (1951) cites examples of the harvesting of plant pests from Bangladesh, Benin, Cameroon, China, India, Mexico, Nigeria, Philippines, and Sudan. Bristowe (1932) records consumption of insect pests in Thailand. The plant pests consumed were primarily beetles (Coleoptera), true bugs (Hemiptera) and grasshoppers and locusts (Orthoptera). One of the more recent benefits of harvesting plant pests is that it could result in the reduced use of synthetic insecticides. Conversely, there is the danger that insects could have high levels of pesticides as in one case of locusts in Kuwait (Saeed *et al.*, 1993). In South Korea, rice field grasshoppers were a traditional food until large population declines occurred due to the mandatory application of insecticides in the 1970-1980s. Reduced insecticide use in the late 1980s saw an increase in grasshopper numbers and the revival of grasshopper consumption in the 1990s (Pemberton, 1994). In the Philippines, an outbreak of *Locusta migratoria* was mitigated by paying people to collect the locusts to sell as food or feed because authorities were not able to source insecticides (Anonymous, 1995).

Does harvesting plant pests for consumption actually reduce pest impact? The patanga or Bombay locust (*Patanga succincta*) occurs in several Asian countries (Steedman, 1990). In the 1970s, *P. succincta* was a widespread and destructive pest of maize in Thailand, and from 1978-1981, there was a programme to promote its use as food. Now it is a popular food and is not considered a pest anymore; some farmers even grow maize as a food source for the locust (Hanboonsong, 2010). The harvesting of locusts as food originated because the sale of pesticide contaminated insects resulted in illnesses and possibly death amongst human consumers (Goton, 1988 in De Foliart, 2005). As pesticide control of locusts was not working anyway, authorities in Prachin Buri Province convinced villagers to collect them as food and in 1983, 10 tons were used as food in that province (Lewvanich *et al.*, 1999 in Hanboonsong *et al.*, 2013). To meet demand now, 170 tons are imported annually from Cambodia (Ratanachan, 2009 in Hanboonsong *et al.*, 2013).

In Nigeria, the preferred method to control the stinking grasshopper (*Zonocerus variegates*) is capture and consumption rather than using insecticides (Idowu and Modder, 1996). The decline in grasshopper outbreaks in parts of Nigeria over the past three decades is attributed to the establishment of profitable businesses collecting grasshoppers as food (Sharah, 2012). People in the grasshopper trade want to see the cessation of practices that reduce grasshopper population viability, namely chemical pest control and also bush-burning. In Mexico, the grasshopper *Sphenarium purpurascens* is controlled by insecticides. Cerritos and Cano-Santana (2008) compared the capture of grasshoppers for human consumption to the conventional application of insecticides as a pest management strategy and found that manual harvesting effectively reduces the density of *S. purpurascens.* Harvesting grasshoppers resulted in a profitable food item, monetary savings from reduced insecticide use and the associated reduced risk of environmental contamination (Cerritos, 2009). Less pesticide use also results in the reduced chances of insecticide resistance developing amongst the insects. Cerritos (2011) suggests that endemic pest species should only be harvested to the extent of reducing the population but introduced pest species should be harvested until they are eliminated. Some exotic species are important as food insects (e.g. the exotic mole cricket *Gryllotalpa africana* in Thailand), and it would be interesting to see if consumers would want it eliminated. In Northern Benin, most of the insects consumed by the Wama were minor pests but they were considered a resource to be protected for future consumption and managed communally to avoid depletion (Riggi *et al.*, 2013).

Conflicts can arise in relation to pest control; in Brazil, the Suruí Indians use the caterpillar of a notodontid moth (*Lusura* sp.) as food. This species erupts in very large numbers on Brazil nut trees, denuding them of foliage. There are contrasting views about these caterpillar infestations among different inhabitants of the forest because the Suruí consider it a desirable food delicacy but the Caboclos Indians view it as a destructive pest defoliator of the Brazil nut tree (Coimbra, 2012).

The future prospects of harvesting pest insects for food will very much depend upon the type of pest, whether it has a seasonal or perennial food host plant and the biology and population dynamics of the insect. For example, predicting the occurrence of pest insects on a specific localised seasonal crop is much easier than a highly mobile polyphagous species. Keeping up predictable supply is something that is necessary if consumers come to rely on them as a major contribution to their diet. Long term pest periodicity is difficult to understand. Locust outbreaks are not regular, although there are methods now that assist prediction of population build-ups (Ceccato *et al.*, 2007; Despland *et al.*, 2004; Stige *et al.*, 2007). One insect species used by North American Indians (Weaver and Basgall, 1986) with a known history of outbreaks is the Pandora moth (*Coloradia pandora*). Episodic outbreaks of this species defoliated ponderosa pine (*Pinus ponderosa*) and other pine species in the western USA. Tree-ring samples provide a long-term record of outbreaks and Speer *et al.* (2001) reconstructed a 622-year record of 22 individual outbreaks in 14 old-growth ponderosa pine stands. Intervals between pandora moth outbreaks were highly variable within individual forest stands, ranging from 9 to 156 years. China has records of outbreaks of *Locusta migratoria manilensis* for 1000 years (Stige *et al.*, 2007), but these types of long-term records are rare.

The benefits of harvesting plant pests are: (1) increased plant food productivity; (2) an additional food resource (the insects); and (3) health and environmental benefits of reduced insecticide use. The practical issues are the availability of appropriate techniques to harvest the insects, whether harvesting pests does keep them at manageable levels, and whether they are a long-term sustainable supply of food. The examples cited above suggest that it may work and Cerritos and Cano-Santana (2008) found that households in Mexico could catch 50-70 kg of grasshoppers/week, adequate for subsistence and for selling at markets.

A cautionary note is that there is the inherent danger that a common pest species could become extinct. The Rocky Mountain grasshopper (*Melanoplus spretus*) was the most serious agricultural pest in the western USA and Canada before 1900. In the late 1800s, this species began a precipitous decline, and the last living specimen was collected just after 1900. Extinction of this species was not due to harvest for human consumption, but due to loss of riparian habitats required for this species for egg laying (Lockwood and DeBrey, 1990).

4. Wild harvesting

Sustainable harvesting

Lande *et al.* (1997) define sustainable harvesting as: '… strategies that maximise yield while accounting for stochastic dynamics, uncertainty, and risk of resource collapse or extinction.' Most work on sustainable harvesting has involved wildlife, fisheries (including marine invertebrates) or plants (Hilborn *et al.*, 1995), and its application to insects is a very new field, although it could be argued that the opposite is used in pest management through economic thresholds assessments for decision-making on pest control (Farrington, 1977).

Why does over-harvesting of edible insects occur? There are four main reasons: (1) famine and the need to get food for survival; (2) increasing commercialisation resulting in the demand for more supply; (3) unsustainable collection methods especially by untrained commercial collectors; and (4) new technologies for collecting, transport and storage. The new technologies may encourage over-collecting and insects can be safely stored to provide a supply out of season. Reduction in food insect availability can be manifested to collectors by: (1) the decline in numbers over time; (2) the need to travel further to get insects; and (3) the need to spend more time collecting. The reduction may not be necessarily due to over-harvesting, but it could be due to other factors (e.g. habitat destruction, climate change) or an interaction between environmental change and harvesting.

