EDIBLE FOREST INSECTS

HUMANS BITE BACK!!

Food and Agriculture Organization of the United Nations

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Forest insects as food: humans bite back

Proceedings of a workshop on Asia-Pacific resources and their potential for development

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Edited by

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Foreword

In this fast-paced modern world, it is sometimes easy to lose sight of valuable traditional knowledge and practices. There is a tendency to think of traditional habits and customs as outdated or primitive. Yet, experience across numerous fields has highlighted the value and benefits to be gained from combining customary knowledge and approaches with modern science and understanding.

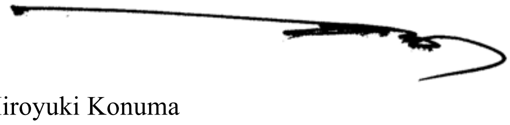
Such is the case with edible forest insects. The practice of eating insects goes back thousands of years and has been documented in nearly every part of the world. In modern times, however, consumption of insects has declined in many societies and is sometimes ridiculed as old-fashioned and unhealthy. Yet, it would be prudent to carefully consider the value of customary knowledge before discarding it too readily. Scientific analysis confirms, for example, the exceptional nutritional benefits of many forest insects, and studies point to the potential to produce insects for food with far fewer negative environmental impacts than for many mainstream foods consumed today.

Aside from their nutritional and environmental benefits, experts see considerable opportunity for edible insects to provide income and jobs for rural people who capture, rear, process, transport and market insects as food. These prospects can be enhanced through promotion and adoption of modern food technology standards to ensure that the insects are safe and attractive for human consumption.

Traditionally, most edible insects have been harvested from natural forests, but surprisingly little is known about the life cycles, population dynamics, commercial and management potential of most edible forest insects. Among forest managers, knowledge and appreciation of how to manage and harvest insects sustainably is limited. On the other hand, traditional forest dwellers and forest-dependent people often possess remarkable knowledge of the insects and their management, offering excellent opportunities for modern science and traditional knowledge to work together.

In an effort to more fully explore the various facets of edible forest insects, the FAO Regional Office for Asia and the Pacific organized an international workshop, entitled "Forest Insects as Food: Humans Bite Back" in Chiang Mai, Thailand, in February 2008. The workshop brought together many of the world's foremost experts on entomophagy – the practice of eating insects. Specialists in the three-day workshop focused specifically on the science management, collection, harvest, processing, marketing and consumption of edible forest insects, as well as their potential to be reared commercially by local farmers.

It is hoped that this publication, containing the edited proceedings of the Chiang Mai workshop, will help to raise awareness of the potential of edible forest insects as a food source, document the contribution of edible insects to rural livelihoods and highlight linkages to sustainable forest management and conservation.



Hiroyuki Konuma
Officer-in-Charge and Deputy Regional Representative

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Edible forest insects: exploring new horizons and traditional practices

Patrick B. Durst[1] and Kenichi Shono[2]

Humans have consumed insects for thousands of years – in some cases as emergency food, in other circumstances as a staple, and in still other instances as delicacies. Estimates of the number of insect species that are consumed by humans vary, but worldwide at least 1 400 species have been recorded as human food. In modern times, entomophagy (the practice of eating insects) has declined in many societies, and has often been shunned as old-fashioned, dirty or unhealthy. Yet, among various cultures scattered throughout the world, insects remain a vital and preferred food and an essential source of protein, fat, minerals and vitamins. For some members of the rapidly growing upper and middle classes of urban society in some developing countries, insects are "nostalgia food", reminding them of earlier, simpler days in the rural countryside.

Old traditions – new opportunities

Historically, most insects consumed for food have been harvested from natural forests. But, even though insects account for the greatest amount of biodiversity in forests, they are the least studied of all fauna by far. Surprisingly little is known, for example, about the life cycles, population dynamics and management potential of many edible forest insects. Similarly, little is known of the impacts that overharvesting of forest insects might have on forest vegetation, other forest fauna and the ecosystems themselves.

Among forest managers, there is little knowledge or appreciation of the potential for managing and harvesting insects sustainably. There is almost no knowledge or experience in manipulating forest vegetation or harvest practices to increase, maximize or sustain insect populations. Indeed, because many insects cause massive damage and mortality to valuable commercial trees, many forest managers consider virtually all insects as potential destructive pests. What knowledge does exist with respect to managing insects in these respects is often held by traditional forest dwellers and forest-dependent people.

The capturing, processing, transporting and marketing of edible forest insects provide interesting income and livelihood opportunities for an undetermined number of people around the world. Traditionally, these activities were all locally based and largely under-recognized. Recently, however, more sophisticated and wide-reaching marketing and commercialization of edible forest insects have been advanced, including attractive packaging and advertising.

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Some advocates believe that creating a wider market for food insects could provide an economic incentive for conserving insect habitats. Considerable challenges and barriers remain, however, in promoting forest insects as human food more widely.

Recent volatility in food prices, anxiety over rising food insecurity and increasing concerns related to climate change and the large contributions of the agriculture sector to greenhouse gas emissions are motivating many experts to reassess diets and various approaches for food production, especially protein production. This has led to more serious consideration of the potential for edible insects to contribute to food security and prospects for commercial farming, or rearing, of insects for food.

Plate 1. Insects on sale alongside other delicacies (northern Thailand) *(Courtesy P.B. Durst)*

Benefits of insect consumption

Insects offer particular benefits to those who want to reduce their environmental footprint, because they are exceptionally efficient in converting what they eat into tissue that can be consumed by others – about twice as efficient as chickens and pigs, and more than five times as efficient as beef cattle. Factoring in their astounding reproduction rates and fecundity, the actual food conversion efficiency of insects may be 20 times that of cattle. Moreover, insects feed on a far wider range of plants than conventional livestock.

Insect consumption may also help to reduce the adverse environmental impacts of livestock production as insect rearing requires far less space and generates less pollution.

As a food source, insects are highly nutritious. Many insect species contain as much – or more – protein as meat or fish. Some insects, especially in the larval stage, are also rich in fat and most insects contain significant percentages of amino acids and essential vitamins and minerals.

Insects that are collected from forest areas are generally clean and free of chemicals, and in some areas are even considered to be "health foods". Some insect species are also reputed to have beneficial medicinal properties. With movement in some locations toward insect farming or collection of insects from the wild in larger numbers, however, concerns arise regarding handling and processing practices, hygiene and overall food safety. New efforts and standards will be required to assure increasingly sophisticated and health-conscious consumers of the nutritional quality and safety of insect foods.

Potential for widening the market

Insects are unlikely to make major contributions to the world's food supply in the near term, but the idea that insects might help overcome global hunger and malnutrition is not as far-fetched as it might first seem. Insects offer significant advantages in food production, especially when compared with traditional livestock production. Even with only a relatively few species being eaten by humans, the incredible numbers of insects in the world – by some estimates, there are as many as 10^{18} (10 quintillion) individual insects alive at any given time – add up to massive quantities of potential food. Added to the advantage of sheer numbers are insects' rapid reproduction rates and high fecundity.

However, despite all the environmental and nutritional advantages entomophagy offers, insect eating is unlikely to become a mainstream dining option in Europe or North America anytime in the near future. Nonetheless, there is considerable potential in widening the market for edible insects by incorporating insect protein in supplements, processed foods and animal feeds. The key will be in fostering understanding and respect for insect eating and raising awareness of the potential contributions that edible forest insects can make to the environment, nutrition and livelihoods.

In many parts of the world where insect eating has been a common element of traditional culture, the practice is waning due to modernization and changing attitudes. In these areas, reviving the tradition of eating insects has significant potential to improve rural livelihoods, enhance nutrition and contribute to sustainable management of insect habitats. The outcome will not be the reduction of hunger *per se*, but could contribute to revitalizing traditional cultures, instilling a sense of connection with nature and fostering a better understanding of the role of humans in the natural world.

As researchers in northeastern Thailand have discovered, local people consume edible forest insects not because they are environmentally-friendly or nutritious – or because they are cheap compared to meat or poultry that are widely available. Rather, they choose to eat insects simply because they taste good! This realization – coupled with renewed respect for traditional practices and knowledge – could provide the basis for incremental improvements in diet, rural livelihoods and environmental management.

Workshop scope and objectives

To address the various aspects of forest insects as food, the Food and Agriculture Organization of the United Nations (FAO) Regional Office for Asia and the Pacific organized a workshop entitled, “Forest Insects as Food: Humans Bite Back” in Chiang Mai, Thailand from 19 to 21 February 2008. The workshop focused on all aspects of edible forest insects, including management, collection, harvesting, processing, marketing and consumption. Social, environmental, and economic aspects were explored, including opportunities and issues related to income generation and livelihoods. The focus of the workshop was on knowledge and experiences from Asia and the Pacific, but the meeting also drew on examples and resource persons from other regions of the world. Consideration was given to insects and their edible relatives, such as spiders and scorpions.

The objectives of the workshop were to:

- Raise awareness of the potential of edible forest insects as a human food source.
- Document the significance of food insects to people’s livelihoods and assess their linkages to sustainable forest management and conservation.
- Identify key challenges to promoting edible forest insects in wider markets and possible solutions to address these challenges.
- Develop working relationships and contacts among experts and specialists dealing with issues related to edible forest insects.
- Share existing knowledge on the collection/capture, processing, marketing and consumption of edible forest insects in the Asia-Pacific region and fill gaps where information is insufficient.
- Develop recommendations and strategies for promoting forest insects as food on a regional scale.

The workshop included introductory and overview presentations as well as technical presentations on entomophagy in various Asia-Pacific countries and on specific aspects of managing forest insect resources, insect harvesting/collection, processing and marketing of edible forest insects. Discussion groups considered the current status of edible forest insects in Asia and the Pacific, key constraints to future development and recommendations for near- and long-term actions. The discussion groups focused on the following three thematic areas: 1) taxonomy and ecology; 2) harvest practices and management implications; and 3) postharvest processing, shipping and marketing.

The workshop generated 19 technical papers that are contained in these proceedings. A summary of the workshop recommendations is also included for reference and consideration by interested individuals.

The contribution of edible forest insects to human nutrition and to forest management

Dennis V. Johnson[1]

Introduction

In the broadest sense, insects have enormous economic value in terms of the ecological services they provide. A recent study in the United States, for example, found that the annual value of insects' services amounted to more than US$57 billion. The study found that native insects are food for wildlife that supports a US$50 billion recreation industry, generate more than US$4.5 billion in pest control and pollinate crops worth US$3 billion (Losey and Vaughan 2006). If such a study were expanded to include the entire world, the total figure indeed would be staggering.

In addition to the ecological services provided by insects, there is also a long historical relationship between insects and human culture that extends back to antiquity. In the nineteenth century, useful insects were studied in considerable detail and were divided into the following seven categories: 1) insects producing silk; 2) insects producing honey, wax, etc; 3) insects as sources of dyes; 4) insects producing manna (sap or juice exuded by a plant pricked by an insect); 5) edible insects; 6) insects as sources of medicine; and 7) insects as ornaments (Bodenheimer 1951). The foregoing categories are not mutually exclusive because many useful insects fit into more than one category, but in all cases there is a close linkage to ecological services.

The eating of insects appears to be culturally universal, only varying with location, insect populations and ethnic group. It is very likely that progenitors of modern humans in Africa ate insects as part of their diet; the living primates of today consume certain insects with gusto. Exactly how insects (which are not obviously edible) became human food cannot be determined with any certainty. One plausible scenario is that harvesting and eating wild honey led to the collecting and consumption of bee brood (honey, eggs, larvae and pupae in the hive) as a source of protein. This discovery could have led to sampling other insect larvae and pupae (and, perhaps later, adults) that were encountered. These were presumably adopted, over time, as normal, ritual or emergency food sources.

Wherever forest insects are part of the human diet, they have generally been collected from the wild. In most cases, minimal management of forest vegetation has been practised in association with the exploitation of forest insects, and actual domestication of insects thus far has been limited to only a few species such as silkworms and bees. The most commonly eaten insect forms are larvae and pupae, usually with little or no processing of the insects before they are consumed.

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As an academic discipline, entomophagy (the human consumption of insects) is necessarily inter-disciplinary, with relationships to several different recognized fields of scientific study. While entomology is the core related discipline, edible forest insects are also closely linked to the fields of forestry, human nutrition (including famine food and ritual food), traditional medicine, anthropology, agriculture and livestock raising. Contributions from these allied disciplines are exceptionally important to understanding the past and present roles, as well as to the future potential of food insects.

The lack of any one institution in the world with a strong research focus on edible insects is an impediment to conducting research on the subject. Relevant information is scattered far and wide among a variety of books and articles from different university departments and research facilities.

Edible forest insects and their food uses

Worldwide, nearly 1 700 insect species are reported to be used as human food. Table 1 identifies them according to taxonomic orders, common English names and number of species. Four insect orders predominate, in rank sequence: Coleoptera, Hymenoptera, Orthoptera and Lepidoptera, accounting for 80 percent of the species eaten (Ramos-Elorduy 2005).

Table 1. Number of edible insect species reported in the world

Order	Common English name	Number of species
Thysanura	Silverfish	1
Anoplura	Lice	3
Ephemeroptera	Mayflies	19
Odonata	Dragonflies	29
Orthoptera	Grasshoppers, cockroaches, crickets	267
Isoptera	Termites	61
Hemiptera	True bugs	102
Homoptera	Cicadas, leafhoppers, mealybugs	78
Neuroptera	Dobson flies	5
Lepidoptera	Butterflies, moths (silkworms)	253
Trichoptera	Caddis flies	10
Diptera	Flies, mosquitoes	34
Coleoptera	Beetles	468
Hymenoptera	Ants, bees, wasps	351
Total		**1 681**

Source: Ramos-Elorduy (2005).

Geographically, Ramos-Elorduy (2005) identified the Americas and Africa as recording the highest number of insect species eaten as food (Table 2). However, when the Pacific countries (listed together with Australia in Table 2) are combined with Asian countries, the region registers more than 500 insect species consumed for food. It is likely that the total number of species eaten in Asia is considerably higher than this number, as research on the subject appears to have been less rigorous in Asia and the Pacific compared with work conducted and published in Africa and the Americas.

Table 2. Number of edible insects per continent and number of consumer countries

Continent	Number of species recorded	Percent of total	Number of consuming countries
Asia	349	20	29
Australia	152	9	14
Africa	524	30	36
Americas	679	39	23
Europe	41	2	11
Total	1 745*	100	113

* The world total is actually 1 681; some species occur in more than one continent, hence the higher total.
Source: Ramos-Elorduy (2005).

Edible forest insects represent rich sources of protein for the improvement of human diet, especially for individuals suffering from poor nutrition because of a protein deficit. Gram for gram, insects often contain more protein and minerals than meat. In fact, nutritionists represent the leading group of researchers in food insects, motivated by a desire to remedy the problems associated with protein-deficient diets.

Table 3. Protein content of common insects on a dry weight basis

Common English name	Protein percentage
Leafhoppers	56.22
Yellow mealworm beetle larvae	47.76
House fly larvae	54.17
House fly pupae	61.54
Darner larvae	56.22
June beetle larvae	42.62
Agave billbug larvae	55.56
Honey bee larvae	41.68
Honey bee pupae	49.30
Water boatmen and backswimmer eggs	63.80
Water boatmen adults	53.80
Stink bugs	44.10
Leafcutting ants	58.30
Paper wasp pupae	57.93
Red-legged locusts	75.30
Corn earworms	41.98
White agave worms	30.28-51.00
Red agave worms	37.10-71.00
Treehoppers	44.84-59.57

Source: Ramos-Elorduy (1998).

The Asia-Pacific perspective

Within Asia and the Pacific, edible forest insect species counts have been compiled for Thailand individually, as well as for various groups of other countries in the region. The compilations are based largely upon the work of DeFoliart (2003), augmented by other sources. The perspective is incomplete, however, since data for China – a major insect consuming country – are not easily available, and lists from Japan and Australia are not included.

Taken together, all the insects identified in the compilation highlight the predominance, in sequence, of the Coleoptera, Orthoptera, Hymenoptera and Lepidoptera Orders. These are the same four Orders found most commonly at the global level (Table 1), suggesting that the types of insects eaten in Asia and the Pacific mirror world patterns.

Thailand: A total of 81 insects reportedly are eaten in Thailand.[2] Compared to the other countries of Asia and the Pacific, Thailand appears to have been better studied. General press accounts document that forest insects are popular snacks in Thailand, from rural villages to the crowded streets of Bangkok. Thai insects are also available canned; products include cooked crickets, cooked silkworm pupae and cooked bamboo worms. Chiang Mai is a centre of interest for Thai insects in general and edible insects in particular. The city is also home to the private World Insect Museum.

Plate 1. Cricket farming in northern Thailand *(Courtesy K. Shono)*

Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines and Vietnam: These countries as a group account for a total of 150 to 200 edible insect species. A study by Yhoung-Aree and Viwatpanish (2005) provides aggregated data (164) on edible insects in Lao PDR, Myanmar, Thailand and Vietnam. It is obvious from the data that the countries of Indo-China, along with Myanmar, are quite underrepresented. Indonesia and the Philippines are only slightly better off. The most comprehensive new study was done in Sabah, Malaysia (Chung *et al*. 2002). Different ethnic groups were systematically surveyed and the edible insects were identified by entomologists. This study should stand as a model of the type of field research needed elsewhere, including the other states of Malaysia.

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[2] Note that data presented by Sirimungkararat *et al.* in these proceedings indicate that the total number of edible insect species in Thailand may be as high as 194, but with 81 species indicated as edible forest insects.

India, Nepal, Pakistan and Sri Lanka: These four countries have a large combined land area, but information sources revealed a total of only 57 edible insects. In part, the low number may reflect the presence of large Hindu and Buddhist populations, which are largely vegetarian. One interesting pattern relates to the silkworm (*Samia ricini*), which is raised in both India and Nepal for fibre. In India the pupae are eaten by humans, but in Nepal they are not, although they are being experimented with as feed for poultry and pond fish.

Papua New Guinea and the Pacific Islands: A total of 39 forest insects reportedly are eaten in this huge area. Nearly all the reports are from Papua New Guinea. Information is very incomplete with regard to the Pacific Islands, highlighting the need for more document and field research on the subject.

Interaction between edible forest insects and forest ecosystems

Insects, edible and non-edible alike, are key life forms in forest ecosystems, functioning as pollinators, aiding in the decomposition of dead plants and animals and aerating soil through their burrowing. Insects are important food sources themselves for birds, reptiles, etc. and even provide food directly to carnivorous plants such as the Venus Flytrap (*Dionaea muscipula*). In some cases, mutualistic symbiotic relationships have evolved; for example, between ants and acacia trees, where apparently in exchange for nutritious leaf sap the ants protect the leaves from leaf-cutting caterpillars.

The scientific identities and details about the life cycles of many forest insects are not known. Forest degradation and clearing may unintentionally disrupt the life cycle of an insect species and could result in its extinction. Globally, this represents the leading cause of insect extinctions. Insects account for the greatest amount of biodiversity in forests, but are the least studied of the biota.

A few edible insects enhance their habitat in specific ways. For example leaf-cutter ants in South America, cultivate "fungus gardens" that convert cellulose into carbohydrates; termites in Africa increase local plant species diversity because some plants can only grow on termite mounds (DeFoliart 1997).

Overexploitation of food insects for socio-economic purposes is a danger in some areas. In Hidalgo, Mexico, field studies revealed that out of about 30 species of insects used as food, 14 species are under threat as a result of current levels of commercialization. Previously, insects primarily had been gathered for local subsistence purposes. Because edible insects are not recognized at the national level as a food resource, there are no regulations on the exploitation of natural populations. The culture of edible insects would seem to be the most practical remedy because their care is simple and has minimal environmental impact (Ramos-Elorduy 2006, 2005).

A recent study by Samways (2007) identified six basic interrelated principles to guide synthetic conservation management of insects. They are to: 1) maintain reserves; 2) maintain as much landscape heterogeneity as possible; 3) reduce the contrast between remnant forest patches and neighbouring disturbed habitats; 4) promote the concept of land sparing outside reserves;

5) simulate natural conditions and natural disturbance; and 6) connect similar patches of quality habitat with protected corridors.

All projects or programmes aimed at promoting edible forest insects should carefully ascertain the conservation status of the insect species directly involved, to avoid risk of contributing to species extinctions. The World Conservation Monitoring Centre (WCMC) in the United Kingdom maintains separate searchable animal and plant databases, accessible on the Internet, containing the identity of species of conservation concern, meaning they are under some level of threat of extinction in the wild. For those species identified, information is provided on the accepted scientific names, common names, geographic distribution, conservation status and related information. Species that do not appear on WCMC lists are assumed not to be under threat. The WCMC database can also be used to verify the conservation status of insect host plant species.

Commercial potential of edible forest insects

The capturing, processing, transporting and marketing of edible forest insects provide important income and livelihood opportunities for an undetermined number of people around the world. Traditionally, these activities were all locally based and largely underrecognized. Recently, however, more sophisticated and wide-reaching marketing and commercialization of edible forest insects have been advanced, including attractive packaging and advertising. Some advocates believe that creating a wider market for food insects could provide an economic incentive for conserving insect habitats.

Published research thus far has paid little attention to the subject of marketing and commercialization of edible forest insects in Asia and the Pacific. The absence of economic data represents a serious constraint to the commercial development of edible insects.

Realizing the commercial potential of edible forest insects must go hand-in-hand with one or more of the following: 1) increased production of wild edible insects through expansion or intensification of the harvests; 2) adoption of forest management practices to enhance productivity; 3) steps toward insect ranching and domestication (see Box 1). These and other topics are addressed in a recent book, *Ecological implications of minilivestock* (Paoletti 2005). This book represents a clear benchmark in the state of knowledge about edible insects and is the most significant technical study on the subject since the comprehensive *Insects as human food* (Bodenheimer 1951).

Box 1. Commercialization of insect farming in Northeast Thailand

Edible insects are increasingly being farmed commercially in Northeast Thailand, expanding an industry that has sprung up since 1999. Entomologists and agricultural extension agents at Khon Kaen University have developed low-cost, cricket-rearing techniques and offered training to local residents. Currently, 4 500 families in Khon Kaen Province raise crickets, as do nearly 15 000 others elsewhere throughout Thailand. A single family can manage cricket rearing as a sideline activity without outside help, needing only a few hundred square feet of land. The 400 families in just two local villages produce some 10 metric tons of crickets in summer, the peak yield period. As the weather cools, yields may eventually fall by 80 percent or more. Still, that translates to extra, year-round income of US$130 to US$ 1 600 a month per family – quite a windfall for residents of one of Thailand's poorer regions.Most of the farmed crickets go to big city markets, like outdoor stalls in Bangkok. However, some are exported to neighboring cricket-consuming nations, such as Laos and Cambodia. Thai families also farm ants, another popular edible insect. Khon Kaen University experts have also developed new rearing techniques for farming grasshoppers and the giant water bug (a Thai favorite). A recent survey of Thai insect consumers found that 75 percent eat bugs simply because they're tasty – especially as a snack with beer. Excerpted from an article published in the *ScienceNews* (Vol.173 No.18).

Existing practices to gather forest insects for local subsistence purposes must not be impacted negatively by commercialization. In fact, commercialization may increase the quantity of edible forest insects available for local consumption and thereby provide positive nutritional benefits, as well as create local employment opportunities. Development of edible forest insects must be considered with respect to local, domestic, interregional and international markets because each presents a different set of challenges and requirements for success. In the absence of research results, the extent to which edible forest insects possess commercial potential is difficult to ascertain and generalize about because contemporary dietary habits vary so widely among different populations and ethnic groups.

Plate 2. Wide variety of insects on sale at a local market in northern Thailand *(Courtesy P.B. Durst)*

Although challenging, the introduction of new food items to the human diet is not without precedence. The negative impressions associated with certain foods can be overcome. For example, consumers discovered that certain cheeses with a strong taste and odour were in fact very palatable. Similarly, the eating of live animals (oysters) and raw flesh (sushi) has become commonplace. Adoption of alternative names also has helped to expand and increase consumption of certain foods perceived to be unappealing.

In developed countries, thus far edible insects represent a novelty or snack food to a considerable extent, as evidenced by the products being offered such as, in the United States, fried insects embedded in chocolate or in hard candy, and fried and seasoned larvae. A recent magazine article stated that a restaurant in Dresden, Germany, offers maggot ice cream and maggot salad to the adventurous eater (Klosterman 2006). Several books have been published on the eating of insects, detailing how they are eaten alone and in recipes for the preparation of dishes with insects as a major ingredient (Menzel and D'Aluisio 1998; Ramos-Elorduy 1998; Taylor and Carter 1992; Comby 1990; Taylor 1975). The ultimate goal is to elevate certain edible insects to gourmet food status; if that is accomplished, demand will follow.

In instances where insects are traditional food among a certain group, this fact can serve as an avenue to commercial development. Rural people who move to the city bring with them their traditional food preferences and represent a strong initial potential market. The same is true of individuals who have emigrated to foreign countries. The ethnic restaurants and markets that such groups establish provide a source of what some have called *nostalgia* food, which brings back fond memories of the homeland. Patrons experimenting with new and different ethnic foods have an opportunity to try such dishes.

The issue that would be most beneficial to commercializing edible forest insects involves the promotion and adoption of modern food technology standards for edible insects that are sold live, dried, smoked, roasted, or in some other form. Benefits would accrue from the local to the international markets.

Insect exploitation and forest management

Insect collection activities generally have a nominal impact on forests and management practices involving timber and non-wood forest products. The minimal impact is likely because edible insects are simply collected from forests, most often on a small scale.

Among land managers, there is little knowledge or appreciation of the potential for managing and harvesting insects sustainably. There is almost no knowledge or experience in manipulating forest vegetation or harvest practices to increase, maximize, or sustain insect populations. Indeed, as many insects cause massive damage and mortality to valuable commercial trees and crops, virtually all insects are considered undesirable pests by many farmers and forest managers. What knowledge does exist in these respects is often held by traditional forest dwellers and forest-dependent people.

Despite this lack of formalized knowledge, the great diversity of forest habitats harbouring edible insects presents an array of opportunities for innovative management of food insects so as to simultaneously contribute to maintaining habitat diversity for other life forms. DeFoliart (1997) suggested five general approaches to protecting forest biodiversity, focused on the insect populations, as follows:

- Enhance forest management by taking into consideration the wishes and needs of local people. A good example is to be found in Central Africa where seasonal burning practices are essential to sustain caterpillar populations that represent a traditional food item.
- Allow sustainable exploitation by local people of edible insects within otherwise protected areas to reduce illegal poaching pressures. For example, the collecting of caterpillars in Malawi woodlands.
- Reduce the use of pesticides in agriculture by developing efficient methods of harvesting pest species that are also traditional foods, such as grasshoppers.
- Increase overall productivity by developing dual product systems, where appropriate, which accrue economic and environmental benefits. Examples are silk for fabric and silk moth larvae and pupae for food; honey as a sweetener and honey bee brood for food.
- Reduce organic pollution by recycling agriculture and forestry wastes into food or feed, using palm weevils and fly larvae as the processors.

While the level of knowledge about the relationships that exist between edible insect collection/management and general forest management is limited, various examples do exist around the world that demonstrate the potential for such symbiotic approaches. The following three examples are highlighted for reference:

Sago grubs in New Guinea. In parts of New Guinea where the sago palm (*Metroxylon sagu*) occurs in extensive stands in swampy sites, the sago grub is raised as a by-product of sago starch production, with the stumps and stem tops left in the field for insect colonization. In some parts of the Sepik River valley, another species of sago palm (*M. rumphii*), which is an inferior producer of stem starch, is specifically felled for grub production. Squares are cut into the stem to give the beetles easier access to the pith for oviposition. Under both approaches, harvesting of the beetle larvae can begin about a month after the trees are felled, and continues for another two months. The production system is sustainable because only mature palms are felled and the palm regenerates vigorously by naturally occurring basal suckers; moreover, the swamps are not suitable for most other types of agriculture (Mercer 1997).

Caterpillar management in Africa. Edible caterpillar exploitation in Northern Zambia involves traditional harvesting and management practices, such as monitoring of caterpillar development and their abundance in the forest, protecting host plants and eggs against bush fires and temporal restrictions on harvesting (Mbata *et al.* 2002). Edible caterpillar populations in mid-western Zambia fluctuate greatly in nature from year to year (Silow 1976), requiring careful observation and monitoring to ensure sustainable collection of caterpillars. Abundant sunshine along with early, heavy rains result in a good caterpillar season, whereas cooler weather and low rainfall will produce relatively few larvae. If such fluctuations in insect populations are common in other locations where rainfall is strongly seasonal, the fluctuations need to be taken into account to ensure sustainable production.

In another example of caterpillar management from Africa, people in the Democratic Republic of Congo frequently bring young caterpillar larvae back from the forest and place them on acacia trees near their homes where they are reared until ready to eat (Latham n.d.). Various other insect harvesting in Africa involves cutting tree branches or felling trees, practices generally detrimental to forest management (Balinga *et al.* 2004), suggesting further opportunities to enhance management by adjusting practices.

Domestication of insects that are food sources. Insect domestication is an incremental process beginning with collecting the wild resource, gradually increasing levels of wild resource management and culminating in full domestication where the insect through evolution becomes distinct from its progenitors and may be incapable of survival in the wild. The point is that domesticated insect species have as part of their domestication histories, examples of resource and forest management. Two major types of insects have been domesticated successfully: silkworms and bees. Although sources of silk and honey were the primary motivation for these domestications, the insects also represent a food source – pupae and bee brood, respectively.

The mulberry silkworm (*Bombyx mori*) may represent the oldest domesticated insect in the world – domesticated for silk and the edible pupae as far back as 5 000 years ago in China. The pupae of wild silk producers (also Lepidoptera) are also eaten. Also in China, thousands of acres of oak are under cultivation to provide feed for moths that produce tussah silk as well as edible pupae. In such instances, the insect raising leads to improved forest management through reforestation with the appropriate tree species to promote silk production. Other species of silkworms in India, China, Japan and Africa are exploited under similar circumstances (DeFoliart 1995).

Food products from bees are derived from wild, semi-domesticated and fully domesticated species. In addition to the obvious attraction of sweet honey, insect larvae and pupae (bee brood) contained within the hive are eaten in Asia, Africa and the Americas. Domesticated and semi-domesticated bees typically are reared in wooden hives, old tree trunks or other containers in settlements within or near to forest stands, which the bees continue to visit to gather nectar. Bee hives are used on fruit tree plantations (for example citrus) to enhance pollination and fruit set. Wild honey is common in Southeast Asia; harvesting of honey, wax and brood may have little impact if only the hives are exploited, but in some instances trees are felled to reach hives higher up in the branches, a destructive practice also found in parts of Africa (DeFoliart 1995).

Wild silk and wild honey extraction, and the associated edible stages of these insects, are compatible with larger forest management schemes and do not interfere with other forestry activities providing that tree felling is avoided. Forests also benefit indirectly from the rearing of silkworms (host tree planting) and bees (pollination).

Ramos-Elorduy (1997) enumerated 65 edible insect species that are cultured to some degree, in Mexico and other countries. She points out that in general the culture of edible insects does not require complex infrastructure; they feed themselves, or can utilize residues of plant or animal organic matter and their care is simple. Insect rearing clearly offers opportunities compatible with forest management.

Key research and development deficiencies

To promote forest insects as a human food source, six major deficiencies need to be considered.

1. Geographic information gaps. The level of detailed information on edible forest insects is inconsistent over the Asia-Pacific region. Areas where more data are needed are Peninsular Malaysia, Indochina, Myanmar, Nepal, Pakistan, Taiwan Province of China and the Pacific Islands, especially Micronesia and Polynesia.

2. More accurate insect identification. The literature about entomophagy from subject areas outside of entomology often provides incomplete or inaccurate information on the exact identity of the insects being eaten. In some instances, an ethnographic study may simply refer to the fact that a certain number of insects are eaten, without even a rough indication of their identity. A major difficulty is that often it is the insect larvae and pupae that are consumed and at these stages identification is exceedingly difficult. In areas where forest insects are plentiful and being eaten, follow-up studies may be required to clarify the insect identities before proceeding with development efforts. A simple guide to the known edible forest insects could be prepared, illustrated with line drawings; it would be of considerable value to individuals without formal training in entomology.

3. The ecological role of edible forest insects. Forest entomology has focused almost exclusively on pest management and the control of insect populations adversely affecting valuable timber species, using chemicals or integrated pest management. The degree to which harmful forest insect populations are also edible species is poorly known. Certain

beetles and grasshoppers likely play a dual role. Insects are key pollinator species in forests, but information is lacking about which edible insects may be involved. Before designing any insect management scheme for food, this fundamental question needs to be answered.

4. Investigations into insect rearing for food and other purposes. Successfully functioning systems of insect rearing exist in beekeeping, silkworm farming and to produce feed for livestock and insectivorous captive animals; these can serve as models for insect rearing for human food.

5. Postharvest handling of insects and improved processing and storage. Investigations are needed to examine modern food science practices and, where appropriate, how they could be applied to edible forest insects.

6. Economic and marketing data. Almost nothing is known about this subject in terms of existing edible forest insect production. Research on this subject would benefit from linkage to work related to improving identification of insects eaten as food.

It would be extremely useful to facilitate research on the six topics identified – and others – if an institution were established to serve as a clearinghouse for information on edible forest insects in the Asia-Pacific region. Such a clearinghouse would logically focus on technical publications within the region, published in Asian languages. Work could potentially be conducted in collaboration with the Bureau for Exchange and Distribution of Information on Minilivestock (BEDIM), based in Gembloux, Belgium. Important, but expensive, new reference works such as the *Encyclopedia of insects* (Resh and Cardé 2003) and *Encyclopedia of entomology* (Capinera 2004), are not likely to be readily available to researchers in the region, so ideally the suggested clearinghouse should have strong existing interest in entomology and excellent library resources.

Case studies

The following case studies exemplify in more detail the potential of forest insects as human food.

Case study 1: palm insects as human food

Throughout the tropics, humans eat larvae and adults of the palm weevil, *Rhynchophorus* spp. and other Coleoptera infesting palms that store starch in their trunks. When a starch-bearing palm falls or is felled intentionally, trunk pith is exposed and attracts palm weevils to lay their eggs on the starchy surface where they develop into fat, white larvae. As the palm stems rot and are tunneled by the feeding larvae, they can easily be broken apart and the larvae extracted.

The sago palm (*Metroxylon sagu*) is a prime source of food insects. The Sanio-Hiowe of Papua New Guinea eat the adult palm weevil and larvae (grubs). Their use of grubs has two aspects: grubs obtained for the daily diet and those gathered in anticipation of a feast. The grubs eaten in small quantities in the daily diet are gathered by women from the unworked portions of sago palm trunks cut a month or more earlier. The sections of the trunk nearest the ground and just below the crown are lowest in starch yield and are not utilized for starch extraction. One or two months before a feast, men cut sago palms specifically for grub production and notch the logs so that the weevils can readily deposit their eggs. Palms selected for this purpose are of a low-yielding variety referred to as "grub sago". In this way, the Sanio-Hiowe are allowing the grubs to convert the smaller quantities of starch into fat and protein, an efficient manner of exploiting the lowest-yielding sago palms.

In other New Guinea societies, similar use is made of sago grubs, depending upon the relative abundance of sago palms. The Arapesh collect grubs from any rotting sago trunk, whereas other indigenous groups in the lower Sepik River area deliberately fell and cover sago palms so as to accumulate large quantities of grubs to be smoked for feasts. Also in the Sepik region, the Gadio Enga work only the midsection of each sago palm trunk for starch extraction. The lower section is chopped up for pig food and the section below the crown is reserved for grub colonization.

Sago grubs have an important ceremonial role for the Asmat of Irian Jaya. In the consecration ritual for a rebuilt men's house, large numbers of the larvae are placed in a cylinder made of palm leaves. At the conclusion of a dance the cylinder is chopped open and the larvae tumble out. They are then shared as feast food. Asmat management of sago resources for starch and grubs reflects their sociocultural change from semi-nomadism to settlement in large permanent villages. Sago palms near the village are used for starch production, whereas more distant stands are designated for producing grubs for ritual use.

The eating of sago grubs is reported from several other Southeast Asian areas. The Tasaday in the Philippines leave a substantial portion of the trunks of *Caryota* and *Arenga* palms from which they have prepared sago. They return months later to collect the grubs from the rotting trunks. The Melanau of Sarawak highly prize grubs taken from sago palm stumps. Grubs are eaten live with salt, boiled or fried. Traditional Melanau marriage feasts include sago grubs. Sago grubs are also considered a delicacy on Siberut in the Mentawai Islands.

In Africa and Latin America, palm grubs also are eaten, lightly roasted or raw, by indigenous people. The larvae of *Rhynchophorus* and other genera are harvested from several different palms. Sago grubs represent a good source of nutrients (Onyeike *et al*. 2005; Ruddle *et al.* 1978).

Plate 3. Deep-frying of bamboo worms (northern Thailand)
(Courtesy P.B. Durst)

Case study 2: edible forest caterpillars in Central Africa

A recent FAO-supported study focused on edible forest caterpillars in Central Africa. It described the commercialization of this traditional food source and the measures that need to be taken to develop and integrate edible insects into forest management.

Individual studies of edible caterpillars (e.g. *Imbrasia* spp. and *Anaphe* spp.) were carried out in Cameroon, Central African Republic, the Democratic Republic of Congo and Republic of the Congo. Information was obtained through questionnaires given to consumers, merchants and other target groups.

Two principal harvesting techniques are employed. Caterpillars are gathered by hand from the ground and from the trunks, branches and leaves of the trees. Or, trees or branches are cut and the larvae harvested. Gathering caterpillars is a seasonal activity coinciding with the rainy season. Little if any management of the resource is practised. Harvested caterpillars can be kept in live storage for a maximum of three days. After being purged, washed and usually cooked, the larvae can be preserved by either sun-drying or smoking. Smoked caterpillars can be stored for up to three months. Commercialization of living or preserved larvae is most frequently conducted through wholesalers and retailers. Only full-grown caterpillars are sold as they are of better quality. Customarily, merchants go to rural villages to purchase larvae for resale in the cities. Direct commercialization is practised by women and children who sell them at markets. Caterpillars are sold in units, measured in glasses, bowls, handfuls, buckets and sacks. In Bangui, Central African Republic, dried caterpillars are sold by producers for US$1.70 per kilogram. There is significant trade in edible insects among countries in the Central African region, and also with Sudan and Nigeria. Export figures are rarely reported, but annually, from the Democratic Republic of Congo, France imports about 5 tonnes of dried caterpillars and Belgium about 3 tonnes. Caterpillars are a standard seasonal ingredient in the local diet, eaten as a side dish, cooked with spices, vegetables and fish or meat, or consumed as a snack. One hundred grams of dried caterpillars contain 52.9 grams of protein, 15.4 grams of fat, 16.9 grams of carbohydrates and have an energy value of 430 kcal. They are also rich in different minerals and vitamins. The prevalence of caterpillar consumption and species preferences depends upon culinary traditions. In some cultures there are restrictions on caterpillar consumption, with the larvae being reserved for dignitaries and the wealthy.

Harvesting caterpillars for human consumption has positive and negative impacts on forests. Reducing caterpillar populations is beneficial to host trees, although harvesting practices that include cutting of branches or felling trees contribute to forest degradation and deforestation. Extensive collection of caterpillars does not negatively affect their reproductive capacity. Felling of host trees can lead to a gradual decrease of host-specific insect populations, however. Forest fires may reduce populations of edible caterpillars, but allow an increase in more resilient insects such as non-edible beetles.

The studies recommend that scientists investigate the biological potential of edible forest insects taking into account insect conservation, forest management, agriculture, nutrition and food processing. Socio-economic studies are also called for to assess and possibly enhance the subsistence, food security and commercial value of edible insects, especially among the poorest populations. With the results of the proposed foregoing studies, it will be possible to integrate forest insects as a non-wood forest product into sustainable forest management practices and explore opportunities for domestication of forest insects and host plants (Balinga *et al.* 2004; Illgner and Nel 2000).

Case study 3. entomophagy among Amazonian Indian groups

Descriptions of how insects are consumed by indigenous groups in South America parallel those elsewhere in the world and are a strong indication that development potential exists wherever insects figure in human diets. Information was aggregated on reported entomophagy among 39 ethnic groups in the Amazon Region and compiled in a database. The database lists 209 insect species that are scientifically identified. Predominant are beetles (Coleoptera); bees, wasps and ants (Hymenoptera); butterflies and moths (Lepidoptera); and termites (Isoptera). Species eaten are identified by stage of the insect life cycle (larvae, pupae or adult) and the manner of consumption (raw, roasted in leaves, fried, baked, roasted, or smoked). In most cases, the insects exploited are truly social insects (ants, bees, wasps, termites) or have a large body size such as beetles. Eating of bees (brood and pupae) is closely linked to honey gathering.

Typically, immature forms like larvae, caterpillars and pupae are preferred, but adults are also collected and eaten. Grasshoppers and caterpillars are eaten only after cooking. Caterpillars are generally gathered when they descend in mass from trees and are ready to pupate in the soil. Most groups eat a variety of species of caterpillars, but these species are very poorly known. Grasshoppers are gathered in several ways, including fire drives, mosquito nets and by hand.

Most groups use the larvae of the palm weevil. Some groups manage the production of larvae by deliberately cutting down palm trees to produce forage for adult Coleoptera and four to six weeks later gather the fat larvae. Numerous species of wood-boring Coleoptera are also eaten.

Insects are included in the human diet throughout the year as well as during special time periods. Insects and other small invertebrates make a significant contribution to human diets among some groups. The Yukpa Indians in Colombia are reported to prefer some traditional insect foods to fresh meat. Very limited data are available on the quantity of insects eaten and how their nutritional composition compares with other available protein sources. Identification of many of the insects eaten and their biology, including timing of collection and their host plants remains largely unknown. To promote and maintain insects as food resources without destroying the forest, practical rearing plans are required with experimentation at village levels (Paoletti and Dufour 2005).

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Entomophagy and its impact on world cultures: the need for a multidisciplinary approach

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Ever since the publication of Insects as human food *in 1951 by Fritz Simon Bodenheimer, considerable progress has been made in mapping the consumption of edible insects around the world. However, many regions and ethnic groups have yet to be examined. Existing qualitative studies need to be supplemented by quantitative data that cover different seasons; economic as well as ecological aspects of entomophagy have to be addressed; indigenous medicinal uses of insects need to be documented; ways to breed important species have to be evolved; and the cultural impact of insects must not be neglected. If we do not record the many uses of insects soon, it will be too late, for as habits change and traditions are lost, information on the role(s) of insects in human cultures and societies will ultimately become irretrievable.*

Keywords: ethnoentomology, food energy, insect farming, medicinal insects, protein

Terminology

The scientific term for the consumption of insects is “entomophagy” but the term “insectivory” is also used. How then do entomophagy and insectivory, both basically the same in meaning, differ from each other? Generally speaking, the terms insectivore and insectivorous are used to describe species (or an entire taxon, for example the Order *Insectivora*, whose major, if not exclusive, food items are arthropods). The term entomophagy is preferred when the consumed arthropods represent only one component of a diet, which normally includes many other food categories as well. Thus, an omnivorous organism, feeding on fruit, vegetables, eggs, fish and meat may also be entomophagous, i.e. an eater of insects.

Entomophagy research

Although some earlier publications have dealt with human entomophagy (McKeown 1936; Bristowe 1932; Campbell 1926; Bequaert 1921; Holt 1885), it was Fritz Simon Bodenheimer, who, with his 1951 book entitled *Insects as human food*, put the study of entomophagy on a scientific footing: For the first time a global survey on insects as food was presented and discussed in an historic context. Bodenheimer pointed out that almost every group of insects is eaten among the various cultures of the world and that the use of insects for human consumption undoubtedly goes back to the dawn of humanity. It is, after all, specifically mentioned in the Bible (Leviticus 11:21).

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Since Bodenheimer's treatise, entomophagy as a field of scientific inquiry has received increasing support. For example, Szent-Ivany (1958) noticed that insects regarded as crop pests often had a higher nutritional value than the crop being saved; Bates (1959) wrote the article "Insects in the diet" for the journal *American Scholar*; Schimitschek reviewed the cultural impact of insects in 1968; and Meyer-Rochow (1973; 1975a) compiled lists of edible insects amongst tribal peoples of Papua New Guinea and Central Australia. A provocative article by Meyer-Rochow (1975b) in the Australian journal *Search*, suggested that entomophagical practices in many parts of the world were discontinued by locals in the false belief that they would be more readily accepted as civilized and cultured individuals by representatives of the Western world. Meyer-Rochow warned against this attitude and encouraged the West to view insects as a valuable food source to be used either directly (as part of the human diet) or indirectly (as poultry feed, for instance) and not simply as pests that need to be destroyed. Moreover, he pointed out that the huge sums of money needed to develop and spray insecticides with the risk of contaminating land and people could be used more efficiently in many other ways.

Such articles encouraged others to study the potential of insects as food and in the wake of these early publications numerous investigations on the chemical composition and nutritional value of insects were published (Bukkens 2005; Cerda *et al*. 2005; Mitsuhashi 2005a; Yhoung-Aree and Viwatpanich 2005; Ramos-Elorduy *et al.* 1982; Meyer-Rochow 1976). Furthermore, food insects from different parts of the world were investigated, for example, Africa (Malaisse 2005; Van Huis 2005; Nonaka 1996), Papua New Guinea (Meyer-Rochow 2005; Tommaseo-Ponzetta and Paoletti 1997), Central Australia (Yen 2005; Meyer-Rochow 1975a), Northeast India (Meyer-Rochow 2005), Japan (Mitsuhashi 2005a), China and Southeast Asia (Luo 2005; Yhoung-Aree and Viwatpanich 2005; Watanabe and Satrawaha 1984) and South America (Cerda *et al.* 2005; Onore 2005; Paoletti and Dufour 2005). A number of popular books on insects as human food were published (Nonaka 2005, 2007; Menzel and d'Alusio 1998; Mitsuhashi 1984; Watanabe 1983; Taylor 1975), review articles were written (Hoffmann 2006; Ratcliffe 2006; Luo 1997; DeFoliart 1989) and the topic of entomophagy began to feature at international conferences, such as the Pacific Science Congress in Seoul (South Korea) in August 1987, the International Conference on Minilivestock in Beijing (China) in September 1995 and the recent conference on Edible Forest Insects in Chiang Mai, Thailand in February 2008.

Entomophagy: history and geography

The value of insects as a food item is undisputed. In many locations insects are abundant and can be cultivated easily, requiring minimal space. In contrast to larger domestic food animals, whose bones, blood and offal are almost unusable as food, the entire insect can be used or processed into food. Insects are generally rich in protein and they contain lipids of easily digestible fatty acid composition, moderate amounts of carbohydrates and a balanced and valuable admixture of minerals. Few insect species are poisonous and some survival books, for example Hildreath (1974), actually recommend the consumption of insects rather than the uptake of unknown plants when marooned in the wilderness.

Assuming that insects were also consumed by Europeans in preChristian times (Bates [1959] provides ample evidence), one wonders why the insect-eating habit disappeared. At present we still do not have a satisfying answer to this interesting question, but the fact that the Inuit in the coldest parts of the northern hemisphere consumed insects (Meyer-Rochow 1972) suggests that it was not the relatively small size of boreal insect species, or the long insect-less winters, or the difficulty with which large insects could be collected. From an ecological perspective (Krebs 2001) an underutilized food resource will ultimately be exploited by a species or some populations (Figure 1).

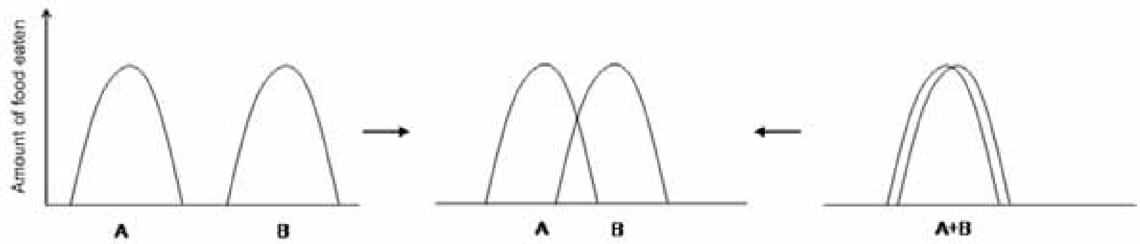

Figure 1. When two species or populations (A and B) encounter an underutilized food source, both will tend to exploit it and move towards the central situation. However, if their food preferences begin to overlap too much and both are competing for the same food (seen on the right), the tendency is reversed.

Once a resource has been discovered and is being utilized, neighbouring species or populations will compete for this resource, until finally one monopolizes the resource or both shift their food preferences away from the disputed resource. It helps if the resource dwindles and thus becomes less attractive. A seasonally abundant food source (including seasonally abundant food insects) can lead to temporary competition between individuals and entire populations, but peaceful interactions could prevail at other times.

When a particular food item, in this context insects (and edible spiders and myriapods), has become a regular component of a people's diet, fluctuations in the availability of this food item or increasing difficulties in its procurement will not stop the consumer from pursuing his/her customary share. McFarland (1989) illustrates such food resilience with human coffee-drinking and fish-eating habits, presumably in a western cultural setting: McFarland observed that when the price of fresh fish increases, people tend to buy less fish and switch to other food items, but when the price of coffee is increased, people continue to buy about the same amount of coffee as before, but cut back and save on other items. Thus, coffee resilience is high, while that of fish is low, i.e. it is "elastic".

Returning to food arthropods, we can expect cultures in which the consumption of these food items has been an age-old practice to exhibit a greater food insect resilience than cultures in which the consumption of insects has not had the same length of time to become an established, traditional component of the culinary local culture (Figure 2).

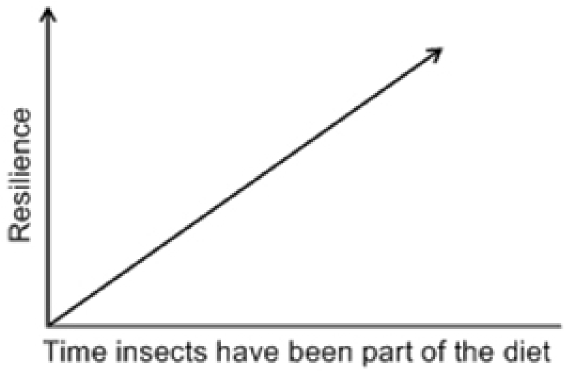

Figure 2. The resilience of a food item increases with the duration it has been part of the established diet.

We can draw parallels to investigations on island biogeography: Similar to an island that can only provide niches and habitats for a certain number of species, human cultures also appear limited with regard to the types of food they consume. Humans tend to utilize only a fraction of the full food potential of their environment. Although this fraction of food items varies among cultures, apparently no culture uses all the available food items. For example, according to Hill and Hurtado (1989) the Ache of the Paraguayan jungle only collect 40 species of the hundreds of edible plants available and only 50 species of the hundreds of edible mammalian, avian, reptilian, amphibian and piscine species serve as food. Approximately 98 percent of the food energy in the Ache diet stems from only 17 different food sources. Thus, the sum of all items used as food in a human culture is not infinite. Consequently, new foods, arriving from the *outside* can, and usually will, replace older, traditional food items. Thus, at any one time, a balance between long-established and newly acquired foods has to exist and given the finite nature of different food items consumed by humans, some foods will go out of fashion, while others become established (that is, become fashionable).

More isolated cultures, or those buffered by surrounding cultures with similar habits and traditions, will have fewer new food items arriving in their midst compared to cultures that engage in trade, have extensive external links, are easily accessible and are prepared to accommodate new ideas. This balance between newly arriving food items (or food preparation methods) and long-established practices, threatened by the new arrivals, is influenced by the degree of *openness* or *isolation* of a culture (Figure 3).

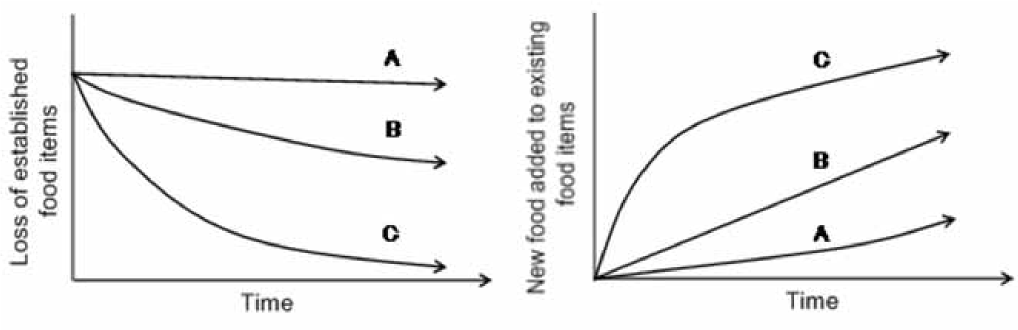

Figure 3. Left: Established food items are given up more easily by societies that are open to outside contacts (C), rather than by those that are more isolated or buffered by surrounding cultures (A). B represents an intermediate situation. Right: New food items are more readily added to existing food items in societies that are open to outside influences and ready to accommodate new ideas (C) than in those that are more isolated or buffered by surrounding cultures (A). B represents an intermediate situation.

Understanding such correlations could assist us to unravel how entomophagous practices have spread from one region to another, for one of the basic questions in entomophagy research remains, “Where did the practice of entomophagy begin and how did it spread?”

It is well-known that human entomophagy has a long history and obvious that insects and their products have been used by humans since ancient times: The word *honey* is mentioned 55 times in the Bible. In fact, our closest animal ancestors, the primates, are known to collect and eat insects (Nickle and Heymann 1996), often during the search for fruit. Thus, it is perhaps not too far-fetched to conclude that the first insect species that found acceptance by humans were those that were eaten in conjunction with picking fruit (Dudley 2000; Andrew and Martin 1991). Such insects were either sweet or at least associated with a sweet food item.

Human sense of taste detects the difference between sweet and sour. We can also taste fatty, oily food items, but we do not possess a specific taste for protein (note that *umami*, a disputed taste category, has been described as a meat flavour taste), but even if *umami* were indeed to represent a fifth taste category, it would still not qualify as a ubiquitous protein taste (Fuke and Konosu 1991).

Following the acceptance of sweet or fruit-related insect species as a human food item, greasy, lipid-containing insects would have been the second group to find acceptance. Reim (1962) observed that amongst Australian Aborigines, whose other food items were deficient in fat (O’Dea 1991), lipid-containing insects and grubs were a favourite food item, while protein-rich species like locusts and grasshoppers played almost no role at all. Admittedly, other and additional reasons (such as religious beliefs, taboos) may have played a role as to which insect a tribe or group of people ultimately found acceptable as food, but a sequence from sweet via greasy to protein-rich insect species as food, given the historic perspective, seems plausible (Figure 4).

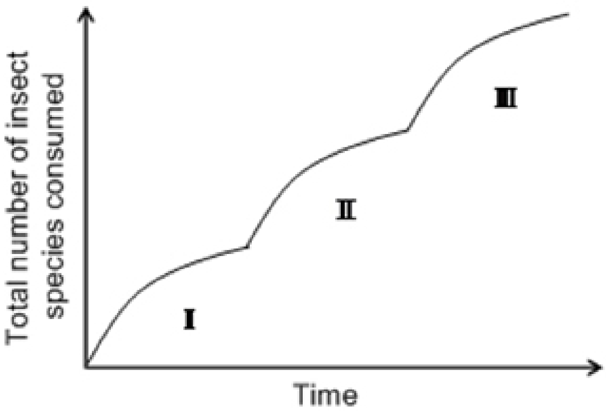

Figure 4. The first insects to be accepted as food (I) were possibly species that had a sweet taste and contained sugary substances. The second group of insects to be accepted (II) were probably fatty, lipid-containing species and finally protein-rich species (III), now constituting the bulk of edible insects, were added.

Given the dearth of knowledge on this matter, it is very interesting in this context to note that Australian Aborigines have more in common in terms of accepted food insects with South Indian tribals than with the nearby tribes of Papua New Guinea. Could it be that the earliest Australian immigrants, supposed to have originated from southern India (Birdsell 1967), brought with them the preference for sweet and fatty insects? Food habits and recipes, written or unwritten, can be extremely durable, especially in situations of geographic isolation (Australian Aborigines) or cultural isolation/segregation from surrounding cultures (Kovalainen 1975). On the other hand, it is obvious that neighbouring cultures share insect food practices through interchange of ideas, intermarriage and trade links when we examine entomophagy in South and Southeast Asian regions (Figure 5). Although evidence for some of the interactions postulated in Figure 5 is strong, we still know too little to be able to draw an overall and comprehensive picture. Thus, there is a call for more research, especially incorporating interdisciplinary approaches.

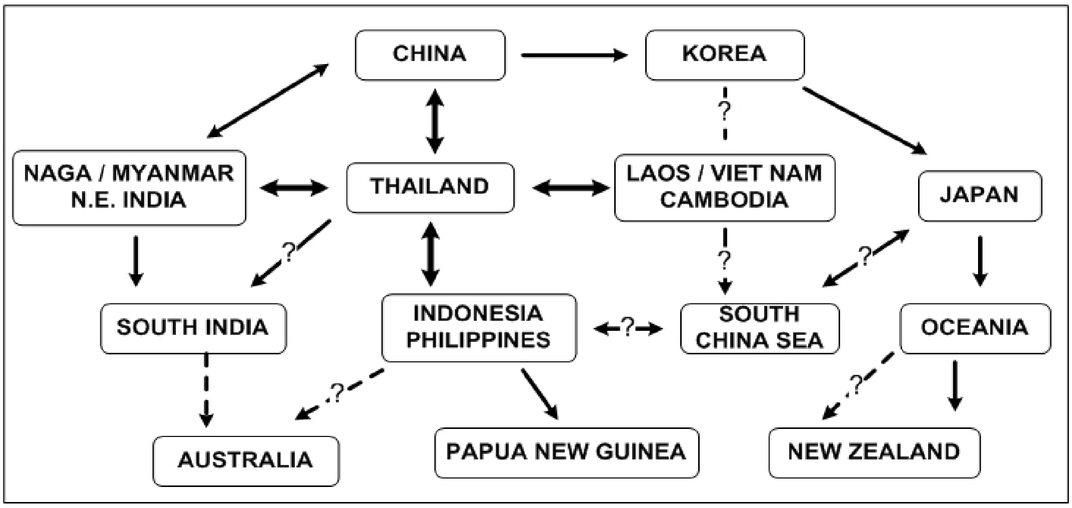

Figure 5. Regions rather than political entities are listed. Insect-eating practices clearly link the Northeast of India via Naga/Myanmar to the Thai region and Indochina. Bilateral exchanges also occurred with China. In other regions of Asia the flow of entomophagous practices seems to have been more monodirectional. Broken arrows indicate possible prehistoric contacts and question marks indicate areas on which we can only speculate about which way entomophagy was possibly spreading.

Non-food insect uses

In addition to the use of insects as human food items, insects have played (and are still playing in many cultures) a role in indigenous medicinal practices. Theoretically, no species of insects would be available exclusively for medicinal use if all potentially usable insects were also used as a regular food item. On the other hand, even in cultures, in which the consumption of insects ceased centuries ago, some use of insects and their products still lingers on in indigenous medicines (Figure 6). Thus the medicinal use of insect species is of considerable importance, not only to trace cultural links between insect-using peoples, but also to *test* whether, in some cases, practices that have been in use for thousands of years today have some merit in treating certain disorders. A plea is therefore made to expand the study of entomophagy and include the documentation of insects used in indigenous medicinal practices. This has been increasing in extent (Ding *et al.* 2005; Costa-Neto 2000; Pemberton 1999; Read 1982).

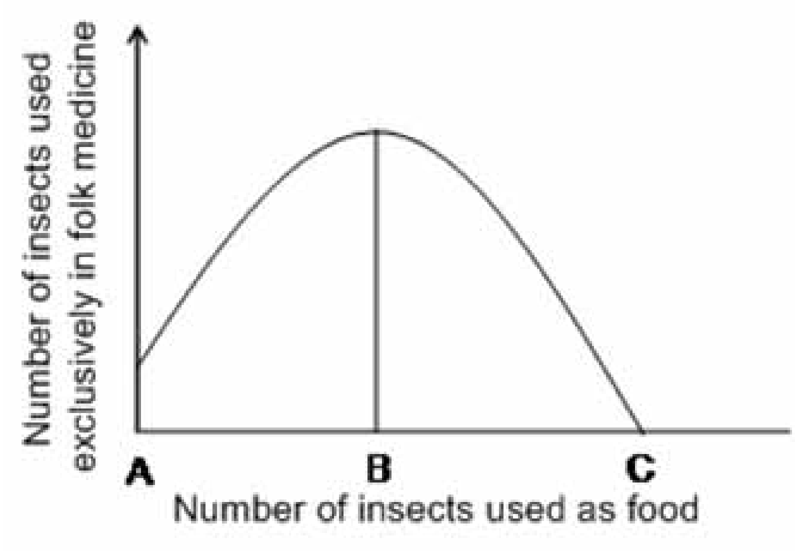

Figure 6. Assuming a culture uses all available insects as food (C), then none is exclusively used for indigenous medicinal practices. On the other hand, in cultures in which insects are no longer used as food (A), some species still find acceptance in folk medicines (e.g. for the treatment of warts, rheumatism, etc.). The situation depicted in B shows that some insects find acceptance as food, but others are only used in folk medicine.

A multidisciplinary approach for the future

Indeed, much could be gained from a more interdisciplinary, multipronged approach, which suggests some recommendations. These recommendations are based largely on basic and not the applied side of ethnoentomological research. This does not diminish the value of applied research; it is simply a reflection of the author's interests and academic upbringing.

1. For many tribes or tribals, ethnic groups, traditional or indigenous populations and societies little is known about the extent to which insects are being used as food items or what role they play in local medicinal practices. In some cases, investigations towards this end are still possible through visits to the areas in question, through interviews or the involvement of local researchers, but for others researchers must rely on oral lore, on diaries, observations by early explorers, adventurers' log books, letters written and notes taken by missionaries. Such older documents need to be scanned and studied for relevant information.
2. In the past, insects (and other arthropods) used for human consumption have frequently been recorded in a haphazard, irregular and unplanned manner, not unlike photographic snapshots. Long-term observations are needed on insect uses, covering different seasons, for even in tropical regions different insect species may be abundant at different times of the year.

3. Although accumulating lists of edible and medicinally important species of insects and other arthropods is important, the documentation of the different preparation methods and, where appropriate, traditional storage and preservation methods has to be recorded as well.
4. Qualitative observations are required, but equally essential in the context of studies on the sustainability of the arthropod resource and its role in the overall nutritional budget of a person (or a people), are quantitative data. Are some insect species being more heavily sought after than others? What is the percentage of the insects consumed in relation to total food production and total food intake? How many of each species are consumed under which specific circumstances?
5. More analyses of the chemical composition of food and medicinal insects and other arthropods need to be carried out and related to different seasons and the food (frequently plants) the arthropods in question need to survive. Moreover, the nutritional (and medicinal) value of these arthropods has to be determined.
6. The economic situation of the collectors of food and medicinal arthropods and that of the vendors, intermediaries and consumers of commercially valuable insects and other arthropods should be investigated.
7. The possible domestication and husbandry/farming of useful arthropod species should be considered and the commercialization of food and medicinal insects has to be assessed. The feasibility of insect tissue cultures (as suggested by Mitsuhashi, personal communication), in combination with genetic improvements, should be investigated.
8. Suggestions for improvements in storage and transport of useful insects and other arthropods as well as innovative methods to freeze, can, dry, pickle or otherwise preserve insects (even in shapes that do not betray the "insect origin" like pastes or powders) should be examined.
9. If insect farming proceeds, insect diseases and insect pests need to be addressed, not only in view of the acceptability of the insect product by human consumers, but also in regard to the economic/financial viability of such insect-breeding facilities (Boucias and Pendland 1998).
10. Apart from the positive role of insects and other arthropods with regard to the extraction of compounds useful in the treatment of certain diseases, spider and insect phobias, allergies to insects and their compounds and food taboos related to insects need to be studied (Meyer-Rochow 2009).
11. The ecological impact and consequences of long-term insect use and insect exploitation in the natural environment have to be scrutinized scientifically. Can ecological balance be damaged by the removal of specific highly sought after species (or, alternatively, the introduction of species desired by locals as edible insects)?
12. An ethnological approach would require comparisons of the usage of insects and other arthropods between different ethnic groups.
13. Etymological research could assist in determining the origins of vernacular names of insects and spiders and thus support conclusions on the *flow* of entomophagous practices from one region to another.
14. Insect classification, according to the traditions of local people, could shed light on the importance, value and use of certain species.
15. Studies of the roles of insects and other arthropods in religion, myth, legend, song, and dance could be illuminating (Meyer-Rochow 1978/79).

16. Surveys of insects as parts of, or models for, decorations, paintings, sculptures etc. could reveal the regard to which insects are held in a given society. Moreover, they can be a reflection or commemoration of historical events like plagues, diseases and famines.
17. Studies of insects and other arthropods as objects of play and entertainment can reveal the closeness of a people to the arthropods surrounding them.
18. Investigation of references to insects and other arthropods in idioms and proverbs can reveal how they are perceived by a certain people (cf. Meyer-Rochow *et al.* 2000; Hogue 1987).
19. Studies of the roles of insects as *messengers*, indicators of suitability (for example palatable versus foul water), of sickness or of the time of death of a person (as in forensic examinations: Smith 1986) in different ethnic groups could be rewarding.
20. Finally, the prehistory of entomophagy and other uses of insects and arthropods is a fascinating field, which to a large extent draws upon field and laboratory observations of primates as our closest animal ancestors.

Conclusion

In order to achieve some of the goals outlined in the aforementioned list, ethnoentomology has to become recognized as a serious field of research with inputs from a wide range of disciplines covering the life sciences (zoology, entomology, ecology, genetics, taxonomy, medicine, biochemistry, pharmacology, nutrition, etc.), the humanities (psychology, philosophy, linguistics, anthropology/ethnology, geography, the arts, musicology, etc.) economics and management. This field of research, which concerns all humanity, needs all the publicity it can get, through television coverage, interviews, Web sites, blogs and through books,[2] review articles in different languages,[3] sponsorship by foundations and benefactors and through the support of international organizations. It must always be remembered that once a practice has died out, it is virtually impossible to recover the lost information that disappeared with it. Unfortunately, we are already too late with regard to numerous cultures (to name but a few the Ona, Yahgans and Alakaluf of Tierra del Fuego, the Tasmanian aboriginals, the Polynesian inhabitants of a variety of Indo-Pacific Islands, the Chatham Islanders, etc.); they have vanished forever or have irretrievably lost their traditions.

It is important that concerted efforts be made now to collect and record as much ethnobiological information as possible lest we regret later having been irresponsibly complacent now.

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[2] Nonaka (2007, 2005); Paoletti (2005); Menzel and d'Alusio (1998); Mitsuhashi (1984); Watanabe (1983); Taylor (1975).

[3] For example Chinese: Yang and Hou (2002); English: Meyer-Rochow *et al*. (2008); Estonian: Meyer-Rochow (1990); Finnish: Meyer-Rochow (1988); German: Hoffmann (2006); Japanese: Meyer-Rochow (1982); Mitsuhashi (2005a,b); Nonaka (2005); Portuguese: Costa Neto (2004); Spanish: Ramos-Elorduy and Pino (1990).

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Forest insects as food: a global review

Hans G. Schabel[1]

Many forest insects are decried as pests but they can serve as food for humans or as items in trade and commerce. After a period of cultural estrangement in some parts of the world, entomophagy may now be on the verge of recapturing its former respectability and broadening its significance in the tropics. As a nutrient-rich food source, certain insects can contribute to a balanced diet and thus have the potential to promote human health, while improving food and income security, especially among economically disadvantaged populations. At the same time, these once abundant resources may be jeopardized by habitat destruction/degradation and unsustainable rates or modes of extraction, unless they are managed as minigame in the wild or raised as semi- or fully domesticated minilivestock. Hopefully, dependence on and appreciation of insects as valuable food sources will also enhance environmental awareness and help to foster positive conservation attitudes.

A brief global review of traditional and contemporary aspects and trends associated with entomophagy highlights its merits while pointing out limitations and challenges. An argument is made for entomoforestry*, that is, deliberate interventions to manipulate trees for the sake of insects, especially multipurpose insects, and their integration with other land-use management schemes.*

Keywords: entomoforestry, entomophagy, forest resource, human food, nutrient source

Introduction

Throughout history, forests have provided humans with numerous wood and non-wood products, as well as environmental and social benefits. They remain very important for human welfare, especially for subsistence communities. Non-wood forest products (NWFPs) include numerous plants and animals, or their products, whose value in the tropics frequently rivals or exceeds that of timber (Anderson *et al*. 1998; Robbins and Matthews 1974).

Faunal NWFPs are derived from virtually every group of vertebrates. They can be eaten (bushmeat and fish) and their body parts are used for clothing, shelter, tools, ornamentation, pharmaceuticals and fertilizer; these animals can also serve as pets or be instrumental in teaching and research. Many forest invertebrates, including annelids, molluscs and various arthropods (crustaceans, arachnids and insects) have also been traditionally eaten as minibushmeat and have provided various useful products or services. Although most invertebrates are much smaller than mammals, they collectively account for 90 percent of animal biomass. Ants alone, important food and medicinal insects in many parts of the world, may outweigh all other animals together. These facts are important where wild vertebrate resources have been depleted and conditions for husbandry with large livestock are limited.

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Insects are particularly diverse in terms of number of species; estimates range from 7 to 30 million, and they occupy every conceivable habitat on the planet, except the oceans. Many are considered to be pests as they pose challenges to agriculture, horticulture, forestry, food storage, the integrity of wood and the health of animals, including humans. However, some of the same insects provide various services, and are of use in their entirety, or yield products sought by man (Table 1). Most of the insect goods listed are tree-related and could in the future provide sustenance and contribute to forest-based insect industries at various economic scales as they have done in the past or continue to do (Plate 1).

Table 1. Insect goods mostly from the forest

IA. Insects *in toto*

General use	Specific application
Animal bait or feed	Hunting, fishing, animal husbandry
Human food	Emergencies, snacks, ingredients, delicacies
Specimens (dead or alive)	Research, teaching, display, art, decoration, ambience, pets, collections
Incubators	Production of biocontrol agents (entomophages and entomopathogens)

IB. Insect products

Product	Application	Producers
Silk	Textiles, strings for leaders in fish lines, musical instruments and wound sutures	Bombycidae, Lasiocampidae, Saturniidae, Thaumetopoeidae
Honey	Food, beverages	Apidae
Honeydew (manna) and honeydew honey	Food, beverages	Homoptera in combination with Formicidae or Apidae
Mushrooms (*Termitomyces* spp.)	Food	Termitidae (Macrotermitinae)
Extractives a. Beeswax	Candles and more than 100 other industrial uses	*Apis* (Apidae)
b. Insect wax	Candles, polish, paper colouring, sizing	*Ceroplastes ceriferus* Anders. (Coccidae)
c. Pigments "Tuna blood"	Dye for textiles and leather, food colouring, cosmetics	*Dactylobius coccus* Costa (Coccidae)
Shellac	Paint, varnish, ink, food dye	*Kerria* (=*Laccifer*) *lacca* Kerr (Lacciferidae)
Niij	Lacquer, paint, unguent	*Llaveia axin* (Llave) (=*L. axin axin* Cockerell) (Margarodidae)

	Oak red	Dye	*Kermes* (=*Coccus*) *ilicis* (*Kermococcus vermilis*) (Kermidae)
	Armenian red	Dye for oriental rugs	*Porphyrophora hamelii* Brandt (Margarodidae)
	Polish red	Dye and food colourant	*Margarodes polonicus* (Margarodidae)
	Iron gall nut	Ink	Cynipidae
d.	Arrow poison	Hunting	*Diamphidia* spp., *Polyclada* sp. (Chrysomelidae), *Lebistinia* sp. (Carabidae)
Pharmaceuticals		Treatment or function	
a.	Flower and honeydew honey	Antioxidants, skin and respiratory problems	Apidae, Homoptera in combination with Formicidae or Apidae
b.	Propolis	Antibiotic	Apidae
c.	Royal jelly	Cholesterol-lowering, dietary supplement	Apidae
d.	Chinese caterpillar fungus	Tonic, astringent	*Cordyceps sinensis* infecting *Hepialus armoricanus* Oberthuer (Hepialidae)
e.	White muscardine fungus	Stroke	*Beauveria bassiana* infecting *Bombyx mori*
f.	Frass	Antidiarrhoeal	Certain Phasmidae and Lepidoptera
g.	Soil	Geophagy	Isoptera, Sphecidae
h.	Antivenin	Wasp and bees stings	Vespidae, Apidae
i.	Bee venom	Apitherapy (arthritis)	Apidae
j.	Chinese galls	Sores, cough, diarrhoea, astringent	*Malaphis chinensis* (Bell) (Pemphigidae)
k.	Ants	Hepatitis B	Formicidae
l.	Blister beetles	Vesicatory	Meloidae

Plate 1. Bee hunting as practised traditionally is often destructive. At least the tree in this case was not cut down in its entirety (Lake Eyasi, Tanzania) *(Courtesy H. Schabel)*

The history of entomophagy

> *My eyes widened. My mouth dropped to the forest floor. My stomach churned in disbelief! Shock, horror, even physical distress set in as I experienced entomophagy first hand.* (Fish 1999)

The practice of entomophagy has, at one time or other, been established on every continent except Antarctica, although evidence from Europe is meager and generally restricted to its more southern and eastern regions (Tommaseo-Ponzetta 2005; Bodenheimer 1951). All tropical continents and even North America to this day have certain epicentres of entomophagy, such as the American Southwest and neighbouring Mexico, the Amazon Basin in Ibero-America, Central and southern Africa, Southeast Asia and aboriginal Australia (Paoletti 2005). This practice generally seems to extend 45º north and south, with silkworms (*Antheraea pernyi*: Saturniidae) in Manchuria (Yang *et al.* 2000), grasshoppers (*Oxya* spp.) and certain other insects in Japan (Mitsuhashi 2005), the pandora moth (*Coloradia pandora*: Saturniidae) as well as several Saltatoria in the Inner Basin of North America and huhu grubs (*Prionoplus reticularis*: Cerambycidae) on the South Island of New Zealand (Meyer-Rochow 2005). In the northern- and southernmost regions of the world, lengthy dormant seasons and relatively low average temperatures depress developmental rates and the general activity of cold-blooded animals such as insects. It should, however, not be overlooked that certain forest pests, especially defoliators, sporadically and periodically reach epidemic proportions and impressive biomass in these latitudes. As biodiversity, activity, developmental rates and the size of many insect groups tend to increase towards the equator, so do opportunities for entomophagy, the menu generally being richest in the humid regions.

We can only speculate that entomophagy for our human predecessors initially developed on a trial-and-error basis and eventually evolved as a successful strategy for survival (Tommaseo-Ponzetta 2005). Insects that did not taste good, caused discomfort, or shortened lives, either discouraged consumption or were fatal. Over eons possibly more than 2 000 insect species globally, representing at least 14 Orders, came to be selected as edible (Malaisse 2005). Species in certain Families and Orders (Coleoptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, Orthoptera) are valued almost universally. The vast majority depend on trees or wood. Systematic screening of additional species of insects would undoubtedly yield many more candidates for entomophagy, just as bioprospecting for chemicals and other useful plant and fungal properties during the last decades has resulted in a plethora of new or potential materials and applications.

Earliest records from the Near East and from China document entomophagy as far back as at least the second and first millennia CE (Lanfranchi 2005; Zhi-Yi 2005). During the age of exploration numerous European travellers, naturalists, geographers, missionaries, adventurers, colonial officials and anthropologists reported on aspects of this practice among traditional societies with a mix of revulsion, fascination or detached scientific interest. Various records reflect not only which insects were being eaten (at least local names), but how they were captured, prepared, eaten, stored, or dispersed in commerce. They also reported often perplexing discrepancies in the acceptance or importance of entomophagy within closed groups of people, among neighbouring peoples and between regions. Entomophagous taboos and privileges were often gender-, status- or age-specific, rooted in age-old cultural or religious traditions, and sometimes simply based on cultural arrogance. For instance, pastoral people have often considered the sedentary lifestyle and habits of agricultural neighbours to be inferior. Colonial invaders also frequently dismissed entomophagy as a primitive or barbaric practice, implying superiority of their own culture and food, while they themselves relished other invertebrates as well as molluscs as gourmet food.

However, many traditional societies remained unaffected by such arrogance and, resisting stigmatization, happily continued to enjoy edible insects. About three decades ago, in response to surging human populations and concomitant threats to biodiversity and food security, numerous rural development initiatives started in developing countries, including science-driven efforts to explore insects as feed for livestock. By serendipity, the nutritional merits of entomophagy also came under closer scrutiny and a stock of supportive data logically led to attempts to promote this practice as well. In 1988, Gene DeFoliart started publishing *The Food Insects Newsletter*, which eventually reached audiences in at least 82 countries. This partially humorous, but sufficiently serious publication became a forum for the exchange of documentation for contemporary as well as historic information on entomophagy from remote corners of the world. In the process, earlier suggestions for using edible insects as minilivestock (Osmaston 1951), a dynamic concept that continues to capture the imagination, were revived (Paoletti 2005; Hardouin 1995).

The resulting flurry of publicity spawned some serious research efforts and resulted in numerous synopses on entomophagy for specific people, regions, countries and continents. Much of this growing body of knowledge is reflected in the references listed by various contributors in Paoletti (2005). It also increasingly attracted a crowd of curious thrill-seekers in the western world and resulted in at least six cookbooks for entomogourmets. Entomophagy was incorporated in certain university curricula, featured in movies and insect feasts (bug banquets) were staged in conjunction with entomological conferences, nature centres, state fairs, zoo and museum exhibits, school events, parties and military or wilderness survival training exercises. Several companies in the United States explored the marketability of insect food products (Plate 2). In Australia, "bush tucker" supplies became commercially available, a restaurant chain and an airline adopted insects as signature food, several relevant books were published and a TV show featured the "Bush Tucker Man", a rugged survivor who heavily relied on a diet of insects (Yen 2005; Menzel and D'Aluisio 1998). There were even two conferences on "Insects as a Food Resource".

Plate 2. An American multimillion dollar business sells insects for pet food, fish bait and embedded in candy, in this case a meal worm *(Courtesy H. Schabel)*

Not surprisingly, the western media had a heyday reporting on these novel developments, which may have helped to gradually diminish some of the prejudice in that part of the world (DeFoliart 2005). However, despite this flush of publicity, it is unlikely that entomophagy will move into the western mainstream soon. As food dictates culture and culture dictates food, visions of widely available *bugburgers* may be premature. There is little to suggest that bratwurst, steaks and pork chops will compete with grubs, caterpillars, pupae and grasshoppers. At the same time, countries with significant Asian, Central American and African migrant populations, increasingly offer the adventurous and discriminating gourmet access to edible insects at ethnic markets and restaurants, and green segments in the western world may eventually take to edible insects in the same way that organic food enthusiasts and (*mu*) *shroomers* have already embraced naturally grown and wild food. Rationally speaking, it would be an easy step to eat gypsy and nun moths, tent caterpillars, white grubs, cock chafers and other such tree insect pests in temperate zones, especially considering that people there routinely consume small stowaway insects, such as aphids and mealworms, hidden in vegetables, fruit and flour, making even a strict vegetarian diet an illusion. Ecotourists, who like to combine nature appreciation with cultural dimensions, have already begun to venture into edible insects (Plate 3), perhaps in time helping to break through the cultural barrier of acquired tastes (Cerda *et al.* 2005).

Plate 3. Ecotourist about to devour a live caterpillar of *Xyleutes capensis* (Cossidae), a borer of *Cassia* spp. and *Ricinus communis* (Marangu, Tanzania) *(Courtesy H. Schabel)*

Merits of entomophagy

If you cannot lick them: eat them, don't treat them. (The author)

Powerful arguments in support of entomophagy include nutritional benefits, poverty reduction through food security and the potential for income generation. Incentives for pesticide avoidance and conservation of bio- and cultural diversity are also frequently cited as motives to promote this practice (DeFoliart 2005).