One of the main factors leading to economic over-exploitation is the desire to maximise yield, and controlling exploiters is a major management problem (Hilborn *et al.*, 1995). It is important that the range of sustainable harvest intensities of the product that are both sustainable and economically viable are identified first, and then determine the impacts of the harvest intensity on the ecosystem (Boot and Gullison, 1995). Low-intensity harvesting can have a low impact on biodiversity at the landscape scale. However, commercialisation leads to increased demand which is met through: (1) more intensive harvesting; (2) more extensive harvesting; or (3) intensified management. Reduced availability can lead to increased product value, which in turn can result in more competition for the product and harvesters collecting immature specimens or harvesting beyond sustainable levels in the belief that competitors will harvest them if they do not. When prices drop, harvesters may harvest more to break even (Belcher and Schreckenberg, 2007). Intensified management, such as semi-domestication or farming, can result in better quality products and there can be more control over the timing of production but may encourage conversion of more natural vegetation into cultivated plots.

Can over-harvesting threaten insect species? Human history is full of examples where a species is over-utilised and there is no reason why this does not happen to insects. The effects of over-harvesting reduce the population sizes and ranges of the species and can result in either local or total extinction of the species. The following are some examples where use of insects (or invertebrates) as food has led to either extinction or threatened the species.

In Mexico, 14 of the 30 edible species in Hidalgo are now threatened. In most cases, increasing commercialisation has led to more harvesting. Factors other than harvesting (e.g. environmental changes) may also be responsible for their decline (Ramos-Elorduy, 2006).

Declines have been reported for *Melipona beecheii* bee in Mexico (Villanueva-G *et al.*, 2005) and tarantulas in Cambodia (Yen and Ro, 2013). In Botswana, the plant *Colophospermum mopane* is host to mopane caterpillars (*Imbrasia belina*) and the silkworm *Gonometa postica*; both are harvested for subsistence and for trade, but higher harvest rates are recorded during times of crop failure (Sekhwela, 2010). The populations of the giant water bug (*Lethocerus indicus*) are declining due to environmental and habitat changes and pollution in Thailand and it is not known what collecting pressures operate for this species. Large numbers of giant water bugs sold in Thailand are collected in Cambodia and Myanmar (Hanboonsong *et al.*, 2013).

Placostylus, a genus of land snails found on south west Pacific islands. *Placostylus fibratus* is threatened by over-harvesting for human consumption in Melanesia (Bresica *et al.*, 2008). It is a traditional food on the Isle of Pines where snails are an important source of protein but became popular in Nouméa around 1950 and harvesting on the Isle of Pines progressively increased and reached 48 tons (about 700,000 snails) in 1993. Export from the Isle of Pines was prohibited in 2000 to reduce the number harvested. A survey conducted from 1995-2004 estimated that the population of *P. fibratus* on the Isle of Pines is now stable and harvesting for local use is now permitted. There is potential to semi-domesticate *Placostylus* (Bresica *et al*,. 2008; Stringer and Grant, 2007).

Traditional harvesting methods are often the knowledge of particular people (e.g. senior people, women) who monitor the development of the target species and know appropriate times to collect, appropriate collecting methods, and the land or water management regimes required to increase insect (Ramos-Elorduy *et al.*, 2012). One important aspect is to leave enough breeding stock for the next season by limiting the collecting season and setting aside non-collection areas. Traditional methods are being overlooked with increasing pressures of commercialisation, issues of land tenure, competition with other animals for food resources, and different product demands (plant products versus insects). It is important to determine whether exploitation is traditional or a recent innovation. In Africa, traditional regulation of caterpillar harvesting involved: (1) having an understanding of the life cycle and behaviour of the caterpillars; (2) monitoring for edible caterpillar development and abundance and for changes in caterpillar habitats; (3) protecting host plants and moth eggs; and (4) temporal restriction of edible caterpillar harvesting (Maviya and Gumbo, 2005; Mbata *et al.*, 2002; Toms, 2007). The traditional harvesting of edible caterpillars by the Bisa people of Zambia is controlled by the chief who designates the start and end of the harvest season. Cutting of food plants is not permitted unless given permission by traditional leaders. Population pressure and commercialisation has weakened traditional regulation and there is more harvesting of caterpillars by cutting plants (Mbata and Chidumayo, 2003). The increasing importance of mopane caterpillars in the urban diet has caused over-exploitation of the insect in Namibia and there has been a shift from harvesting mopane caterpillars for subsistence to trading them in both rural and urban markets (Thomas, 2013).

Weaver ants (*Oecophylla smaragdina*) are very popular in Thailand and Laos and consumer demand is higher than the natural supply. The numbers of weaver ants have been decreasing and they are more difficult to find in the wild with longer travel distances to find nest sites (Hanboonsong *et al.*, 2013; Sribandit *et al.*, 2008; Van Itterbeeck *et al.*, 2014). The main problems include the increasing number of people collecting ants and a decrease in forest area (Sribandit *et al.*, 2008; Van Itterbeeck *et al.*, 2014). This decrease has ecological implications because weaver ants are also important biological control agents (Hanboonsong *et al.*, 2013). Experimental removal of nests of the medicinal ant *Polyrachis vicina* in China suggested that collecting 25-35% of nests did not adversely impact nest density, while 75% collection resulted in severe reduction in nests (Wang *et al.*, 2001).

Traditional methods may not always be sustainable. In Hawaii, a large cricket-like animal (*uhini pa'awela*) was a favourite food until it became extinct in the late 1880s. There are no extant specimens of this species, so its identity is unknown (Howarth and Mull, 1992). On the positive side, there is always the potential to improve harvesting methods. Bamboo caterpillars (*Omphisa fuscidentalis*) are collected in China when young bamboo plants are chopped down and the numbers of caterpillars in the next season will depend upon the number of overwintering populations that survive (Yi *et al.*, 2010). In Thailand, they are also collected by cutting down entire bamboo clumps to harvest the caterpillars but a less invasive collection method is now available that involves only slicing open infested internodes to obtain the larvae without cutting down the whole plant (Hanboonsong *et al.*, 2013).

An example of the effects of consumer demand resulting in massive increase in retail prices involves the medicinal insect *Ophiocordyceps sinensis*. It is actually a parasitic fungus that attacks hepialid caterpillars in the Himalayas and Tibetan Plateau. High demand has seen retail prices as high as US$ 25,000/kg (Winkler, 2010). It is an important livelihood in Bhutan, China, India, Nepal and Tibet, and over-harvesting has reduced supply (Shrestha and Bawa, 2013). There are three options to reduce the chances of local extinction: (1) managing wild harvesting; (2) farming; and (3) managing consumer expectations. Habitat management includes leaving some unharvested areas each season (Negi *et al.*, 2006), educating collectors about the life cycle of the insect and fungus (Winkler, 2013), reducing the length of the collecting season (Winkler, 2013), and long-term monitoring programmes to assess changes in population sizes (Cannon *et al.* 2009). Farming has resulted in the production of a cheaper cultured form (Dong, 2013; Liang, 2011), but it is not as popular as wild collected specimens (Liang, 2011), and farming may adversely affect local livelihoods unless they are locally based small-scale enterprises (Cannon *et al.*, 2009). While local participation is important in maintaining a sustainable industry in the wild, there are always problems such as poachers (Cannon *et al.*, 2009).