The most compelling argument in favour of insects as food is their nutritional value and thus the potential to bolster food security and a balanced diet for better health. Insects are often eaten as fresh snacks on an opportunistic basis, or as a stopgap during famine, especially in semi-arid environments where food choices are limited and emergencies are recurrent events. One-third of the population of Africa alone is chronically malnourished (Sene 2000). However, insects are rarely considered staples in the diet, but more likely sought as condiments, food additives, delicacies or for rendered fat. Whenever their supply exceeds short-term needs, they can function as reserves for periods of dearth, or provide income through barter and trade. Food caterpillars and forest bees in particular are important for generating income, especially in Africa where their value often exceeds that of common agricultural crops (Balinga *et al.* 2004; Vantomme *et al.* 2004; Munthali and Mughogho 1992). Where certain Orthoptera (or other edible insects) can generate higher income than agricultural crops, such as in Africa, the Philippines, Thailand, Mexico and the Republic of Korea, powerful arguments can be made for their conservation and against expensive and environmentally dubious pesticide applications in forests and on crops (Yeld 1986). About 30 years ago, American Paiute Indians actually succeeded in stopping the USDA Forest Service from spraying insecticides against pandora moth caterpillars (*Coloradia pandora*), a Saturniid defoliator of pine and a traditional food for these people (DeFoliart 1991c).

The scientific merit of entomophagy has by now been well-established by numerous papers documenting the undisputed nutritional value of many edible insects (Paoletti 2005). Their nutrient profiles are often very favourable from the point of view of dietary reference values (DRVs) and daily requirements for normal human growth and health. In general, insects tend to be a rich source of essential proteins and fatty acids, as well as dietary minerals and vitamins, and thus, today, as in the past, play important roles in traditional diets (Bukkens 2005; Ramos-Elorduy 2005; DeFoliart 1989).

However, now that the poorer segments of society in many developing countries no longer benefit from such traditional diets, protein deficiencies (kwashiorkor) in particular are more common, especially in Africa. Adequate daily protein requirements for adults, as established by biennial FAO/WHO/UNU expert consultations, are listed at around 0.72-0.75 grams/kilograms/day, or about 10 percent of daily energy uptake, slightly less for women than for men. Plant proteins are generally considered to be of poorer quality than animal proteins, but in combination provide a better balance of certain essential amino acids than one alone. Insect proteins tend to be low in methionine and cysteine, but high in others, especially lysine and threonine (DeFoliart 1992). Eight of the 20 standard amino acids, isoleucine, leucine, lysine, methionine, phenylalamine, threonine, tryptophan and valine are not synthesized by humans themselves and thus must be obtained from food, as they are considered essential for normal growth and health. In Mexico and Central Africa, crude protein contents of numerous edible insects on a dry weight basis exceed 50 percent and range as high as 82 percent, with digestible protein as high as 64 percent (Ramos-Elorduy 2005; DeFoliart 1989).

The chemical nature of fatty acids is of great interest, as it pertains to potential long-term health threats or benefits. From a nutritional point of view, saturated fats are generally less desirable than mono- and polyunsaturated varieties. Almost all of the latter are essential fatty acids (EFA), such as omega-3s, which can only be obtained from the diet and are good for the heart. Insects range from less than 10 to over 30 percent fat on a fresh weight basis and their fatty acids are similar to those of poultry and fish in their degree of unsaturation, but are higher in polyunsaturates (DeFoliart 1991a). Termite alates contain 44.3 percent fat on a dry mass basis, which is very low in cholesterol and almost rivals that of groundnuts with 47 percent (Phelps *et al*. 1975), making it a healthy cooking fat. Cholesterol in insects varies with their diet (Ritter 1990).

In addition to C, H, N and O, certain dietary minerals, including macrominerals (Ca, Cl, Mg, P, K, Na, S and NaCl) as well as trace minerals (Co, Cu, F, I, Fe, Mn, Mo, Ni, Se, V and Zn) are required for normal growth and health. Caterpillars tend to provide many of these minerals in abundance (Paoletti 2005; Balinga *et al.* 2004) and the majority of edible insects have a very high proportion of K, Ca, Fe and Mg (Ramos-Elorduy 2005). Interestingly, geophagy, the eating of earthy substances such as soil from termitaria and sphecid nests during pregnancy, religious rituals or as medicine, as reported from Africa and parts of the United States, purportedly augments mineral-deficient diets (Van Huis 2005).

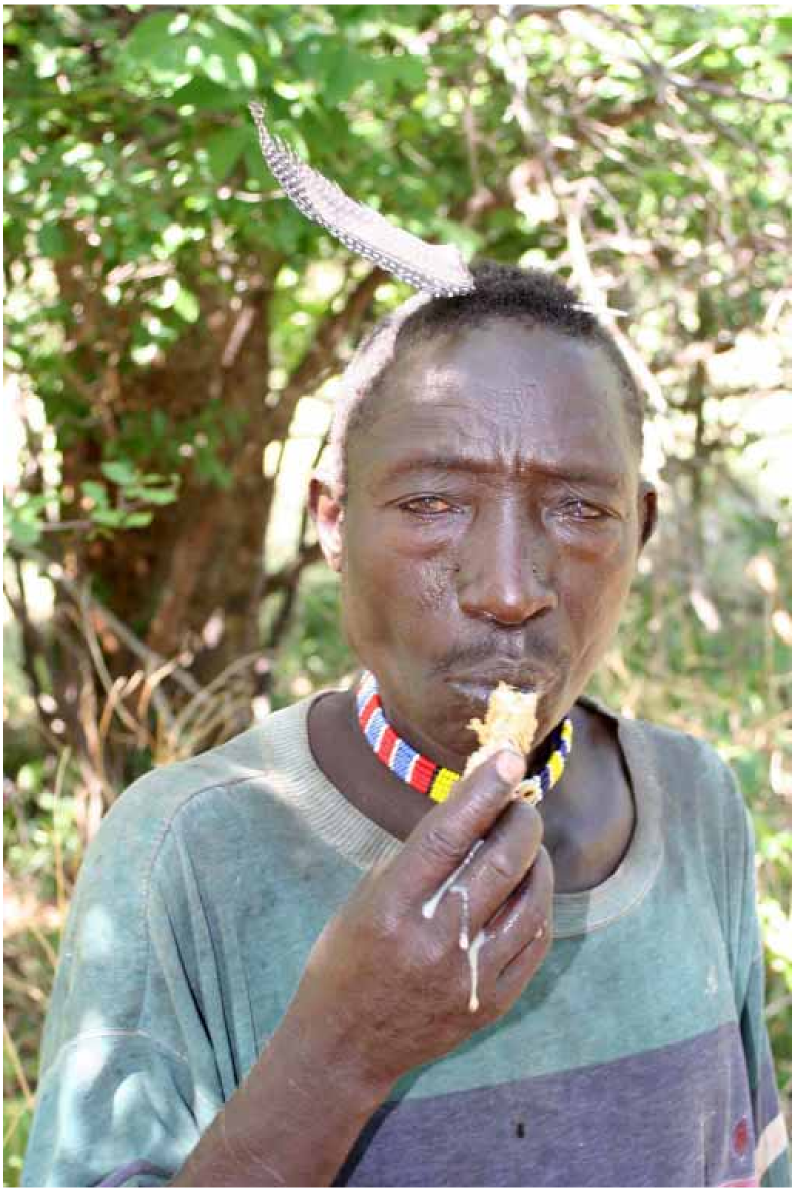

Plate 4. A Hadza (Tindiga) bushman consuming freshly collected bee comb including bee brood (*Apis mellifera* var. *scutellata*), the ultimate food (Lake Eyasi, Tanzania) *(Courtesy H. Schabel)*

Vitamins A, $B_{1\text{-}12}$, C, D, E, K are biochemical substances needed in tiny amounts for normal growth and health. Caterpillars are especially rich in B_1, B_2 and B_6 (Ramos-Elorduy 2005; Balinga *et al.* 2004). Bee brood (pupae) is rich in vitamins A and D (Hocking and Matsumara 1960).

Daily human requirements for calories, as obtained from fat, protein, carbohydrates and alcohol range from about 1 000 for children to 3 900 for adult males. Variance is not only based on age and gender, but also on body size and activity levels. Calories obtainable from insects run as high as 776.9 kcal/100 grams of insects, often exceeding those from soybeans, maize and beef, but not pork (Ramos-Elorduy 2005; DeFoliart 1999). Under favourable circumstances, collecting edible insects can also be highly labour-efficient. According to one study in Utah, USA, the collecting of locusts (*Melanoplus sanguinipes*) yielded an average return of 273 000 calories per hour of effort invested by one collector (Anon 1989).

While many edible insects may excel in one or several nutritional components, bee combs consumed with all their contents, including immature stages of the bees themselves (Plate 4), may come close to being the ultimate food and health supplement in terms of calories and a balance of carbohydrates, proteins, fats, minerals, vitamins and purported medicinal properties (Hocking and Matsumara 1960).

In various parts of the world, many species of insects have been used in traditional and folk medicine (entomotherapy and entomoprophylaxis) (Paoletti 2005). In fact, about 4 percent of extracts evaluated from 800 species of terrestrial arthropods showed some anticancer activity (Oldfield 1989). However, hard evidence still appears to be lacking, especially for most cases of folk medicine. Most intriguing in the context of traditional medicine is the Chinese caterpillar fungus *Cordyceps sinensis*, an entomopathogen of *Hepialus armoricanus* (Hepialidae). Potions made from the mummified body of this insect containing the fungal mycelium and sporophore are said to bolster immunity, endurance and, according to an Internet advertisement “to regulate and support the gonads”. Since being partially credited for the outstanding performance of Chinese long-distance runners (Hobbs 1995; Steinkraus and Whitfield 1994), demand for this product has risen dramatically and spawned a frantic search for artificial production as a tonic and health supplement. Similarly, caterpillars of *Bombyx mori* infected by the white muscardine fungus *Beauveria bassiana* are considered useful in the Republic of Korea in the treatment of strokes (Pemberton 2005).

Liabilities of entomophagy

If it doesn’t kill you, it will make you stronger. (Anonymous)

While the nutritional and other merits of entomophagy generally support the consumption of insects, one should not overlook potential liabilities such as food safety or unsustainable and destructive collecting that could threaten preferred species and/or their habitats.

Insects and another important NWFP, mushrooms, share numerous characteristics. Both include pest species, but collectively provide significant ecosystem benefits. Many mushrooms and insects are tree-dependent and thus tend to originate in pristine environments. Both tend to be seasonal, scattered in occurrence and sometimes hard to find. They even share an unusual building block, chitin, which as a biopolymer has potential for interesting agricultural, medicinal and industrial applications (Goodman 1989). Many species are sought-after human and animal food, and sometimes cultivation and commerce items. Many species prey on each other, most intriguingly in the case of insect mycoses.

Given these commonalities it is vital to also remember that although all mushrooms and insects are edible, some can only be eaten once, with possibly even fatal consequences. Like certain mushrooms, some edible insects are delicious, safe and easy to identify, making them popular. At the other end of the spectrum are those that may cause serious health problems, even death. In between are numerous species that are only conditional candidates for consumption, or those without redeeming qualities. Some may resemble edible species while remaining unpalatable or poisonous; some may be edible in some regions but not in others; some that are normally safe may be unhealthy if they come from certain plants or from a polluted and pesticide-treated area; and some may be safe for some consumers but less (or not at all) for others. Furthermore, some require special capture, preparation, storage or transportation methods to render and keep them safe.

Being nutritious is obviously an intrinsic design flaw for many insects. However, to compensate for their six-fold Achilles' heels, insects evolved numerous mechanisms for escape: small size, camouflage and other bluff or hiding tactics, swift escapes, mass aggregations, armour and chemical warfare, representing a vast arsenal of survival strategies. The latter is particularly effective, as potential consumers learn to avoid chemically charged insects. Chemicals responsible for repellency or toxicity are acquired in two different ways, either by sequestering phytochemicals directly from the food plant, or by autonomous production of defense chemicals (Duffey 1980; Blum 1994; Berenbaum 1993). Many such insects benefit by advertising their chemical makeup through warning (aposematic) colours, often supplemented by repulsive foams or liquids, torpidity and winglessness. Others have taken advantage of this by imitating a chemical model while being edible (Batesian mimicry), or by sharing with the model repellent or toxic qualities (Müllerian mimicry).

Human mortality as a result of entomophagy is rare but not unheard of. Blum (1994) documented several cases of fatal or near-fatal poisonings from the use of certain blister beetles (Meloidae) as an aphrodisiac, and in the Republic of South Africa, where grasshoppers are habitually eaten, a child died following consumption of a foam grasshopper (*Phymateus leprosus*) (Steyn 1962). While many grasshoppers and other Orthoptera may be safe, certain Families in this Order, such as the Pyrgomorphidae are not, or only conditionally so. For instance, (*Zonocerus* spp.) are considered edible in the Republic of South Africa, Cameroon and Nigeria, but poisonous elsewhere. Some polyphagous insects, including *Zonocerus* spp., are known to sequester more than one phytochemical from a range of food plants of differential toxicity (Duffey 1980) and in some cases, certain modes of processing may result in detoxification. Another foam grasshopper, *Phymateus viridipes*, is considered edible in the Zambezian region, but not so elsewhere (Malaisse 1997).

In general, insects can be very clean, especially after moulting. However, contamination and spoilage before they reach the consumer are possible, as happened when five individuals in Kenya died of botulism following the consumption of termites (Nightingale and Ayim 1980). In this case, the insects had been enclosed in plastic bags, in anaerobic storage during four days of transportation. Fuller (1918) lists several other historic records of discomfort or even death in areas where termites were habitually eaten. Explanations ranged from, *it must have been due to an orgy following a period of starvation*, to *eaten out of season and improperly prepared*, to *queen termites believed to be medicinal, however overindulgence lead*(ing) *to distress and possibly death*, and finally the accidental eating of poisonous termitophile beetles (Staphylinidae). Botulism was also thought to be responsible for the death of three persons in Namibia following a meal of caterpillars (Mbangula 1996). The importance of proper processing, handling, drying and storage was further stressed by a study from Botswana, after unacceptable levels of aflatoxins were documented in some commercial lots of mopane worms (*Gonimbrasia belina*: Saturniidae) (Mpuchane *et al.* 1996).

A number of edible insects require ageing or special preparation for the removal of odours, stings and toxins. Instinctively, stink bugs (Pentatomidae) do not seem candidates for food, but certain species are nevertheless popular morsels, rich in oil, throughout the tropics, and there is little evidence for their toxicity to vertebrates (Berenbaum 1994), although their pungent excretion can harm the eyes (Faure 1944) and irritate the throat (A.Y.C. Chung, personal communication). Repeated boiling or soaking, followed by removal of the head and sun drying of the remains is reported to render the poisonous stink bug *Nezara robusta* palatable and safe (Esbjerg 1976). Because of their meconia, wasp larvae are said to taste terrible, while their pupae are sweet (DeFoliart 1992), and certain other Hymenoptera with powerful venomous stings and the potential for anaphylaxis, need to be handled with care. Orthoptera and Coleoptera often have powerful mandibles, sturdy legs, wings and other appendages that could puncture or lodge in the intestines, as they have in certain animals, unless removed before ingestion. Many caterpillars are routinely purged and irritating hair and other protuberances are burned off or otherwise removed to avoid lepidopterism, which may result in dermatitis, algogenic reactions, allergenicity and even death (Blum 1994; Muyay 1981). Given the possibility of carcinogens, smoking over fire is generally discouraged in favour of other cooking methods.

Unexpected, individual reactions to entomophagy, such as allergies, are not widespread but have been reported (Phillips 1995; Vetter 1995). Also, in most of sub-Saharan Africa *Anaphe* spp. (Thaumetopoeidae) are popular food caterpillars and generally considered safe, but in Nigeria malnourished individuals were diagnosed with ataxic syndrome after eating such caterpillars (Adamolekun 1993). Similarly, the eating of many pupae of *Eucheirasocialis* (Pieridae) in Mexico sometimes led to vomiting and headaches (Anon 1992).

The question of parasites and entomopathogens on nutrient benefits or safety of their food insect hosts apparently has not yet been investigated. However it is known that certain parasites can sequester the food of their hosts (Duffey 1980) and in one instance, three people in China who had eaten large quantities of cicada nymphs infected with *Cordyceps* sp. were hospitalized (Hoffman 1947). In Japan, the large larvae of *Batocera lineolata* (Cerambycidae) are considered safe to eat raw when collected in living or dried wood, but the same insects from rotten wood are said to cause parasitoses (Mitsuhashi 2005). It would be most interesting to see whether host and parasite nutrient profiles tend to be similar or possibly complementary. In this case, parasitism of edible insects, generally a limiting factor for production, might be looked at more positively.

Other than the possible food safety issues just discussed, entomophagy may entail certain liabilities for the environment. For instance, some destructive methods of collection, such as felling of trees and unwise use of fire, contribute to forest degradation, and together with overcollecting may threaten the authenticity and sustainability of entire forest communities.

Management of forest insects for food

> *I foresee the day…when establishment and care of vast termitaria may be an important commitment of some government department…as being domestic stock…They would be fed on the Forest Department's fuel plantations…and their produce, after raising local standards of nutrition far above the Medical Department's hopes, will be exported to the four corners of the world…*(Osmaston 1951)

While a 2002 study by FAO optimistically predicted that by 2030 global food production will still exceed population growth, it also acknowledges that hundreds of millions of people will remain hungry nevertheless. NeoMalthusians are likely to take a dimmer view, by pointing out that in parts of the world rampant population growth in conjunction with forest destruction and degradation has already sharpened competition in the scramble for diminishing resources, including edible insects, to the point of non-sustainability. Insect shortages, only one dimension of a larger bushmeat crisis, and concomitant social conflict have already been reported from the Democratic Republic of Congo (Latham 2002; Leleup and Daems 1969), Nigeria (Ashiru 1989), Mexico (Kevan and Bye 1991), Malawi (Makungwa *et al*. 1997; Munthali and Mughogho 1994), the Republic of South Africa (Illgner and Nel 2000; Styles and Scholtz 1995), Zambia (Mbata 1995), Namibia (Marais 1996), and probably elsewhere in the tropics.

Given that most edible insects are forest-based, the general absence of foresters from relevant discussions is conspicuous and surprising. At this time there are remarkably few references dedicated to the management of edible insects in forests, and most are restricted to parts of Africa where the sustainability of such resources is already in jeopardy. Foresters worldwide have traditionally looked at insects as either a nuisance or as tree and wood pests, something to be avoided, suppressed or controlled. After trying this approach for almost 200 years, we currently seem to have more forest pest problems than ever, and with the current invasion of exotics and anticipated effects of global warming, the trend appears upward. As a result, in at least parts of the world a rethinking from forest entomology, the management of pest insects for the sake of trees, to *entomoforestry*, which concerns itself with managing trees and forests for the sake of edible and other useful insects may be in order, opening up at least supplementary perspectives for forest management and potentially fostering the development of forest-based insect industries (Table 1) (Schabel 2006). Especially where food security is at stake, traditional entomophagy must become a priority and be taken from opportunistic extraction to the next level, that is, regulatory mechanisms and the deliberate, science-based manipulation of forest edible insects, in or out of their natural habitat.

Conceptually, management of forest edible insects may entail gradations from extensive (*in situ*) to intensive (*ex situ*) levels, that is, from wild minigame to semi-wild, semi-domesticated or fully domesticated minilivestock. This encompasses a range of possibilities, from conservation or restoration of natural or near-natural habitats in conjunction with regulated extraction, to silvicultural manipulation, to seeding and ranching of wild stock near homesteads, to the breeding of edible insects under highly controlled, captive conditions, or a best case scenario of complementary combinations of several or all of these possibilities.

***In-situ* protection and conservation of natural habitats:** Like many other natural resources, edible insects have traditionally been common property, free for the taking either opportunistically or targeted by specific collecting expeditions during years or seasons of abundance. For instance, in the large tracts of natural forest in Central and southern Africa, insect collection served subsistence needs, or at most localized trade, and as relatively few collectors extracted only segments of an insect population, these traditions assured sustainable, if fluctuating supplies of edible insects, especially caterpillars. Now, a combination of drought, frequent late-season fires, forest loss, erosion of traditional, regulatory authority and increasing numbers of collectors competing to supply a lucrative international trade have conspired to send caterpillar populations into a downward spiral and challenge this relatively informal system (Balinga *et al.* 2004). As fewer caterpillars are available, even the younger instars and pupae, previously spared, are increasingly collected and stocks suffer even more; or wild bees fail to benefit from bee pasture and sufficiently long recovery periods to rebuild colonies (Munthali and Mughogho 1992). Adverse effects on ecosystems due to overcollecting have also been noted elsewhere, such as in Southeast Asia (Yhoung-Aree and Viwatpanich 2005).

To avert or reverse such tragedies of the commons, attempts at regulation and forest management have begun in the Democratic Republic of the Congo (Muyay 1981; Leleup and Daems 1969), Zambia (DeFoliart 1999; Holden 1991), Malawi (Makungwa *et al.* 1997; Munthali and Mughogo 1994, 1992), Zimbabwe (Makuku 1992) and Namibia (Anon 2007; Marais 1996). In these countries collecting seasons may be restricted, caterpillar hunting permits may be required and bag limits, insect stages and areas for collecting may be specified by governments or local authorities.

However, for those systems to work, leadership needs to be sufficiently strong to enforce compliance with regulations. In parts of the world, traditional authority previously assured protected status for certain community forests, or at least their components, mostly for spiritual or religious purposes, or as reserves for resource emergencies. In many instances such traditional leadership has been eroding, yet a 50-hectare community forest in Zimbabwe is said to have persisted since the eighteenth century due to a visionary leader (according to legend he had four eyes!) and his successors. This Norumedzo forest appears to be the first community-designed protected area dedicated to the conservation of a food insect, the harurwa bug (*Enchosternum* (syn. *Natalicola*) *delegorguei* (syn. *N. circuliventris*, *Gonielytrum circuliventre* ??: Tesseratomidae) (Makuku 1993; Maredza 1987). A system of permits and incentives was said to assure annual mass appearances of this highly valued stink bug until recently, when there were first signs of resource decline (C. Dzerefos, personal communication).

Another solution for the protection of edible insects and their hosts envisions forest fire control and prescribed burning schemes, as have been suggested or implemented in semi-arid woodlands of Africa (Latham 2002; Mbata *et al.* 2002; Munthali and Mughogo 1994, 1992; DeFoliart 1991b; Holden 1991; Muyay 1981; Leleup and Daems 1969). Fire bans or benign, early season burning are generally considered beneficial for the regeneration and growth of host trees and for synchronizing caterpillars with the most nutritious foliage, while hot, late-season fires can damage or kill even savannah trees, as well as the vulnerable stages of food caterpillars. Livestock interests generally opt for conversions from woody to non-woody vegetation, and late-season fires tend to accelerate this successional regression.

Just as late-season wildfires contribute to the degradation of natural resources, so do the indiscriminate and excessive pruning and felling of trees for charcoal and fodder, to obtain bark or logs for bee hives, or to more easily raid bee colonies and edible insects such as wood boring grubs, caterpillars or stink bugs massing in the crowns of trees (Holden 1991; Esbjerg 1976; Leleup and Daems 1969). At one time, such methods may have been ecologically and socially tolerable and perhaps even beneficial from a silvicultural and edible insect production point of view, in that the felling of individual or groups of trees stimulated natural regeneration, improved community structure and provided vigorous saplings often preferred by certain food caterpillars. However, with more human intrusions, optimum levels of silvicultural intervention need to be calibrated to assure future supplies of edible insects and other demands on forests.

Another silvicultural consideration relevant to edible insect production in conjunction with logging is evident in the Central African Republic, where forest concession rules require the retention of at least one sapelli tree (*Entandrophragma angolense*) per 10 hectares. This rule discourages high-grading to assure the regeneration of this valuable mahogany, but also benefits certain food caterpillars (*Nudaurelia oyemensis*: Saturniidae) dependant on this tree (Balinga *et al*. 2004).

While these are examples of recent attempts to institute regulation and management for edible insects in natural forests, there is also some evidence of traditional, low input management of edible insects in various parts of the tropics, such as the use of trap trees in natural forests. In Papua New Guinea and Indonesia for instance, one rotting sago palm trunk may yield as many as 500 to 600 sago grubs (*Rhynchophorus bilineatus* [syn *R. ferrugineus papuanus*]: Curculionidae), a highly nutritious, sizeable food insect (Mercer 1994). In South America and Africa, closely related palm weevil grubs, *Rhynchophorus palmarum* and *phoenicis*, respectively, have also been manipulated to provide artificial concentrations in predictable places and for predictable times (Cerda *et al.* 2005; Tommaseo-Ponzetta and Paoletti 2005; DeFoliart 1990). Similarly, the large grubs of certain rhinoceros beetles (*Oryctes monoceros* and *O. owariensis*; Scarabaeidae) concentrate in dead standing or rotting palm logs (DeFoliart 1995), while many other, large and common wood-boring larvae (notably Buprestidae; Cerambycidae; Cossidae; Siricidae and other Scarabaeidae) are attracted to certain other tree hosts in various stages of decline. This has been exploited not only opportunistically but also deliberately, such as by Australian Aborigines who lop grass trees (*Xanthorrhoea* spp.) to be able to later collect buprestid grubs (Yen 2005). As dead wood serves numerous ecosystem functions, the artificial enhancement of trap trees seems to be an attractive management option, especially because timber stand improvement, wildlife management, pest control objectives and fuelwood procurement can be compatible with this option.

While in many places it may be simply too late or unrealistic to hope for ideal model forests as promoted by WWF/IUCN and proponents of analogue forestry, the outlook for other areas appears more optimistic, as the concept of rural development forests with an emphasis on community-based conservation takes hold in various parts of the world. As a result, one may yet see forest conservation plans and the zoning of more forest reserves for caterpillar conservation and production become reality, as has been suggested repeatedly (Balinga *et al*. 2004; Chidumayo and Mbata 2002; Leleup and Daems 1969). Controlled access to otherwise protected zones for the collecting of caterpillars or for beekeeping constitutes one such pragmatic community-minded solution, making former poachers co-owners and protectors of these areas, as well as potential allies of land management authorities (DeFoliart 2005).

***Ex-situ* ranching:** When wild and common resources free for the taking are remote, random, elusive or declining, and leadership fails to reverse the trend through policies and some social contract or management, individuals either move or otherwise adjust. At one time similar circumstances and convenience may have prompted the domestication of wild game to become livestock and it is only natural to suggest relevant attempts with certain edible insects.

One solution is to bring wild stock to community plantations, fields, gardens or homesteads; this can improve access, protection, manipulation and monitoring of these resources, often on relatively little land (Fromholz 1883). The first step in this transition is often for individuals to claim personal ownership of certain edible insect production sites, such as individual trap trees, caterpillar trees or termitaria (Ramos-Elorduy 2005). Claiming a stake on community land is, however, only good if others are willing to honour it, for which reason importing wild stock to trees on tenured land or closer to home may provide better control (Latham 2002).

Being relatively immobile, caterpillars in particular are not likely to abscond and thus lend themselves to being planted as eggs or larvae (wild or reared) on suitable hosts (Latham 2002; Muyay 1981; Leleup and Daems 1969). Also, certain female moths are either flight-averse or even wingless and thus tend to stay nearby to naturally reseed neighbouring host trees, to provide egg stock for transfer to other sites, or to be transported elsewhere for restocking a new site.

Individual trap and caterpillar trees or plantations seeded with edible insects represent a form of semi-containment and thus incorporate elements of ranching as opposed to controlled cultivation of captive minigame or fully domesticated minilivestock. For a long time, several wild or hybridized Asian silk worms (Saturniidae) have been semi-domesticated for the production of silk and food/feed, but still can be considered semi-wild. For instance, in Liaoning, Manchuria and other parts of China, 400 000 hectares of coppiced and pollarded oak forests are managed for production of the Chinese oak *tussah* (or *tasar*) caterpillar (*Antheraea pernyi*) for silk and food. Management includes optimal stocking, pruning of trees to restrain crown development and to flush new leaves, as well as fertilization with legume fallows (Yang *et al.* 2000). Armed caterpillar police patrol these forests to prevent bird and human theft of this precious insect. A similar ranching programme with essentially wild insects involves the cultivation of weaver ants (*Oecophylla smaragdina*) on a Chinese farm (Chen and Akre 1994). Beekeeping represents yet another excellent example for the semi-domestication of wild edible insects.

The concept of trap trees could be expanded to apply to entire groups of trees or even plantations. By providing an abundance of certain hosts, monocultures often become insect magnets, which traditionally required pest control measures. Why not take a bad situation and make the best of it by eating the pest, or even start plantations for its production? In Kenya for example, plantations of exotic *Cassia siamea* that had been established on difficult sites were severely afflicted by the wood-boring caterpillars of *Xyleutes capensis* (Cossidae) (Plate 5), a close relative of the famous witchetty grub (*Endoxyla leucomochla*) of Australia (Speight 1996). Rather than considering this plantation a fibre failure, it could have been declared a protein production success. *Xyleutes capensis* is appreciated as a food insect in parts of East Africa, where it not only attacks *Cassia* but also the often weedy castor beans.

Plate 5. The caterpillar of *Xyleutes capensis* (Cossidae), locally called *ndoko*, is, to this day, one of several wood-boring pests eaten as a snack at Kilimanjaro, Tanzania *(Courtesy H. Schabel)*

Raising early instars in captivity and releasing older ones either in the wild or under more controlled conditions may help restore wild stocks or improve survival rates for ranched animals. For instance, in two caterpillar ranching projects in German and British East Africa in the early 1900s, *Bridelia micrantha*, the main food tree of *Anaphe panda* caterpillars, was cultivated plantation-style to obtain the large silken nests of this edible insect, some of which were harvested, while others were planted in natural forests to expand and sustain the resource (Schabel 2006). The nests of these insects are often collected when they contain advanced instars and are held as a fresh store near the home for gradual consumption days or weeks later. Similarly, *Eucheira socialis*, a pierid caterpillar feeding on *Arbutus* in Mexico, lives in large silken bags, with often as many as 20 of these nests per tree. As a result of habitat degradation and dwindling supplies of wild stock, some of the nests are frequently transferred to other trees, while a few are left for natural restocking (Kevan and Bye 1991).

Given space and other constraints, the incorporation of edible insect production into agroforestry schemes may, overall, offer the greatest opportunities for ranching and captive production (Holden 1991; Pawlick 1989). Agroforestry technologies as researched during the last three decades, envision a wide range of schemes for different conditions throughout the tropics and beyond, from extensive shifting cultivation or improved fallows in the transition to wild land, to *taungya*[2] systems in conjunction with tree plantations, to highly intensive, richly

[2] Planting of cash or food crops between newly planted forest seedlings in a reforestation project.

structured systems such as home gardens. Silvipastoral and agrosilvipastoral applications of agroforestry specifically refer to the simultaneous or sequential use of trees in combination with agri-/horticultural crops and livestock. In this context the concept of *livestock haven*, hitherto meant to describe shade trees over pastures of large livestock, could be expanded to include minilivestock dimensions. Although not for food, the ranching of collectible butterflies in agroforests of Papua New Guinea and elsewhere, offers a comparable and successful model for the production of minilivestock (Schabel 2006).

As the overriding concern in agroforestry is the retention or improvement of soil fertility for the sustained production of multiple outputs (shade, mulch, fodder, fuel, fruit, seeds, medicine), nitrogen-fixing woody legumes are particularly useful. Many edible insects preferentially feed on tree legumes (Turk 1990). At the same time, other trees may be of interest and strategies for selection of multipurpose trees should not ignore their melliferous aptitude and potential for the production of edible insects (Malaisse 2005; Pawlick 1989).

The *miombo* forest of southern Africa is mostly composed of tree legumes, which support many of this region's important food caterpillars. At one time shifting cultivation in this cover type tended to favour the regeneration of certain species and thus their associated edible insects, but now shorter fallow cycles among other factors have begun to disrupt this sustainable system (Chidumayo and Mbata 2002; Latham 2002). To reverse trends, the feasibility of improving caterpillar production in conjunction with such a traditional shifting cultivation system was recently demonstrated in Zambia's *miombo* forests (Chidumayo and Mbata 2002). The greatest caterpillar crops were obtainable in the early years of the fallow cycle, that is when the favourite legume host, *Julbernardia paniculata*, abounded as pioneer saplings.

Many palms are also multipurpose trees and thus are common components of agroforestry systems. Several wild palms are sources for edible palm grubs, the foremost being *Oryctes* and *Rhynchophorus* spp. As certain of these grubs develop in dead palms, mulch and other organic waste, which abound around homesteads and in gardens, grub production for human consumption or animal feed may help to curb these pests, some of which are potential vectors of palm pathogens (DeFoliart 1990). In this context it would also be interesting to compare the relative merits of palm plantations for the production of oil, as opposed to the healthier fat derived from the grubs. Because palm grub production differs among various palm species, it would be equally interesting to investigate mixed palm plantations for potentially higher financial returns and greater diversification of crops than is possible with one palm species alone. In Thailand, attempts are underway to rear the bamboo borer (*Omphisia fuscidentalis*: Pyralidae) on at least 11 species of bamboo. Other non-legume trees, such as mulberry, have also been traditional components of home gardens in Asia where they support cottage industries for silk and food/feed from *Bombyx mori.* Mulberry also happens to yield a high quality honey (Plate 6) and thus lends itself for a system of api-sericulture, as attempted in German East Africa, with bee pollination services supplied for added benefit (Schabel 2006). Mulberry trees are usually maintained as coppiced or pollarded dwarfs, as are many woody components used in agroforestry, as well as the silkworm oak forest in Manchuria and the Norumedzo community forest in Zimbabwe. This tree habit allows easier access to edible caterpillars.

Plate 6. Stingless bees (Apidae) are among multipurpose insects that produce several commodities and can be managed as minigame in the wild as well as semi-domesticated minilivestock *(Courtesy H. Schabel)*

Captive breeding: Butterfly collectors and breeders frequently raise insects under fully controlled conditions, either in cages with potted or rooted food and nectar plants, or by periodically supplying cut-and-carry food (Schabel 2006). After thousands of years of such cultivation, the silkworm *Bombyx mori* (Bombycidae) has completely lost its ability to survive in the wild, and similarly the eri silk moth *Samia ricini* (Saturniidae) has essentially become fully domesticated minilivestock (Peigler 1993). While the former is primarily raised for its silk, secondarily as food, the reverse is true for the latter. Both are examples of successful domestication of forest insects, while the potential for such intensive management of other candidates still remains to be determined. Based on a small pilot project under field conditions in Zaire involving caged caterpillars of *Anaphe panda* (= *A. infracta*), another edible caterpillar and producer of silk, commercial production was considered to be at least theoretically feasible (Munyuli bin Mushambanyi 2000).

The commercial mass production of various insects (Plate 7) for silk and human food, animal feed, or as pets, experimental animals or fish bait has already developed to a considerable extent in parts of the world (Paoletti 2005; Menzel and D'Aluisio 1998). This experience provides valuable technical clues and economic advice for future attempts to breed forest insects under captive conditions.

Plate 7. The common garden cricket *Gryllus bimaculatus* (Gryllidae) is a common nursery pest throughout much of the Old World. Experience concerning the mass production of crickets and other insects already exists. *(Courtesy H. Schabel)*

Candidates for semi-domesticated ranching or full domestication of forest insects: Prime candidates will be those that are already popular as wild stock, and whose economic value as human food trumps their pest potential. Being wingless and cold-blooded, caterpillars in particular are prime candidates. Whether under ranching or captive conditions, they transform plant biomass into animal biomass possibly ten times more efficiently than cows (Lindroth 1993), and on much less land. Multipurpose insects that provide more than one benefit, such as silk-producing, edible caterpillars are obvious favourites, as are social insects. Specific, positive attributes of candidate insects include multivoltinism, safety, good size, gregarious behaviour, swarming or epidemic tendencies, reasonable reproductive and survival potential, nutritional benefits, potential for storage, ease of manipulation and food plant cultivation, as well as marketability and a propitious cost-benefit ratio. The more these criteria apply to one species, the greater is its potential. Also, crop plants that can simultaneously host more than one species of edible insect may deserve special attention. For instance, *Ricinus communis* not only supports the castor bean borer (*Xyleutes capensis*) (Plate 3), but also the silkworm *Samia ricini*, a popular and easily manipulated food caterpillar from southern Asia.

Other forest insects may deserve to be tested for cultivability. For instance, the artificial inoculation of wood bolts with edible grubs (for example Buprestidae, Cerambycidae, Scarabaeidae, Siricidae), similar to the artificial production of gourmet mushrooms on wood sections, would be interesting to explore. Also, because certain termites have enormous reproductive capacity, depend on cellulose and facilitate gourmet mushroom production (*Termitomyces*), it would be most interesting to explore their potential for the controlled production of these two foods on sawmill refuse or low-grade wood, or, as suggested by Osmaston (1951), in fuel plantations. These termites, together with associated mushrooms may be increasingly threatened in parts of their range, primarily as a result of land conversion and their status as pests. Last but not least, in exploring unconventional ideas, the controlled production of seeds infested with seed weevils (Bruchidae) or similar seed predators might result in a product high in complementary animal and plant proteins worth more than the mere seed.

In the long term, it is conceivable that more attempts will be made to develop artificial diets, as has already been done with *Rhynchophorus* spp. (Cerda *et al*. 2005), and perhaps pheromone traps for edible insects, and to selectively breed edible insects for larger size, fecundity, disease resistance, storage characteristics or other desirable traits, as has happened with other livestock.

For edible insects, the future may have barely begun.

Conclusions

Entomophagy is an age-old practice that continues to this day in many parts of the world. Possibly more than 2 000 species of insects, mostly forest-based and often classified as pests, have been serving as human food for subsistence and/or in commerce. Science increasingly provides data corroborating the nutritional and health benefits of entomophagy, suggesting broader acceptance of this practice, while giving due consideration to certain risk factors. At the same time that acceptance of entomophagy seems to be on the rise and demand is increasing, the sustainability of wild insect stock is in question. Where rampant loss and degradation of forest habitats or overexploitation of insect resources are jeopardizing traditional forms of extraction of food insects, their regulation and management become more critical.

To enhance food security and potentially generate extra income, edible insects can be managed at various levels of intensity, from minigame *in situ* to more intensive management of semi- or fully domesticated minilivestock *ex situ*. Currently, the tropical Americas still seem to rely on edible insects as minigame to a considerable extent, while semi-domestication is progressing in Africa as well as in Asia, where full domestication is most advanced.

Where natural or near-natural forests still exist or can be restored, certain insects can be treated like other game animals. This applies especially to those with limited potential for domestication, such as univoltine insects, species with low fecundity, long developmental periods and only random or periodic abundance. To guide extraction levels and other criteria, their population status and trends must be monitored. Silvicultural practices need to be investigated with respect to implications for edible insect population dynamics, such as is being conducted with fire management. Rules for insect extraction must be fine-tuned to decide who gets a licence, where and when to collect, what stage of insect is legal to collect, how many can be collected and by what mode. This approach assumes not only functional forests but also functional policies and social contracts on a community basis, to assure equitability and a proper balance of incentives and enforcement. As many other forest benefits accrue from natural or near-natural forests, their preservation, conservation or restoration assumes the highest significance and thus should always be the first priority.

Where this ideal does not exist, however, where wild resources need a reprieve from unsustainable collecting pressures and where certain edible insects allow a higher degree of manipulation, they can be managed *ex situ*, that is in conjunction with social forests or on private property. This allows users better control over security, production and quality, easier physical and legal access and the sustainability of stock. Plantations of insect fodder trees, or the selection of multipurpose trees with insect production potential in conjunction with various agroforestry schemes, appear particularly suited to insects with relative immobility (caterpillars), as well as those with strong food preferences (mono- or oligophagous) or homing instincts (social insects and wood borers). Planting wild stock onto caterpillar trees or disseminating them from there, maintaining termite colonies on cultivated land, providing trap trees and establishing plantations for insect production near homesteads are all examples of semi-domestication of ranched minilivestock. Because of the higher investment in time, effort and resources, full domestication of captive minilivestock insects promises to be optimal with multipurpose insects – edible insects with additional attractions (for example silk, collectibles) and market potential.