Harvesting is not the only factor affecting population numbers and distribution. Besides over-harvesting, species have to survive environmental stresses. Natural stresses include natural enemies, competition between species for food resources (Choo, 2008), and stochastic events such as flood, fire and drought. Anthropogenic stresses include habitat destruction, alteration or fragmentation, pollution, introduced plants and animals (Baxter *et al.*, 2004; Halwart, 1994), altered water flow regimes (Baird, 2007, 2011; Wyatt and Baird, 2007), inappropriate floods or fires, artificial barriers that disrupt natural insect movement (Yhoung-Aree and Viwatpanich, 2005), and climate change. In Africa, climate change has influenced the emergence periodicity of edible insects through the unpredictability of the onset of the rain season and other weather activity (Ayieko *et al.*, 2010). The impacts of climate change will vary across the Asia Pacific region. Warmer temperatures and increased carbon dioxide levels will impact upon food production efficiency (either positively or negatively), and sea level rises will cause loss of low lying agricultural lands and could increase salinity in coastal freshwater systems. From an edible insect perspective, the main issue could be more unpredictability in rainfall and also water, and increased frequency of extreme weather events. These can influence both terrestrial and aquatic ecosystems. In terrestrial ecosystems, changes in plant phenologies can have a flow-on effect to the insects that depend upon these plants. In aquatic systems, changes in flow rates could affect aquatic invertebrates, and irrigation regimes for crops could be threatened. Climate change could have unforeseen impacts on the supply of traditional foods such as insects (Lynn *et al.*, 2013) and also upon the way land and water are managed traditionally (Voggesser *et al.*, 2013).

Ecological implications of over-harvesting

Ticktin (2004) found that harvesting of non-timber forest products from plants can affect ecological processes at individual, population, community and ecosystem levels although the impacts on any one species can vary greatly over space and time. Over-harvesting is most likely to have species and/or ecosystem implications. There could also be ecological implications when there is mass trapping of non-target species, such as occurs with light trapping as a means to collect food insects.

The list of edible insects collated by Jongema (2014) was divided into terrestrial or aquatic species and then into their presumed trophic levels in each of the main biogeographical regions. When the Asia Pacific region is assessed, the North Asian species were extracted from the Palaearctic region. All allocations to trophic levels were made at the family taxonomic level, acknowledging that some species may fit into more than one category. Assigning insect families to trophic levels and assessing changes to the trophic composition is a way of determining if there are potential ecosystem function changes irrespective of the identity of the species. The trophic levels chosen for this exercise are derived from Moran and Southwood (1982): herbivores (which included folivores, wood borers and termites), predators, omnivores, detritivores, pollinators (including bees), frugivores, parasites, and ants. Ants are considered a separate trophic level because of the large number of ecological functions which they perform.

At the global level, 88% of edible insect species are terrestrial and the remaining are aquatic (Table 2). When the same is considered for the Asia Pacific region, the percentages are very similar (87% are terrestrial) (Table 3). In terms of geographical distribution of the number of terrestrial species, the descending order is Neotropical, Oriental, African, Palaearctic, Australasian and lastly Nearctic.

Table 2. Number of species of known edible insects in the biogeographic regions of the world (data from Jongema, 2014).

Region	Terrestrial	Aquatic
Africa	387	17
Australasia	90	5
Nearctic	75	15
Neotropical	608	82
Oriental	472	90
Palaearctic	289	52
Total	1,921	261

Table 3. Number of species of known edible insects in the major sub regions of the Asia Pacific region (data from Jongema, 2014).

Sub region	Terrestrial	Aquatic
Australia	57	3
Papua New Guinea	34	2
Pacific Islands	4	4
Oriental	608	82
North Asia	262	52
Total	965	143

For aquatic species, the descending order is Oriental, Neotropical, Palaearctic, African, Nearctic and Australasia.

When all edible insect species are considered globally, there are 1921 terrestrial species and 261 aquatic species. With terrestrial species, most edible insect species are herbivores (54%), followed by ominivores (18%), predators (8%), pollinators (7%) and detritivores (6%). This contrasts with aquatic insects which are dominated by predators (69%), herbivores (14%) and omnivores (14%) (Table 4). Clearly the majority of terrestrial edible insect species are plant feeders, while the majority of aquatic edible insects are predators. These figures do not reflect all the trophic interactions in terrestrial and aquatic systems because they do not include non-marine molluscs (many of which are herbivorous, although a few are predatory) and groups of non-insectan aquatic herbivores and omnivores such as molluscs and crustaceans.

When terrestrial herbivores are considered (global figure of 54%), they constitute 83% (Africa), 64% (Australia), 58% (Nearctic), 43% (Neotropical), 40% (Oriental) and 59% (Palaearctic). This differs from the aquatic species which are mainly predators (global figure of 69%). The biogeographic regional distribution is 40% (Oriental), 28% (Neotropical) and 20% (Palaearctic).

When the Asia Pacific region is considered, (Table 5), there are 965 terrestrial species and 143 aquatic species. With terrestrial species, most edible insect species are herbivores (49%), followed by ominivores (14%), predators (12%), pollinators (11%) and detritivores (6%). This contrasts with aquatic insects which are dominated by predators (63%), herbivores (18%) and omnivores (13%).

The composition of edible insects differs for each of the biogeographical regions and some regions are dominated by particular groups of insects. The African region is dominated by herbivores (mainly caterpillars of foliage feeding moths), bees dominate the Neotropical region, and scarab beetles dominate the Oriental region (Jongema,

Table 4. Trophic groups (no. of species) of known edible insects in the biogeographic regions of the world (data from Jongema, 2014).

Habitat	Trophic level	Region						Total	%
		Africa	Australasia	Nearctic	Neotropical	Oriental	Palaearctic		
Terrestrial	Predator	8	5	4	85	34	28	164	8.54
	Herbivore	322	58	44	262	192	171	1,049	54.61
	Ommivore	12	12	10	88	194	44	360	18.74
	Detritivore	21	3		44	29	21	118	6.14
	Pollinator	18	1	5	104	16	8	152	7.91
	Ants	6	11	10	21	6	17	71	3.7
	Frugivore				2			2	0.1
	Parasite			2	2	1		5	0.26
	Total	387	90	75	608	472	289	1,921	
Aquatic	Predator	12	3	5	51	73	37	181	69.34
	Herbivore	2	2	5	18	6	6	39	14.94
	Omnivore	2		5	11	11	9	38	14.56
	Detritivore				1			1	0.38
	Parasite	1			1			2	0.77
	Total	17	5	15	82	90	52	261	

Table 5. Trophic groups (no. of species) of known edible insects in the Asia Pacific region of the world (data from Jongema, 2014).