Entomoforestry, the management of trees and forests for the sake of insects still poses numerous ecological, economic, technological and social challenges, and thus will be fertile ground for relevant research for years to come. Rewards in terms of long-term food security, income potential, pesticide reduction and nature conservation are conceivable and thus entomophagy may be in the best interest of sustainable development.

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Edible insects and other invertebrates in Australia: future prospects

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At the time of European settlement, the relative importance of insects in the diets of Australian Aborigines varied across the continent, reflecting both the availability of edible insects and of other plants and animals as food. The hunter-gatherer lifestyle adopted by the Australian Aborigines, as well as their understanding of the dangers of overexploitation, meant that entomophagy was a sustainable source of food. Over the last 200 years, entomophagy among Australian Aborigines has decreased because of the increasing adoption of European diets, changed social structures and changes in demography.

Entomophagy has not been readily adopted by non-indigenous Australians, although there is an increased interest because of tourism and the development of a boutique cuisine based on indigenous foods (bush tucker). Tourism has adopted the hunter-gatherer model of exploitation in a manner that is probably unsustainable and may result in long-term environmental damage. The need for large numbers of edible insects (not only for the restaurant trade but also as fish bait) has prompted feasibility studies on the commercialization of edible Australian insects. Emphasis has been on the four major groups of edible insects: witjuti *grubs (larvae of the moth family Cossidae),* bardi *grubs (beetle larvae), Bogong moths and honey ants. Many of the edible moth and beetle larvae grow slowly and their larval stages last for two or more years. Attempts at commercialization have been hampered by taxonomic uncertainty of some of the species and the lack of information on their biologies. This has made it difficult to establish rearing facilities that can raise large numbers of edible insects in a short time. Even if effective mass rearing techniques for edible insects can be developed, the next hurdle is overcoming the cultural barriers against consuming insects in Australia. Notwithstanding these problems, there is considerable potential for greater use of insects as human food (either as insects* per se *or as food supplements) or as stock food (especially for poultry and fish). This will result in more energy-efficient food production and facilitate environmental conservation.*

Keywords: Aborigines, animal food, conservation, entomophagy, indigenous food, protein

Entomophagy

At a time when scientists acknowledge the importance and need for ecosystem services provided by insects, western society does not seriously consider them for human consumption. Their small body sizes, difficulty in collection and processing and unpredictability in obtaining large numbers in the wild are major practical impediments. There

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are two main barriers to the acceptance of eating insects: (1) the bad reputation they have as unhygienic and disease-spreading species; and (2) their association with the concept that they are only eaten in times of starvation or as a food source of primitive hunter-gatherer societies (MacEvilly 2000; DeFoliart 1999). There is legislation in some countries regarding insects in food products, ranging from zero tolerance in the United Kingdom to allowing maximum permissible levels in the United States (MacEvilly 2000; Gorham 1979); the basis of this legislation is food contamination and perceived health issues associated with insects (Gorham 1979).

Over 1 500 species of insects are known to be consumed by humans from over 300 ethnic groups in 113 countries (MacEvilly 2000). Most of this entomophagy occurs in central and southern Africa, Asia, Australia and Latin America, and can provide 5 to 10 percent of the annual animal protein consumed by various indigenous groups as well as fat and calories, and various vitamins (A, B_1, B_2 and D) and minerals (iron, calcium) (Gullan and Cranston 2005; MacEvilly 2000).

Entomophagy and the Australian Aborigines

Until European settlement, Aborigines lived as nomadic hunter-gatherers. Survival required a comprehensive knowledge of the flora and fauna and their responses to varying geographic and climatic conditions (O'Dea 1991). They consumed a varied diet in which plants provided fibre but animal foods predominated. This diet was not high in fat as the meat was lean most of the year. Most food was either eaten raw, roasted on ashes, or baked whole in an earth oven. Most Aborigines lived in bands based on extended family groups (20 to 30 individuals) and there were larger gatherings for traditional ceremonies when there was sufficient food available to support larger numbers. Examples included men gathering in the Alps of southeastern Australia during summer to feast on Bogong moths (Flood 1980) and groups meeting at Waikerie on the River Murray in South Australia to collect adult giant swift moths (*Tricenta argentata*) that emerge in autumn after rain (South Australian Museum, n.d.). Men and women contributed differently; women provided subsistence diet (plants, honey, eggs, small vertebrates, invertebrates) and men were primarily hunters of larger vertebrates. Hunting and gathering was time-consuming, and there was generally only one main meal late in the afternoon after a day of hunting or gathering (O'Dea 1991).

Traditionally, Aborigines in Central Australia of different language groups considered the honey ant an important object of ritual and ceremony, and they were linked by the song cycles and ceremonies associated with it (Devitt 1986). The search and excavation for honey ants involve much time for relatively little return (Devitt 1986), and it was an important group activity for women and children who learned about and *looked after their country*.

Information on entomophagy among the various groups of Australian Aborigines has been summarized by Yen (2005), Meyer-Rochow (2005, 1975), Defoliart (2002), Tindale (1966), Reim (1962), Bodenheimer (1951), McKeown (1936) and Campbell (1926). The information is very patchy and has been confused by linguistic issues, incorrect recording of information, traditional beliefs of the Aborigines, incorrect use of common and scientific names of insects and lack of information on the biology and distribution of most species (Yen 2005). This has resulted in more detailed information about entomophagy among Australian Aborigines involving a small number of charismatic species (or species groups): *witjuti* grubs, *bardi* grubs, honey ants, *Bogong* moths and sugar bags (native bees).

The common names of some of these insects are based on Aboriginal names. As there are 270 different Aboriginal languages with 600 to 700 dialects in Australia (Australian Info International 1989), this has led to much confusion and different spellings. For example, the name *witjuti* grubs (also spelled *witchetty* or *witchety*) is derived from the Pitjantjatjara name for *Acacia kempeana*, but it has now been loosely applied to many edible grubs across Australia. Among the Arerrnte, the same species is known as *tyape atnyematye*, with *tyape* indicating edible grub, *atneyeme* is the *witchetty* bush and *atnyematye* is the grub from the root of the *witchetty* bush (Central Land Council 2007b). The name *bardi* grubs is based on a buprestid beetle from *Xanthorrhoea* in southwestern Western Australia, but has also been loosely applied to edible grubs across Australia. Some Aboriginal groups had a better naming system for edible grubs: they used a term for *edible grub*, such as *maku* in Pitjantjatjara, followed by the name of the plant (Yen *et al.* 1997). Hence the edible grub from *Acacia kempeana* is known as *maku witjuti* among Pitjantjatjara speakers or *tyape atnyematye* by the Arrernte (Plate 1).

Plate 1. Witjuti grub from Central Australia *(Courtesy A.L. Yen)*

An important question is whether the information we have available today is an accurate reflection of the full range of insects (and other invertebrates) eaten by Australian Aborigines. Other edible insects may not have been recorded in the literature. In addition, there is the question of why groups of insects eaten by other indigenous groups outside of Australia were apparently not favoured in Australia. For example, termites (Isoptera), leaf-feeding caterpillars (Lepidoptera) and grasshoppers (Orthoptera) are major components of insect diets in most other continents (Banjo *et al.* 2006b; DeFoliart 2005; Malaisse 2005; FAO Départment des Forêts 2004; Paoletti *et al.* 2003; Bodenheimer 1951), but only figure as minor items in a few Australian records (Meyer-Rochow and Changkija 1997; Meyer-Rochow 1975; Reim 1962).

To better understand entomophagy in Australia, it is important to consider the Australian environment and how it was exploited by the Aborigines before European settlement. Australia is an arid continent with soils poor in nutrients, unpredictable availability of water (droughts and floods) and wildfire hazards. The unpredictable climatic patterns result in a huge variation in plant species composition and reproduction, and population fluctuations of animals, leading to opportunistic and flexible activities that resulted in the seasonal movements of Aborigines (Allen 1974). There was no cultivation of grain and little agriculture as we know it (O'Dea 1991). The main habitat manipulation to increase plant production was controlled mosaic burning or *fire-stick farming* (Jones 1980).

The Australian environment is dominated by two plant genera, *Eucalyptus* and *Acacia*. This has resulted in enormous diversification of several families of insects (Yen 2002), and may be one reason for the absence of leaf-feeding caterpillars in the diet of Australian Aborigines. Many of the larger species feed on eucalypts and the oils and other chemicals in the eucalypt leaves make the caterpillars unpalatable. The major factor is climate unpredictability resulting in enormous variation in occurrence and abundance of insects. Many insects have long periods of relative inactivity or have well-protected immature life history stages; some have long life cycles, followed by mass emergence at times of adequate resources.

The nutritional value of insects to the pre-European settlement Aboriginal diet has received relatively little attention compared to the contribution of larger vertebrates. For many years, even the value of plants in the diet has been underestimated and only in recent years has this matter been addressed. With insects, more information is required about the role of entomophagy in traditional diets. It is difficult to generalize about the diet of Aborigines because it would have varied considerably across the continent, which is generally semi-arid or arid but with subtropical environments in the north and temperate conditions in the east, southeast and southwest. The insect diets would have reflected availability and need. Did entomophagy represent a need for proteins, fats and other substances of animal origin? How much of entomophagy is due to food deficiency (protein) or to tradition? It has to be remembered that Australian Aborigines ate their food raw, roasted on ashes, or baked in ashes. They did not use cooking utensils (except wrapping food in leaves or bark in northern Australia), and there was a lack of herbs and spices. The current indication is that insects provided sugar (honey ants, sugar bags, lerps) and fat (grubs, *Bogong* moths), although *witjuti* grubs have 38 percent protein and nearly 40 percent fat (a composition similar to olive oil [Naughton *et al.* 1986 in O'Dea 1991]). Native bees and honey ants were important seasonal sources of carbohydrates (Plate 2). Interestingly, Orthoptera are rich in proteins but were not eaten widely in Australia. Bukkens (2005) summarized nutrient aspects of insects for human diet around the world, but detailed information from Australia is lacking. Rich (2006 citing Miller *et al.* 1993) provided information on the nutritional value of raw and cooked *witjuti* grubs (species not cited) and the abdomen of *Bogong* moths.

The importance of insects in the diets of Australian Aborigines varied across the continent before European settlement, reflecting both the availability of edible insects and of other plants and animals as food. The hunter-gatherer life style adopted by the Australian

Aborigines involved patterns of movement determined by resource availability, and this, combined with low population numbers, reduced the danger of overexploitation of food resources.

Plate 2. Honey ants *(Courtesy R. Start)*

Current status of entomophagy in Australia

Over the last 200 years, entomophagy among Australian Aborigines has decreased because of the increasing adoption of European diets, changed social structures and changes in demography.

Entomophagy has not been readily adopted by non-indigenous Australians, although there is an increased interest because of tourism and the development of a boutique cuisine based on indigenous foods (bush tucker). Tourism has generally adopted the hunter-gatherer model of exploitation in a manner that is probably unsustainable and may result in long-term environmental damage. The exceptions are (1) promotion of iconic Aboriginal insect foods (*witjuti* and *bardi* grubs, honey ants) either as a boutique cuisine or part of a bush tucker tourism experience; (2) use of freshwater and burrowing crayfish as food items in their own right; (3) farming of exotic garden snails (*Helix aspera*) for restaurants; (4) insects, crayfish and earthworms (both native and introduced species) as recreational fish bait; and (5) insects bred as pet food (primarily for reptiles). Except for the first category, indigenous Australians are rarely associated with these activities.

There is a small industry in Australia that breeds the exotic snail *Helix aspera* for the restaurant trade and for personal consumption. There have been government-funded feasibility studies on this snail (Murphy 2001; Begg 2006, 2003). Snails are reared and purged on a high fibre diet before processing. They are sometimes cooked, de-shelled and sold bottled. Regulatory authorities in Australia face a dilemma in that on the one hand, they want to encourage the development of alternative farm products such as snails, yet on the other hand, they need to protect existing industries (such as crops) from pest snails. Teo (2004) gives an example of the adverse environmental effects of a snail introduced to provide protein but escaping and becoming a crop pest. The same issue applies to the breeding of exotic earthworm species that are sold to gardeners and farmers.

Recreational fishing is a major industry in Australia, and there is a wealth of information on the use of live insects and other invertebrates (freshwater crayfish and earthworms) as bait, in fishing magazines and on fishing organization Web pages. While the information is interesting, some of it is full of errors and biases. Recreational anglers generally use fresh insect bait, and there is a preference in temperate Australia for what are incorrectly call *bardi* grubs found in the ground under River Red Gums. These are in fact hepialid moth larvae, more akin to *witjuti* grubs. They are dug up, stored separately (or else they can damage each other) either in the refrigerator or they are blanched in milk and frozen. They are sold for A$1.50-2.50 each.

These activities have environmental and social consequences. The wild harvests of *witjuti* and *bardi* grubs and honey ants were sustainable activities when small numbers of traditional owners traveled by foot and collected them at appropriate times of the year. Today, tourism companies take bus loads of visitors to dig up edible insects. Some of these tourism ventures are led by traditional owners. However, the sustainability of a tourism-driven market using motor vehicles to access food has to be determined. Large numbers of recreational anglers digging up *bardi* grubs, in conjunction with other threats to forests (inappropriate forestry, fuelwood collection, eucalypt dieback due to changed hydrological regimes, cattle grazing, to name a few) could threaten the long-term viability of these grubs. There are now artificial grubs available, including a mould to make a *bardi* grub out of soft cheese!

Commercialization issues

The need for large numbers of edible insects (not only for the restaurant trade but also as fish bait) has prompted feasibility studies on the commercialization of edible Australian insects. Emphasis has been on the four major groups of native edible insects: *witjuti* grubs (larvae of the moth family Cossidae), *bardi* grubs (beetle larvae), *Bogong* moths and honey ants (Rich 2006), and the exotic snail *Helix aspera* (Berg 2006, 2003). Many of the edible moth and beetle larvae grow slowly and their larval stages last for two or more years. Attempts at commercialization, either by wild harvest or by mass rearing, have been hampered by taxonomic uncertainty of some of the species and the lack of information on their biologies. The small sizes of insects make collection or rearing and processing difficult; in the wild their locations and population numbers are unpredictable. This has made it difficult to establish rearing facilities that can raise large numbers in a short time.

Large-scale harvest or production of insects for human consumption has several issues that have to be considered, including the practicality of collecting from the wild and the possibility of overharvesting, economic mass rearing techniques, preservation and storage of the products and marketing.

Despite these issues, it has to be remembered that many invertebrates are unsafe to eat; some are inedible while others may initiate allergic reactions among humans (Gullan and Cranston 2005; MacEvilly 2000; Phillips and Burkholder 1995; Blum 1994; Berenbaum 1993), although this equally applies to all other plant and animal foods. Although many insects contain toxic chemicals, there are few records of harm to humans (Gorham 1979). Insects may also contain pathogenic microbes as a result of improper processing or handling, just like all food products, and preventive measures need to be in place (Banjo *et al.* 2006a).

Collecting (harvesting)

Most edible insects are harvested from the wild (DeFoliart 1995). The availability of edible insects in Australia is unpredictable, both in time and location. There are suggestions that wild harvesting of crop pests is a possibility (Banjo *et al.* 2006) and that this can also reduce pesticide use (DeFoliart 2005; Gullan and Cranston 2005). There is another aspect, as some insects may contain higher than acceptable levels of chemicals (as will be discussed with *Bogong* moths later). In Australia, the major mobile plant pest is the Australian plague locust, *Chortoicetes terminifera* (Hunter 2004), although Schulz (1891) reported that the Aborigines around the Finke River region would not eat them.

Better management of sustainable harvesting of wild populations and more dependable supplies based on economically feasible mass rearing will only be possible in Australia with more information about the biology of edible species. This will require involving indigenous groups to participate and benefit from the exercise.

Mass rearing

Rich (2006) examined the feasibility of establishing a closed production system facility to rear *witjuti* grubs commercially under controlled conditions. The proposed method involved: (1) sourcing a generic pool from the wild; (2) rearing larvae through to adults; (3) getting adults to mate; (4) female oviposition and eggs transferred to bark crevices in containers (each female may carry up to 20 000 eggs); (5) egg hatching; (6) caterpillars maintained and farmed when they have grown to up to 15 centimetres in length. Rich (2006) defined *witjuti* grubs as moths in the Cossidae family (wood moths with stem-boring or root-feeding larvae) of which there are over 100 species in Australia (Common 1990), hepialid moth larvae and some beetle larvae.

The life cycle of wood moths takes over two years (Monteith 2006). The question has been raised as to whether the life cycle can be hastened by diet using synthetic diets or semi-synthetic diets such as those used for the hepialid *Wiseana copularis* in New Zealand (Allan *et al*. 2002). Even the life history of well-known species such as the giant wood moth (*Endoxyla cinerea*) is not completely understood; although later stage caterpillars live in trunks, the biology of younger stages is not known and they may be root feeders (Monteith 2006). Dann (2003) inadvertently reared two *bardi* grubs through to pupation by keeping them in sawdust, indicating that a fully functional trunk may not be required for their survival.

To fully utilize mass insect rearing facilities, Rich (2006) suggested supplementary production activity of other insects such as *Bardistus cibarius* (*bardi* grub), honey ants, and the *Bogong* moth (*Agrotis infusa*). *Bardi* grub rearing would be suitable for the protocol outlined by Rich (2006); however, the other two species have their own unique biological characteristics that could make mass rearing a challenge.

The honey ant (*Melophorus bagoti*) is a social species that relies on two other biological components for successful production of honey by the repletes: its host *mulga* trees (*Acacia aneura*) and the scale insect *Austrotachardia acaciae* (Latz 1995). The honey ant workers collect honeydew from the scale insect to feed the repletes. Keeping social species like ants in captivity for food production can be difficult and the output is low compared to the commercial honey bee (*Apis mellifera*); individual honey ant nests rarely supply more than 100 grams of honey, comparable to commercial honey (Gullan and Cranston 2005). In Australia, other ant species have been maintained in culture for either venom research or as a source of chemicals such as antibiotics (Beattie 1994); these efforts may provide useful information on mass rearing for edible ants.

The *Bogong* moth is characterized by adult flight involving distances of more than 1 000 kilometres that may be necessary for breeding. Their life cycle is about six to seven months (eggs to adult). The main breeding grounds are pastures west of the Dividing Range and adults fly to the Southern Alps for the summer (Common 1954). The Aborigines (generally men) collected adults in the Alps, cooked and ate the bodies (over 60 percent of which is fat) or ground them into cakes for storage (Flood 1980). The *Bogong* moth can be an agricultural pest, but it faces several threats itself: loss of summer alpine habitat (cattle-grazing, wildfire, climate change) and accumulation of arsenic from agricultural sprays such as the herbicide monosodium methylarsenate. While individual moths have low arsenic content, accumulation from large numbers of moths has resulted in high arsenic levels in alpine soils at summer sites. Furthermore, the *Bogong* moths are a main food item of the endangered mountain pygmy possum (*Burramys parvus*) (Green *et al.* 2001).

There are over 100 species of freshwater crayfish in Australia, including the world's largest species, *Astacopsis gouldi* from Tasmania which reaches weights up to 4.5 kilograms (Short 2000). Some species, for example the burrowing crayfish (*Engaeus* species), are actually terrestrial but live in subterranean cavities full of water, while others live in freshwater bodies (*Cherax, Euastacus*, *Astacopsis*). Australian Aborigines ate the yabby (*Cherax destructor*) (Gillon and Knight 1986), and it has been suggested that they translocated this species into central Australia (Horwitz and Knott 1995). Australia currently has three species that are commercially exploited for the food industry: the yabby (*Cherax destructor*), redclaw (*C. quadricarinatus*) and marron (*C. tenuimanus*). The yabby naturally occurs in southeastern Australia, but the main production output is from populations translocated to southwestern Australia. Redclaw is produced in Queensland and northern New South Wales. The marron occurs in southwestern Western Australia but has been translocated to South Australia for production. Both redclaw and marron are bred in aquaculture facilities, while yabbies are mainly harvested from farm dams. From 1996 to 1999, production of these three species in Australia amounted to 421 tonnes (valued at approximately A$5 million), and the projected output in 2004/2005 was 1 589 tonnes (Piper 2000). Many of the burrowing and freshwater crayfish are restricted in their distribution, and several threatened species are listed (O'Brien 2007).

Preservation and storage

The mass rearing of insects for consumption or sustainable harvesting from the wild is an important hurdle that needs to be overcome. Australian Aborigines generally ate the food they collected or caught on the same day or not long after. There are only a few recorded examples of Aborigines preserving insect food to eat later. These include making *Bogong* moths into a cake (Flood 1980), a caterpillar (could be *muluru* of the Wangkangurru and Yarluyandi people or *anumara* of the Arrente people) that fed on grass that had its head pulled off, its body contents squeezed out and the body dried in hot ashes and was either eaten or stored (Hercus 1989; Kimber 1984) and collection of psyllid lerps from eucalypt leaves (Plate 3) that were rolled into a ball that could be stored for months (Central Land Council 2007b; Bin Salleh 1997). The *ayeparenye* caterpillar feeds on tar vine (*Boerhavis* spp.) and was collected in large numbers and gutted (*werlaneme*) and cooked in hot ash; it can also be stored (Central Land Council 2007b). *Witjuti* grubs that are dug out from inside a piece of *Acacia kempeana* root will seal up the exposed ends of the root and they can be kept alive for several days and transported within the root (author, personal observation).

Plate 3. Lerps or sweet secretions of psyllid bug nymphs *(Courtesy A.L. Yen)*

The storage and transport of fresh insects is a problem if large distances are involved, while dried, canned or bottled specimens are common (Ramos-Elorduy 2005). With modern food preservation methods such as freeze drying and cryovacking, long-term storage for transport should not be a major problem. If international export of insects is to be considered, one important issue that requires consideration is the contamination level of the insects, which may breach quarantine regulations in different countries.

Marketing

Possibly the most difficult task in expanding the value of entomophagy is getting people to accept the practice. The shunning of entomophagy is primarily cultural (Gullan and Cranston 2005). The first step is to counter western bias against insects as food; this strong public bias in the west also influences perceptions of entomophagy in traditional societies (Morris 2004). The issues that need to be considered are whether people in western societies will eat insects and whether they will aid developing nations that may need to mass produce insects as food.

In Australia, a market evaluation survey indicated that the idea of consuming *witjuti* grubs was a challenge for nearly half the 1 273 people interviewed; 33 percent were neutral, and only 20 percent considered them acceptable (Rich 2006).

People need to be given reasons why insects should be eaten other than the fact that they play a crucial role in diets of many peoples (Morris 2004). The messages should be that: (1) most insects have high food conversion efficiency compared with conventional livestock (Gullan and Cranston 2005); (2) cultivating insects for protein is less environmentally damaging than cattle ranching; (3) minilivestock (insect farming) can be a low-input, sustainable form of agriculture (Gullan and Cranston 2005);[2] and (4) semi-domestication of invertebrates could reduce pressures on natural populations (Paoletti and Dreon 2005; Paoletti and Dufour 2002).

The ways in which insects are eaten also need to be addressed. They can be eaten by people directly (either insects *per se* or insect additives to food), or indirectly by having them in the food production chain.

Eating insects whole or their body parts can be difficult for those brought up in western societies. This is overcome by presentation (mixing insects into more complex dishes) or by comparing them to currently accepted food types (especially crustaceans). If we are seeking to include insects for nutritional reasons, then perhaps we should consider the addition of ground-up insects in prepared foods (such as flour or pastes). This raises the question of whether we simply farm known species such as silkworms (*Bombyx mori*), house flies (*Musca domestica*) and mealworms (*Tenebrio monitor*). The answer is that we probably need to find out what other insects can provide that these species do not.

Insects and other invertebrates such as earthworms can be an important food for domesticated animals, and there are many examples of where they are used as feed for fish, poultry and pigs (Oyegoke *et al.* 2006; Gullan and Cranston 2005). The earthworm *Eisenia fetida* fed to

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[2] Insects could provide alternative forms of income to current production farms and involve much less land. In a study on the feasibility of commercializing bush food plants in Queensland, Phelps (1997) found that there was less interest while income from more traditional forms of farming was greater.

aquarium fish (*Poecilia reticulata*) resulted in significantly increased brood numbers (double) compared to standard food (Kostecka and Paczka 2006).

The future: entomophagy and conservation in Australia

What are the main requirements if entomophagy is to be advocated as a serious option for Australia? They involve advocacy (DeFoliart 1989); more attention to the biological potential of edible forest insects, including conservation, forest management, agriculture, nutrition and processing and storage (includes inventory of species); and stakeholder involvement (Vantomme *et al.* 2004).

Advocates

Advocacy for entomophagy needs a concerted effort (DeFoliart 1989). This can be at several levels involving: (1) scientists and conservationists on the potential benefits of entomophagy from an energy and conservation perspective; (2) nutritionalists on dietary advantages; and (3) farmers to establish minilivestock activities. A clear message needs to be delivered that entomophagy is not simply a developing world phenomenon, and developed nations can benefit if it is more widely adopted.

It could be a three-pronged advocacy strategy: (1) promoting iconic species as food for direct human consumption (*witjuti* and *bardi* grubs, yabbies, honey ants, etc); (2) allowing insects as food additives for provision of protein and other nutrients; and (3) encouraging the use of insects as animal (poultry, pig and fish) food.

Museums and zoos could play an important role as advocates. Live invertebrate displays are paramount in improving the profile of "creepy-crawlies" (Yen 1993) and many of these displays have associated captive breeding. This is an opportunity to study the biology of edible species and promote the use of edible invertebrates.

More information on edible insects

An up-to-date inventory of entomophagous insects in Australia is required. This will involve both working with traditional landowners to obtain more information on which species they consider edible as well as information on their biology, collecting, preservation and cooking techniques. Research is also needed on the potential of species that are not eaten by traditional landowners.

Agreement is needed on definitions of scientific and common names for edible insects. As Yen *et al.* (1997) indicated, some Aboriginal groups have more accurate naming systems for edible grubs than those used by scientists. This situation is due to insufficient study on the taxonomy and distribution of these species. However, entomologists need to provide the lead on using correct names (such as *witjuti* and *bardi* grubs); the guide for the official common names of Australian insects (Naumann 1993) lists three taxa of insects as *bardi* grubs: the hepialid moths *Trictena atripalpis* and *Abantiades marcidus* and cerambycid beetles; the term should only be applied to beetle larvae and strictly to the buprestid *Bardistus cibarius* (Yen 2005).

Involvement of stakeholders

There are four groups of stakeholders that need to have active involvement: (1) traditional owners; (2) landowners (whether government or private); (3) industry (food production, processing and marketing; and (4) consumers (Charnley *et al*. 2007).

With regard to the traditional Australian Aboriginal owners, there is an urgent need to document information and traditional stories because the loss of local knowledge is a major issue (Paoletti and Dreon 2005). This information is being lost with the passing of the current generation of elders and often the information is not being handed on to the next generations.

It is not simply a matter of recording the information because traditional knowledge is a complex mixture of language and custodianship (initiated and uninitiated; men and women; and the custodians of knowledge for a particular area). There have been attempts to document insect names among Australian Aborigines (Yen *et al.* 1997; Meyer-Rochow 1975), and the Aborigines themselves have provided much information on the species that they eat (Central Land Council 2007b; Dann 2003; Goddard and Kalotas 2002; Bryce 1998; Bin Salleh 1997; Latz 1995; Turner 1994; Hercus 1989; Devitt 1986; Gillon and Knight 1986).

There are often deeper meanings to names and ceremonies that involve restricted knowledge associated with looking after the land or with growing up. For example, some Central Australian songs and dances about *witjuti* grubs may refer to more complex social issues related to growing up and marriage (Roheim 1933). In another example, Spencer and Gillen (1899) described a *witchetty* grub ceremony at Emily Gap near Alice Springs in Central Australia. But the site is not known for the grub that feeds in the roots of the *witjuti* bush (*Acacia kempeana*). Instead, Emily Gap is a very important location for the traditional Arrernte owners because it is where *arlperenye* (the green stink beetle) decapitated the *ayeparenye* (the caterpillar that feeds on tar vine, *Boerhavis* spp), *ntyarlke* (the caterpillar that feeds on pigweed, *Portulaca olearacea*) and *utnerrengatye* (the caterpillar that feeds on the emu bush, *Eremophila longifolia*), and spilled their innards everywhere. It is the place where the caterpillars that are considered the main creative ancestors of Alice Springs originated (Central Land Council 2007a,b). These three caterpillars were food items and were ritually gutted before eating. A hole was dug and the guts were squeezed into the hole and buried; this gutting process is called *werlaneme* and had to be done according to Arrernte Law because these *tyape* (edible caterpillars) were very sacred to the area and the Arrernte people (Central Land Council 2007b). Interestingly, the scientific identities of these three species are still uncertain.

Documenting information from traditional owners requires acknowledgement that some sensitive information cannot be made public. For example, information on whether a particular insect is edible and how it is collected is often forthcoming, but information on Aboriginal understanding of the biology and mythology (which can be associated with creation and movement across the country) may not be.

Consultation with Aboriginal communities is essential because they will, in many cases, have important information on edible insects, may retain some ownership of land involved and they could be an important contribution to small local economies (Vantomme *et al.* 2004). Aboriginal involvement would involve gaining community support, provision of training, support services (developing a business plan, funding, site selection, species and plant), marketing and issues associated with intellectual and cultural property (Miers 2004).

Controlled mass production including economical mass harvest methods

Two factors work against mass harvest of edible insects from the wild in Australia: unreliability of supply and the potential for habitat destruction. As outlined earlier, Australian Aborigines were able to utilize edible insects in a sustainable manner because of low population densities and tracking resources by moving across the country. There are questions as to whether harvesting for tourism and restaurants is sustainable because motorized transport has increased the area that is searched for food and at a much higher rate. There is unsubstantiated anecdotal evidence that sugarbags (native bees) have declined in the southern parts of Australia; whether this is due to better access or due to other environmental factors, remains to be determined.

The mass harvesting of pest insects is another matter. Whether this is economically feasible needs to be addressed. Pest outbreaks can also be unpredictable, and the mode of collection will depend on the target species. Collecting plague locusts would be difficult because of the vast areas that they cross in a short time, and access to some of these areas can be difficult. Locust control in Australia is based on spraying hopper beds to reduce adult numbers, and this may prevent collection of adults. Some pests of agricultural crops or horticulture could be mass collected by light or chemical (pheromone) traps. Initially it would be necessary to determine if these species are of entomophagous value to humans.

There has been limited study on mass rearing of edible Australian insects (Rich 2006), and the techniques are better developed for snails (Berg 2006, 2003) and crayfish (Piper 2000). There is certainly an opportunity to research mass rearing of selected insects other than the known iconic species as well as determining more efficient ways of rearing *bardi* and *witjuti* grubs. This research needs to be conducted in conjunction with research on food quality and safety. While discussion has focused on using the products within Australia, the value of international export markets needs to be kept in mind.

If minilivestock enterprises are to be established in Australia, it is necessary to consider the design, location and integration of these enterprises with other production systems. These need to be considered in relation to their purpose and how they operate (for example recycling systems for converting organic wastes into high protein feed supplements for humans, poultry, pigs and fish), and how farmers could augment their main income with minilivestock operations. New ventures should be considered, such as the possibility of using appropriate termites to produce compost from sawmill waste in certain locations, and at the same time harvest termites as animal feed (D. Ewart, personal communication, 2008).

Conservation

Besides reliability of supply, the other main argument for developing mass rearing facilities for edible insects is habitat conservation. While much of Australia is semi-arid or arid (but still with considerable vegetative cover), forests and woodlands have been severely depleted since European settlement. Many woodlands were cleared for agriculture, while some of the remaining forests are still used for timber production. The major threats to Australian forests and woodlands include alienation and fragmentation, altered hydrology regimes, stock grazing and other forms of activities that affect the understorey and ground layers and inappropriate fire regimes.

A survey of entomophagy in Central Africa found that forest caterpillars (Lepidoptera) and grubs (Coleoptera) provided high nutritive value and were a main source of protein, and unlike those from agricultural land, they were free of pesticides. Gathering (by hand or chopping off branches or felling trees) was probably not as much of a threat as logging, bushfires or other forms of forest disturbance (FAO Départment des Forêts 2004). The situation in Australia is different in that more forest has been cleared or alienated than in Central Africa, and although not many insects are being harvested, the effects (especially digging for fish bait) could be quite severe. Also, unlike Central Africa, Australian commercial forests are sometimes sprayed with chemicals (insecticides, fungicides and herbicides).

Mass rearing of insects, even if it is only for recreational fishing, would help the conservation of Australian forests. As part of environmental restoration in Australia, there are numerous tree-planting programmes to replace lost forests (and also part of carbon-trading schemes). These programmes range from those with purely conservation goals (planting endemic species with a structure that imitates natural conditions) to purely commercial agroforests. There is a need to consider whether some of these programmes can be integrated into a system that will also involve the production of edible insects.

Conclusions and recommendations

The consumption of insects is not a major component of diet in Australia today. It is confined to some groups of Aborigines (where it is in decline due to preference for processed western foods), as part of the bush tucker tourism experience and in a very small number of restaurants. There are commercial operations involving the mass rearing of freshwater crayfish and *Helix aspera* for human consumption. There is high demand for edible insects as bait in recreational fishing.

There are enormous opportunities to develop and expand entomophagy in Australia on three levels: (1) human consumption of selected species; (2) as a nutritive supplement in food for humans; and (3) as food for fish, poultry and other animals. Most edible Australian insects are difficult to collect in large numbers (and often in isolated locations that make transport to markets an issue), are unpredictable in their occurrence and inappropriate harvesting could result in significant damage to both their population numbers and their habitats.

Mass rearing of edible insects would be the most appropriate solution to increase their availability. This involves research in raising insects from different habitats (leaf feeders, wood and root feeders, honeydew feeders, etc.) and species that can be highly mobile (for example *Bogong* moths). Mass rearing and preparation of edible insects is a research area that could facilitate more cross-continental collaboration. For example, the Asmat in Papua rear the palm weevil (*Rhynchophorus ferrugineus*) in rotting trunks of sago palm to enable the collection of large quantities (Paoletti 1995); can this idea be applied to edible trunk and root grubs in Australia?

If wild harvesting of edible insects and other invertebrates is to be undertaken, then there needs to be further research on the distribution and population dynamics of these groups so they can be harvested without destroying forests and other environments (Paoletti *et al.* 2000; Paoletti 1995).

The list of widely adopted edible insects in Australia is relatively small (for example *witjuti* and *bardi* grubs, *Bogong* moths, honey ants). This is partly due to taxonomic impediments and the actual number of species of Lepidopteran and Coleopteran larvae eaten (at the moment collectively lumped into the *witjuti* and *bardi* categories) could be quite large. There is an urgent need to document further information from Australian Aborigines because this disappearing traditional local knowledge could be lost forever (Paoletti *et al.* 2000). There could be more edible species in Australia, and it is necessary to learn how the various Aboriginal groups found, collected and cooked them.

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Review of the nutritive value of edible insects

Chen Xiaoming, Feng Ying, Zhang Hong and Chen Zhiyong[1]

Insects have not been fully used and developed as a food source. Based on analysis and study, the nutritive value of edible insects was reviewed. The results showed that insects have rich protein (20-70 percent), amino acid (30-60 percent), fat (10-50 percent), fatty acid, carbohydrate (2-10 percent), mineral elements, vitamins and other activated elements that promote human health. As protein sources, the nutritive value of edible insects is as good as other animals or plants. Insects are characterized by rich species diversity and large populations, therefore as nutritive resources, edible insects can be widely used and have great development potential. In promoting insects as human food, relative nutritive values should be taken into consideration to provide the maximum benefit to human consumers.

Keywords: amino acid, carbohydrate, fat, fatty acid, protein, trace elements

Introduction

Insects represent a significant biological resource that is still not fully utilized around the world. There are many species and vast numbers of insects. Insect bodies are rich in protein, amino acids, fat, carbohydrates , various vitamins and trace elements. Therefore insects offer an important nutritional resource for humans and are worthy of development (Chen and Feng 1999; Yang 1998; Hu 1996; DeFoliart 1992; Mitsuhashi 1992; Comby 1990; Ramos-Elorduy and Pino 1989; Zhou 1982; Zhou 1980).

During human evolution, it was customary in many countries and regions to eat insects. In ancient China it was common to consume insects as food. According to the famous entomological historian Zhou Shu-wen, the Chinese began to eat insects more than 3 000 years ago (Zhou 1982), moreover many old documents detail the eating of insects; some insects were even sent to the king and high officials as tribute. Until now, in many regions of China, especially in areas where minority groups live, people are still accustomed to eating insects.

Besides being a delicious food commodity, the nutritive value of edible insects has attracted the attention of nutritionists, health workers and physicians. Many insects not only have high nutritive value, but are also considered to have health-enhancing properties, such as Chinese caterpillar fungus, ants, termites and silkworms; some have been processed into health foods.

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Other countries have also paid considerable attention to edible insects. As early as 1885, the English entomologist Vincent M. Holt published *Why not eat insects?* (Holt 1885). Since then many entomologists have made further studies on the nutritive value of insects, identification of edible insects, customs related to eating insects and other aspects. The French entomologist Bruno Comby wrote *Delicieux insectes* (Comby 1990); Professor G.R DeFoliart of the University of Wisconsin has edited *The Food Insects Newsletter*; Japanese entomologist Jun Mitsuhashi published *Edible insects of the world* (Mitsuhashi 1992); Japanese entomologist Dr Umeiya Kenji described edible insects and medical insects in *Insect resources of Asia*; and in 1989 Dr Julieta Ramos-Elorduy of the National Autonomous University of Mexico investigated and analysed the nutritive elements of edible insects in Mexico, with excellent results (Ramos-Elorduy and Pino 1989).

Zhou (1982) and Zhou (1980) conducted research on insects of ancient China and both wrote books on historical entomology in China. In these books, Chinese edible insects are discussed. Zhou (1982) in particular describes the nutritive value and eating customs of edible insects in ancient China. In recent years, *Resource insects and utility* (Hu 1996) and *Utility of Chinese resource insects and their industrialization* (Yang 1998) have also addressed some edible insects. In *The edible insects of China* (Chen and Feng 1999), 11 orders, 54 families, 96 genera and 177 species are recorded. The value of edible insects has made scientists pay much greater attention to the subject.

Protein and amino acids of edible insects

Protein is the basis of all organism activity and constitutes many important materials such as enzymes, hormones and haemoglobin. Protein is an important component of antibodies as it bolsters the immunity function of the body. It is the only material to produce nitrogen for maintaining acid and alkali balance, transforming genetic information and transporting important materials in the human body. As a nutritive element that produces heat, it can supply energy.

Insect bodies are rich in protein. In nearly 100 analysed edible insects (Chen and Feng 1999; Yang 1998; Hu 1996; DeFoliart 1992; Mitsuhashi 1992; Comby 1990; Ramos-Elorduy and Pino 1989), at egg, larva, pupa or adult stages, the raw protein content is generally 20-70 percent. Raw protein content is 66.26 percent in Ephemeroptera larvae, 40-65 percent in Odonata larvae, 40-57 percent in Homoptera larvae and eggs, 42-73 percent in Hemiptera larvae, 23-66 percent in Coleoptera larvae and 20-70 percent in Lepidoptera larvae. Protein content of Apidae, Vespidae and Formicidae in the Hymenoptera Order is also high (38-76 percent). According to analysed data, the protein content of insects is higher than most plants; the protein content of some insects (e.g. larvae of *Ephemerella jianghongensis* [66.26 percent], *Sphaerodema rustica* Fabricius [73.52 percent]) is higher than that of commercial meat, fowl and eggs (Table 1).

Protein is composed of more than 20 types of amino acid that benefit the human body; among them eight are necessary for human nutrition as they cannot be synthesized in the human body (Jin 1987). Analysis of nearly 100 types of edible insects has shown that necessary amino acid content is 10-30 percent, covering 35-50 percent of all types of amino acids, which is close to the amino acid model proposed by the World Health Organization and FAO (Table 1).

Table 1. The protein and amino acid content of edible insects in some insect orders (% dry weight)

Order	Protein			Amino acids			Necessary amino acids			N amino acids/ amino acids		
	high	low	ave.	high	low	ave.	high	low	ave.	high	low	ave.
Ephemeroptera			66.26			65.97			23.81			36.09
Odonata	65.45	46.37	58.83	51.70	36.10	46.03	19.08	13.04	16.12	36.91	34.05	35.69
Isoptera				58.27	33.96	44.03	20.88	12.77	16.74	40.05	35.73	38.04
Orthoptera	65.39	22.80	44.10	57.51	20.23	38.87	19.92	7.98	13.95	39.45	34.64	37.05
Homoptera	57.14	44.67	51.13	53.19	32.59	42.45	21.92	12.38	16.34	41.21	35.42	38.21
Hemiptera	73.52	42.49	55.14	59.68	38.09	48.72	22.18	14.73	18.65	42.72	34.77	38.41
Coleoptera	66.20	23.20	50.41	62.97	13.27	39.74	28.17	4.45	17.13	50.49	26.65	42.79
Magaloptera			56.56			53.31			19.51			36.60
Lepidoptera	68.30	14.05	44.91	61.84	13.27	32.88	25.60	4.45	13.92	47.23	26.65	40.35
Diptera			59.39									
Hymenoptera	76.69	12.65	47.81	81.27	21.0	45.18	33.62	8.42	16.23	46.41	30.56	35.78

Sources: Yang (1998); Hu (1996); Mitsuhashi (1992); DeFoliart (1991); Comby (1990); Ramos-Elorduy and Pino (1989); and the authors.

Fat in edible insects

Fat is an important component of the human body, storing and supplying energy as well as supporting and protecting different organs. Fat can also help in the absorption of vitamins. Phosphate, carbohydrate and cholesterol are components of many tissues and cells; combined with protein, they can form fat protein and cell membranes. Recent studies show that phosphatide is good for the brain and liver, reduces blood fat, produces clean cholesterol, helps cells and skin to grow and postpones senility (Jin 1987). Fatty acids can be separated into saturated fatty acid and unsaturated fatty acid. Unsaturated fatty acid can help human growth, protect the skin and reduce the formation of thrombi and clotting of blood platelets.

According to reports and analysis (Feng *et al.* 2001 a,b,c; 2000 a,b; 1999; Chen and Feng 1999; He *et al*. 1999; Lu 1992; DeFoliart 1991), many edible insects are rich in fat (Tables 2 and 3). During edible larvae and pupae stages, their fat content is higher; during the adult stage, the fat content is relatively lower. The fat content of edible insects is between 10 and 50 percent; the fat content of *Oxya chinensis* (Thunberg) of Orthoptera only reaches 2.2 percent; some larvae and pupae of Lepidoptera have higher fat content, such as *Pectinophora gossypeilla* Saunders (49.48 percent) and *Ostrinia furnacalis* Gunnee (46.08 percent). The fatty acid of edible insects is different from animal fat; it has higher fatty acid that the human body needs, such as that found in the larvae and pupae of *Dendrolimus houi* Lajonquiere, larvae of *Musca domestica* Linnaeus, *Chilo Fuscidentalis* Hampson and some ants.

Therefore, the fat of edible insects has good nutritive value. Edible insects have similar fat materials, such as phosphatide, which has health benefits.

Table 2. Fat content of some edible insects (% dry weight)

Order	Fat		
	high	low	average
Odonata	41.28	14.23	25.38
Orthoptera			2.2
Homoptera	30.60	24.85	27.73
Hemiptera	44.30	9.73	30.43
Coleoptera	35.86	14.05	27.57
Lepidoptera	49.48	5.0	24.76
Diptera			12.61
Hymenoptera	55.10	7.99	21.42

Sources: Lu *et al*. (1992); DeFoliart (1991); and the authors.

Table 3. Fatty acids of some edible insects (%)

Species	Saturated fatty acids		Unsaturated fatty acids		
Macrotermes annandalei (Silvestri)	18.54	9.98	51.14	13.01	0.65
Macrotermes subhyalinus	33.0	1.4	9.5	43.1	3.0
Oxya chinensis (Thunberg)	25.0	26.1	27.1	2.3	
Locuta migratoria migratorioides (R. & F.)	25.5	5.8	47.6	13.1	6.9
Melanoplus sanguinipes (Fabricius)	11.0	4.0	19.0	20.2	43.0
Schistocerca gregaria (Forska) male adult	40.3	6.7	31.7	7.5	3.6
Schistocerca gregaria (Forska) female adult	34.6	5.8	37.6	10.2	6.2
Rhynchophorus phoenicis (Fabricius)	36.0	0.3	30.0	26.0	2.0
Tenebrio molitor L.	23.6	1.4	44.7	24.1	1.5
Antheraea pernyi Guérin-Méneville pupa		2.37	27.81	24.74	24.87
Dendrolimus houi Lajonquiere pupa	3.038	4.40	29.77	9.96	22.24
Dendrolimus houi Lajonquiere adult	36.64	7.84	32.82	6.0	8.79
Galleria mellonella L.	39.6	3.1	47.2	6.5	
Musca domestica L. larva	12.7	2.3	18.2	32.5	3.3
Polyrhachis dives Smith	21.14	2.29	62.44	1.39	1.21

Sources: Lu *et al*. (1992); DeFoliart (1991); and the authors.

Carbohydrates of edible insects

Carbohydrates are important nutritive elements in the human body. They are the main heat source, can reduce consumption of protein and help detoxification. They are also important constituent materials of the human body. They can combine with protein and fat and their compounds have important physiological functions (Jin 1987).

Edible insects have rich protein and fat, but less carbohydrate (Table 4). Types of edible insects differ and their carbohydrate contents also vary (1-10 percent). An unusual source is insect tea, the excrement of insects, which has higher carbohydrate content (16.27 percent). Recent research has revealed that insects have considerable amounts of polysaccharide that can enhance the immunity function of the human body (Sun *et al*. 2007).

Table 4. Carbohydrate content in some insect orders (% dry weight)

Order	Carbohydrate		
	high	low	average
Odonata	4.78	2.36	3.75
Orthoptera			1.20
Homoptera	2.80	1.54	2.17
Hemiptera	4.37	2.04	3.23
Coleoptera	2.82	2.79	2.81
Lepidoptera	16.27	3.65	8.20
Diptera			12.04
Hymenoptera	7.15	1.95	3.65

Sources: Yang (1998); Hu (1996); and the authors.

Chitin is a macromolecular compound that has high nutritive and health food value. Chitin can be made into a health food that has medicinal value for it can stop bleeding, prevent thrombus and help wounds to heal; it can be made into a medicinal film and can also be used in making cosmetics. The body and skin of edible insects are rich in chitin; different forms of edible insects have different chitin content (5-15 percent), such as *Bombyx mori* L. dried pupa (3.73 percent), defatted pupa (5.55 percent) and *Dendrolimus houi* Lajonquiere pupa (7.47 percent) and adult 17.83 (percent) (Chen and Feng 1999; He *et al*. 1999). The scientific study of the chitin of insect bodies is just beginning, with potential for many human uses.

Inorganic salts and trace elements in edible insects

Inorganic salts and trace elements are important components of the human body. They are necessary materials to maintain normal physiological functions (Jin 1987).

According to analysed results (Table 5), edible insects have rich trace elements such as potassium (K), sodium (Na), calcium (Ca), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn) and phosphorus (P). Many edible insects are also high in calcium, zinc and iron. Therefore, edible insects can supply necessary nutritive elements for human body functions.

Table 5. Trace element content of some edible insects (% dry weight)

Species	K	Na	Ca	Mg	Cu	Zn	Fe	Mn	P
Gomphus cuneatus Needham	2 620	590	4 180	880	64.3	124.8	728.9	74.8	1 470
Lestes paraemorsa Selys	2 930	2 020	2 160	970	64.8	147.7	1198	58.9	2 470
Crocothemis servilia Drury	3 330	2 310	1 510	950	50.6	103.8	461.6	27.2	1 420
Darthula hardwicki (Gray)	2 120	610	280	4 500	56.9	544.3	100	13.6	
Ericerus pela Chavaness, egg	6 300	89.51	353.7	1 200	23.6	164.2	133.1	26.74	6 000
Cyclopelta parva Distant	4 720	1 680	480	1 530	2.4	155.8	119.7	19.9	8 200
Eusthenes saevus Stal.	610	780	280	260	45.4	78.0	98.3	16.3	1 520
Cyrtotrachelus buqueti Guérin-Méneville	2 620	650	270	1 050	38.4	306.1	64.7	21.0	5 190
C .longimanus Fabricius	1 740	510	390	480	22.9	127.1	66.3	25.9	2 920
Holotrichia oblita (Faldermann)			397.22	455.78	18.86	101.33	1313.7	46.50	
Anomala corpulenta Motschulsky			434.94	297.04	26.82	84.51	2 299.5	61.61	
Protaetia aerata (Erichson)			187.47	303.65	35.56	97.48	338.54	20.03	
Aromia bungii Faldermann			131.56	220.54	23.97	98.76	102.5	15.47	
Anoplophora nobilis Ganglbauer			133.56	105.2	10.42	95.42	105.33	9.56	
Apriona germari (Hope)			150.68	254.36	25.46	102.34	96.56	20.47	
Pectinophora gossypeilla (Saunders)			113.40	163.21	33.40	87.01	36.78	0	
Corcyra cephalonica Stainton			148.66	156.81	17.13	78.29	264.81	6.87	
Ostrinia furnacalis (Gunnee)			140.53	184.06	14.84	91.78	70.26	4.56	
Papilio machaon L.	1 250	90.5	384	279	1.5	3.5	18.0	0.9	457
Chilo fuscidentalis Hampson	2 620	740	880	1 060	11.1	109	57.1	41.8	1 690
Antheraea pernyi Guérin-Méneville	13 390	620	790	3 800	19.01	141.8	0.01	8.73	690
Musca domestica L.	15 600	2 700	1 200	12 300	59	570	520	406	17 900
Polyrhachis dives Smith female adult			613.34	172.36	32.66	155.42	378.36	104.35	
Polyrhachis dives Smith male adult			585.28	163.78	27.08	148.83	391.56	101.89	

Sources: Hu (1996); Rong *et al.* **(**1987); and the authors.

Vitamin content of edible insects

Vitamins are one group of organic compounds that are necessary for metabolism in human bodies. As vitamins cannot be synthesized in the human body, they must be supplied constantly by food.

Studies on vitamins in edible insects are insufficient. But according to analysed results (Feng *et al.* 2001 a,b,c; 2000 a,b; 1999; Chen and Feng 1999; He *et al*. 1999; Lu 1992; DeFoliart 1991), edible insects have vitamin A, carotene, vitamins B_1, B_2, B_6, D, E, K, C, etc. For example, the vitamin A content of *Macrotermes annandalei* Silvestri reaches 2 500 IU/100 gram, vitamin D reaches 8 540 IU/100 gram, vitamin E reaches 1 116.5 mg/100 gram and the vitamin C content of insect tea reaches 15.04 mg/100 gram. Edible insects are rich in vitamins for human health and nutrition.

Conclusion

Edible insects are rich in protein and amino acid, especially essential amino acids for the human body. They are one source of good protein. They can supply rich fat, fatty acid, nutritive elements, vitamins and carbohydrates, especially high unsaturated fatty acid, which has excellent nutritive value. There are other substances in insects that are good for human health; for example, antibacterial protein and peptide, enzymes and hormones. Certain insects constitute superior health food. As a nutritional resource, edible insects and their industrialization should be focused on in future studies.

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Common edible wasps in Yunnan Province, China and their nutritional value

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Wasps belong to the Order Hymenoptera and feed on other insects. They have been consumed by humans for a long time, both in China and abroad. They are common edible insects in Yunnan Province. Research indicates that there are 12 species of edible wasps in Yunnan: Vespa velutinia auraria *Smith,* V. tropica ducalis *Smith,* V. analis nigrans *Buysson,* V. variabilis *Buysson,* V. sorror *Buysson,* V. basalis *Smith,* V. magnifica *Smith,* V. mandarinia mandarinia *Smith,* V. bicolor bicolor *F.,* Provespa barthelemyi *(Buysson),* Polistes sagittarius *Saussure and* P. sulcatus *Smith.*

The larvae and pupae of wasps are nutritious and rich in protein and amino acids. The average protein and amino acid content is 52.96 and 44.77 percent, respectively. The average amount of seven types of amino acids necessary for human nutrition is 16.62 percent, constituting 37.12 percent of total amino acids. Among the edible insects, wasps can play an important future role in human nutrition.

Keywords: amino acid, nutrition, *Polistes*, protein, *Provespa*, *Vespa*

Introduction

Wasps belong to the Order Hymenoptera and feed on many kinds of other insects, including various agricultural and forestry insect pests. Therefore wasps can be an important element in biological control programmes (Li 1993). The apitoxin excreted by female wasps can alleviate thrombus and can be used as a medicine.

Wasp larvae and pupae are also edible. Records show that it has been customary for Chinese people to eat wasps since ancient times. Wasp collecting and cooking techniques are documented in a book from the Tang Dynasty (618-907) (Zhou 1982). Wasps are also eaten in other countries, such as Mexico, Japan and Thailand (Wen 1998; Satoshi *et al.* 1996; Mitsuhashi 1992). The larvae and pupae of wasps are commonly eaten in Yunnan Province, southwestern China; in summer and autumn they are sold with the nest in local markets. Dishes of cooked wasps are also served in restaurants. Research on edible wasps is insufficient despite their popularity in China. The amino acids of *Vespa velutina auraria* Smith and *V. tropica ducalis* Smith were analysed by Wang *et al.* (1998). The analysis of edible wasps in Yunnan is the subject of this paper and is based upon Chinese studies of edible insects conducted by scientists over many centuries.

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Plate 1. Wasp larvae and pupae soup (steamed larvae and pupae of wasps with bamboo shoots and vegetables), Ruili, Yunnan *(Courtesy Feng Ying)*

Materials and methods

Specimens were investigated and collected in Kunming, Shimao, Dali, Honghe and Xishuangbanna prefectures of Yunnan Province. Protein was analysed using the Kjeldahl quantitative determination method. Amino acids were analysed by an automatic amino acid analyser.

Results and analysis

Eating practices and common species

Wasps are common edible insects in China. Eating wasps has been practised throughout China since ancient times and is particularly common in Yunnan Province. The Han, Dai and other minority groups have consumed wasps and offered them to guests for a long time. Local people collect wasp nests to sell at the markets. When a wasp dish is prepared, the larvae and pupae are removed from the nest. In this way, the insects can be kept clean and fresh. The most common way to prepare wasps is deep-frying or frying with chicken eggs, similar to cooking methods employed for edible insects in general. The Dai people who live in Jinghong and Ruili towns of Yunnan Province prefer to steam and mix the insects with vinegar and other seasonings.

There are 12 species of edible wasps in Yunnan, belonging to two insect families. Vespidae accounts for ten species: *Vespa velutinia auraria* Smith, *V. tropica ducalis* Smith, *V. analis nigrans* Buysson, *V. variabilis* Buysson, *V. sorror* Buysson, *V. basalis* Smith, *V . magnifica* Smith, *V. mandarinia mandarinia* Smith, *V. bicolor bicolor* F. and *Provespa barthelemyi* Buysson. The remaining two species are in the Polistidae Family: *Polistes sagittarius* Saussure and *P. sulcatus* Smith.

Protein and amino acid content

The protein content of four wasp species larvae was analysed by the authors. Results showed that the protein content of larva of *V. basalis* Smith*, V. mandarinia mandarinia* Smith, *Polistes sagittarius* Saussure and *P. sulcatus* Smith was 53.18, 54.59, 46.17 and 57.88 percent, respectively. The average of these four species of larvae is 52.96 percent, higher than the protein content of pork (21.42 percent), milk (28.04 percent) and eggs (48.83 percent) (INFS 1998). These results clearly show that wasp larvae are very rich in protein.

Plate 2. Fried wasp larvae and pupae, Ruili, Yunnan *(Courtesy Feng Ying)*

Table 1 presents the results of amino acid analysis for six species of wasp larvae. The contents of 16 types of amino acids of *V. basalis* Smith, *V. mandarinia mandarinia* Smith, *P. sagittarius* Saussure, *P. sulcatus* Smith, *Vespa velutina auraria* Smith and *V. tropica ducalis* Smith were 43.91, 52.20, 36.11, 45.02, 49.03 and 42.44 percent, respectively. The average content of amino acids was 44.77 percent. The contents of the seven essential amino acids for the human body were 15.15, 24.43, 12.57, 16.08, 16.78 and 14.68 percent, respectively. The average amount of these seven essential amino acids was 16.62 percent, constituting 37.12 percent of total amino acids.

Table 1. The amino acid content of six species of wasp larvae (%)

Amino acid	*V. basalis* Smith†	*V. mandarinia mandarinia* Smith†	*P. sagittarius* Saussure†	*P. sulcatus* Smith†	*V. velutin auraria* Smith‡	*V. tropica ducalis* Smith‡
Aspartic acid	3.36	3.30	2.96	3.32	4.53	4.32
Threonine*	1.75	1.74	1.52	1.86	2.12	1.94
Serine	1.91	1.82	1.59	2.02	3.15	2.05
Glutamic acid	7.47	6.89	6.23	6.88	5.91	5.70
Glycine	3.58	3.29	2.50	3.97	3.90	3.70
Alanine	3.41	3.41	2.59	4.01	3.54	3.34
Cystine	ND	ND	ND	ND	ND	ND
Valine*	2.59	2.59	2.37	3.00	3.38	3.24
Methionine*	0.90	0.35	0.48	0.88	1.35	0.53
Isoleucine*	2.64	2.38	2.04	2.83	2.91	2.32
Leucine*	3.54	3.24	2.81	3.61	3.65	3.51
Tyrosine	2.51	2.14	1.78	2.17	3.69	2.29
Phenylal-anine*	1.87	5.53	1.77	1.98	1.98	1.78
Lysine*	1.86	8.60	1.58	1.92	1.39	1.36
Histidine	1.07	1.11	1.09	1.14	1.53	0.58
Arginine	1.73	1.71	1.64	1.82	3.14	3.04
Tryptophane*	Untested	Untested	Untested	Untested	Untested	Untested
Proline	3.72	4.10	3.16	3.62	2.89	2.79
Total	**43.91**	**52.20**	**36.11**	**45.02**	**49.03**	**42.44**

*The essential amino acids. ND = not detected.

Sources: † data from the authors; ‡ Wang *et al.* 1998.

The highest protein content was in four larvae of *P. sulcatus* Smith (measured at 57.88 percent). The lowest was in *P. sagittarius* Saussure, at 46.17 percent. The highest content of amino acids was in six larvae of *V. mandarinia mandarinia* Smith, at 52.20 percent. The seven essential amino acids for the human body constituted 24.43 percent, comprising 46.41 percent of total amino acids. The lowest content of amino acids was in *P. sagittarius* Saussure.

Discussion

A total of 177 species of edible insects have been recorded in China (Chen and Feng 1999). Among them, wasps are widely eaten by many Chinese people. This paper discussed 12 species of wasps. In fact more than 12 wasp species are eaten and the others need to be studied scientifically. Based upon the results presented here, the protein and amino acid content of wasps in the larval stage is higher than in common foods, such as eggs and pork.

Protein is one of three important nutrients for the human body. It consists of 20 amino acids, among them eight types of essential amino acids only obtained from food. The amino acids of different protein may have a complementary function (Dai 1994). Therefore, larval wasps can effectively supplement protein supply by complementing other animal protein sources.

Adult wasps and wasp nests also contain amino acids – even higher than in larvae and pupae (Wang *et al*. 1998). Adult wasps do not taste as good as larvae and pupae and it must be noted that they contain apitoxin. Nevertheless, the adults and nests of wasps have been used in traditional medicine and as a health food by local people since yesteryear in China. In this context, scientific research needs to focus on wasp utilization in medicine and health care.

Wasps also have a positive role in the control of forest pests, as they feed on other insects. Protection and sustainable utilization must be considered in the exploitation of this insect. One promising approach is through artificial feeding of wasps.

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Teak caterpillars and other edible insects in Java

Dwi Retno Lukiwati[1]

*Teak (*Tectona grandis*) is a versatile wood that is excellent for building, furniture making and also fine carving. Among the defoliating insects frequently encountered in plantations is the teak caterpillar or* enthung jati *(*Hyblaea puera *Cramer; common name: teak defoliator), which is the sole genus of the Family Hyblaeidae. An estimated 2 000 insect species are consumed around the world; some people do not just eat insects, they relish them. The quantity of insects harvested from forests or agricultural areas varies greatly according to species and the prevalence of their food plants. Many insect species are lower in fat and higher in protein compared to beef, lamb, pork, or chicken. Crickets (*Brachytrupes portentosus *Lichtenstein), grasshoppers (*Valanga nigricornis *Burmeister and* Patanga succincta *L.), dragonflies (Order Odonata, species* Pantala flavescent *F.), red palm weevils (*Rhynchophorus ferrugineus *F.,* Chalcosoma atlas *L.) and bees (*Xylocopa latipes *Drury) are especially palatable, nutritious and easily obtained in Indonesia.*

Keywords: teak caterpillars, bees, crickets, cooking methods, dragonflies, grasshoppers, palm weevils

Introduction

Teak (*Tectona grandis*) is a versatile wood that is excellent for building, furniture making and also fine carving. In Javanese, the name for teak, *kayu jati*, also means “real wood”. Most of the teak can be found growing in villagers’ forest gardens called *kebun*, especially in traditional teak-producing areas, such as Wonogiri, Blora, Cepu (Central Java), Bojonegoro, Lamongan and Ngawi (East Java) on Java island. One of the defoliating insects frequently encountered in plantations is the teak caterpillar.

Teak caterpillars as a food source

The teak caterpillar or *enthung jati* (*Hyblaea puera* Cramer) is the sole genus of the family Hyblaeidae (Intachat 1997). Some people can consume teak caterpillar cocoons, but others break out in an allergic rash when they eat this seasonal delicacy. For a snack, the teak

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caterpillar cocoons are fried in coconut oil or African palm oil and seasoned with salt. Teak caterpillar cocoons were abundant in 2007 owing to rain in October, which allowed the leaves of the deciduous teak to bud early. As soon as the teak has a full cover of leaves the caterpillars attack, and as soon as the cocoons appear the cocoon collectors enter the forest. The entire neighbourhood participates, young and old, men, women and children. They forage and collect each curled teak leaf containing the tiny cocoon (Sari 2007). Frequently, and especially if large quantities are harvested, some are sold at local markets at US$3/ kilogram). Consuming teak caterpillar cocoons is believed to enhance vitality.

Other selected edible insects

An estimated 2 000 insect species are consumed around the world. There are 1 462 recorded species of edible insects (Price 2008). In fact, most insects are edible, but there are a few species that are especially palatable, nutritious and easily obtainable in Indonesia. Some insect groups and their use as food are described hereunder (LIPI 1980).

Grasshoppers (Order Orthoptera)

The short-horned grasshopper (*Valanga nigricornis* Burmeister, local name *belalang kayu*) is found in rubber plantations or rice paddy fields, and also in teak plantations at the end of the rainy season.

Rice grasshoppers (*Patanga succincta* L., local name *belalang patanga*) occur in lowlands (0-600 metres), underbrush, maize and paddy fields at the beginning of the dry season. This species is lower in fat and higher in protein compared to beef, lamb, pork, or chicken (Table 1).

Grasshoppers belong to the Phylum Arthropoda, Order Orthoptera and Family Acrididae, as evidenced by the ring-like segments of their bodies, their jointed appendages and their exoskeletons. Grass-feeding species of grasshoppers are the most numerous in grasslands (Pfadt 1994). They are often roasted, after first removing the wings and legs. Seasonings such as onion, garlic, chili, or soy sauce may be added. According to Ramos-Elorduy and Pino (1990), the nutritive value of the five highest Orthoptera (grasshopper nymphs and adults) of 20 species examined, averaged 4 168 kcal/kilogram.

Table 1. Nutritive value of livestock compared to rice grasshoppers* (%)

Animals	Protein	Fat
Cattle	15.8	24.3
Sheep	14.6	30.5
Pigs	13.0	33.3
Poultry	20.5	4.3
Patanga succincta* L.*	**24.4**	**1.5**

* Paul and Southgate (1978).
** Dwi Retno Lukiwati (1991).

Crickets (Order Orthoptera)

The cricket *Brachytrupes portentosus* L. is called *gangsir* in Javanese. It has a brown or dark-brown body colour and is found in the dry sandy soil of lowlands (0-600 metres) dominated by agricultural crops and plantations in the dry season. The adult lays its eggs in the ground. Egg production of this species is about 100-160 eggs per period. Cricket intestinal contents are removed prior to cooking. According to Price (2008), 100 grams of cricket contain 121 calories, 12.9 grams of protein, 5.5 grams of fat, 5.1 grams of carbohydrates, 75.8 milligrams (mg) of calcium, 185.3 mg of phosphorus, 9.5 mg of iron, 0.36 mg of thiamin, 1.09 mg of riboflavin and 3.1 mg of niacin.

Dragonflies (Order Odonata)

The name for the dragonfly (*Pantala flavescent* Fabricius) in Javanese is *capung ciwet*. It has a red and yellowish body colour and yellow spotted wings. They are found in lowlands and uplands (0-2 800 metres), especially among swamp plants.

Weevils and beetles (Order Coleoptera)

Among the most important of the larval stem borers is the red palm weevil (*Rhynchophorus ferrugineus* F.) or *ulat sagu* in Javanese. Larvae of this weevil are associated with dead sago palm trees or other dead trees. The larvae have soft bodies and can be fried without removing the gut content.

Scarab beetles (*Chalcosoma atlas* L.) or *kumbang tanduk* are found in lowland and upland areas (0-1 700 metres). The caterpillars of *Chalcosoma atlas* are known as *uret* in Javanese. They feed on debris on the ground and the roots of plants. *Uret* contain a good amount of fat and can be fried without additional oil for a snack.

Drury bee (Order Hymenoptera)

Drury bees (*Xylocopa latipes* Drury) or *tawon endas* feed on the pollen and nectar of flowers. They have a full black body colour. Nests are commonly found underground or in cavities in bamboo or trees and are made by the female bees. Usually the larvae and pupae are taken from the nests and eaten. They are fried with butter or fried with onion and salt.

How to prepare a batch of edible insects

Edible insects must be killed, cleaned and cooked before being eaten. Normally they can be eaten after roasting or frying with coconut oil, mixed with cassava leaves, cooked with salt and a few hot peppers, or simply fried with salt and onions.

The desired quantity of live insects should be rinsed in water and allowed to dry. This is easy to do with larvae or pupae/cocoons, but fairly difficult with winged insects. For winged insects, the gut content, head, hind legs and wings are removed and the insects are placed into a colander and covered with wire screening or cheesecloth. The insects are again rinsed and dried by shaking the colander until all the water drains out. The insect bodies are placed in a plastic bag and kept in a freezer for 15 minutes (but not allowed to freeze). The insects are then taken out of the freezer and rinsed again, after which they are ready for cooking. Two recipes are provided below:

Fried grasshoppers (*belalang goreng*)

Ingredients
- 2 cups of grasshoppers
- 1 cup of wheat flour
- 1 egg
- salt, pepper, garlic
- coconut oil or African palm oil

Method
Soak the grasshoppers in boiling water for one minute and then dry them. Mix and stir the egg, salt, pepper, garlic and add a little water; then dip the grasshoppers individually in the mix and fry them in hot coconut oil. Serve with hot coffee or tea.

Hot sweet teak cocoons (*kering enthung*)

Ingredients
- 2 cups of teak cocoons
- salt, *salam* leaf (*Eugenia polyantha*), a slice of crushed galangal (*Alpinia* spp., a relative of ginger), coconut sugar
- 3 shallots, 3 onions, 5 chilies raw and chopped
- sweet soy sauce

Method
Rinse the cocoons with boiling water. Fry all ingredients (except the cocoons) in a tablespoonful of oil until the aroma rises. Add a little water and keep stirring until the sugar caramelizes and then add the cocoons. Serve with warm white aromatic rice.

Conclusion

Edible insects are generally abundant, nutrient-rich and marketable; they contribute significantly to the livelihoods of many rural families in Indonesia, although historically data have not been collected on them. Very little research has been done on edible insects in Indonesia, but they have considerable development potential.

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Edible insects in Papua, Indonesia: from delicious snack to basic need

Euniche Ramandey and Henk van Mastrigt[1]

The Indonesian province of Papua occupies the western portion of New Guinea; it is equatorial in latitude and consists of lowland, hill and mountain habitats up to 5 000 metres. Local people inhabit villages up to 2 300 metres. About 60 to 100 insect species, representing ten insect Orders, are eaten by indigenous people. Consumption focuses on larger insects that do not need special equipment for capture and which are edible raw or after some roasting. Among large insects, preferences vary from tribe to tribe, probably based upon taste, abundance and custom. Among lowland people, Rhynchophorus bilineatus *is the most commonly eaten insect. Its larvae are used as subsistence food and are sold in local markets. In mountainous areas a wider diversity of insects is consumed, but their collection is more incidental and exclusively for subsistence purposes. In Papua, there is broad indigenous knowledge of edible insects, which is reflected by insect names in the local language, traditions and insect habitats. In the lowlands, edible insect populations are on the decline because of loss of sago forests. In mountainous areas, incidental edible insect collection is expected to continue and could be promoted as additional scientific information becomes available.*

Keywords: entomophagy, New Guinea, protein, *Rhynchophorus,* subsistence, tribal groups

Introduction

Ethnoentomology is still a young science and little research has been published on the use of insects or insect products in Papua as food, medicine or for other purposes. Nevertheless, knowledge and use of insects as food is widespread among indigenous tribes.

Papua Province of Indonesia occupies the western part of New Guinea, bordered to the east by the independent state of Papua New Guinea. Including its surrounding islands, the province has an area of 421 981 square kilometres and a human population of about 2.7 million. It is the easternmost part of Indonesia, situated between 130º and 141º east longitude and 9º north and 2º25' south latitude. There is a wide variety of habitats in this huge area, broadly divided into lowland (up to 800 metres) and mountainous areas (800- 5 000 metres). Lowlands mainly consist of sago forests, mangrove forests and swamps in the coastal areas. In the Merauke area and in the Birdshead Peninsula there are extensive grasslands. Lowlands generally have a greater number of alternative animal protein resources apart from insects, such as salt- and freshwater fish, wild pigs, birds, couscous (a marsupial) and lizards.

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Mountainous zones, with primary and secondary forests and many garden plots close to villages, generally have fewer animal protein resources with wide variation from area to area. In some locations insects are very important protein resources, especially when fewer alternatives are available. The indigenous people in mountains raise pigs and chickens, but typically restrict consumption of these valuable animals to weddings, exchanges and traditional ceremonies. Insects, especially grasshoppers, leaf and stick insects, cicadas and large moths and their caterpillars, remain an important protein source in the daily diet of many Papuan populations.

Precise data about numbers of insects in Papua are not available. Petocz (1987) approximated between 50 000 and 100 000 insect species in New Guinea, including about 30 000 Coleoptera and 5 000 Lepidoptera. The number of described species of insects in Papua has not been quantified yet. Based on Parsons (1999) and our own data, there are approximately 800 butterfly species in total. Recent surveys of various insect Orders (beetles, damsel flies and dragonflies, butterflies and moths) have shown that the number of recognized species is likely to increase considerably in the years to come.

Data sources

Besides the information provided by Tommaseo-Ponzetta and Paoletti (2005) and Duffels and van Mastrigt (1991), the data in this paper are based on observations by the authors and other members of the Entomological Group in Papua, and the results of interviews with indigenous people. The first author surveyed the life cycle of *Rhynchophorus bilineatus* larvae during her studies at Cenderawasih University (2001-2005); the second author has been working as a missionary in Papua since 1974, has visited many areas and villages all over Papua, and has built up a collection of insects, especially Lepidoptera.

Edible insects

General

Many insects are edible; however, consumption focuses on larger insects that can be collected and eaten without the use of special equipment. Insects that are edible in a raw state or that require minimal cooking are preferred. A summary of edible insects in Papua is provided in **Appendix 1**.

Seasonal conditions influence consumption. Insects that occur in small numbers are rarely utilized; however, insects that emerge in large numbers in a short time, either dependent on weather or other natural circumstances, are often collected and consumed by local people. Examples include Cerambycid beetles, which congregate during the pandan (*Pandanus conoideus*) fruiting season, one-day flies (Ephemenoptera) at the beginning of the rainy season, and *Cosmopsaltria waine* (Homoptera), which has – exceptionally for *Cosmopsaltria* – a two-year life cycle.

Records

In lowlands (areas along Papua's coastline), by far the most important edible insects are the larvae of *Rhynchophorus bilineatus,* the sago beetle (Plate 1). The larvae are collected one month after palm trees (*Metroxylon sagu*) are cut down for production of sago starch (Ramandey 2007; 2004). Normally they are consumed raw or after some roasting. Children in boarding houses in Jayapura and in the interior (for example Moanemani) receive parcels from their home villages containing live sago grubs, which are consumed raw with great relish. The consumption of the sago beetle larvae by the Citak and Asmat people has been documented extensively and found to vary according to both everyday and ritual life. Tommaseo-Ponzetta and Paoletti (2005) mention *Rhyncophorus ferrugineus* and add that possibly two species of Curculionid grubs are collected.

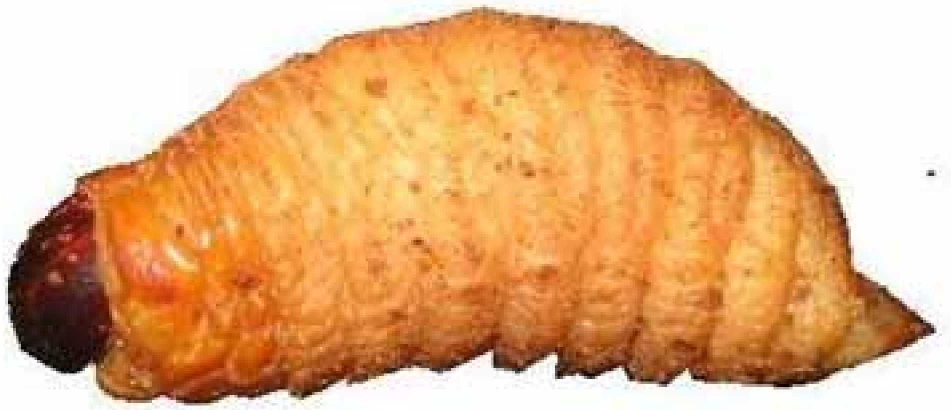

Plate 1. Sago larva (*Rhynchophorus bilineatus*) *(Courtesy E. Ramandey)*

In the southern lowlands, north of Merauke (in Tanahmerah, Mindiptana and Iwur) a one-day fly or mayfly (Ephemenoptera) is collected by the Muyu people and other tribes seasonally, after they emerge and die in enormous numbers above rivers and creeks. Mosquito nets are used to collect the floating insects, which are then packed in wild banana leaves and roasted on embers or just heated in a pan before consumption. At the end of the 1970s, the second author heard stories about enormous numbers of white butterflies dropping in rivers and being collected by local people for consumption. Recently it has become clear that the white butterflies were members of Ephemenoptera. In other parts of Indonesia one-day flies (in Indonesian *laron*) are collected during rainy evenings by putting a basin of water beneath the light of a gas lamp.

Information was obtained from the Ayamaru area in the Birdshead Peninsular of Papua about the occurrence and consumption of beetles in the pandan fruiting season, when fruits are collected by local people and processed. Within a few hours, discarded fruit seeds attract hundreds of beetles that consume traces of fruit on the seeds. The authors have not seen specimens of the beetles collected by local people, but after inspection of the KSP (Collection of Papuan Insects in Jayapura), Cerambycidae species were pointed out, probably in the genera *Xixuthrus*, *Osphryon* and *Macrotoma*. Further information must be obtained to be sure of the exact taxonomic identity of the consumed species. Apart from these beetles, various Sphingidae caterpillars are collected from the leaves of *keladi* (*Colocasia* sp.), the food plant visited most frequently by Sphingidae, to be consumed after some roasting by local people.

During visits from 1984 to 1989 to Timeepa (3º58' south latitude, 135º47' east longitude) and Modio (4º03' south latitude, 135º47' east longitude), the second author discovered that cicadas and moth caterpillars are an important food source for the Mee people in the Mapia area, at the foothills of the Kobowre Mountains (formerly the Weyland Mountains), at 1 400 and 1 280 metres above sea level respectively (van Mastrigt 2007).

The wild pig is hunted and has been domesticated. The population of wild birds around these villages is sparse, probably due to excessive hunting. Women and children catch forest rats, small fish, shrimp and crabs, and occasionally insects, such as cicadas and caterpillars of a Saturnid moth, *Syntherata apicalis* Bouvier, which congregate in communal silk nests.

The Mee people are knowledgeable about the life cycle of cicadas (Hemiptera) and recognize many distinct species for which they have different names in their local language, all ending with "-tege" (*kegaitege*, *pepatege*, *uwaitege*, *ditege* and *enijatege*), except for *waine*. In the Mee language outside the Mapia area *waine* is used for all *Cosmopsaltria* species, while in the Mapia area this name refers to a single species of cicada. The *waine* is easily recognized by the indigenous people by its sound. It is a seasonal species that occurs every other year (emerging in odd numbered years) in large numbers in the dry season (September to November). All kinds of adult cicadas are eaten by the Mee people in the Mapia area, but they most favour the *waine*, especially when collected early in the morning as the adult cicadas emerge from the underground pupae. The insect known as *waine* was new to science and has since been described as *Cosmopsaltria waine* Duffels (Duffels and van Mastrigt 1991).

In other parts of Papua, in the central mountain range indigenous people also consume various cicadas, but there is no location where the knowledge and exploitation of *Cosmopsaltria* is as developed as in the Mapia area. In the Star Mountains (near the Papua New Guinea border) the Ngalum people recognize three different kinds of cicada in their local language, although the number of *Cosmopsaltria* found in the area is probably twice that number.

At Sumbole, Landikma local people consume the complete nests of bees including wax, honey and larvae (personal observation, van Mastrigt). Beetles (Coleoptera) are eaten in many areas. As mentioned earlier, species of the Cerambycidae Family associated with the pandan fruit are consumed in the Birdshead Peninsula. *Xylotrupes gideon* (Dinastynae, Scarabaeidae) is eaten by inhabitants of the Arfak Mountains in the Birdshead Peninsula and at Walmak (about 140º east longitude) on the north side of the central mountain range.

At Langda, close to Mt Goliath (also about 140º east longitude, but at the south side of the mountain range), people collect *Cotilis* spp. (Cetoniinae, Cetoniidae) on high flowering trees, which are skewered on a small stick like sate and roasted before consumption. At least five species of the larvae of *Batocera* spp. and *Dihamnus* spp., Blattodea, found in decayed wood, *Palyzosteria* (?) sp. are part of the diet of the Langda people (Tommaseo-Ponzetta and Paoletti 2005).

Adult *Rosenbergia mandibularis* (Cerambycidae) are collected by the Maribu people (Sentani, Jayapura) from the breadfruit (*sukun)* tree (*Artocarpus communis*) and eaten after roasting. In the Pass Valley (close to the Baliem Valley) children play with the green shield bugs, called *babukulit* (*Nezara viridula* L., Pentatomidae) and eat them raw or roasted. According to the local children, it is the most delicious of the various insects that they consume, including grasshoppers (Orthoptera), cicada (Hemiptera) and some beetles (Coleoptera, including *Behrensiellus glabradus* Pascoe). Their knowledge of beetles is evident in the use of local names such as *fulug* (Passalidae), *fua* (Lucanidae), *bomboli* (snout beetle in general), *singgabit* (*Rhynchophorus richteri*) and *gulangge jangge* (*Behrensiellus glabradus*) (Menufandu 2007a,b).

Tommaseo-Ponzetta and Paoletti (2005) recorded seven local names for insects consumed by indigenous people at the Bime Valley (4º25'-4º30' south latitude; 140º12'-140º15' east longitude):

- *dunkala*, the yellow caterpillar of *Acherontia achesis,* as well as several other sphingid caterpillars used as food, Sphingidae (Lepidoptera);
- *due*, the larvae of Melolonthinae beetles, at least six edible species of Scarabeidae;
- *dyk dyk*, adults and larvae of Passalidae;
- *bulutnamgme*, larvae of Cerambycidae, at least three edible species (all Coleoptera);
- *wisin*, larvae of Tettigoniidae, at least five species have been indicated as edible;
- *pho*, adults of Gryllidae (both Orthoptera), with at least three edible species; and
- *philipalala*, the adults of *Extatosoma* sp. (?) Podacanthinae (Phasmatodea).