Habitat	Trophic level	Region					Total	%
		Australasia	Papua New Guinea	Pacific Islands	SE Asia	North Asia		
Terrestrial	Predator	1	4		85	28	118	12.23
	Herbivore	39	19	3	262	152	475	49.22
	Ommivore	4	8	1	88	41	142	14.72
	Detritivore	1	2		44	18	65	6.74
	Pollinator	1			104	6	111	11.5
	Ants	11	1		21	17	50	5.18
	Frugivore				2		2	0.21
	Parasite				2		2	0.21
	Total	57	34	4	608	262	965	
Aquatic	Predator	1	2		51	37	91	63.64
	Herbivore	2			18	6	26	18.18
	Omnivore				11	9	20	13.99
	Detritivore				1		1	0.7
	Parasite				1		1	0.7
	Total	3	2	4	82	52	143	

2014). These figures may also be an indication of the level of knowledge of the edible insects within each region. They do not reflect the importance of individual species or groups as food or feed. However they do give some indication of where resources are required if edible insects are to be produced sustainably; for example, management of the host plants is of high importance if the edible caterpillars are to be managed sustainably.

Cardinale *et al.* (2006) suggest that loss of species affects the functioning of a wide variety of organisms and ecosystems, but the magnitude of these effects is ultimately determined by the identity of species that are lost. The ecological effects of the loss or reduction of herbivorous species will depend upon which part of the plant that they feed on. As there are often competing herbivorous species on each host plant species, reduction or loss of one species may see increasing numbers of another species (although it may not be edible). The loss of termites may affect nutrient recycling. Herbivores are an important resource for predators and parasitoids, and reduced numbers can see flow on effects up the food chain. Reduced herbivory can result in increased plant biomass which in more xeric systems, result in more fuel that could result in increased fire intensities or frequency. Bees and beetles are important plant pollinators; the degradation of primary forests in Thailand has seen a reduction in bee populations required for pollination; bee numbers are further reduced when honey collectors take entire nests rather than just the honeycomb (Boongird, 2010). As there are fewer predatory species than herbivores, the loss of a predator may have more severe ecological implications. Predators are more sensitive to environmental change than organisms from lower trophic levels. When a predator is lost from the community, the response of the lower trophic level is highly dependent on the remaining predator species and is also dependent upon the body mass of the predator (larger predators feed on larger prey) (Finke and Denno, 2004; Schneider and Brose, 2013). The effects can cascade down to the plant level and loss of predators could result in reduced plant productivity because of decreased predator pressures on herbivores. Harvesting is another form of predation and understanding the roles and levels of predation on edible insects may assist our understanding of the levels of sustainable harvesting. The loss of other trophic groups such as detrivores, omnivores and ants also have implications but because their roles are not as clear cut as herbivores, predators and pollinators, it is more difficult to identify potential ecological consequences.

Over-harvesting can have potential adverse flow on effects on other species that may result in an altered food web that is not ecologically viable in the long term. An example of the complexity of the food web is the threatened giant water bug *Kirkaldyia deyrolli* in Japanese rice fields. It is major predator of frogs and conservation of the bug relies on conserving frog populations. However, the giant water bug prefers loaches (*Misgurnus anguillicaudatus*), which inhabited these habitats in the past before modern rice growing methods inhibited loach migration and reduced the abundance of their spawning grounds (Ohba *et al.*, 2012). As a consequence, the water bugs are now forced to eat frogs.

Food webs are very complex and cross ecosystem boundaries (Knight *et al.*, 2005). Species with complex life histories often shift habitats during their life cycle and local interactions that affect predator abundance in one ecosystem (e.g. a larval habitat) may have reverberating effects in another (e.g. an adult habitat). For example, fish can indirectly facilitate terrestrial plant reproduction by reducing larval dragonfly abundances in ponds, leading to fewer adult dragonflies nearby. Adult dragonflies consume insect pollinators and alter their foraging behaviour. As a result, plants near ponds with fish have more pollinators than plants near fish-free ponds. There could also be subtle ecological interactions between human and wildlife use of insects. In Thailand, predation by the wrinkle-lipped bat (*Tadarida plicata)* on the white-backed planthopper (*Sogatella furcifera)* is estimated to prevent the loss of 2,900 tons of rice per year (Wanger *et al.*, 2014), but bat population decline as currently observed in Southeast Asia could result in the availability of more edible insects, but it is at a cost to the ecosystem.

5. Semi-domestication of insects and insect farming

Semi-domestication

Van Itterbeeck and Van Huis (2012) provide an historical summary of three types of edible insects whose production was enhanced by environmental manipulation: the eggs of aquatic Hemiptera by water management and provision of oviposition sites (Mexico), cutting down palm trees to provide palm weevil breeding sites (South America, Africa and Papua New Guinea), and manipulating host plants of folivorous caterpillars and also translocating selected caterpillar species (Africa).

Palm weevils occur are semi-domesticated in Indonesia (Rana, 2014), Malaysia (Chung, 2010), Papua New Guinea (Mercer, 1997), and Thailand (Hanboonsong *et al.* 2013), and there are historical records of their use in Sri Lanka (Tennent, 1861). The palm weevil is also a serious pest of palm trees, including the coconut tree, so farmers are confronted with balancing palm larvae production with palm tree production. In Thailand, 120 farmers produced 43 tons of palm weevil larvae in 2011 (Hanboonsong *et al.*, 2013). The traditional method involves getting adult beetles to deposit eggs in palm trunks or stems and harvesting the resultant larvae after 40-45 days. The same palm trunk can be used for up to eight months, but increased demand has resulted in reduction of palm tree numbers. The weevils can be bred in plastic containers filled with ground palm stalk and mixed with pig feed, but this has not been widely adopted. Palm weevil faeces are a by-product of the process sold as an organic fertiliser. The grub of the sago weevil *Rhynchophorus ferrugineus papuanus* is the most widely eaten insect in New Guinea where it is a by-product of sago starch production. However, around Lae and in some parts of the Sepik River, the thorned trunk sago palm is not eaten because it produces an inferior sago, so it is specifically felled and prepared for sago weevil grub production (Mercer 1997). Each felled palm will produce between 500-600 grubs. This production system appears sustainable in that only mature palms are felled just before they flower and die. The sago palms regenerate vigorously, and as the swamps are not used for agriculture, the palm forests are left to grow to maturity.

In southern China, edible diving water beetles are rare in the wild due to habitat alteration. They are now bred in captivity to supply domestic demand (Jäch, 2003). In Japan, *Vespula* wasp nests are collected and placed in wooden hive boxes to feed and protect from predators (Nonaka, 2010).