A wide range of edible insects is found at Borme (900 metres elevation) on the north side of the Star Mountains. Phasmida, Mantodea, Orthoptera and Coleoptera, and many larvae and adults of various species of moths (Lepidoptera) are common food for the indigenous people. During our first visit to Borme in 1998 it became clear that this area has few mammals and birds, probably due to hunting. Cicadas were not seen or heard during a one-week stay in September 1998. In 2006, a few cicadas were collected, but they were uncommon and therefore of little significance in the local diet.

We observed a local woman returning from the forest with two frogs and some spiders as additional food for her family. While collecting moths at light traps for scientific purposes, we noticed that many of the large-bodied species were consumed, in our absence, by local people. Many kinds of caterpillars and adults are eaten, especially of the larger moths – all Sphingidae and Saturniidae, many Geometridae and Noctuidae and a single Uraniidae (*Nyctalemon patroclus goldiei*).

The relationship between the behaviour of the people at Bime and Borme (two different tribes) is probably not only due to the same habitat and circumstances (villages at close proximity in the eastern part of the central mountain range), but also attributable to the large migration of Bime people to Borme in 1977 after a strong earthquake affected Bime villages and gardens.

Some tribes in the Merauke District of Papua consume many kinds of caterpillars of moths, many beetles and other insects; specific data must be collected from field surveys.

Some interesting information about insect eating in Papua New Guinea has come to light and it seems safe to assume that the same customs would be found among indigenous people in Papua, as the localities in Papua New Guinea are close to the border with Papua.

The Maring people who inhabit the northern slopes of the central range in the Western Highlands of Papua New Guinea are reported to use at least seven unidentified species of insects for food, one species for medicinal purposes and one for decorative purposes (Rappaport 1967).

The large longicorn beetle *Batocera wallacei* is often consumed by schoolchildren who roast the whole insect on fire embers, before removing the legs and wing casings and consuming the fat-filled abdomen. The Simbai people living just north and at slightly lower elevations than the Maring, decorate ceremonial headdresses with the reflective green elytra of Cetonid beetles. Several hundred insects are required to make one headdress (C. Davenport, personal observation).

Parsons (1999) reports that the gregarious larvae of *Papilio lagleizei* are a popular human food item in various parts of Papua New Guinea and are found in village markets at Garaina Central Province, Karimui in Simbu Province and Koinambe in the Western Highlands.

Trade and farming

People collect insects for a number of reasons:

- As an important seasonal food source, particularly in areas where game and/or agricultural resources are limited;
- Incidental, opportunistic collecting of a minor food source during other activities such as gardening or hunting of mammals and birds;
- As recreation by children, who play with and consume many kinds of beetles;
- For ceremonial purposes such as making headdresses and other body decorations; and
- For medicinal purposes.

Most insects collected by indigenous people are solely for their own consumption and are not found in local markets in the mountainous interior of Papua. In some lowland markets the larvae of the sago beetle (*Rhynchophorus bilineatus*) are offered for sale; at the Sentani Market (Plates 2-3), near Jayapura, the price of a bag of 100 to 120 larvae is IDR20 000 (US$1.00 = IDR9 455 [October 2009]), equivalent to the price of 3 kilograms of rice or 20 eggs.

In the last decade, the area of sago forest has been reduced considerably through felling and the establishment of oil-palm plantations, which will inevitably impact on the trade and consumption of sago beetle larvae. In spite of the importance and popularity of this food source, there has been no research or field work to develop husbandry of these insects.

Plate 2. Sago larvae for sale at Sentani Market, near Jayapura *(Courtesy E. Ramandey)*

Local differences and preferences

Caution must be exercised in generalizing information relating to any one ethnic group to the entire island of New Guinea. For instance, earthworm collection and human consumption is reported by P. Agnoletto (personal communication) from the nomadic Bisoro people in the upper reaches of the Salumei River, a Sepik tributary, in Papua New Guinea, but has not yet been documented in the western half of the island (Tommaseo-Ponzetta and Paoletti 2005).

In the western part of the island, reports about the exploitation of food insects by a few widely dispersed ethnic groups should not be generalized because they are dependent on various localized factors such as elevation, forest cover, customs and traditions, concentration of insect species and seasonal patterns of availability and alternatives, as well as individual taste.

In the lowlands only a few insects are known to be consumed regularly. This may be due to the strong influence of customs such as dietary taboos rather than the absence of edible species of insects.

In some mountainous areas, cicadas are the most favoured insects; in other areas grasshoppers, leaf and stick insects are preferred. This preference appears to be influenced by availability. In localities where grasshoppers, leaf and stick insects are popular for consumption (Baliem Valley and Borme), cicadas are less abundant; the reverse is true in the Mapia area and the high Star Mountains (1 400-2 500 metres).

Language is an important parameter of the relationship between local people and insects. This knowledge is often conveyed by traditional stories and by the number of local words for certain families or genera of insects. Detailed knowledge (often correct, but sometimes wrong) includes awareness of factors such as life cycles, habitat preference, edibility, toxicity and beauty.

Regrettably, this indigenous knowledge of nature is being lost as younger generations, exposed to many new influences, do not have such an interest in their environment as their parents and grandparents, with the consequence that the number of names in local languages for particular animals is decreasing quickly.

Future expectations

Urbanization will proceed in lowland areas; more people will become employees and the income of local people will increase, with the consequence that gardening and farming will receive less attention. Land (including sago forests) will be sold and converted to oil-palm projects or cleared and used for other commercial and social purposes. It may be assumed that the utilization of wild sago palms and the associated collection of *Rhynchophorus bilineatus* larvae will become much less common, although the larvae are considered to be a real delicacy by the local people.

In the mountainous areas the importance of insects as necessary food will also decrease. However, incidental, recreational and seasonal collecting are so strongly ingrained in the daily life of indigenous people that this will continue for the foreseeable future.

No surveys of the behaviour of migrants from other islands of Indonesia (about half of the population in Papua) have been carried out. Many of them come from cultures with traditions of collecting and eating insects (such as Homoptera, Orthoptera and Ephemenoptera). However, it seems that these traditions are rarely continued in their new environment.

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Appendix 1. Edible insects in Papua, with locations

Blattodea: Bime	1 species
Phasmida (stick and leaf insects)	
4 Families: Borme/Bime	5-8 species
Orthoptera (grasshoppers)	
Tettigoniidae: Borme/Bime	>5 species
Gryllidae: Bime	>3 species
Mantodea	
Mantidae: Borme	3-5 species
Hemiptera	
Pentatomidae: Pass Valley *Nezara viridula*	1-2 species
Homoptera	
Cosmopsaltria sp. (Cicada) Mapia (Kobowre Mountains), Baliem Valley, Star Mountains	>7 species
Coleoptera	
Scarabaeidae and Cetoniidae	>10 species
Curculionidae *Rhynchophorus* sp. – larvae	2(?) species
Cerambicidae: Bime	>5 species
Sentani *Rosenbergia mandibularis*	1 species
Passalidae: Bime	>1 species
Ephemenoptera (one-day flies): Mindiptana, Tanahmerah, Iwur	1 species
Lepidoptera	
All large moths of five Families: Borme	
Sphingidae – all large-sized species + caterpillars	>25 species
Saturniidae – all species + caterpillars (3 genera)	± 10 species
Noctuidae – all large imagines	>10 species
Uraniidae – *Nyctalemon patroclus goldiei*	1 species
Geometridae – Ennominae	>5 species
Hymenoptera – nest with bees: Sumbole, Landikma	1-2 species
Total	**> 95 species**

The future use of insects as human food

Jun Mitsuhashi[1]

Shortages of food, especially animal protein, are predicted for the twenty-first century so it will be necessary to look for new sources of animal protein. In this context, insects are suitable, although most people in developed countries dislike or hesitate to consume them – probably because they are repulsed by the appearance of insects, not their taste. Insects can be accepted favourably in the future by processing and mixing them with other foodstuffs. Edible insects may be used as space-travel food in the distant future. For long voyages to other planets, their cell culture will provide animal protein in a spacecraft, within which the area for the production of foodstuffs will be limited. If humans ever live in huge airtight domes on other planets, food production will have to be developed within the confines of the domes. Breeding of large livestock will not be practicable because of space limitations. The alternative will be to use insects to provide a source of animal protein. For such purposes, species such as silkworms, termites and flies have been suggested, taking into account the effective recycling of organic substances.

Keywords: animal protein, cell culture, flies, silkworms, space food, termites

Introduction

Increases in world population will require the production of vast amount of foods in the latter half of the twenty-first century. However it will be difficult to increase productivity to a level that satisfies food demand, mainly because of limited availability of new farm land. This will lead to shortages of food, especially animal protein. When total food resources are insufficient, it is unwise to feed livestock with grain and other foodstuffs, which can be consumed directly by humans. Therefore, it becomes necessary to look for new sources of animal protein such as insects, which are rich in nutrients. Most insects are edible, although there are some toxic species, and they can thrive on a diet that humans cannot consume. Some insects are even scavengers, such as saprophagers or coprophagers. The latter can contribute to recycling of animal waste.

Insect eating: the cultural context

Many people dislike or hesitate to consume insects; they indicate that insects are dirty, harmful or inspire fear. However, this is not true for most insects, especially edible insects. Some of the major edible insects, such as grasshoppers, and lepidopteran or coleopteran larvae, mostly eat fresh plant leaves or wood and are therefore cleaner and more hygienic than crabs or lobsters, which eat carrion. Although, insect-eating campaigns are becoming active in some developed countries (Table 1), many people still despise insects. This abhorrence is not

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inherent however. It is formed during infancy by the people surrounding the child. This is evidenced by some infants at insect-eating events who clearly enjoy insects. Therefore, insect hatred should be viewed as a prejudice that can potentially be eliminated. It is probable that people are repulsed by the image of insects, but not by their meat.

People who dislike insects have consumed insects or parts of insects before, which contaminated food during food production or processing. It is almost impossible to avoid contamination by insects or their parts in food. In fact, the Food and Drug Administration of the United States has prescribed permissible levels of insect contamination in food (FDA 1998). Therefore,
people are regularly eating insects unconsciously, without serious complications. This shows that people can eat insects if they do not know what they are eating, with the exception of individuals who have allergic reactions.

These factors suggest that transforming insects will facilitate their consumption in the future. In practice, dried insects may be crushed or pulverized, and raw or boiled insects ground or mashed, making their insect form unrecognizable. They simply become masses of protein and lipids that can be mixed with other foodstuffs such as grain, ground meat and mashed potatoes to make a variety of dishes (Table 2). Such dishes will be acceptable to most people. Some recipes of such dishes have been published (Ramos-Elorduy, 1998; Tayler and Carter, 1992).

Table 1. Organizations that host insect-eating events

Country	Organization
Australia	New South Wales Entomological Society.
Canada	Alberta State Museum; Ontario Joint Entomological Meeting; L'Insectarium de Montreal.
Japan	Tokyo Tama Zoo, Insectarium, Tokyo.
Republic of South Africa	South African Entomological Society.
United States	Audubon Zoo Insectarium, LA; Buffalo Museum of Natural History, NY; Cincinnati Zoo, OH; Crowley's Ridge State Park, AK; Garfield Park Nature Center, OH; Invertebrate in Captivity Conference, AZ; Iowa State Univ., Department of Entomology, IA; Los Angeles Museum of Natural History, CA; New York Entomology Soc., NY; Northwest College, WY; Oregonridge Nature Center, OR; Pennsylvania State Univ., Department of Entomology, PA; Purdue Univ., Department of Entomology, IN; San Francisco Zoo, CA; Smithsonian Institution, Museum of Natural History, DC; State Botanical Garden, GA; Univ. Illinois, Department of Entomology, IL.

Table 2. Examples of foodstuffs and cuisine

Insect	Treated form	Other ingredients to be added	Form to be eaten
Mealworms	Dry flour	Maize flour	Tortilla
Crickets	Dry flour	Wheat flour, buttermilk, baking powder	Bread
Grasshoppers	Ground	Miso, sugar, minced walnut	Paste
Wasp larvae	Minced	Wheat flour, soybean flour, mashed potato, vegetables	Wasp ball
Any insect	Ground	Minced meat, wheat flour, onion, mashed potato, egg	Insect burger

If and when insects are used as a major food resource, large quantities will be required. Naturally occurring insects may not meet demand; if too many wild insects are collected, ecosystems will be damaged. Insects used as foodstuffs should be raised. Clean and uniform insects will be produced through artificial rearing. This will contribute to sustaining ecosystems and avoiding overexploitation of wild insects. Several industrial plants are producing insects on a large scale, such as for projects to eradicate screwworms and fruit flies. The facility for the mass production of melon fly, *Bactrocera cucurbitae* in Okinawa, Japan is shown in Plate 1. In this plant, 40 million matured larvae are produced every week. Most of the procedures for raising larvae are controlled automatically. This system could be a model for the mass production of edible insects in the future.

Plate 1. A plant producing sterile melon flies for their eradication: (1) larvae, (2) adults, (3) main building, (4) part of the automated rearing system, (5) feeding trays for larvae *(Courtesy Jun Mitsuhashi)*

Insects as space-travel nourishment

In the more distant future, the use of insects as space-travel food is suggested. This application may be considered in two contexts: (1) consumption of insects by humans during long duration space travel; and (2) consumption by people colonizing other planets.

In the first case, during long space voyages, there may be a need to produce food within the spacecraft where space is limited and large animals cannot be kept. Small animals like insects will be a suitable animal protein source. The species used should satisfy the following criteria: (1) it can be reared in a small space; (2) it has a high reproduction rate; (3) it is easy to reproduce; and (4) it is easy to handle. Thus, *in vitro* cultured insect cells, instead of entire insects, could provide animal protein efficiently in a spacecraft. The cells, which constitute insect bodies, could be cultured in an artificial culture medium *in vitro* (i.e. cell culture). Initially, insects would be surface-sterilized and the tissue to be cultured excised from the insect bodies aseptically. The tissue would be cut into small pieces and placed in culture flasks with a liquid medium. The medium would consist of minerals, amino acids, sugars, vitamins and growth-promoting substances (Table 3). In the flasks, cells contained in the explanted tissue would emerge from the tissue and scatter around it. Such liberated cells would multiply by mitosis, if the culture condition is suitable. When cell density in the flask increases to a particular level the multiplication rate can be expected to decrease. Some of these cells would then be transferred to another flask to decrease cell density. This removal of cells would stimulate cell multiplication again. By repeating these procedures, the cell population, which multiplies continuously, will be obtained. Such a cell population is called a continuous cell line (Plate 2).

These techniques have been developed already and many insect continuous cell lines have been created (Mitsuhashi 2002). However, there are some insect groups whose cells cannot be cultured with present techniques. This problem should be solved in the near future.

In order to culture cells in a liquid medium under zero gravity in a spacecraft, culture vessels may be fixed on a rotation drum, which creates gravity by centrifugal force. Or, when people travel to other planets, an artificial gravity vehicle may be used. The cell culture procedures can be controlled automatically by computer (Plate 3). The system does not occupy a large space – a major consideration for spacecraft. By using several hundred-litre jars or thousand-litre tanks, large volumes of cells could be grown and harvested. When the cell density reaches saturated state, the cells could be collected by centrifugation of the culture and used as a protein source.

The advantages of using insect cultures compared to cell cultures of livestock such as cattle or swine are that insect cell culture does not require special equipment for controlling carbon dioxide gas concentration in the culture vessel, and also does not require strict control of temperature. Therefore, use of (insect) continuous cell lines is easier and more efficient.

Table 3. A simple culture medium (MM-SF)

Material	g/1 000 ml	Material	g/1 000 ml
NaCl	7	$NAHCO_3$	0.12
KCl	0.2	$CaCl_2 2H_2O$	0.2
$MgCl_2 6H_2O$	0.1	NaH_2PO_4	0.2
Glucose	4	TC-yeastolate	5
Lactalbumin hydrolysate	6.5		
pH: 6.5			

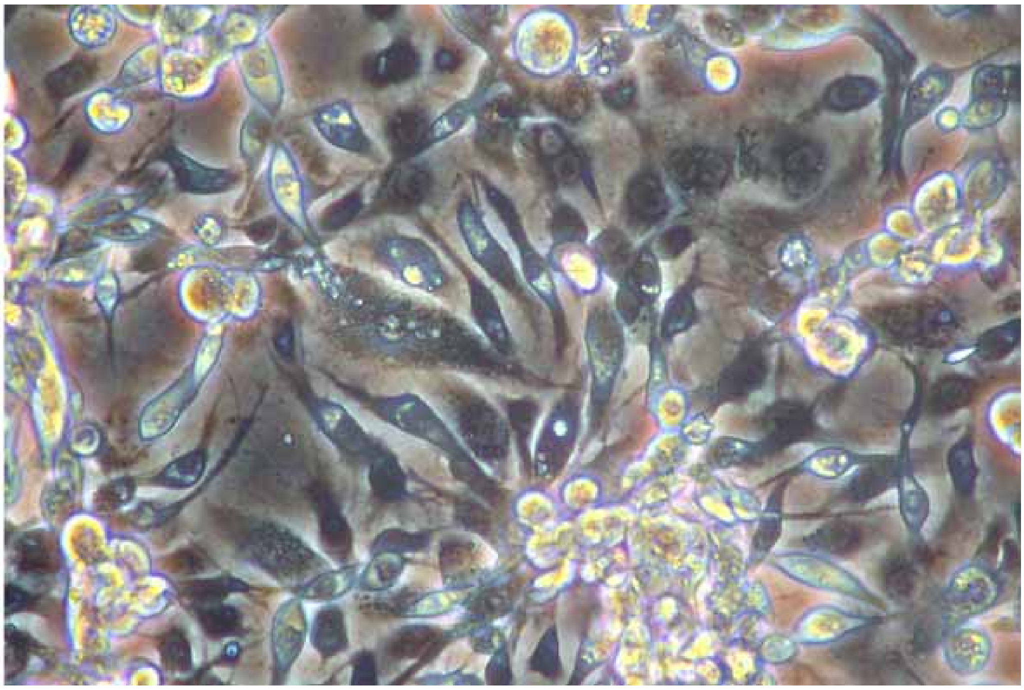

Plate 2. A continuous cell line obtained from the diamondback moth, *Plutella xylostella (Courtesy Jun Mitsuhashi)*

Plate 3. A model of a programmed cell culture system with glass jars *(Courtesy Jun Mitsuhashi)*

The second scenario for insects as space-travel nourishment relates to human colonization of other planets, likely living in air-tight domes. Within the domes, subsistence agriculture will have to be developed to supply food. One of the challenges is providing animal protein. Breeding of large livestock will not be practicable because of space limitation. The alternative is to use insects to provide a source of animal protein (Katayama *et al.* 2008; 2005). Silkworms, termites and flies offer potential for this purpose. The commercial silkworm (*Bombyx mori*) is a well-studied insect and people of many countries have eaten silkworm larvae, pupae and adults for centuries. Dried silkworm pupae contain roughly 50 percent protein and 30 percent lipids and are known to be rich in nutrients. It is commonly said that three silkworm pupae are equivalent to one hen's egg. The silkworm has been completely domesticated and is easy to rear (sericulture). Silkworms eat mulberry leaves, but an artificial diet has also been developed. Furthermore, an automatic rearing system has been devised.

Termites are eaten widely in tropical Asia, Africa and South America. There are many species of termites and they contain high levels of protein and lipids, although contents vary in different species. Termites consume wood and produce protein. Therefore, they can be used not only for human food, but also for breaking down woody waste.

Fly larvae have not been consumed commonly by humans to date, although some people eat fly larvae in Thailand (Kuwabara 1997), China (Chen and Feng 1999; Hoffman 1947) and even in Europe (Ramos-Elroduy 1998). The larvae or pupae of the house fly (*Musca domestica*) are nutrient rich. They contain 50-60 percent protein and 10-20 percent lipids on a dry matter basis. When fly larvae or pupae are used as food, vast numbers of flies are needed because of their small size. The reproduction rate of flies is very high; the house fly, for example, lays 500 eggs. If there are no predators, parasites or disease agents $2x250^{25}$ larvae are produced after a year (26 generations). If one larva weighs 25 milligrams, over a year this amounts to a theoretical gross amount of $5x10^{46}$ million tonnes of larvae. In order to rear vast numbers of flies, industrial plants similar to those used for mass production of screwworms or melon flies (Plate 1) will be necessary. Species belonging to Muscidae, Calliphoridae or Sarcophagidae are preferable, because of their size and feeding habits. The larvae of some species belonging to these families thrive on organic waste, especially on dead animal flesh and excreta. If these waste materials are used as part of the fly diet, they will contribute to recycling of organic substances. This would be particularly important within domes on another planet.

Conclusion

The examples of past and present utilization of insects as human food set the stage for the next and perhaps the most important application in light of food demand generated by increases in world population. Space travel and the colonization of other planets present a huge challenge in terms of the provision of foodstuffs. Food derived from insect rearing and insect cell culture represents the most feasible solution to feeding humans traveling in spacecraft or living in domed structures on other planets.

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Cultural and commercial roles of edible wasps in Japan

Kenichi Nonaka[1]

*Insects such as long-horned beetle caterpillars and wasps are consumed in the mountainous areas of Japan. Although insect eating has generally declined in Japan, the collection and eating of wasps (*Vespula *spp. and* Vespa *spp.) can still be found. In particular, yellow-jacket wasp larvae and pupae (*Vespula *spp.) are preferred in the mountainous areas of central Japan, where they are treasured as an autumn delicacy. The larvae and pupae are also available commercially at high prices. Insect materials used in canned foods are imported from other countries to satisfy demand. Communal management has begun to maintain the populations and habitat of* Vespula *spp. as a food resource.* Vespa *spp. are also collected for subsistence use and for commercial sale by local people who must use special protective gear for collection. Culturally and commercially, wasps are regarded as an important food resource for the sustainable development of rural mountain villages.*

Keywords: insect eating, traditional food, *Vespa*, *Vespula*

Introduction

Edible insects are important cultural resources in Japan that reflect the country's rich biodiversity. However, increases in demand could lead to competition and overexploitation, resulting in their future decline. Insect habitats are also likely to be impacted in areas affected by overdevelopment. It is necessary to raise awareness on the importance of edible insects in order to ensure that they are exploited sustainably and to promote their proper use and conservation.

There were once many edible insects in Japan, although consumption of most has declined. Among those still utilized as food, wasps are a popular food in mountainous regions. They are highly valued, not only for personal consumption, but also for commercial purposes. In some areas, resource management has been carried out to preserve their habitats as well as to maintain population numbers (Nonaka 2007; 2005).

This study focuses on traditional wasp-eating practices in Japan. The data are based on the author's 20 years of fieldwork in Japan that focused on insect consumption, collection methods and regional variations.

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The custom of eating insects in Japan

In a report submitted in 1919, 55 edible insect species were listed in Japan (Miyake 1919). After the Second World War, this number decreased owing to environmental and social changes (Nonaka 1987). However, some insects such as grasshoppers and wasps are still popular as food, although there are regional differences in their consumption; regions where this food custom remains common are declining. Grasshoppers are collected in Japan's many paddy fields, which are very common because rice is a staple component of the Japanese diet and the country's most important agricultural product. More than 70 percent of Japan's land area is classified as mountainous and insects are consumed primarily in the uplands. Long-horned beetle caterpillars were popular among people living in mountainous areas 50 years ago when fuelwood was used for cooking and heating. Many senior citizens recall that they were very sweet and tasty. Nowadays, there are fewer opportunities to catch caterpillars as a result of decreased use of fuelwood.

Wasps are one category of insects that continue to be commonly collected and eaten. In Japan, two species of *Vespula* and three species of *Vespa* are eaten. Some people wonder why people in Japan enjoy collecting and eating wasps, as they are so dangerous. It is hard to imagine how the wasps are collected. When an Australian entomologist observed the practice in an area where the activity is still common, he was incredulous when he saw people collecting the nest and removing the wasps. He was astonished as he watched the way in which collectors handled the wasps and cooked them.

Collection methods

Species of *Vespula* are commonly found in fields and mountainous regions. They appear during summer and autumn and build their nests underground. The nests are not easy to locate.

In order to find the nests, unique and skillful methods have been established in regions where *Vespula* are popular, particularly in central Japan. The worker wasps are attracted with bait (Plate 1). They carry the balls of meat, with tiny ribbons attached, back to the nest. The ribbons make it easier to follow the wasps and locate the nest. The chase begins as the team follows the tagged wasps. Members of the team display great skill and close teamwork as they climb up trees and run up and down hills trying to determine the wasps' route. When the entrance to the nest is discovered, smoke is used to sedate the wasps inside. The nest is dug out while the wasps are sedated. By digging the whole nest out, one can determine its weight.

Plate 1. *Vespula flaviceps* starting to carry a meat ball with tiny ribbons attached back to the nest *(Courtesy Kenichi Nonaka)*

A similar method is used for giant hornets (*Vespa mandarinia*), which are the largest wasps in Japan. A meatball with a tiny ribbon attached is not required in this case, because the worker wasps are much larger and can be tracked more easily. Protective suits, which have to be specially ordered, are essential when collecting the hornet nest during the day time, because these insects are very dangerous (Plate 2). Some people tie a tiny white ribbon around the waist of the worker wasp while it is eating the bait. Others, wary of attacks, prefer to collect wasps at night when the workers are sleeping.

Plate 2. Collectors wearing protective suits against *Vespa mandarinia* approaching the nest *(Courtesy Kenichi Nonaka)*

Cooking

The harvested nests are brought home and prepared for cooking by members of the family. The larvae and pupae are removed one by one. This process is time-consuming, but the time is used to share the experience, recalling how the wasps were collected, and imagining how the wasps must have lived. They are usually boiled with soy sauce or fried with salt. The whole family gathers to remove the live larvae from the combs, taking great care not to crush them in the process. It takes considerable time and effort to do this, but it provides an opportunity for the family to interact with each other. The larvae are boiled to a hard consistency with soy sauce, sugar and sake. The cooked wasp larvae are then mixed with rice (Plate 3).

Plate 3. Mixed rice with *Vespula flaviceps* (Courtesy Kenichi Nonaka)

A variety of dishes are prepared using species of *Vespula.* Wasps simply boiled with soy sauce are good with rice and also make good accompaniments for sake. Mixed rice is a popular dish. *Gohei-mochi*, or skewered rice cake, is made by mashing up rice and reforming it into a flat oval shape, which is then grilled with a sauce. *Hebo-gohei-mochi* is another kind of *gohei-mochi*, which is prepared using a sauce made from mashed *Vespula*. Various kinds of sushi are also made using *Vespula*. Recipes for wasp larvae dishes vary greatly from household to household, bringing a varied autumn feast to the dinner table.

Hornets are much larger than *Vespula* and their meat is cooked in different ways. The intestines are removed before they are cooked. *Vespa* can be used in sukiyaki and tempura, popular Japanese dishes. A type of liquor made with hornets is reported to have health properties.

Marketing

Wasps are also sold live at the markets during the harvest season in autumn. They are quite expensive at around US$100 per kilogram for an entire nest. Demand is increasing, so wasp foodstuffs are imported from other countries such as Republic of Korea, China and New Zealand and then cooked at the shops where they are sold. *Vespa mandarinia* is similarly retailed at the same price, but is not being imported yet.

Raising *Vespula*

In central Japan, when a colony of *Vespula* is found at an early stage it will be brought home and set in a wooden hive box. Care is then taken to position the nest where it will be sheltered from the elements. The colony is protected from predators and given food. Hives come in various shapes and sizes, depending on the environment they were found in.

A roof is put over the hive to protect it from direct sunlight and the wasps are fed with meat, fish and sugared water (Plate 4). Raising *Vespula* requires tender care, originality and ingenuity.

Plate 4. An example of a protected *Vespula* spp. hive *(Courtesy Kenichi Nonaka)*

Group raising of *Vespula* is becoming popular throughout central Japan and a network of *Vespula* societies has been established. The people involved recognize the importance of both resource conservation and indigenous knowledge of local customs.

Social entertainment

A Wasp Festival is held each year, with people competing for the biggest nest, whether raised at home, or collected in the fields or mountains. People congregate for all manner of festivities celebrating the harvest (Plate 5). Food products made from wasp larvae are popular delicacies and make interesting souvenirs for visitors. The main event of the festival is the nest-weighing contest. This is where contestants can witness the results of the year's efforts. The nests are sold directly on site. This is a good opportunity for people to share information on raising wasps.

Plate 5. The winning wasp nest *(Courtesy Kenichi Nonaka)*

Nature, wasps and society

The practice of eating wasps in Japan involves a relationship between nature and society. People's desire to eat wasps encourages awareness of the wasp's living environment as well as indigenous knowledge about wasps. The commercial use of insects can generate extra income for less affluent groups. Wasps are regarded as an important food resource and contribute to the sustainable development of rural mountain villages. It is hoped that people's desire to eat wasps will lead to awareness of the natural environment that forms their habitat and encourage them to sustain wasp numbers.

Commercialization

Commercialization of wasp consumption is involving more international trade. One cause for concern is that the people of Japan may destroy wasp habitats in the same way that other ecosystems are being degraded worldwide. However, wasps are unappreciated species in some countries, such as New Zealand, Australia and South Africa; people in these countries are glad to have such dangerous threats eliminated. On the other hand, their proper use may lead to the creation of new jobs in mountainous regions of Asia, or even in European countries where *Vespula* exists. In domestic situations, encouraging communal activities will not only promote the appropriate use of wasps, but will also raise environmental awareness. While this is indeed a local activity, it will also attract people from other areas who do not cohabit with wasp-eating cultures. Spreading networks of communal activities will again encourage environmental conservation through the appropriate use of resources.

Conclusion

Edible insects not only serve as a source of food in mountainous areas of Japan, but also reflect rich cultural traditions and diverse biological resources. As edible insects are good resources for generating income, there is likely to be an increase in the numbers of edible insects collected. However, increases in demand could lead to competition and overexploitation. If such insects are to be used in a sustainable manner, appropriate commercial use depends on people's awareness of the insects' habitats and related environmental issues.

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Edible insects in a Lao market economy

Somkhit Boulidam[1]

A study of edible non-wood forest products (NWFPs) in the forest village of Dong Makkhai and the Sahakone Dan Xang fresh food market revealed the importance of edible insects as nutritious food for villagers and as a source of household cash income. A total of 21 species of edible insects are collected by the villagers; five of them are among their most important edible NWFPs. Bestselling edible insects and their products at the market include weaver ant eggs, grasshoppers, crickets, honeycombs, wasps, cicadas and honey bees.

Orthoptera, Coleoptera and Hymenoptera are the three most important insect orders in the study area. Sustainability of the current extractive system requires forest conservation, improvements in the collecting, handling and processing of insects, and the rearing of certain species to assure adequate supplies in the future.

Keywords: edible insects, crickets, cicadas, grasshoppers, honeycombs, weaver ant eggs

Introduction

Until just a few years ago, research targeting edible insects in Lao PDR was almost non-existent, despite the fact that insects have represented a food item in the country for a very long time. In general, the insect species of Lao PDR are poorly known. Only medical entomology has received scientific attention thus far and it has not included studies of any edible insects. Some anecdotal information on eating insects exists in the anthropological literature and in writings about Lao cuisine.

The Lao Government has identified the development of the non-wood forest product (NWFP) subsector as a national priority. This is in recognition of the potential for NWFPs as a significant component of local and national income and is offered as an alternative to communities that are engaged in unsustainable forest exploitation. The greatest diversity of NWFPs is found among edible plant products, edible insect products and ornamental plants.

Natural resources are essential for economic stability and human well-being (Ravaioli 1995). Forests provide multiple products. NWFPs are very important for local and household economies as they are used for both subsistence and trade (Soudthavong *et al*. 2003). Edible insects are an important NWFP category in Lao PDR.

Lao PDR is rich in natural resources, especially within its forests, which cover about 47 percent of the land area (Sisouphanthong and Taillard 2000). Forests are important for both the

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national economy and the livelihoods of rural people (Bouapao 2005); they provide many kinds of food, herbs and fuelwood, contributing to socio-economic well-being (Smith and Maltby 2003). Most Lao people are subsistence farmers, who rely on NWFPs for their basic needs and as a source of supplementary income to purchase manufactured goods.

The research results on edible insects presented in this paper have been extracted from a broader study of edible NWFPs (see Appendix 1). Additional data are included from a new study by Nonaka *et al.* (2008) on edible insect biodiversity in the Vientiane area and from Yhoung-Aree and Viwatpanich (2005) who surveyed edible insects in Lao PDR, Myanmar, Thailand and Viet Nam and documented approximately 164 insect species eaten across the four countries.

The research setting

Field research study on edible NWFPs was carried out from 1996 to 2006 at two related locations: Dong Makkhai village and Sahakone Dan Xang fresh food market. Dong Makkhai is a forest village; paddy rice is the staple food crop and some livestock are raised. In 2007, the village had a population of 1 547, representing 316 households.

Village farmers established the Sahakone market primarily to sell edible NWFPs that they collect from the rich government forests surrounding the village, where they have use rights. The small food market is located on a main road about 3 kilometres from Dong Makkhai and 13 kilometres from the centre of Vientiane.

Descriptive data on gathering edible NWFPs, including edible insects, were derived from interviews with 56 percent of the households in Dong Makkhai. On average, villagers have been gathering edible NWFPs for 21 years, with each household engaging in activities five times per week on average. Women play the lead role in gathering NWFPs, aided by husbands, children and grandparents. The average distance traveled to gather NWFPs is 3 kilometres; products are gathered by hand or by using simple tools such as knives, nets and traps. On average, 23 percent of village household income is derived from edible NWFPs.

Villagers reported that they now spend more time in gathering similar quantities of edible NWFPs compared to ten years ago. The main reason is the larger number of collectors competing for the insect stock. Collecting locations and the target species have remained the same over the ten-year period. Certain insects are more numerous seasonally. For example, crickets are collected from March to December, stink bugs from February to May and cicadas from March to May; grasshoppers can be collected year around. Stink bug populations are now in decline in forests around the village because of the felling of their chief host, the *khor* tree. One new species, never eaten before, has been added to the array of edible insects, the walking stick or praying mantis (*meang hamphee* or *meang mai*).

The efficiency and productivity of insect gathering as an economic activity cannot be quantified because most captured insects are not weighed and the time expended is not recorded; grasshoppers and weaver ant eggs are the exception. Gathering and selling of other insects are measured on the basis of insect bodies. Villagers, however, estimate that a typical household collecting activity yields 1-4 kilograms of edible insects; in the case of wasps this is much greater.

All categories of edible NWFPs are important for personal consumption; 15 percent of the households gather products solely for their own subsistence needs. In the remaining households, the products are used for both subsistence and commercial purposes, in varying proportions.

Villagers were asked to rank the most abundant edible NWFPs they gathered. The results are given in Table 1. Wild vegetables predominate, accounting for seven items, including *dok kachea,* which is the most important; edible insects are in second position with five items. Wildlife accounts for the remaining four products.

Table 1. Most abundant edible NWFPs in Dong Makkhai village

Rank	NWFP	Percentage
1	*Dok kachea* – herb, tuber (*Curcuma angustifolia* Roxburgh ?)	23
2	*Takkaten* – grasshoppers	14
3	*Chak chanh* – cicadas	12
4	*Het* – mushrooms	9
5	*Nou* – rats	8
6	*Meang kieng* – stink bugs	7
7	*Phak kadon* – leafy green vegetable	6
8	*Phak van* – young leaves	4
9	*Chinae* – crickets (possibly others as well)	3
10	*Phak khayeng* – aquatic herb(*Limnophila gloffragi* Bonati)	3
11	*Phak kanchong* – aquatic herb(*Limnocharis flava* [L.] Buchennau)	3
12	*Nok* – birds	3
13	*Khi lek* – vegetables	1
14	*Khead* – frogs	1
15	*Khai mot dieng* – weaver ant eggs (larvae and pupae)	1
16	*Ngou* – snakes	1

Source: Interviews with villagers.

Sahakone Dan Xang fresh food market was first established in 1990 and expanded to its present size in 2003. It operates year around, but the greatest activity occurs during the dry season (December to March), when edible NWFPs are in abundance. There are 93 vendors; 37 sell edible NWFPs. Interviews were conducted with 92 percent of the vendors. Individual traders had experience of one to 40 years, meaning that some had worked at a prior market location.

The 21 species of edible insects sold at Sahakone market come from 23 different villages, with Dong Makkhai being the leading source, accounting for 27 percent of the total quantity of edible insects reaching the market. The bestselling category of edible NWFPs in Sahakone market is insects with wild vegetables ranking second. Wildlife ranks a distant third, mainly because the government has enacted restrictions on the trade of most wildlife.

Among the edible insects, the biggest sellers are weaver ant eggs (23 percent), grasshoppers (23 percent), crickets (13 percent), honeycombs (13 percent), wasps (9 percent), cicadas (5 percent) and honey bees (5 percent). These preferences are basically the same as ten years ago. The highest price is paid for young cicadas – about US$25/kilogram.

Results

A total of 21 edible insects was found in the field research; they were identified to the extent possible, but sometimes only by a local common name (Table 2). It must be emphasized that the data presented in the table are provisional; they are incomplete with respect to precise identification and representative of only the study area. The village survey also turned up one unidentified species of a large spider (*beuang*) that is eaten; it is not included in the table because spiders are not insects in the strict sense, but arachnids, although local people would make no such distinction.

Orthoptera, Coleoptera and Hymenoptera are the three leading insect orders, in ranked sequence, represented in Table 2, and together account for more than 50 percent of the total. This result compares favourably with global patterns of important edible insect orders (Ramos-Elorduy 2005).

Table 2. Edible insects in the area of Dong Makkhai village, Lao PDR

English	Lao	Order, Family, Genus, Species
Bamboo worms	*Daung-nor-mai*	Lepidoptera, Pyralidae, *Omphisa fuscidentalis* Hampson
Beetles	*Meang chi noun*	Coleoptera, Scarabaeidae ??
Chik tree insects	*Meang chik*	?
Cicadas	*Chak chanh*	Homoptera, Cicadoidea, *Orientopsaltria* sp.
Crickets (large)	*Chinai*	Orthoptera, Gryllidae, *Brachytrupes portentosus* Lichtenstein
Crickets (small, black)	*Chi lor*	Orthoptera, Tettigoniidae, *Teleogryllus testaceus* Walker Orthoptera, Gryllidae, *Acheta domesticus* L.
Crickets (small, white)	*Chileed*	Orthoptera ?
Dung beetles (larvae, pupae)	*Boa* or *duang chud chii*	Coleoptera, Scarabaeidae, *Helicopris bucephalus* F.
Dragonflies	*Meang naa gam (ee niue)*	Odonata ?

Giant water bugs	*Meang da*	Hemiptera, Belostomatidae, *Lethocerus indicus* Lepeletier & Serville
Grasshoppers	*Takkaten*	Orthoptera, Acrididae, *Caelifera* sp.
HoneycombHoney bees	*Hang pheung Nam pheung*	Hymenoptera, Apidae, *Apis* spp.
Khor tree insects	*Meang khor*	?
Horned beetles	*Meang kham*	Coleoptera, Scarabaeidae, *Xylotrupes gideon* L.
Mole crickets	*Meang xone*	Orthoptera, Gryllotalpae, *Gryllotalpa africana* Palisot & De Beauvois
Silkworms	*Dak dir*	Lepidoptera, Bombycidae, *Bombyx mori* L.
Stink bugs	*Meang kieng*	Hemiptera, Pentatomidae, *Tessaratoma quadrata* Distant
Praying mantis	*Meang hamphee* or *Meang mai*	Mantodea, Mantidae*Hierodura* sp. ?
Wasps	*Tor*	Hymenoptera, Vespinae,*Vespa* spp.
Water scavengers	*Meang ee tao*	Coleoptera, Hydrophilidae, *Hydrophilus affinis* Sharp
Weaver ants (eggs)	*Khai mot dieng*	Hymenoptera, Formicidae, *Oecophylla smaragdina* F.

Sources: Nonaka (2008); Boulidam (2007); Yhoung-Aree and Viwatpanich (2005).