Weaver ants (*O. smaragdina*) are widespread in the Asia Pacific region and are found from China south into northern Australia and as far west as India. They are used as food (Hanboonsong *et al.*, 2013; Offenberg and Wiwarwitaya, 2010), feed (Césard, 2004), medicine (Yen, 2005) and as a biological control agent (Peng *et al.*, 2011). Generally weaver ants are collected from the wild and are harvested seasonally (Hanboonsong *et al.*, 2013). The ants live in above-ground nests constructed from living leaves, and the nests can be collected and translocated (Van Mele and Nguyen, 2007). Offenberg and Wiwatwitaya (2010) found that harvesting of weaver ants could be compatible with biocontrol; worker ant densities estimated shortly after the ant harvest did not differ significantly between harvested and unharvested plots. The yield can be increased through appropriate management such as supplementary feeding of the ants (Offenberg, 2011).

In Australia, some Aborigines cultivated the bardi grub (cerambycid beetle *Bardistus cibarius*) by deliberately knocking off the tops of grass trees (*Xanthorrhoea*) to promote decay that increased breeding of grubs (Campbell, 1965; Meagher, 1974). A more complicated form of semi-domestication in Australia was the use of fire to increase insect numbers; lerps are sugary secretions of insects known as psyllids found on eucalypt trees and were an important source of sweet food (Dawson, 1881; Cleland, 1957; Bin Salleh, 1997). They were collected from the leaves, dried and rolled into a ball that can be stored for months (Bin Salleh, 1997). Psyllid numbers are often higher on the coppice eucalypt growth that regenerates after fire, and often lerp numbers are higher in the year following a fire. Aborigines maintained small-scale habitat mosaics of different fire ages that increased productivity (Bliege Bird *et al.*, 2008). However not all country was burnt because they may contain resources that will be lost if the country is burnt too intensely; for example, witjuti grubs depend upon certain *Acacia* species and if burnt, the grub supply is lost (Cane, 2002).

The benefits of semi-domestication are greater control on the predictability of the target species, increased availability, and more sustainable production while placing less exploitation stress on the general environment. The techniques involved vary in scale and complexity and range from the simple introduction of target insects on to food plants, to the manipulation of or planting of appropriate food plants to increase insect populations. The use of alternative host plants is another option; in Bas-Congo, the introduced Australian plant *Acacia auriculiformis* is planted for fuel wood and other purposes, and five species of native edible caterpillars can feed on its leaves (Latham, 2003). Semi-domestication that involves broader habitat manipulation, such as the use of fire or the alteration of hydrological regimes, is more complex because they involve a greater number of animal and plant species. The issue is how these modes of production can meet increased demand (commercialisation) without increased adverse environmental effects.

Farming

Farming can produce large amounts of insects. For example, silkworm pupae are produced by many countries. Global production is dominated by China (290,000 tons in 2005), followed by India (77,000 tons), Thailand (5,000 tons), Vietnam (3,000), Democratic People's Republic of Korea (1,500) and Japan (600 tons) (http://www.fao.org/economic/ess/en/#.U9eHe8scRYU).

Insect farming for food was probably initially a by-product of silk production. In China, mulberry silkworm farming started over 5,000 years ago (Yi *et al.*, 2010; Zhang *et al.*, 2008), and the Chinese honeybee has been farmed for over 3,000 years (Yi *et al.*, 2010). A variety of insects are currently farmed in China for food, feed and other purposes (Zhang *et al.*, 2008). These include over 260,000 tons of mulberry silkworm (*Bombyx mori*) and tasar silkworm (*Antheraea pernyi*) pupae annually for silk, food, medical research and as a host for cultivating the fungus *Ophiocordyceps militaris*; the honeybees *Apis cerana* and *A. mellifera*; 200 tons annually of Chinese white-wax scale *Ericerus pela* from which the wax is extracted from insects and insect bodies are as pig feed; over 3,500 tons of lac insect (*Kerria* species); cochineal (*Dactylopius coccus*); wasps (*Vespa magnifica*); medicinal cockroaches (*Opisthoplatia orientalis* and *Eupolyphaga sinensis*); the housefly (*Musca domestica*) as feed for pets, eels and poultry; 100 tons of the mealworm (*Tenebrio molitor*) as pet food; and the sphingid moth *Clanis bilineata*.

Cricket farming in Thailand was started in 1998. It now has 20,000 farmers involved with an annual production of 7,500 tons (Hanboonsong *et al.*, 2013). The cricket farms initially involved three native species. The house cricket (*Acheta domesticus*) was introduced later from North America and is now the commonly farmed species because consumers prefer it for their better taste and texture. The techniques associated with cricket farming have changed, especially the types of cages used and the food used. The cricket farmers still have an issue with cricket food and rely mainly on high-priced commercial chicken feed. Other issues faced by Thai cricket farmers are the future danger of cricket densovirus diseases (Weismann *et al.*, 2012) and inbreeding. Cricket farming has been introduced to Lao PDR (Hanboonsong and Durst, 2014) for the domestic house cricket and the common cricket (*Gryllus bimaculatus*) through technology transfer from Thailand.

Insect farming can occur at different scales. It can be as simple as a single cage through to a large semi-automated factory. While factory scale production is preferred to produce large amounts of insects, the production model in Thailand involves a large number of individual farmers producing crickets that are processed and distributed by an intermediary (Figure 1) (Hanboonsong *et al.*, 2013). The establishment of the smaller farm model is relevant to a lot of the Asia Pacific region because of cheaper establishment costs (compared to a factory), greater access to a subsistence food product for the farmers, and the ability to establish enterprises in a range of different environments: urban, peri-urban, rural and non-productive environments. It will allow increased food production grown domestically and increasingly in more 'marginal' or 'fragile' lands. Insects may not necessarily be the main form of food or income for the farmers, but insect farming provides a potential longer term resilient food supply (Barthel and Isendahl, 2013). If widespread insect farming is adopted, it is important to utilise insect diversity and to avoid the global problems associated with dependency on limited number of species as experienced with some food animals and crops (Khoury *et al.*, 2014). The development of insect factories may encourage the use of fewer species, whereas the small farm model has the potential to breed a greater diversity of insects, reduce loss of genetic diversity, and reduce the chances of an insect disease destroying a whole colony. The environmental benefits of farming include habitat conservation but the natural environment needs to be retained as a source of renewal and also as a safety net and will still be important for local food supply and livelihoods (Scherr and McNeely, 2008). One disadvantage of farming is the potential for exotic species introduced for farming to escape, become established and have detrimental impacts on the natural environment.

6. Knowledge gaps and future requirements

The increasing demand for insects as food has led to increased commercialisation. As wild harvested insects are still the main source in the Asia Pacific region, commercialisation is increasing harvesting pressures in the wild. Farming is currently a very minor component of the edible insect market. The implications for future sustainability are unclear, and there are knowledge gaps that need to be addressed.