Discussion and conclusion

Dong Makkhai village and Sahakone Dan Xang fresh food market represent a useful paradigm of how edible insects can play a dual role in advancing human nutrition and generating household income. However, any model based upon the exploitation of wild biotic resources is fraught with uncertainty about sustainability.

This study of a small area in Lao PDR can be viewed as a microcosm of the global situation, which will determine the future of NWFPs. The following comments apply equally to edible insects and other edible NWFPs. The sustainability of edible forest resources is under threat from a menacing combination of deforestation, which indirectly degrades or destroys NWFPs, and overexploitation of certain forest products through greater collecting pressures generated by increasing rural human populations. NWFPs allow rural people to supplement their diets and livelihoods through cash income to buy manufactured goods.

The immediate and longer-term solutions rest in addressing three issues.

First, overall sustainable forest management and conservation should acknowledge the true value of NWFPs as significant forest resources and make allowances for the NWFP needs of local people; they must be brought, as stakeholders, into the process of planning and management of land units that have a direct bearing on their livelihoods.

Second, applied research should target improvements in NWFP collection, handling and primary processing, to maximize resource benefits on both subsistence and commercial levels.

Third, an assessment should identify NWFPs that have the greatest potential and value; they should be brought under better management within the forest itself and/or the steps to be taken toward plant domestication and animal rearing to increase productivity and to reduce pressures on wild populations should be mapped out.

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Appendix 1. Summary of the complete study

The full study (Boulidam 2007) describes the gathering of edible NWFPs in Dong Makkhai village and their trading at the Sahakone Dan Xang fresh food market. A key objective was to understand NWFP activities and changes over the past decade, by identifying the major edible plant and animal species collected and traded in the village and the demand for the products in the market. An attempt was made, over the ten-year period, to determine any changes in the abundance of edible NWFPs in this forest-dependent village, to investigate the local knowledge of natural resource management and to assess the sustainability of the edible NWFP resources. Individual surveys were conducted in the village and in the local market; the Yamane method was used to select sampling size. Using only simple tools, all of the villagers surveyed gathered edible NWFPs, comprising 31 species of wild vegetables, 21 species of insects, 1 species of spider and 10 species of other wildlife. Wildlife species numbers are rapidly decreasing, while the numbers of species of wild vegetables and insects are stable. However, the abundance of wild vegetables and insects has declined.

Most species of NWFPs found in the market come from many locations: 31 species of wild vegetables from 17 locations, 21 species of insects from 23 locations and 4 wildlife species from 10 locations. Most NWFPs delivered to Sahakone Dan Xang market come from Xaithany District, particularly Dong Makkhai village. Of the 16 most common NWFPs in Dong Makkhai village, 7 were vegetables, 5 were insects and 4 were animals. Market demand for wildlife NWFPs typically is greater than the supply.

Local people have a keen interest in sustaining NWFP sources. They believe they should practise forest conservation, avoiding harvesting NWFPs during the full moon and on moonless days and reducing overall NWFP gathering. However, in reality, local people expand and intensify their NWFP gathering to meet the growing market demand. Local villages need to be guided to protect the forests as common land by participatory community programmes for sustainable resource utilization. Government and international development agencies should provide villages with interim alternative income sources while technical assistance programmes are being implemented to cultivate and to rear edible NWFPs with high market demand.

Appendix 2. Insects for trade in Sahakone Dan Xang market in the dry season *(all plates Courtesy S. Boulidam)*

Bamboo worms

Cicadas

Crickets

Small black crickets (*Chilor*)

Dragonflies/shrimps

Grasshoppers

Honeycomb

Honey

Mole crickets

Silk worms

Stink bugs

Wasp nest

Water scavengers

Weaver ant eggs

Edible insects and entomophagy in Borneo

Arthur Y.C. Chung[1]

Collecting insects and insect products for food by local people is still practised in some rural areas in Borneo, although it is becoming less common. Unlike urban areas, food in the interior is sometimes scarce; thus, some local people eat insects as an alternative source of protein. Insects are abundant in the forest and are more easy to procure than other animals. Various stages of insects are collected for food: eggs, larvae or nymphs, pupae or adults. Insect products, such as honey and pollen, are sought after as nutritional food. Local people also use certain insects and insect products as medicine because it is difficult to find treatment from a doctor in very remote areas.

In Borneo, more than 80 species of insects are known to be eaten. Out of this figure, more than 60 species were documented among various villages throughout Sabah; they are mainly collected by the Kadazandusun, Murut and Rungus people. The most common insect groups that are consumed are the honey bee brood, grasshoppers and sago grubs. Others include crickets, rice bugs, cicadas, termites, ants and beetles. Insects are often collected for food when they are abundant and easily obtainable in the field. The methods for preparing the insects as food are highlighted. More than 25 species of edible insects were also documented in the Dayak Lundayeh community adjacent to the Kayan Mentarang National Park in Kalimantan during a two-week transboundary expedition in 2003. Some insects and insect products with medicinal value are also discussed in this paper.

Keywords: brood, collection, crickets, grasshoppers, preparation, sago grubs

Introduction

Insects are eaten in many parts of the world. Archaeological evidence suggests that entomophagy has been practised since humans first appeared; today insects still remain an important food source. In Africa, various grasshoppers, termites and the large moth caterpillars *Gonimbrasia belina* (Lepidoptera, Saturniidae) are widely eaten. Insects are also important to South and Central Americans, Australian Aborigines, as well as Middle Eastern and Asian populations. Filipino farmers flood their fields to capture mole crickets that are sold to restaurants, while the Thais eat crickets, grasshoppers, water bugs, beetle larvae and dragonflies. Fried insects are sold at roadside food stalls in Bangkok. The Royal Thai Government has even included six insect species in a manual published for the public on nutritional food. The Chinese also eat a wide range of insects, many of which are for medicinal purposes. Similar consumption patterns can be found in Japan, Republic of Korea and Indonesia.

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A general perspective on eating insects in Borneo

“Eating insects is disgusting, primitive and weird.” This was the general response, especially from urban dwellers, during interviews with people on edible insects in Sabah. The eating of insects, or entomophagy, is not a common activity among urban people, mainly because of taboos related to culture, religion and upbringing. At a very young age, most urban children have been firmly prejudiced against “creepy-crawlies” by adults. Ironically, bird’s nest soup is widely appreciated and is thought to be one of the most delicious and nutritious soups among the Chinese. The price is exorbitant – a kilogram of unprocessed bird nests may fetch up to a few thousand ringgit. Yet, what is the nest made from? It is constructed with the bird’s saliva. Sometimes, one may find swiftlet’s blood on the nest. Unappetizing to say the least.

Although entomophagy in urban areas, as well as some rural areas, is quite unpopular, some elderly rural people in Sabah, Sarawak and Kalimantan have eaten insects in some form, for their superior nutritional value and even as a delicacy. In the interior, some people consume insects as a source of protein because at times it is difficult and expensive to obtain fresh meat or fish. Scientifically, insects are higher in protein, lower in fat and have a better feed-to-meat ratio than beef or chicken. They are also easy to find. Many insects are far cleaner than other creatures. For example, grasshoppers and crickets eat fresh, clean, green plants whereas crabs, lobsters and catfish eat any kind of foul decomposing materials. However, not all insects are edible. Some are toxic and may cause allergy problems.

Sampling methodology

Surveys were carried out via interviews with villagers in Sabah and during an expedition with the Desa Pa’ Raye villagers adjacent to the Kayan Mentarang National Park in Kalimantan. The data gathered from the interviews included opinions on and reasons for eating insects and other uses, how they were used or cooked, some ecological information on the insects and respondents’ background information. Reference materials with clear illustrations were used for insect identification among the villagers because some live insect specimens were not always available during the survey. The author did not conduct any surveys in Sarawak. The information compiled in this paper comes from published material and Internet searches.

Edible insects and entomophagy in Sabah

During the surveys in Sabah, more than 60 species of edible insects were recorded. Compilation of information presented here is based on ethnoentomological surveys in Sabah conducted by Chung *et al.* (2001; 2003; 2002; 2004; 2005a; 2005b; 2007).

The sago grub is one of the most commonly eaten insects. The grub is actually the larval stage of a snout beetle or weevil *Rhynchophorus ferrugineus* (Coleoptera, Curculionidae). Among the Kadazandusuns in western Sabah, the grub is known as *butod*, *wutod* or *tobindok,* while in Telupid it is also called *sungut*. The creamy yellow larvae are collected from the sago trunk after it is felled and left to decay for about two to three months. In places where

Plate 1. Sago grubs are a delicacy among the local communities and are often sold in Sunday markets *(Courtesy A.Y.C. Chung)*

sago palms are scarce, breeding may occur on fallen trunks of arenga and coconut palms. The villagers have various ways of cooking the grubs. After cleaning, the unsavoury guts are sometimes discarded by peeling off the dark-brown head capsule. They can be made into porridge with thin slices of ginger or stir-fried with soy sauce and shallots. Sometimes they are skewered on a small stick, like satay, and are then thrust briefly into the fire to toast lightly. Some local people may eat them raw. Besides their high protein content, some villagers claim that the grubs are good for treating diarrhoea. Conversely, one of the many respondents reported that she experienced rashes after eating the grub, and she never ate it again. The sago grubs are occasionally sold in local markets. The adult can also be eaten, though it is not as popular as the grub. It is normally roasted over an open fire. Scientific studies have revealed that a weevil of the same genus contains far more iron and vitamin B (thiamine, riboflavin and niacin) than beef or fish.

Planters and farmers who work in paddy fields often search for various species of grasshoppers (Orthoptera, Acrididae) as food. The pointed-nose grasshoppers (*tombuzungus*), short-horned grasshoppers (*butoh*), leaf-like grasshoppers (*kazap*) and the valanga grasshoppers (*gedoh*) are among the most common. They are usually collected when clearing the field for paddy planting. Unlike sago grubs, grasshoppers are collected for family consumption only and are not sold in the market. Cooking is simple. They are first lightly salted, boiled in a little water and then simmered until dry. Sometimes, they are stir-fried while the bigger ones are deep-fried until crispy, like fried prawns. They can be roasted as well. Normally, they are served as one dish and are not mixed with vegetables or meat.

The mole cricket, *Gryllotalpa longipennis* (Orthoptera, Gryllotalpidae) is also sought after in the paddy field. Locally, it is called *suruk* or *tongook*, in Malay, *sorok-sorok*, meaning to hide. This insect is adapted to life underground. The forelegs, like those of the mole, dig rapidly into the soil and it often feeds on paddy roots. Thus, mole crickets are often collected when ploughing the field before planting. Although there may be various ways to cook them, farmers prefer to stir-fry the insects without oil. Perhaps they taste better or are even more nutritious this way.

The honey bee brood is also widely accepted as nutritious food, besides their honey product. Consumption is particularly common among the Kadazandusun people in Telupid. More than two-thirds of the respondents had eaten wild honey bee larvae and pupae, *Apis dorsata* (*petiokan*). These bees are commonly seen nesting on the majestic mengaris tree (*Koompassia excelsa*). Sometimes many colonies may be seen on a single tree. The brood of cultivated honey bees *Apis cerana* (*pomosuon*), hornets *Vespa* spp. (*surun*) and wasps *Ropalidia* spp. (*tampiperes*) are also consumed. They can be eaten raw, boiled with porridge or rice, stir-fried or drunk together with honey. Sometimes, the brood together with the hive is squeezed to extract liquid, which is then boiled. Subsequently it will congeal, like fried eggs. The adult bees are seldom eaten, although this is widely practised in other parts of the world. The bees have to be boiled in order to break down their poison, which is basically protein, and at boiling temperatures, the stinger softens. Pounding them before boiling is also effective.

Plate 2. Honey and other bee products are much sought after and are often sold at local stalls together with other agricultural produce *(Courtesy A.Y.C. Chung)*

Some stink bugs from the Order Hemiptera are eaten. The rice ear bug *Leptocorisa oratorius* (*pesisang*) and the green stink bug *Nezara viridula* (*tangkayomot*) from paddy fields are also relished by villagers. *Leptocorisa oratorius* is a paddy pest and fairly abundant when the grains are at the milk stage. Both adults and nymphs feed on the grains, thus posing problems to the yield. To many of us, the pungent and foul-smelling fluid emitted by the bugs would be a deterrent, but the elderly villagers of Tambunan mash the bugs with chili and salt, and cook them in hollow bamboo stems. The dish is then served as a condiment. One has to be careful not to eat the brown stink bug, *Scotinophara coarctata,* as it causes inflammation with a burning sensation on the lips, mouth and even the throat.

Some moths and butterflies (Lepidoptera) are consumed by the Kadazandusuns. Macromoths of the Sphingidae family are eaten. After removing their wings, they are boiled until dry. The banana leaf-roller pupae, *Erionata thrax* of the Hesperiidae family, are also sought after as food. The pupa, locally known as *bingog* can be eaten raw or boiled until dry. The larva, known as *tataro,* often covered with a white powdery substance, is not preferred as food. However, some elderly Kadazandusuns believe that the powdery substance has medicinal properties that can treat pimples. Another hesperiid pupa that is also eaten is *Anchistroides nigrita*.

Some villagers enjoy eating cicadas. Brown and green cicadas, *Orientopsaltria* spp. (*tengir*) and light green cicadas *Dundubia* spp. (*tavir*) are often roasted over an open fire. According to local people, roasted cicadas taste good and are crunchy. Sometimes they are also stir-fried with some salt and other flavourings, but without oil. The wings are often removed before cooking. The cicada populations are seasonal. They are abundant when their host plant, *Pongamia* spp. starts to produce young shoots. The cicadas feed on the sap of these shoots. Collecting cicadas is normally done at night. Their presence and abundance on a tree can be detected through their collective sound produced by the males and the excess water excreted by them. The fine droplets of water are produced after feeding on the plant sap. When there are many cicadas on a tree, it may appear as if a shower of rain is falling from the tree (hence the expression "raining tree"). Once the host tree with cicadas has been identified, a fire is set beneath the tree. The insects eventually drop onto the ground while the tree is being smoked.

Termites (*tanai*) are widely consumed. They are the second most eaten insect worldwide, after grasshoppers. Live termites provide about 350 cal/100 gram with 23 percent protein and 28 percent fat. Villagers normally collect the reproductive males and females that are attracted to light at night during the termite's nuptial flight. This mating flight often occurs on a relatively cold and wet evening after a prolonged dry period. Termites are usually collected by placing a basin of water right under the light source. The light's reflection on the water attracts the termites and eventually they are trapped on the water's surface. The termite's body is very soft. Thus, sometimes they are eaten raw, with their wings removed. They are also stir-fried, but without oil, or cooked in porridge or rice. The Chinese consume the raw termite queen for its purported aphrodisiacal and medicinal values. It tastes like condensed milk. Some people gulp the insect with liquor or dip it in alcohol before swallowing.

Some ants are eaten, although they are very small in size. The common weaver ant *Oecophylla smaragdina* (*laga*) and the brood are edible and tasty. The adults are often mixed with chili and salt and served as condiments, while the brood is eaten raw or cooked with porridge or rice. In Peninsular Malaysia, the natives use the giant forest ant *Camponotus gigas* as flavouring because it contains high concentration of formic acid. The acid mostly disappears when it is boiled.

Large adult beetles of the families Scarabaeidae, Lucanidae, Cerambycidae, Buprestidae, Dytiscidae and Chrysomelidae are also consumed. They are normally roasted and the hard parts of the body and legs are removed before eating. For the fairly large beetles, the gut is often removed because of its bitter taste. Some beetle larvae are also eaten using the same culinary skills employed for cooking the sago grub. Other insects consumed by local people in Sabah include cockroaches, stick insects, moth bugs, dragonflies and praying mantis.

Edible insects and entomophagy in Sarawak

Although not much information is available from published papers, there should be many similarities between the edible insects and entomophagy practices in Sabah and Sarawak. The commonest example is the sago grub, which is a delicacy among the Melanau communities and is often featured in various documentaries (Anon 2008). It has been reported that the Dayaks of Borneo sometimes mix worker weaver ants, *Oecophylla smaragdina* in their rice for flavouring (due to the formic acid). Bragg (1990) has mentioned how, in Sarawak, the eggs of the stick insect *Haaniella grayi grayi* (Westwood) are eaten as a delicacy by the local people.

Edible insects and entomophagy in Kalimantan

According to a survey in Kayan Mentarang, Kalimantan (Chung *et al*. 2003), all the respondents consumed insects in various forms. Seventy-five percent indicated that they liked eating insects, while the remainder tried them out of curiosity. The villagers do not deliberately hunt for insects (unlike hunting for wild boar), but they collect them when they are abundant in the field. It is interesting to note that most of the villagers, including children, knew the local names of many of the insect species. For example, there are different local names for different grasshopper species. This shows the proximity of the relationship between the Dayak Lundayeh community and insects.

More than 25 species of insects are consumed by the villagers of Desa Pa' Raye of Kayan Mentarang. The most commonly consumed insect group is the grasshoppers and bush crickets (Orthoptera), followed by the wild sago grubs (Coleoptera, Curculionidae), bee, wasp and hornet brood (Hymenoptera), stink bugs (Hemiptera) and dragonfly nymphs (Odonata). Some insects, especially beetle adults, are often grilled. Some are fried, while the softer ones, for example bee brood, can be eaten raw or boiled in rice.

Besides being eaten, a few insects and insect products are used in traditional medicine. Other ethnoentomological uses include insects as toys for children, fishing bait and as adhesive materials. Some insects are also mentioned in myths and are part of the traditional beliefs of this community.

A number of beetle species are collected for food, but the most common is the giant weevil, *Protocerius* sp. (Curculionidae) of the wild sago palm *Eugeissona utilis*, on the hills along the Pa' Raye River. Identification of this large species is still tentative (Hiroaki Kojima, personal communication). It is different from the common sago weevil *Rhynchophorus ferrugineus*, found on *Metroxylon sago* in Sabah. The larval stage of the weevil is more commonly sought after as food. The creamy yellow sago grubs are collected from the felled sago trunk, which has been left to decay for about two to three months. They may also breed on bamboo shoots and other palms. The grubs are stir-fried, boiled or cooked with rice, while the adult weevils are often roasted.

Besides *Protocerius* sp., one specimen of *Rhynchophorus ferrugineus* was found in a wild sago trunk during the survey. This is a smaller species, measuring about 4.5 centimetres, with a broad bright orange median line on its pronotum.

Other beetles that are eaten include the large long-horned beetles, *Batocera* spp. (Cerambycidae), large scarab beetles *Lepidiota stigma* and *Chalcosoma moellenkampi* (Scarabaeidae) and the stag beetles *Odontolabis* spp. (Lucanidae). Only the adults are consumed. Although the larvae are fleshy and are eaten by some locals in Sabah, they are not consumed by the villagers in Kalimantan. A few *L. stigma* specimens were collected via light-trapping at the village, indicating that they are fairly common within the area.

Mayflies are small, delicate, soft-bodied insects found in the vicinity of freshwater – both streams and ponds. They have two or three long delicate tail filaments. As adults, they do not feed and usually live for only one day. For most of their life cycles they remain as aquatic nymphs and are easily recognized by their tail filaments and abdominal gills for respiration. The adults are usually collected from the sandy area of streams twice a year, using a lamp to attract them. They are often stir-fried.

Stink bugs are commonly eaten, although they produce a pungent smell. Ironically, the elderly villagers like this smell, which is similar to the smell produced by a type of local ginger in Sabah, known as *tuhau* by the Dusuns. This unpleasant smell is emitted from the glands at the base of the legs when the insect is disturbed. Two common species encountered in paddy fields are the rice ear bug *Leptocorisa oratorius* and the green stink bug *Nezara viridula*. They are often eaten raw as a snack while working in the paddy field. Occasionally, they are made into condiments and are eaten with plain rice. The brown stink bug, which is found on fig trees (*Ficus* sp.), can also be eaten, although this is not commonly practised. Other stink bug species are not consumed as they can cause irritation and inflammation to the mouth and throat.

Cicadas are eaten by some villagers, although this is not as common as the practice in Sabah, possibly due to myths and beliefs about cicadas. The larger species, such as *Pomponia merula*, are preferred. The body length is about 6.5 centimetres while its wingspan is about 18.5 centimetres. They are often stir- or deep-fried, the result being crunchy and crispy. The black cicada with green and white bands (*Tosena fasciata* F.) is not eaten, although it is frequently encountered in the forests of Pa' Raye.

The broods of bees, wasps and hornets are often consumed by villagers. Ant broods from the genus *Crematogaster* are also eaten occasionally. The giant honey bee brood, *Apis dorsata* is most commonly eaten, followed by *Provespa anomala*, *Vespa* spp. and *Ropalidia* spp. Many of the broods are often eaten raw or boiled with rice. During the expedition, however, very few *A. dorsata* were seen. It is believed that they are seasonal and are more abundant in upstream Krayan Hulu. *Apis cerana* brood is occasionally consumed. The night wasps *Provespa anomala* are very common and are attracted to artificial light like moths. It is fairly slender and rusty brown in colour. The sting of this wasp is severe, but is only likely to be encountered singly, as experienced by the author during light-trapping. A number of their carton nests were also spotted. *Vespa tropica* and *V. affinis*, on the contrary, are active only during the day. Pollen gathered by the carpenter bee *(Xylocopa* spp.) inside the nest is consumed by the villagers. The brood, however, is not eaten. *Xylocopa* spp. is often seen hovering around the village as they bore into beams and posts to build their nests.

Many dragonflies were observed in Desa Pa' Raye because of suitable habitats such as streams, ponds and paddy fields. The nymphs are aquatic and some may take more than a year to develop. They are predatory, feeding on small aquatic animals, including small fish. Various dragonfly nymphs are much sought after as food. They can be collected in the paddy field using a sieve. The nymphs are often stir-fried.

Grasshoppers and bush crickets are the most commonly eaten insects and are frequently plentiful in hill paddy fields and weedy areas. The villagers have specific local names for various grasshopper species. *Kato tulang* is considered a delicacy and is often collected when the field is cleared for paddy planting. The mole cricket, *Gryllotalpa longipennis* and field cricket *Nisitrus vittatus*, are not eaten, although they are common.

Praying mantises are known for the way they raise their forelegs, folded at the side of the face, in the manner of prayer. They are fierce, predatory insects, feeding on smaller insects and spiders. Only a few villagers indicated that they eat praying mantises, similar to the way they consume grasshoppers.

Conclusion

Entomophagy has declined significantly because of modern upbringing, culture and religion, except in certain very rural areas. Nevertheless, it is important to document this information as a foundation for further research and reference. There may be a new or different perspective on insects for sustainable animal food production in the future in the context of Borneo.

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Philippine edible insects: a new opportunity to bridge the protein gap of resource-poor families and to manage pests

Candida B. Adalla and Cleofas R. Cervancia [1]

The Philippines has a rich host of tropical flora and fauna, with arthropods representing the greatest diversity. The most popular edible insects are honey bees, Apis dorsata *F. and* A. cerana *F., both indigenous species. Bees are popular, not only for their prized honey and related products, but local people also enjoy the larvae as a delicacy. Apiculture is popular and has been contributing significantly to higher agricultural productivity and biodiversity. Among other forest insects eaten by rural people are the migratory locust (popular nationwide, particularly in swampy and grassy areas where outbreaks occasionally occur), field crickets, mole crickets, carpenter ants (eggs particularly), coconut beetles (particularly the grubs), June beetles and some katydid species. Edible arachnids are not common, but some farmers reported having eaten the larger-sized scorpions and centipedes. Korean bugs,* Palembus dermestoides *Fairmaire were also a popular food item in the early 1970s. Descriptions, bionomics and folk recipes of the edible species are presented. Currently, edible insects are underutilized as a general food resource in the Philippines. A deliberate effort is needed to educate Filipinos about this alternative food resource, which may yet offer a significant breakthrough, not only in nutrition but also in its positive impact on pest management.*

Keywords: ants, bees, beetles, crickets, katydids, *Palembus*

Introduction

In the Philippines, the more popular edible insects include June beetles, grasshoppers (particularly the migratory locust), ants (eggs), mole crickets, water beetles, katydids and dragonfly larvae. More recently, the preference for honey bee brood, particularly *Apis cerana* F. and *A. dorsata* F., was documented by Tilde *et al.* (2000). In bee sampling from all over the Philippines for her biodiversity study, Tilde noted that rural people were eating both the sealed and unsealed brood of honey bees in all the areas sampled. It should be emphasized however, that for *A. cerana,* the beekeepers eat only brood that will no longer fit into the frames of prepared beehives.

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Culinary preparation

In general, entomophagy has not become a day-to-day event in the Philippines because the availability of edible insects is seasonal and other food sources are perceived as more nutritious foods.

Public awareness has been enhanced by the serving of edible insects in a specialty restaurant in Metro Manila called Cabalen. It has several branches located in large Metro Manila malls. During the rainy season (June to October) and early dry season (November and December) an insect menu, in particular a mole cricket dish, is served in various restaurants in Northern Luzon (commonly along the national highway), to attract the attention of tourists and to serve local curiosity. During seasons of locust outbreaks, live and cooked locusts are peddled at bus stops and in local public markets.

Mole crickets are the most common insects served in restaurants. At Cabalen restaurants the crickets are cooked *adobo* style (Appendix 1) – a popular Filipino recipe. The crickets are sautéed in garlic and onions and seasoned with soy sauce, vinegar and hot pepper (Plate 1). In some areas, coconut milk is added to create a thick sauce. In villages, the most common species consumed are the extra broods of wild honey bees harvested during honey collection. The broods are either fried, sautéed *adobo* style or sautéed with vegetables. Larger species like adult June beetles and grasshoppers are also grilled and deep-fried.

Plate 1. Cabalen's mole crickets *adobo* style *(Courtesy the authors)*

Nutritive value of insects

Recent reports in Nigeria confirm that insects are indeed excellent sources of protein and other important nutrients (Banjo *et al.* 2006). Aside from high quality protein, the study also found important supplements like minerals and vitamins, even in dried form. Protein content can range as high as 29.8 percent for *Analeptes trifasciata* F., and good quality vitamins A, B2 and C are found in *Apis mellifera* L.

In the Philippines, the nutritive value of *camaru* (mole cricket, *Gryllotalpa* sp.) was analysed and results showed that a 150 g serving of the dish provided 28 and 74 percent of the daily protein and energy requirement, respectively, of average Filipinos between the ages of 19 and 49 (Barrion-Dupo *et al*. 2008).

Clearly, the studies have validated the high nutritive value of edible insects, particularly mole crickets. Yet, insects have remained a specialty meal rather than part of the regular Filipino diet for the following reasons:

- Edible insect species, like all other arthropods, are not available year round. In fact at the Cabalen chain of restaurants, they are not able to serve *adobong camaru* (a mole cricket specialty) on a daily basis due to irregular supply of crickets.

- Availability of alternative food sources perceived to be more nutritious than insects. Some people interviewed claimed that insects are their last recourse and qualify as a survival/emergency food only. At the Cabalen Restaurant, however, people who eat *adobong camaru* claim that the dish is their incentive to come back to the restaurant and they even call up to inquire if the dish is being served before they decide to eat there.

- Perception that insects are "yucky" (possibly influenced by western culture), due to the dirty habits and environments of household insects like flies and cockroaches.

Brief descriptions of certain edible insect species in the Philippines

*Honey bees (*Apis cerana *F.,* A. dorsata *F. and the stingless bee* Trigona biroi *Friese)*

Honey bees (Plate 2) are generally abundant in the Philippines and are primarily sought for honey and other by-products like pollen and propolis[2] (Plate 3). In the process of harvesting honey, the extra larvae and pupae are eaten as a tasty dish or served as appetizers at social drinking and village gatherings. It should be emphasized, however, that only the extra brood of wild honey bees is eaten.

[2] A brownish resinous material of waxy consistency collected by bees from the buds of trees and used as a cement.

Apiculture is a thriving industry in the Philippines and the cultured broods are not eaten because the beekeepers get more income by allowing the broods to develop and produce honey, which is more valuable and easy to sell. Both *Apis cerana* and *A. dorsata* are indigenous species, as well as the stingless bee *Trigona biroi*. All three honey bees are adapted for domestic cultivation.

a. *A. cerena* colonies

b. *T. biroi* chambers

c. *A. dorsata* colonies

Plate 2. The edible honey bees *(Courtesy the authors)*

*Mole crickets (*Gryllotalpa *sp.)*

Mole crickets (the local name is *aro-aro,* Plate 4) are insect pests of field crops like rice, maize and sugar cane, the underground parts of which they commonly attack. Mole crickets are a very popular food among villagers in Central Luzon. Despite the demand from restaurants in Metro Manila like Cabalen, the deliberate farming or mass rearing of mole crickets has not been carried out by farmers in the Philippines.

Of the many edible insect species, this is the most popular and most traded in local markets. Folk recipes include spicy *adobo*, fried and sautéed with vegetables.

Plate 3. Products from stingless bees *(Courtesy the authors)*

Plate 4. The mole cricket *(Courtesy the authors)*

June beetles (**Leucopolis irrorata** ***Chevrolat)***

The June beetle or *salagubang* (Tagalog, Plate 5) is a pest of upland crops, primarily upland rice, maize, sugar cane and coconut. The larva or grub feeds on the roots of the host plants while the adults usually feed on the leaves. The adults also feed on the leaves of broadleaf fruit trees like mango. The insect is abundant during the early rainy season (May to July), which coincides with the active vegetative stage of many of the upland crops mentioned above.

Folk recipes include grubs grilled over charcoal, deep-fried, spicy *adobo* and sautéed with vegetables.

Plate 5. Larvae of June beetles ***(Courtesy the authors)***

*Migratory locusts (*Locusta migratoria manilensis *Meyen)*

This is a highly seasonal species and outbreaks occur in swampy areas when natural vegetation is disturbed and human activities are ecologically disruptive. This insect is a general feeder, eating grassy weeds, cereal crops and some broadleaves. It is endemic in the Philippines, yet does not occur in great enough numbers year round to assure a steady supply as part of the regular Filipino diet (Plate 6).

Plate 6. The migratory locust *(Courtesy the authors)*

*Carpenter ants (*Camponotus *spp.) or karakara*

This insect species is a delicacy in the northern Philippines (Ilocos region). The eggs are the preferred stage, cooked as spicy *adobo* or sautéed in garlic and onions with a small amount of pepper. The egg mass (Plate 7) is collected from tree trunks, but with sufficient care to create the least disturbance to the adult ant, which can be highly aggressive and whose bite can be fatal to people sensitive to insect bites and toxins. The difficulty in collecting the egg mass limits the number of people interested in this edible species.

Plate 7. Egg mass of the carpenter ant or *karakara (Courtesy the authors)*

Korean bugs (*Palembus dermestoides* Fairmaire), a pest of stored cereal grains, were a popular food item in the early 1970s (Dacanay and Cervancia 1989; Chua *et al.* 1977; Yoshida 1974). There are other edible species in the Philippines, but their very highly seasonal nature and low fecundity mean that they are only occasionally tapped for human nutrition.

Eating insects: implication for pest management and biodiversity conservation

Entomophagy is an emerging reality in this era of dwindling traditional food resources. While this is an important development, especially in terms of quality nutrition, care must be taken to insure the safety of the consuming public. Efforts should also be made to ensure that the habitats of insects used as food are clean and free from toxic environmental contaminants. Moreover, there is the potential livelihood implication of farming edible insects that is gaining popularity in the Philippines.

While the traditional collection of edible species in the wild can be continued as an adjunct to the proposed mass production in controlled environments, the former will surely contribute to natural control of the edible species, which are in most cases insect pests as well. Should insects become a popular and widely acceptable food source, then the farmer may be forced to reduce pesticide application and conduct massive collection of these pests instead.

With regard to biodiversity conservation, humans as insect predators are not expected to wipe out any species. For example in mole crickets the stage-specific preference is the adult and therefore the other stages will be spared and allowed to multiply and complete the cycle.

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Appendix 1. *Adobong camaru* (mole cricket)

Ingredients:

250 g	mole crickets, washed and drained
1 head garlic	minced
1 pc onion	chopped
2 tbsp	soy sauce
2 tbsp	cane vinegar
2-3 pcs	hot chili
	salt and pepper to taste

Procedure:

1. Remove hard parts of the insects, particularly the extremities. Wash and drain.
2. Heat oil in a sauce pan, sautée garlic and onion and add the crickets.
3. Add soy sauce, vinegar and chopped chili and season to taste with a pinch of salt and pepper.
4. Cover and cook for five to eight minutes over low flame to allow slow cooking to conserve the flavour.
5. For variation, half a cup of pure coconut milk may be added; extend cooking time until the sauce becomes thick.

Sri Lanka as a potential gene pool of edible insects

M.R.M.P. Nandasena,[1*] D.M.S.K. Disanayake[1] and L. Weeratunga[1]

Sri Lanka hosts 11 144 insect species belonging to 30 insect Orders (based only on museum specimens and limited catalogues). The actual number of edible insect species may be much higher than current data suggest. In Sri Lanka, insect eating is only practised among the Vedda tribal people, who traditionally eat bee brood and larvae of Apis dorsata*,* A. cerana *and* A. florae*. Insects are not eaten by other ethnic groups because the two major religions (Buddhism and Hinduism) do not support the killing of animals for food and this induces a vegetarian diet. On the other hand marine and inland fisheries, along with livestock, provide adequate supplies of protein for society. Forest fragmentation and habitat loss are increasing because of development; thus, insect diversity along with populations of other fauna and of flora is diminishing. Recognition of the island's unique insect biodiversity, coupled with the creation of a programme to protect and conserve the edible insect gene pool, could give Sri Lanka a potential role in the maintenance of an edible insect gene pool for the rest of the world.*

Keywords: bees, conservation, insect biodiversity, religion, Vedda

Introduction

Sri Lanka is a tropical island country in the Indian Ocean with a land area of approximately 65 500 square kilometres. Its unique geoclimatic features support rich biological diversity. Sri Lanka hosts 11 144 insect species belonging to 30 insect Orders (Wijesekara 2006). Insects in Sri Lanka constitute 53 percent of all known organisms (both plant and animal) on the island and 81 percent of the known animal species.

Humans have consumed insects for thousands of years. More than 1 400 insect species are eaten around the world (Johnson 2007), most of which are collected from natural forests. Nowadays, insect consumption is declining in many parts of the world. However, edible insects remain important protein sources for some communities in Asia, Africa and the Americas.

In Sri Lanka insects are only consumed by the Vedda tribal minority (Wijesekera 1964). The Vedda have existed on the island for about 37 000 years and are direct descendants of Sri Lankan Mesolithic prehistoric man (Deraniyagla 1992). The Vedda are accustomed to eating bee brood and bee larvae of *Apis dorsata* (the giant honey bee), *A. cerana* (the common honey bee) and *A. florae* (the dwarf honey bee) (Wijesekera 1964). The ethnic majority groups, i.e. the Sinhalese (ca. 75 percent), Tamils (12 percent), Muslims (8 percent) and Burghers[2] do not consume insects.

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[2] A Sri Lankan of Dutch or Portuguese ancestry.

The objective of this study was to determine how many edible insect species consumed worldwide are recorded in Sri Lanka.

Methodology

The results were based mainly on a three-month literature survey. The findings were checked with both the National Entomology collection and insect catalogues available in the national museums of Sri Lanka.

Results

Sri Lanka has a gene pool of 29 species in six Orders *vis-à-vis* insects consumed worldwide (Table 1). Coleoptera (13 spp.) predominate with six Families: Curculionidae (2 spp.), Dytiscidae (3 spp.), Scarabaeidae (4 spp.), Cerambycidae (2 spp.), Hydrophilidae (1 sp.) and Passalidae (1 sp.). One genus from the Family Buprestidae (*Chrysobothris* sp.) is also recorded. The second largest Order is Lepidoptera (7 spp.) represented by three Families: Aretiidae (1 sp.), Bombycidae (1 sp.) and Saturniidae (5 spp.). The Order Orthoptera (4 spp.) includes three Families: Acrididae (1 sp.), Gryllotalpidae (1 sp.) and Tettigoniidae (1 sp.). The genus *Acrida* from the Family Acrididae is also recorded. Other edible insects are represented by Hemiptera (2 spp.), Hymenoptera (3 spp.) and Isoptera, which includes several edible termite species.

Table 1. Insect species recorded in Sri Lanka that are eaten worldwide

Order	Family	Species/genus
Coleoptera	Buprestidae (metallic woodborers)	*Chrysobothris* sp.
	Curculionidae (weevils, snout beetles)	*Hypomeces squamosus*
		Rhynchophorus ferrugineus
	Dytiscidae (predaceous diving beetles)	*Cybister limbatus*
		Cybister tripunctatus
		Eretes sticticus
	Scarabaeidae (scarab beetles)	*Adoretus compressus*
		Lepidiota stigma
		Oryctes rhinoceros
		Xylotrupes gideon
	Cerambycidae (long-horned beetles)	*Neocerambyx paris ?*
		Xystrocera globosa
	Hydrophilidae (water scavenger beetles)	*Hydrophilus olivaceus*
	Passalidae (bess beetles)	*Passalus interruptus*
Hemiptera	Belostomatidae (giant water bugs)	*Lethocerus indicus*
	Pentatomidae (stink bugs)	*Bagrada picta ?*
Hymenoptera	Apidae (honey bees)	*Apis dorsata*
		Apis laboriosa
	Formicidae (ants)	*Oecophylla smaragdina*
Isoptera	Odontotermitidae (wood-eating termites)	*Odontotermes feae ?*
Lepidoptera	Aretiidae (tiger moths)	*Diacrisia obliqua*
	Bombycidae (silkworm moths)	*Bombyx mori*
	Saturniidae (giant silkworm moths)	*Antheraea assamensis*
		Antheraea paphia
		Antheraea roylei
		Samia cynthia ?
		Samia ricini
Orthoptera	Acrididae (short-horned grasshoppers)	*Acrida* sp.
		Mecapoda elongata ?
	Gryllotalpidae (mole crickets)	*Gryllotalpa africana* = (*orientalis*)
	Tettigoniidae (long-horned grasshoppers)	*Holochlora albida*

Discussion

Excepting the Vedda tribal people, other Sri Lankans do not consume insects for two major seasons: (1) marine and inland fisheries afford easy access to large quantities of fish, along with protein from domestic and wild vertebrate animals; and (2) the two major religions, Buddhism and Hinduism, shun the killing of animals for food.

Sri Lanka has diverse habitats for several insect species consumed worldwide. According to the world edible insect list by Johnson (2007), 29 insect species recorded in Sri Lanka are eaten worldwide. Four species of aquatic bugs and beetles can be found in large numbers in hundreds of ancient reservoirs, millions of hectares of paddy fields and natural marsh lands. The other terrestrial insects are found in natural forests (protected and unprotected) and also in native home garden systems, known as "Kandyan home gardens", which are quite close in structure to the natural rain forest. A few termite species are recorded, but it is not clear which species of termite are consumed by humans worldwide. Most of the edible insects recorded in Sri Lanka are consumed in other countries such as Thailand. In addition, there are two types of honey bee larvae that are consumed by the Vedda, *Apis cerana* and *A. florae*. However, the Vedda are becoming more modernized (living in villages or outside the forest) and they have abandoned some of their old food practices.

Sri Lanka could play a key role in maintaining edible insect gene pools for the rest of the world. Indeed, the number of edible insect species in the country may be much higher than present calculations. Charismatic insect groups such as butterflies and dragonflies have been studied in detail, but other insect groups have received scant research attention apart from initial descriptions. An updated systematic insect checklist for Sri Lanka is also needed. It should be emphasized that present calculations are based solely on museum specimens and limited catalogues in the National Museum of Sri Lanka.

Forest fragmentation and habitat loss are increasing because of development in Sri Lanka, which may well lead to a decrease of insect diversity as well as populations of other native fauna and flora. Therefore, well-planned taxonomic research needs to be carried out, along with a well-executed programme to protect and conserve the edible insect gene pool. With international cooperation and support, Sri Lanka could play an important role in the *in-situ* conservation of edible insects.