Van Huis *et al.* (2013) identified the following issues for the advancement of insects as food or feed: (1) the need for information on the nutritional values of insects in order to more efficiently promote insects as healthy food; (2) understanding the environmental impacts of harvesting and farming insects; (3) clarifying and augmenting the socio-economic benefits that insect harvesting and farming to enhance the food security of the poor; and (4) a clear and comprehensive legal framework to pave the way for more investment to lead development from the household to the industrial scale of insect production. These issues are based on the assumption that we already have adequate knowledge on what insects are used as food or feed, and how they are used traditionally in different cultures. This is certainly not the case in the Asia Pacific region because there is still a lot of baseline information to be gathered. This is an acknowledgement that the status of food insects is at different stages in different parts of the world and that each region may need to move at different rates. Even within the Asia Pacific region, there is no uniformity across the region in terms of the development in the use of food insects, and different strategies will be required for different countries or sub-regions.

Which insects are consumed?

Meyer-Rochow (2010) points out that the extent of human entomophagy is underestimated. The reasons for this are varied, ranging from biases associated with observers to the seasonal and sometimes unpredictable availability of food insects. There is a lack of uniform and accurate recording (Meyer-Rochow, 2010). In most cases, identifications are made by non-entomologists and no reference material is retained, so confusion arises over the correct identities of the species (Yen, 2005). Accurate insect identification is an essential first step if sustainable wild harvesting or farming are to be considered (Johnson, 2010). This includes scientific names at the species level; local names; digital images, and voucher specimens. Proper identification of food insects involves retaining specimens from a wider geographic range in order to record genetic variation associated with each species. Genetics is important for species with small localised populations, for projects involving translocation or reintroduction of species, and for farming. Naming edible insects can be difficult because sometimes it is the immature stages that are utilised (and taxonomy is based on adult stages), and the species may still be undescribed.

How do or did different cultures use or used them?

The subsistence use of insects by indigenous communities usually involves traditional knowledge that is orally handed on down the generations. This involves harvesting, storage and cooking methods, nutritional and medicinal benefits, and information on that may assist semi-domestication or farming (Meyer-Rochow, 2010). This information may belong to different groups within each culture (e.g. elders, men or women). It must be remembered that insects are only one component of the diet, and while dietary information may be dominated by more obvious plants and vertebrates, underutilised wild foods, including insects, should not be overlooked because they can contribute important daily needs of vitamins and mineral (Powell *et al.*, 2013). The increased production, availability, and use of these wild foods by local people can be used to improve food and nutrition security (Kuhnlein, 2014). The dilemma is how to protect the intellectual property rights of traditional owners if their knowledge is developed for the benefit of others(Meyer-Rochow, 2010; Yen, 2010). There needs to be adequate documentation on the extent of entomophagy (Ramos-Elorduy, 2009). In the Asia Pacific region, information is available for some countries, although it is fragmented (Table 1). There is very little published information for peninsular Malaysia, Myanmar, Nepal, Pakistan, the various Pacific islands, and Taiwan (Johnson, 2010), and knowledge gaps in Australia, Indonesia, Papua New Guinea, Philippines, and Vietnam. In has to be remembered that the use of insects as food will change according to social changes. For example, the consumption of meat has increased in West Papua, due in part to transmigration of Indonesians, and subsistence hunting has changed to commercial hunting, resulting in a shortage of mammals (Pangau-Adam *et al.*, 2012), and insects could be used to address the resultant protein shortage.

How will increased wild harvesting impact on the edible insects?

With some exceptions, traditional wild harvesting of insects as food has been sustainable. The development of traditional knowledge on collecting, storage and cooking methods over time is evidence of this. The problem facing traditional cultures is how to respond when there is increasing demand and pressure to commercialise the products and to achieve a balance between subsistence use and commercial utilisation without destroying the resource. The effects and solutions will be location specific. It will depend upon the culture group, the insect species, the extent of the market, and the route to the market. The main question is whether excessive wild harvesting will be detrimental to the long-term survival of the species and whether it is detrimental to the broader ecosystem. It is necessary to determine whether exploitation is 'traditional' or a recent innovation that has developed because of cash derived from trade (e.g. tarantulas in Cambodia, Yen and Ro, 2013). Traditional modes of harvesting need to be studied as a benchmark for new collecting technologies. Unsustainable harvesting often occurs when experienced harvesters are replaced by newcomers (some of whom are poachers) (Ballard and Huntsinger, 2006).

How can technology transfer reduce potential adverse impacts, increase productivity and ensure sustainability?

With regard to the Asia Pacific region, technology transfer would involve: (1) technical advice on sustainable wild harvesting; (2) semi-domestication or farming of edible insects; (3) the application of insects into integrated farming systems; (4) nutritional aspects of edible insects; and (5) food safety.

Technical advice on sustainable wild harvesting. The lack of background information about edible insects makes it difficult to develop protocols on sustainable wild harvesting. The scientific issues revolve around the biology and ecology of the target species. Harvesting and management protocols require adequate identification, distribution information, assessment and monitoring of the target species, assessment of harvesting impacts and an understanding of the impacts of the harvesting technologies and intensities. If enough is known about habitat requirements of the target species, the feasibility of augmenting habitats can be explored. From a research perspective, two important questions need to be addressed. The first is what are the effects of harvesting on the species and on food webs? This can be conducted for selected species by comparing the demographics of populations in harvesting and non-harvesting areas (Chan *et al.*, 2014). The second question is what is the effect of mass trapping techniques (such as light traps) on non-target species with its possible ecosystem effects? This is a question that could be answered by more field empirical data. With regard to managing collectors, Ramos-Elorduy *et al.* (2006) considered that regulations were required to protect threatened populations of edible insects. Education about the benefits of protecting the species for long term gain maybe more appropriate for food insects. Simple harvesting guidelines based on traditional knowledge or simple biological observations may be all that is required to educate collectors: what to collect, when to collect, how to collect and how many you can collect. The development of guidelines involving the local community is better than imposing regulations or even a licensing system. Some sort of certification could be considered if sale of the product will benefit the producer. It can be species or site-based, with benefits to the local community because the product has been collected using environmentally friendly harvesting techniques, some indication of food safety (e.g. pesticide free), environmental stewardship, and fair trade (labour issues) (Shanley *et al.*, 2005).

Semi-domestication and farming of edible insects. Not all species are capable of being semi-domesticated or farmed, so an initial feasibility assessment is required for potential target species. It is preferable that local species be used. Low technology and low cost systems are primary considerations. The scale of the projects is important; small scale projects are better livelihoods and they can be part of larger co-operative in order for farmers to benefit from a larger venture. There are examples of traditional semi-domestication or farming of food insects (Van Itterbeeck and Van Huis, 2012; Yen, 2014) and these need to be considered first before any attempts are made to import new technologies from outside. The issue of establishing large scale insect factories has to be addressed in the future if insects are to play a significant role in feeding the increasing global population. Asia has some of the largest and most populous cities in the world, and it makes sense to recycle waste organic matter from these cities into insect protein as food or feed.

Inclusion of insects into integrated farming systems. There is potential to establish integrated food production systems involving plants, vertebrates and insects. They can be very simple systems (such as putting up a light trap to attract insects to feed fish and poultry) through to more complex systems that produce organic fertilisers, animal feed, human food and other products such as silk (Hilbrands and Yzerman, 2004). A well-studied system previously utilised widely in China is the combination of aquaculture and mulberry trees growing adjacent to ponds, in which silkworm droppings and waste pupae are fed into fishponds along with the washings from silkworm trays (Prein, 2002). Integrated food systems with a long history such as integrated rice field fisheries schemes (Ruddle, 1982) should be assessed first before introduction of new technologies. Agroforestry is another area where food insects can be incorporated.

Nutritional aspects of edible insects. Further research is required on the nutritional and other health benefits of food insects. Hanboonsong and Durst (2014) reported that some mothers in the Lao PDR start to feed insects to their 10-month-old children because children generally prefer the softer insects that are easier to chew. Mothers are willing to increase the amount of insects in the diets of their children as they are aware of their health value but the main impediment for increased use seems to be the availability of insects. Yhoung-Aree (2010) reported that excessive insect consumption can increase the risk of urinary tract stone formation and development of chronic degenerative diseases, so more studies need to be carried out on the risks of excessive insect consumption. Amongst Australian Aborigines, a healthy diet involved a variety of food items that were hunted and gathered (Kouris-Blazos and Wahlqvist, 2000). Tindale (1953) noted the importance of witjuti grubs for healthy babies. An overlooked factor in hunter gatherer societies is the problem of weaning children in the total absence of sources of milk other than the mother. The most important supplementary food amongst Australian Aborigines were various moth and beetle larvae that are all rich in fats and take on greater nutritional importance in times drought because they have a life cycle that lasts 2-3 years (Tindale, 1981). The absence of such supplemental foods led to malnutrition among children and a form of scurvy among adults (Tindale, 1981). The adoption of western life styles has seen less use of wild foods by Aborigines, although they are still preferred. This is a problem across the Asia Pacific region, where people are offered abundant refined and fatty food supply that lead to numerous health problems which can be compounded by a more sedentary life style and over-use of alcohol (O'Dea, 1991; Wahlqvist, 1995; Wahlqvist *et al.*, 1991).

Food safety. One of the main objections to consuming insects is the belief that they are dirty and unsafe to eat. Dietary prejudices aside, eating insects can be dangerous: (1) for people who are allergic to insects (Belluco *et al.*, 2013); (2) for people who have certain health conditions that can be triggered by ingesting insects (Adamolekun, 1993); (3) consumption of insects that have not been prepared properly (Dzerefos *et al.*, 2013); and (4) eating too large a quantity (Yhoung-Aree, 2010). Otherwise the main issue with insects is the same as with all foods: incorrect postharvest handling (processing and storage), especially in undeveloped regions with limited infrastructure (Johnson, 2010). Hanboonsong and Durst (2014) found that the higher levels of contamination in fresh crickets could be reduced and made safer for consumption by boiling or frying for at least five minutes. However, even cooked crickets could become a hazard unless they are stored at lower temperatures. If cold storage such facilities are not available, sun drying or boiling in vinegar are other possible storage solutions. Education about safe food handling and storage procedures is important along with provision of appropriate technologies to implement these procedures.

Pest control

The harvesting of pest insects as a food source has already been discussed in terms of its effectiveness. The main questions are: (1) which species should be collected; (2) how to collect adequate numbers to warrant the effort; (3) are they contaminated (with insecticide); and (4) how sustainable is harvesting pests? The pest insects (and other invertebrates) need not be necessarily used as human food, but can be converted into animal feed. For example, the introduced pest Golden apple snail can be prepared as a substitute for feeding catfish (Phonekhampheng, 2008). This is an area that requires further collaborative studies involving stakeholders who are responsible for pest abatement and stakeholders who want to utilise them as food or feed and would be more achievable if less mobile pests on seasonal crops are considered.

Prospecting insects for useful compounds

While food insects are consumed for nutrition, they may also contain bio-active compounds that have health benefits. The interest in medicinal insects illustrates the untapped potential of finding numerous new and useful bio-active compounds in insects (e.g. Cui, in press). Discovery of a useful bio-active can result in increased commercialisation of the insect and result in over-exploitation. On the other hand, it may put pressure on pharmaceutical companies to assist conservation programmes. The main issue here is the ethno-entomological intellectual property rights of indigenous people who already know about the beneficial properties associated with particular species of insects.

Policy and regulation

In order to facilitate the adoption of insects as food or feed, policies and regulations need to be adopted at the international and national levels. Acceptance at the international level (the UN FAO) as a legitimate food source will be a major step in getting individual nations to amend their food safety and security legislation to enable use of insects. It is not only the use of insects as human food, but the use of insects as animal feed is just as important. Standards can be set by the Codex Alimentarius. The LAO PDR submitted a proposal in 2012 for consideration under Codex Alimentarius for the use of the domestic house cricket (*A. domesticus)* (Codex Alimentarius Commission, 2012). One of the problems faced by the Committee was the lack of information in the region about insect consumption and trade such as: (1) quantities and value of international or regional trade (exports and imports) of edible cricket products; (2) status of edible insects as human food in national food legislations; and (3) recently published or ongoing research projects on safety or toxicology of edible insects or their products. Economic and marketing data on edible insects in Asia and the Pacific is scarce (Johnson, 2010). Even in Thailand, it is difficult to determine the extent of wild harvesting and farming because it involves subsistence use (insects for domestic consumption or as an additional source of income, mainly harvesting wild species) and commercial producers. There is no overriding group that oversees the industry, so obtaining data at any level is difficult. The situation is complicated in the case of wild-harvested insects because many are imported from adjacent countries (Hanboonsong *et al.*, 2013). Also the extent of edible insect trade varies considerably across Thailand, and the nature of the operations also varies.

Information storage and dissemination

The lack of information about the use of insects as food and feed is an identified stumbling block. However getting the required information will not have full impact until there are means to store and disseminate the information at the national, regional and international levels. Data systems are required on the identities of edible insects, how they are collected, stored and cooked, additional ethno-entomological information, ethno-names, distribution, and images (Yen, 2012). The internet can be used for data storage, information transfer, and education. An information system for the Asia Pacific region would enable the integrating of knowledge about edible insects across a broader region. For example, insects such as the giant water bug, the patanga locust and the weaver ant occur across several countries. They have different local names, they may occur at different times of the year in different countries, and they may even move between countries. The system could assist in the preparation of sustainable management plans of important species by assessing distribution and seasonal availability across the region The giant water bug is seasonal in Assam (April-June) and in Thailand (July-October) but found all year round in the Lao PDR and also in Eastern Arunachal (Chakravorty *et al.*, 2013; Doley and Kalita, 2012; Hanboonsong and Durst 2014; Hanboonsong *et al.*, 2013). These regional differences provide the opportunity to plan harvesting location, timing and intensity to reduce exploitation pressure on the species, and information of supplies of insects if translocation is required to bolster declining populations in other areas.

Education

Education is a crucial element in the adoption of insects as food and feed. It requires careful planning because of the major differences in the acceptance of entomophagy amongst different cultures. In countries where insects are not consumed for cultural reasons, more effort is required on getting acceptance of insect foods (Yen, 2009a). Where entomophagy is accepted, there needs to be more effort on promoting the cultural importance of traditional knowledge while also preparing people to think about issues such as sustainable harvesting, semi-domestication and farming of insects, integrated food production systems, and bioprospecting.

Environmental management

Insects are only one source of food, so the environment needs to be managed with several outcomes: sustained food production, biodiversity and environmental conservation, and improved livelihoods. There have been sharp boundaries drawn between urban, agricultural and natural environments in the past, but now it is more about maintaining a matrix of natural, agricultural and urban environments. A group such as food insects can fit very neatly into this matrix: it is possible to harvest insects from agricultural and natural environments, to semi-domesticate insects in all three environments, and to have small insect farms or large factories in cities. A diversity of environments ensures a diversity of potential insect food and feed species, and this is an important safety net as food (Paumgarten, 2005; Raina *et al.*, 2011; Shackleton and Shackleton, 2003).

Insect foods are an important part of Australian Aboriginal culture, health and land management. With regard to individual foods, there can be songs about when they are more likely to occur; Tindale (1953) states that at least three groups have ceremonies around edible grubs. Food had important cultural values (Palmer, 1999; Rigby, 2011; Thomson, 1982) and there were ritual requirements regarding who could collect certain foods, who could eat them, and when they could eat them (Kaberry, 1938; Spencer, 1914). Each traditional Aborigine belongs to a totem group. Many totems have food value (Strehlow, 1965; Walsh, 1990), and there are sometimes rules that prevent an individual eating his or her own totem or permit them to be eaten only at certain times. It is thought that this teaches individual responsibility and encourages group responsibilities (you rely on other totems for food) (Laudine, 2009). In Central Australia, the Aborigines believe that the legendary honey ant ancestors travelled along a 600 km route that had totemic centres along the path. Honey ant verses are sung at each of these centres, and the relevant honey ant groups had to stage the complete ceremonial cycle associated with their centre. The complete performance cycle may have been performed every 15-20 years, but the members of each honey ant clan had to attend honey ant cycles of adjacent honey ant centres (Strehlow, 1970). These ceremonies are about sustainability through appropriate land management.

Edible insect flagship species

The UN FAO has recognised the need for nutritional indicators for biodiversity to provide a link between biodiversity, food and nutrition and the need to enhance sustainable use of food biodiversity to combat hunger and malnutrition (FAO, 2008, 2010). Yen (2009b) proposed the concept of edible insect flagship species as a well to promote food insects and also as a well to advance our knowledge to ensure food security. While it seems to be an apparent contradiction to exploit insects as food and to worry about their conservation status, flagship edible insects can aid biodiversity conservation through: (1) making a closer link between humans and a food source; (2) developing sustainable harvesting protocols; and (3) using important edible insect species as a flagship for the habitats in which they occur. In some circumstances, especially in areas dominated by rural poor, an edible insect would be a more appropriate flagship taxon than species they do not utilise.

In the Asia Pacific region, several species stand out as potential flagship species. This list covers invertebrates from different regions, different environments and different trophic levels. It is an opportunity to assess in greater detail traditional knowledge, impacts of wild harvesting, the potential or the effectiveness of semi-domestication or farming, nutritional and health benefits, and establishment of food safety and security protocols. There are other species that can be added to this list in the future:

1. Witjuti grubs (*Endoxyla leucomochla* and other species) and Bogong moths (*Agrotis infusa*) (Australia). While the use of these species by Australian Aborigines has declined, they represent a unique opportunity to rejuvenate important traditional knowledge and also obtain potential health benefits by reintroducing them to Aboriginal diets. Both species are wild collected, but semi-domestication may be a future option (Yen, 2012).
2. Weaver ants, *O. smaragdina* (Australia to China to India). A widely distributed species with different regional uses. Besides use as food, feed or as medicine, it can be an biological control agent. It has been partially semi-domesticated, and this is an opportunity to incorporate both food production and an ecosystem service into ecosystems (Offenberg, 2011; Van Itterbeeck and Van Huis, 2012).
3. Palm weevils, *R. ferrugineus* (Papua New Guinea, Indonesia, Malaysia, Thailand, Sri Lanka). They are used as food in many countries and produced primarily by semi-domestication (Hanboonsong *et al.*, 2013; Mercer, 1997). This species could be an important flagship for conservation of native forests in the face of increasing forestry or plantation pressures.
4. Giant water bugs, *L. indicus* (Southeast Asia, Southern Asia. A large-bodied aquatic predator that is used in several countries. It is reported to be occurring in reduced numbers (Hanboonsong *et al.*, 2013), and it is important to assess possible ecosystem implications associated with decline.
5. Patanga, *P. succincta* (or Bombay locust) (Southeast Asia). A crop pest that has become a popular food item. Its collecting as food may have resulted in maintenance of populations of this species below the pest threshold levels. It is harder to collect in Thailand and supplies are imported from neighbouring countries (Hanboonsong, 2010).
6. Tarantula, *Haplopelma* sp. or spp. (Cambodia). This is a large terrestrial predator with a relatively long life that has demonstrated nutritional benefits (Münke *et al.*, 2014). There could be unforeseen implications on the web foods in the forests in which this species is found (Yen and Ro, 2013). It is an important source of revenue in parts of Cambodia but the industry could collapse unless sustainable harvesting protocols are established.

7. Conclusions

The use of insects as food and feed occurs throughout much of the Asia Pacific region. It has the future potential to be an even more important source of food for subsistence, but has greater potential for commercial development especially in the area of animal feed. The promotion and adoption of insects as food still has many knowledge gaps to be addressed as outlined above. Identifying what is consumed and how they are consumed is still a necessary first step, and the other important issues such as sustainable harvesting, potential ecosystem impacts of over-harvesting, improving production, food safety, nutritional and health benefits, and education rely on establishing a regional information system. The acceptance of insects as part of the global diet has similar parallels to the acceptance of bushmeats as food. The following quote from the editor of a paper by De Vos (1997) is salient:

> Such is the case with the consumption of wildlife of all kinds for food in developing countries. The significance of this resource is largely ignored by nutritionists, animal production experts and even some wildlife biologists because it is difficult to find statistics about the gathering, marketing and consumption of wildlife. In addition, these foods are mostly strange or even repugnant to the majority of specialists who are working so hard to increase food production and human nutrition levels among the peoples of developing countries. The specialists are inclined to think of the improvement of man's lot in terms of passing on what they are familiar with in their own lives, ideas and things which are often foreign, distant and unconnected to the lives of those whom they want to help.

Ironically with the decline in bushmeats as a food source in many countries, insects could play a more important role in food security. In the Asia Pacific region, there is an opportunity of a two way interchange of information, traditional knowledge and modern technologies, to incorporate insects into the human food chain.

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