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Honey and non-honey foods from bees in Thailand

Somnuk Boongird[1]

Thai non-wood forest products are mainly derived from secondary forests because very little primary forest still exists. Primary forest degradation has led to a reduction of bee populations necessary for forest tree pollination and natural regeneration. Stingless bees have distinctive forest habitats. Large stingless bees, Trigona *spp., prefer tree tops; those of medium size feed on flowers at lower canopy levels; the smallest on flowering bushes and ground cover. Stingless bees nest in tree cavities, forming permanent colonies. Arboreal honey bees,* Apis *spp., usually migrate among forest types as nectar sources are exhausted. Collectors typically take the entire nest, rather than the honeycomb only; as a result, adult nurse and guard bees die within one week; occasionally the queen and worker bees attempt to rebuild the nest nearby, but this is seldom successful. Bee nests are collected in forests open for such activities, as well as in restricted forests where collection is prohibited by law. In general, collected bee products are sold at local markets for cash and not consumed for subsistence. Nests are displayed to attract buyers of bottled honey, which is often adulterated. Non-honey food uses include capped brood mixed with pollen, which is cut into pieces and macerated in alcohol to produce a liquid medicine with some food value. Capped brood may also be roasted and eaten directly, except for the pollen. Eating pollen, especially from stingless bees, generally is avoided because of the fear of allergic reactions. Because wild honey production itself is low, sales of brood comb, pollen comb and propolis represent income sources to collectors. Action is needed to discourage honey collecting in restricted forests and the collection of entire nests, to assure sustainable harvesting of bee products and natural forest regeneration.*

Keywords: *Apis*, brood, honeycomb, pollen, propolis, *Trigona*

Introduction

Bees play a significant role in forest ecology. The following introductory material is drawn in part from Boongird and Khomkham (2005) and Santisuk (2004).

The giant honey bee *Apis dorsata* F. and the dwarf honey bees, *A. florea* F. and *A. andreniformis* (Smith) are recognized as major forest pollinators because of their sizeable populations and division of labour, which increases their efficiency in their visits to flowers. Bees are efficient pollinators and – through cross-pollination – can help produce vigorous seed for the next generation of plants. In nature, forest ecological processes, between specific pollinators and the target flowers to be pollinated, have influenced the development of genetic

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resources for survival, after being subjected to competition or predation. Therefore, forest management should not ignore the activities of bee pollination for maintaining plant life for producing vigorous seed growth in the forest environment. Wild bees living in the forest should be one of the major components of sustainable forest management.

Within forests, migration of the wild honey bee such as the giant honey bee, *Apis dorsata* F. and the Indian honey bee, *Apis cerana* F. occurs annually from place to place. Bee trees are necessary for *A. dorsata* to build their colonies for the next mating season. Indian honey bees need a tree cavity for nesting; sometimes they are unsuccessful because a cavity is already occupied by another colony of *A. cerana* or by stingless bees. This is the reason that Indian honey bees are rare in the forest and tend to live in artificial cavities within urban environments. Migration routes of wild honey bees are the same every year. They return to the same site for nesting and then fly back to their usual location when flowers are in bloom. Tropical forest flowers produce large quantities of various types of pollen from different species, which are attractive to specific insect pollinators.

Permanent colonies of stingless bees (*Trigona* spp.) living in the forest normally forage on flowers to gather nectar and pollen. Pollen is the main component of their food mixture. The food ratio of pollen to nectar is about 80 to 20. Nest provisioning food is regurgitated by nurse bees into the cell before the queen lays an egg on the surface of the food and then the cell is closed until the emergence of the adult. Stingless bees occur in every province of Thailand and most of them live in hollow trees.

Bee hunters prefer the nests of the giant honey bee to those of the dwarf honey bees and stingless bees. If they have no option, they will take the bee nests they find. Bee hunters usually have experience in harvesting honey, but the honey quantity of the colonies is decreasing year by year; therefore, they harvest the entire comb to gain more income. Not only can the honey be sold, but the brood comb also fetches a high price. Pollen comb is separated and placed into a bottle of adulterated honey. Harvesting techniques are not being promoted to sustain wild bee colonies. Beekeeping is the ideal solution, alleviating pressures on wild bee populations.

The numbers of native bees in agricultural areas is insufficient for the pollination of the target flowers. As a result, crop yields are quite low in quantity and quality. Orchard growers tried to use the exotic bee, *Apis mellifera* L. to compensate for low numbers of native bees, but this was unsuccessful because some of the flowers were unattractive to these exotic bees. *A. mellifera* has a floral preference. Stingless bee colonies can be used to fill the pollination gap of native flowers which produce some scent. They visit every type of flower that exists while foraging the canopy. However, their flight range is rather limited in distance. This means that the native honey bees are indispensable pollinators and must be conserved to maintain a stable forest ecology. Some fruit growers protect the giant honey bee nests within their orchards and they do not allow honey hunters to collect the honey from the nests. However some landowners agree to allow bee hunters to enter for a share of the honey.

Plate 1. Wedelia flower visited by *Apis mellifera (Courtesy S. Boongird)*

The application of pesticides to field and tree crops has also caused bee populations to decline. An acceleration of detrimental factors such as bee hunting and insecticide spraying also has been reducing bee populations in the natural environment. Similar problems are reported in Africa (Schabel 2006).

Stingless bee colonies have been hunted for many years for propolis as well as honey, but their pollen is not collected. Bee hunters are fearful of the toxicity of stingless bee pollen, which can cause death or at the very least convulsions if eaten directly. But some stingless bee colonies may not contain toxic pollen if benign flower sources occur in the foraging area. Some collectors of stingless bee pollen, to be on the safe side, detoxify it by putting the pollen into traditional whisky and making an alcoholic macerate similar to a traditional medicine, adding certain herbs and liquefying it into a traditional medicine. The alcohol content of this medicine is very high and taking too much can cause intoxification.

Regulations affecting bee hunting

Wild honey bees, *Apis dorsata* F., *A. florea* F. and *A. andreniformis* (Smith) are beneficial insects and should never be classified as insect pests. Bees represent a major component of establishing and maintaining a healthy forest. They are worth much more than their value as producers of human food. A single foraging bee over its lifetime may visit some 270 000 flowers, assuring successful fruit set. Some flowers have evolved to the extent that they require a specific pollinator, as a result of parallel evolution. Simply put, if the specialized insect pollinators are unavailable for pollination of such plant flowers, the result may cause certain species to be in danger of extinction.

There are four official Thai Government acts for forest conservation and protection, which relate to wild bees. These are the Forest Act B.E. 2484[2] (Krongsin Boonboothara 1996), National Park Act B.E. 2504[3] (Krongsin Boonboothara 1993b), National Reserved Forests Act B.E. 2507[4] (Krongsin Boonboothara 1995) and Wildlife Preservation and Protection Act B.E 2535[5] (Krongsin Boonboothara 1993a). These acts establish that wildlife hunting is prohibited and that forest products shall not be collected or harvested at all. But there is an exception for legitimate research by competent officers.

Forest Act B.E 2484, Section 3 states that the following laws and regulations shall be repealed: (14) Rules and regulations allowing the collection of forest products: collection of bee nests, B.E 2464.

The National Park Act B.E 2504, Chapter III, Protection and Maintenance of the National Parks, Section 16 states that within the National Park, no person shall: collect, take out, or alter by any act whatsoever, endanger or degrade orchids, honey, lac, charcoal, bark or guano.

The National Reserved Forests Act B.E 2507 states that all other laws, rules and regulations shall be replaced by this act. In Section 4, forest products refer to anything that originates from or is found in the forest, for example: carcasses, eggs, hides, horns, tusks, jaws, bone, hair, bird nests, lac, bee nests, honey, beeswax and guano.

Section 15. Logging or collection of forest products in the National Reserved Forests shall be made after permission has been obtained from the competent officer with respect to any particular area of the National Reserved Forests. In granting permission, it shall be given in accordance with the forms, rules and procedures specified in the ministerial regulations.

Section 21. The permission for logging or collection of forest products in the National Reserved Forests, under Section 15, shall be valid for a specified period of time, according to the rules determined by the Director-General, but not to exceed one year from the date of its issue. The renewal of permission shall be in accordance with the forms, rules and procedures specified in the ministerial regulations.

The details of Section 37 in the Wildlife Preservation and Protection Act B.E 2535 set forth that no person other than a competent officer or other officers on duty shall enter a Wildlife Sanctuary, unless written permission has been obtained from the assigned competent officer. Any person obtaining permission to enter a Wildlife Sanctuary shall comply with the conditions as specified in the ministerial regulations.

Despite the legal regulations that apply to the protection of wild bee populations, they have not controlled bee hunting in protected forests. Diminished wild bee populations can negatively affect forest health by allowing other insect populations to increase and to impact

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[2] 1941 CE.
[3] 1961 CE.
[4] 1964 CE.
[5] 1992 CE.

detrimentally on host plants. This could affect the species diversity of forest insects, i.e., a decline in the population of certain species, with some insect pests becoming overabundant due to lack of resistance by host plants. Over time, a plant can be eradicated by excessive numbers of a particular pest.

It is estimated that there are more than 100 000 beehives in Thailand. Annual honey production is about 10 000 tonnes, along with some 100 tonnes of bee pollen. Production does not meet demand, although the bee industry has the potential to supply bee products for everyone in Thailand. It is not necessary for consumers to ask for natural pure honey, brood comb and pollen comb, for consumption. The quality of honey from natural wild sources should be the same as industrial honey, but there is a price differential with the industrial product commanding a lower price than wild honey.

Pollen from industrial beekeeping is collected by means of a pollen trap when there is a surplus. Collected pollen is cleaned, dried, packed and kept in a storage room. Pollen comb from wild bees is exposed to air because it is contained in open cells and may become contaminated by airborne fungi that produce aflatoxin.

Bee products from the wild and from beekeeping are available in markets throughout the year. Consumers need to be made aware that collecting bee products from the wild is causing indirect damage to forests. Producing industrial bee products is not linked to any negative environmental impacts.

Plate 2. Inspection of melliferous bee hive at Bhumipol Dam, Tak Province, Thailand *(Courtesy S. Boongird)*

Eating bees and other insects

Excessive hunting of stingless bees in northeastern Thailand is a very serious problem. Nests of stingless bees have disappeared from the wild because hunters have killed off the populations by nest harvesting and consequent destruction of parent stocks of bees as starter colonies for propagation. This has led to a reduction in bee diversity, which is impacting negatively on the ecological processes of the forest. General forest degradation has also exposed more soils to direct sunlight, increased evaporation rates and reduced the amount of soil moisture available for normal plant growth. This phenomenon of drier soil conditions is one of the causes of poverty among local people. Wild food plant resources have declined and people have resorted to the collection of certain insects and amphibians to supplement their basic food source, which is their annual rice crop.

The decrease in forest cover has forced people in northeastern Thailand to change their eating habits. Some insects never eaten before have become food items. Typically, rural people enter the forest to collect wild food and other products. Because there was not enough to eat, people experimented with eating some insects, which later became traditional foods.

Some insect consumption also originated from insect control strategies. The outbreak of a major pest like the grasshopper (*Patanga succinta*) is one example. A successful campaign was mounted to promote the eating of this grasshopper, which led to a reduction of their populations in maize fields, so that the grasshoppers were no longer a serious economic problem. This example of controlling a maize field pest by collecting the grasshoppers for human food was the inspiration for rearing grasshoppers in Wang Namkiew District in Srakaew Province. Maize fields were planted for the express purpose of rearing grasshoppers for food.

Numbers of bees of the genus *Apis* have become smaller and smaller until they are insufficient for effective pollination, mostly because of bee hunting. At the same time that wild bee products are being collected, other insects encountered, such as crickets, grasshoppers, beetles and Lepidopteran larvae, are taken for food. Food insects are popular among the many low-income people in Thailand. Cricket farming is carried out in a similar fashion to beekeeping. But rearing and wild collecting techniques could be improved.

Eating insects in Thailand has become a cottage industry. Wild insect collection for food can be a sustainable forestry activity and not detrimental to forest ecology. Farming certain insects like crickets also has strong potential. Together, wild and farmed insects can play an important role in human nutrition.

Nutritional benefits of bee products

For at least 2 500 years, humans have known about bees and bee products and their high nutritional value. Honey provides superior energy and has become a “sexy” food. Bee pollen is high in protein, amino acids, enzymes and hormones. Propolis is also used as a treatment for some human diseases; bees collect the plant resins, bud glands and essential oils which are attached to the pollen basket. Bees use propolis as a repellent against other insects attempting to enter their nest. Extracted propolis has become a popular natural product that is sold in markets.

Arboreal bees construct a single open comb that can yield honey, pollen and brood. Bee hunters usually take the entire comb, which is later separated into comb honey, comb pollen and the brood nest. Sometimes they soak the honeycomb in a container for display and pour the syrup into another bottle for a prospective buyer**.** Bee brood is nutritious; it is high in protein, fat and carbohydrate.

Bee brood is also a good source of phosphorus, magnesium, potassium and trace elements such as selenium. It also contains essential amino acids, most of the B-vitamins and vitamin C (Finke 2005). Honey bee larvae represent a richer protein source than pork, and their vitamin and mineral content is comparable to chicken (Chen *et al.* 1998).

Research has shown that the quality of wild honey and industrial honey is the same. Therefore, wild bees should be protected and allowed to play their essential role in nature so that forests can produce other non-wood forest products that can be sustainably harvested for general benefit. At present, the forests of Thailand have been degraded or destroyed by human activities and wild fires. Forest recovery from such impacts is a slow process, but is a goal worth pursuing.

Conclusion

The main objective in collecting bee nests is honey. Pollen and brood are by-products of the same comb. Currently in Thailand, collecting entire bee nests is illegal. Nevertheless, bee hunters often take the entire nest and sell it as quickly as possible because it is difficult to keep the honey fresh. Even today, some Thai people still search for wild colonies of giant bees. The typical bee hunter has little education and is poor and jobless. It is difficult to convince bee hunters to stop their activities because they want to be free of restrictions in their livelihood pursuits. Sometimes bee hunters are able to sell honey to the buyers easily, some of whom want only pure wild honey, even though the buyers may not be able to distinguish pure from adulterated honey. This fascination with pure wild honey is the reason why bee hunters still exist. Buyers should be made aware that industrial beekeeping can supply good quality honey and bee food products to consumers; for example, bee pollen, which has a limited shelf life. Consumers should not insist upon trying to obtain wild honey, for the simple reason that there is no pure wild honey in the markets for sale by vendors. Wild honey has largely been replaced by industrial honey, which is harvested, processed and packaged under sanitary conditions that eliminate the causes of unwanted fermentation.

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Edible insects and associated food habits in Thailand

Yupa Hanboonsong[1]

Insect eating has a long history in Thailand and occurs throughout the country. According to research, more than 150 insect species in eight orders are consumed. Of these, beetles represent the largest group. Insects are consumed at various stages of their life cycles. The preferences of local people vary from region to region. Having an agreeable taste is the main reason for eating insects. Most edible insects are cooked in some way before being eaten; for example deep-fried, fried with spices or roasted. The traditional knowledge of local Thais in the context of insect consumption continues to remain important and provides indicators for future development potential.

Keywords: beetles, collecting, farming, *Patanga* locust, preparation, snack food

Introduction

The inclusion of insects in the human diet is an uncommon, although widespread, practice. Insects are consumed in many countries either as a nutritious food supplement or as a delicacy. For example, Africans eat various grasshoppers, termites and Saturniidae moth caterpillars. Japanese and Koreans eat grasshoppers and silkworm pupae. Hamburger stuffed with crickets and spring rolls stuffed with worms are served as exotic delicacies in some restaurants in the United States. And Mexico's well-known exported edible insect product is the tinned giant skipper larva (Vane-Wright 1991).

Thai people have been eating insects for centuries. In particular, a traditional, well-known delicacy is the giant water bug *Lethocerus indicus,* which is used to make *nam prik maeng daa*, a common Thai dish. Northeastern Thai people favour the silkworm pupae of *Bombyx mori* L., which is a by-product of collecting silk from the cocoons.

Edible insect species are not only associated with local Thai people's way of life or cultural practices. Interestingly, insect consumption is also used as a strategy for insect pest control. For example, 40 years ago there was an outbreak of locust (*Patanga succincta* L.), which was widespread in areas cultivated with maize. Different insect control methods including aerial spraying of insecticide were applied but did not succeed in controlling the outbreak. In the past, the *Patanga* locust was not well-known as an edible species, but from 1978 to 1981 a campaign to promote eating of the *Patanga* locust was initiated (Roffey 1979). Various approaches such as deep-frying, use as a cracker ingredient and fermentation to make a cooking sauce similar to fish sauce were introduced (Amin 1989; Pitug 1986). Currently, *Patanga* locust (deep-fried) is one of the best known and most popular edible insects in Thailand. Consequently, this species is no longer a major pest for farmers. With a

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high demand and price for *Patanga* locust, some farmers even grow a maize crop to feed this insect, rather than to harvest the maize.

Scenarios for eating insect pests have also been suggested for other species such as palm weevil larvae (*Cyrtotrachelus dochrous* F.) and the bamboo caterpillar *Omphisa fuscidentalis* Hampson (Chunram 1993). The latter species has now become a popular edible insect in the northern and northeastern areas of the country. In 2004, a serious outbreak of sugar-cane stem borer (*Chilo tumidicostalis* Hampson) occurred in cane-growing areas of Thailand. One of the successful control methods was biological control by massive human consumption of sugar-cane stem borer caterpillars.

Reasons for eating insects

Insects are commonly eaten in Thailand and their consumption is a particularly symbolic feature of northeastern people's way of life. Moreover, insects are consumed even when other more conventional sources of food are available. Previous research using questionnaires found that approximately three-fourths of the people eat insects because they are *tasty* or make a good *snack*. Less than 1 percent ate insects for pest control purposes.

The reasons for eating insects were surveyed in Northeast Thailand. The results are given in Table 1. Taste appears to be the main motivation. While cost issues were not systematically investigated, cost also appears to play a significant role, as edible insects are easy to find around farms. Such locally available food sources represent a *free supermarket*.

Table 1. Reasons given for eating insects in Northeast Thailand

Reasons for eating insects	Percentage of respondents
Tasty	75
Snack	65
Use as ingredients in cooked meals	48
Traditional medicine	48
As food seasoning	32
Easy to find around the farm	30
Readily available food	22
Accessible for mass production	19
Cultural eating	9
Seasonal food source	2
Local food source	2
Pest control	0.38

Source: Questionnaire survey, Hanboonsong *et al*. (2000).

Edible insect species consumed

Of the millions of insect species known to exist, only a few hundred are eaten by humans around the world. In Thailand, over 150 species from eight insect orders are eaten by the people of the Northeast. Approximately 50 insect species are consumed in the north and about 14 species are eaten by people in southern Thailand (Rattanapan 2000). The different insect-eating habits in various regions may depend on cultural practices, religion or geographical area. The Northeast often encounters natural problems such as drought, infertile soil or flooding, with people living in close proximity to nature. Therefore, natural foods like insects, which are easy to find and harvest, become a part of life and culture.

Although many insect species are eaten by Thai people, some insects are known and consumed only in particular geographic areas, while others such as the giant water bug and grasshoppers are eaten throughout the country. Beetles constitute the largest species group of edible insects. The giant water bug is the most popular edible insect in northern Thailand. Predaceous diving beetles, water scavenger beetles and immature ants are also eaten widely in the country. Bamboo caterpillars and crickets are popular in the northern region. Wasps, bees and termites are well-known edible insects in southern Thailand. The results of an extensive study on edible insect eating in Northeast Thailand are presented in Table 2.

Table 2. Insect species eaten in Northeast Thailand

Order/Family/common name	Scientific name
COLEOPTERA	
Buprestidae	
Metallic wood-boring beetles	*Sternocera aequisignata* Saunders
	S. ruficornis Saunders
Cerambycidae	
Long-horned beetles	*Aeolesthus* sp.
	Apriona germai Hope
	Aristobia approximator Thomson
	Dorysthenes buqueti Guérin-Méneville
	Plocaederus obesus Gahan
	P. ruficornis Newman
Curculionidae	
Snout beetles	*Arrhines hiruts* Faust
	Arrhines 2 spp.
	Astycus gestvoi Marshall
	Cnaphoscapus decoratus Faust
	Episomus sp.
	Genus near *Deiradorrhinus*
	Hypomesus squamosus F.
	Pollendera atomaria Motschulsky
	Sepiomus aurivilliusi Faust

	Tanymeces sp.
	Rhynchophorus ferrugineus Olivier
Hydrophilidae	
Water scavenger beetles	*Hydrobiomorpha spinicollis* Eschscholtz
	Hydrophilus bilineatus Redtenbacher
	Sternolophus rufipes F.
Dytiscidae	
Predaceous diving beetles	*Erectes stiticus* L.
	Cybister tripunctatus asiaticucs Sharp
	C. limbatus F.
	C. rugosus MacLeay
	Hydaticus rhantoides Sharp
	Laccophilus pulicarius Sharp
	Copelatus sp.
	Rhantaticus congestus Klug
Scarabaeidae	
Rhinoceros beetles, Elephant beetles	*Xylotrupes gideon* L.
	Oryctes rhinoceros L.
June beetles	*Adoretus* spp.
	Agestrata orichalca L.
	Anomala anguliceps Arrow
	A. antique Gyllenhal
	A. chalcites Sharp
	A. cupripes Hope
	A. pallida F.
	Apogonia sp.
	Chaetadoretus cribratus White
	Holotrichia 2 spp.
	Maladera sp.
	Pachnessa sp.
	Protaetia sp.
	Sophrops absceussus Brenske
	S. bituberculatus Moser
	S. rotundicollis T. Ihto
	Sophrops 2 spp.
	Sophrops species mean *abscessus* Brenske
	Tribe Sericini 7 spp.
Dung beetles	*Aphodius (Pharaphodius) crenatus* Harold
	A. (Pharaphodius) marginellus F.
	A. (Pharaphodius) putearius Reitter
	A. (Pharaphodius) sp.
	Cathasius birmanicus Lansberge
	C. molossus L.

	Copris (s.str.) carinicus Gillet
	C. (s.str.) nevinsoni Waterhouse
	C. (Paracopris) punctulatus Gillet
	C. (Microcopris) reflexus F.
	C. (Paracopris) sp.
	Gymnopleurus melanarius Harold
	Heliocopris bucephalus F.
	Heteronychus lioderes Redtenbacher
	Liatongus (Paraliatongus) rhadamitus F.
	Onitis niger Lansberge
	O. subopagus Arrow
	Onthophagus orientalis Harold
	O. avocetta Arrow
	O. bonasus F.
	O. khonmiinitnoi Masumoto
	O. papulatus Boucomont
	O. sagittarius F.
	O. seniculus F.
	O. ragoides Boucomont
	O. tragus F.
	O. tricornis Weidemannn
	O. trituber Weidemannn
	Onthophagus sp.
HEMIPTERA	
Belostomatidae	
Water bug	*Diplonychus* sp.
Giant water bug	*Lethocerus indicus* Lepeletier & Sepville
Coriedae	
Leaf-footed bug	*Anoplocnemis phasiana* F.
Stink bug	*Homoeocerus* sp.
Gerridae	
Water strider	*Cylindrostethus scrutator* Kirkaldy
Nepidae	
Waterscorpions	*Laccotrephes rubber* L.
	Ranatra longipes thai Lansbury
	R. varripes Stal.
Notonectidae	
Backswimmers	*Anisops barbutus* Brooks
	A. bouvieri Kirkaldy
Tessaratomidae	
Stink bugs	*Pygopalty* sp.

	Tessaratoma papillosa Drury
	T. javanica Thunberg
ODONATA	
Aeshnidae	
Darner (nymph)	*Aeshna* sp.
Coenagrionidae	
Narrow-winged damselfly (nymph)	*Ceriagrion* sp.
Corduliidae	
Green-eyed skimmer (nymph)	*Epophtalmia vittigera bellicose* Lieftinck
Libellulidae	
Common skimmer	*Rhyothemis* sp.
HYMENOPTERA	
Apidae	
Bees	*Apis dorsata* F.
	A. florea F.
Formicidae	
Ants	*Oecophylla smaragdina* F.
	Carebara castanea Smith
Vespidae	
Wasps	*Vespa affinis indosinensis* Perez
ORTHOPTERA	
Acrididae	
Short-horned grasshoppers	*Acrida cinerea* Thunberg
	Acrida sp.
	Chondacris rosea DeGeer
	Chortippus sp.
	Cyrtacanthacris tatarica L.
	Ducetia japonica Thunberg
	Locusta migratoria L.
	Mecopoda elongate L.
	Oxya sp.
	Parapleurus sp.
	Patanga japonica Bolivar
	P. succincta L.
	Shirakiacris shirakii
	Trilophidia annulata Thunberg
Atractomorphidae	
Short-horned grasshopper	*Atractomorpha* sp.

Catantopidae	
Short-horned grasshopper	*Ratanga avis* Rehn & Rehn
Gryllidae	
Crickets	*Teleogryllus testaceus* Walker
	T. mitratrus Burmeister
	Teleogryllus sp.
	Modicogryllus confirmatus Walker
	Brachytrupes portentosus Lichtenstein
	Gryllus bimaculatus Degeer
	Gryllus sp.
	Gymnogryllus 2 spp.
	Pteronemobius sp.
	Velarifictorus sp.
Gryllotalpidae	
Mole cricket	*Gryllotalpa africana microphtalma* Chopard
Mantidae	
Mantids	*Tenodera ariddifolia sinensis* Saussure
	Mantis religiosa L.
Tettrigidae	
Pygmy grasshopper	*Euparatettix* sp.
Tettigoniidae	
Long-horned grasshoppers	*Euconocephalus incertus* Walker
	Conocephalus maculates LeGuillou
	Conocephalus sp.
	Onomachus sp.
	Pseudophyllus titan White
	Homeoxipha sp.
ISOPTERA	
Termestidae	
Termite	*Macrotermes gilvus* Hagen
LEPIDOPTERA	
Bombycidae	
Silkworm moth	*Bombyx mori* L.
Hesperidae	
Skipper	*Erionata thrax thrax* L.
Pyralidae	
Bamboo borer	*Omphisa fuscidentalis* Hampson

HOMOPTERA	
Cicadidae	
Cicadas	*Chremistica* sp.
	Dundubia sp.
	Orientopsaltria sp.
	Platylomia sp.

Source: Rattanapan (2000).

Occurrence of edible insects

Edible insects can be found in both local markets and in the wild throughout the year. In the northeast, more than half of the species eaten are found during the rainy season from May to July. Thereafter, the number of edible insects gradually decreases from August to April (Hanboonsong *et al.* 2000). Only commercial mass rearing of edible insect species like crickets provides for their availability year round.

Collecting and cooking edible insects

Thai villagers rely on conventional local wisdom to quickly determine which insects are edible as well as where to find and how to catch them. These traditional, highly developed skills have been passed down from generation to generation. This indigenous knowledge has, however, gradually declined with changing socio-economic conditions and dietary habits. Occasionally people have died from eating misidentified poisonous insect species such as the blister beetle (*Mylabris phalerata* Pall, Family Meloidae), which contains the toxic cantharidin substance.

A wide range of edible insect species can be consumed at various stages of their life cycles. For example, silkworms are eaten at both larval and pupal stages. Aquatic insects like dragonflies, predaceous diving beetles and water scavenger beetles are eaten at the nymphal stage. Ants can be consumed at egg, pupae and adult stages.

Local Thai people have used their traditional knowledge for a long time to collect and cook each insect species in a different way. For example, to collect mole crickets which dig holes and make their nests underground, a small hole is made in the ground near the nest and water is poured into it. The crickets come to the surface to avoid being drowned and are easy to collect by hand. Adult cicadas are collected in the early morning when the insect is still resting on grass or low tree branches. If cicadas are resting on grass, they are easy to collect by hand. If they are on higher tree branches, a plastic bag containing some cotton tied to a long stick is used to collect them. The legs and wings of the cicadas come in contact with the cotton which immobilizes them. Dung beetles, which are eaten mostly in Northeastern Thailand, are collected in the early morning by digging them out from cattle and buffalo dung. At that time of day, the beetles are still found around the dung pads and have not yet burrowed deep into the soil to avoid the sun's heat. Only live beetles are caught and are immediately placed into a container filled with water. To avoid drowning, the beetles must make themselves lighter by releasing all the food contained in their intestine. The beetles are soaked for at least 12 hours in the water or until no more food remains in their intestines before they can be used for cooking. Trapping equipment, like black light, is also popular for collecting giant water bugs.

Healthy insects must be caught alive and processed immediately. Usually the wings, hard exoskeletons and intestines are removed before cooking. Most edible insects are cooked in various ways before being eaten: deep-fried, grilled over an open fire, parched and ground, or steamed in banana leaves and curried. Spices and herbs like garlic, basil leaf, chili and lemon grass are also used to increase flavour and mask unpleasant insects' smell.

Cooked edible insects are not only sold at roadside food stalls in various cities of Thailand, but nowadays can also be found prepared commercially in pasteurized cans. Canned insects are easy to prepare and can be stored for several months or years.

Farming edible insects

Many edible insect species are collected in the wild. The quantity collected and the species found depend on season and location. However, several Thai entomologists, as well as local people, have recently developed techniques for mass rearing on a commercial scale for several edible insect species such as crickets, ants and bamboo caterpillars. For example, cricket farming is an easy source of additional income for farmers in the northeast. Farmers use cement tanks or wooden containers, underlain by a plastic sheet. They then add a sandy loam soil layer covered with dry grasses, bamboo shoots or egg cartons to provide shade for the crickets. Cricket egg masses are introduced and the containers are covered with nylon nets. An artificial diet of chick feed along with grasses or weeds and water is provided. After four to six weeks, the adult crickets are ready to harvest (Jamjanya *et al.* 2001).

Conclusion

Edible insects contribute a small fraction to the nutrient requirements of human populations. They are consumed by Thai people, mainly because of their desirable taste. The potential exists for exploiting insects as a nutrient source by evolving techniques for industrial rearing and by educating local populations on the nutritive value of insects, especially during outbreaks of pests.

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Compendium of research on selected edible insects in northern Thailand

Paitoon Leksawasdi[1]

A survey of edible insects was conducted in 1992 via randomized interviews with residents in Jaehom District, Lampang Province. Their background information was correlated to the consumption of insects, principal cooking methods and edible insects in the study area.

Some edible insects were studied in detail during research in 1983, 1988 and 2005, including three species of ants. The first two species, malang mun *and weaver ants, were the most favoured, while acrobat ants were consumed occasionally. Edible beetles in the chafer group, some scarabs and a species of buffalo or elephant dung beetle were studied during 1990, 2002 and 2006, respectively. Data obtained from a joint research project in 2007 on mosquitoes and black flies revealed that Karen hilltribes considered black fly larvae to be a delicacy. The bamboo borer was studied in 1995 and is generally considered to be one of the most popular insects consumed by Thai people. The outcome of the bamboo borer research led to the organization of several training workshops supported by Chiang Mai University; the purpose was to educate farmers in the eight northern provinces of Thailand who collect and sell this edible insect as a part-time activity.*

Keywords: ants, bamboo borers, beetles, black flies, life cycles, rearing

Introduction

From 1983 to 2007, edible insect research in Thailand encompassed the following ten topics:

- Insect consumption in Jaehom District, Lampang Province
- *Malang mun* (*Carebara castanea* Sm.)
- Weaver ant
- Acrobat ant
- Cock chafer beetle
- Dynastid beetle
- Dung beetle
- Black fly larvae
- The bamboo borer and its morphology
- Farmers' training workshops on the bamboo borer

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Research topics

Topic 1: Jaehom survey

A survey of edible insects was conducted in 1992 via randomized interviews with residents in Jaehom District, Lampang Province (402 out of 1 992 people). They were shown specimens of 128 insect species, which were edible and non-edible, and asked which insects they consumed as food. The five edible insects were: grasshoppers (*Cyrtacanthacris* sp.); red palm weevils (*Rhynchophorus ferrugineus*); scarab beetles (*Xylotrupes* sp.); a species of moth, identified only to the family Pyralidae; and termites (*Odontermes* sp.). Respectively, these insects were eaten by 75-100, 51-75, 26-50, 1-25 and less than 1 percent of the people interviewed. In the age classes of 26-60, 15-25 and 6-14 years, 53, 20 and 17 percent, respectively, of the respondents ate insects. Annual income was another factor influencing insect consumption. In the Thai baht[2] income ranges of 0, less than 2 500, 2 501-5 000 and more than 5 000 per year, 36, 22, 24 and 18 percent, respectively, of the respondents ate insects. Insect consumption by gender showed marginal difference — 52 percent (men) and 48 percent (women). Other popular edible insects included weaver ants (*Oecophylla smaragdina*), *malang mun* ants (*Carebara castanea*), short-tail crickets (*Brachytrupes portentosus*), water bugs (*Belostoma european*), giant honey bees (*Apis dorsata*), Indian hornets (*Vespa cincta*), cicadas (*Dundubia* sp.), butterflies (*Cypris* sp.), water beetles (*Hydrous* sp.) and wasps (*Polistes stigmata*) (Leksawasdi and Tumta 1992).

Topic 2: malang mun

Malang mun (*Carebara castanea* Sm.) is an ant that nests underground. This edible insect emerges from a hole once a year during May and June. A detailed study of the external morphology of the workers and the reproductive castes, i.e., female and male, revealed that each caste had biting mouth parts. Workers administer a painful bite; they have neither wings nor compound eyes nor ocelli and the body size is one-tenth that of the female. Nests were found by excavating holes from which the ants emerged and the holes were then marked. Male and female ants emerged from holes set distantly apart. One to five nests were excavated each month for one year. The nests are made of soil and consist of 7 to 24 levels with a diameter of 12 to 31 centimetres and a depth of 11 to 150 centimetres below the soil surface. During nest excavation, only the immature stages of males and workers were found. The larvae and pupae were vermiform and exarate, respectively. Large populations of immature workers were found (Leksawasdi and Jirada 1983).

Topic 3: weaver ant

Weaver ants (*Oecophylla smaragdina* F.) were sampled and studied for two years at Chiang Mai University campus. Nests of weaver ants were found mostly from April to June on many different shrub and tree species. Population peak occurred in February during the swarming of females and males. Reproductive castes were found in the nests from January to July. After the nests were resettled, worker castes increased to take care of the larvae. Large workers exceeded small workers. Because of their very small size, eggs and the short egg stage were

[2] US$1.00 = 25 baht (1992).

rarely found. Female larvae castes were larger than other castes. Pupae and adults of the four castes differed (Wongwiggarn and Leksawasdi 1988).

Topic 4: acrobat ant

A study of acrobat ants was carried out at Houy Koh Hang and Huay Poo bamboo forests, San Poo Laew village, Moo 9, Don Pao subdistrict, Mae Wang District, Chiang Mai Province. External morphology was used for species identification of *Crematogaster* sp. Acrobat ants did not exhibit an antennal scrobe on the petiole and the abdomen was also lacking. The post petiole is joined with the upper part of the remaining abdomen and is heart-shaped. Interviews were conducted monthly from May 2002 to January 2003 with 321 individuals from Muang, Mae Rim, Hang Dong, Sampatong, Mae Wang and Samoeng districts. The purpose was to correlate their basic data to familiarity with acrobat ants and the use of this insect as human food. The basic data collected from the interviews included gender, age, education level, occupation and monthly income. The results indicated that both genders were familiar with acrobat ants, but they were mostly consumed by men. Agricultural workers consume acrobat ants more than people in other vocations. However, the availability of larvae is seasonal. Traditionally, the larval stage of the acrobat ant has been used for consumption in a variety of northern Thai dishes such as *jaew*, *jom*, *kang*, *nam prik* and *abb,* but is now most popular in *jom* (Leksawasdi and Wichai 2005).

Topic 5: cock chafer beetle

More than 40 species of the chafer group are edible beetles. Using fluorescent and black light traps, many species of cock chafer were collected in one year at Jaehom District, Lampang Province. This included *Holotrichia siamensis*, *Anomala chlorochelys*, *Adoreus cribatus*, *H. pruinosella* and *Mimela* sp. — listed in descending order of frequency. The black light trap attracted the cock chafer more than fluorescent light. The external morphology of five species was described as well as the life history of *H. siamensis*. Copulation occurred between 19.00 and 20.00 hours and the average copulation period was 52.3 minutes. During the day, *H. siamensis* was found at 1-5 centimetres beneath the soil where oviposition also occurred. Nine to 21 days elapsed between copulation and oviposition. On average, 31.6 eggs were laid per female over 11 days. Adult females lived for an average of 25.3 days. Eggs had a mean width of 1.8 millimetres and length of 2.1 millimetres and average egg period of 6.3 days. The first instar had a mean head width of 1.1 millimetres and body length of 4.4 millimetres. There were more than six instars of larvae. Levels of infestation of young leaf tips, mature leaves and blossoms of *Tamarindus indica* L. were recorded. Income level and age of the local residents were not related to their preference for eating cock chafers, but more women consumed cock chafers than men. The order of preference of these five species was *H. pruinsella*, *A. chlorochelys*, *Mimela* sp., *H. siamensis* and *Adoreus cribatus* (Leksawasdi 1991-1993).

Topic 6: dynastid beetle

A study on rearing dynastid beetles and their natural enemies was conducted in northern Thailand from September 2001 to September 2003; the species and ecology of elephant beetles were also surveyed. Four species of dynastid beetles were found: *Xylotrupes gideon* L., *Eupatorus gracilicornis* Arrow, *Chalcosoma atlas* L. and *Oryctes* sp. Three methods of rearing elephant beetles were in use: rearing them in the ground in Nan, Payao and Chiang Mai; rearing in cement boxes in Nan, Payao, Lampang, Chiang Rai and Chiang Mai; and rearing in other kinds of boxes in Nan and Chiang Rai, the boxes being half-filled with soil and decaying plants. Host and food plants for the elephant beetles were *Euphoria longan* Steud., *Litchi chinensis* Sonn., *Mimosa pudica* L., *Bambusa* sp., *Sindora* sp., *Cocos nucifera* L., *Castanopsis* spp., *Saccharum officinarum* Linn., *Musa* spp., *Nephelium lappaceum* L., *Psidium guajava* L., *Mangifera indica* L., *Luffa acutangula* Roxb., *Cucumis melo* L., *Cucumis sativus* L., *Citrullus lanatus* Mats, and *Carica papaya* L. A study of the life history of rearing elephant beetles in boxes revealed that one female (*X. gideon* L.) lays 43.18 ± 8.37 eggs. The incubation period of eggs was 17.98 ± 1.39 days; the larval period was 221.60 ± 11.37 days; the pupal period was 34.02 ± 1.82 days; the adult period was 55.82 ± 3.30 days; and the generational period was 337.40 ± 11.30 days. Natural enemies of the elephant beetle in the adult stage are body mites, rats, geckoes, bats and lizards; ants attack the egg and larval stage. Baculovirus and the fungi *Metarrhiziun anisopliae* also destroy larvae and pupae (Leksawasdi and Ramsiri 2003).

Topic 7: dung beetle

The morphology, ecology and behaviour of the dung beetle, *Heliocopris bucephalus,* were studied in Nan Province. The colour of the adults is reddish-brown to black. A large pronotum covers the head with a strong clypeus underneath. The clypeus covers the biting mouth parts. The insects have a pair of compound eyes and lamellate antennae. The front wings are hard and there is a cover sheath of membranous back wings. Females have no horn, the length and width of the body average 4.68 ± 0.23 centimetres and 2.85 ± 0.13 centimetres respectively. The male has three horns, one on the clypeus and two on the pronotum. The length and width of the body average 5.08 ± 0.18 centimetres and 3.08 ± 0.17 centimetres, respectively. Dung beetles were found in areas occupied by water buffalo. The insects made buffalo dung balls and oviposited eggs inside. The overall dimensions of the balls were observed to be 7.08 ± 0.58 centimetres in diameter, 152.20 ± 45.55 grams in weight and 0.64 ± 0.12 centimetres in thickness. The surface of the ball contained an outer area of 1.39 ± 0.14 centimetres in diameter. The observed balls were placed in tunnels with a width of 21.40 ± 2.43 centimetres and a depth of 39.12 ± 4.22 centimetres below fresh dung. The ground surface was porous with a width of 48.30 ± 4.14 centimetres; each tunnel contained six to ten balls. People consume the pupae (Leksawasdi *et al.* 2006).

Topic 8: black fly

Black fly larvae, *Simulium* spp., can be eaten, but apparently this is only done by some Karen hilltribes. The practice was revealed during a joint project on mosquito and black fly. The fly larvae were observed to aggregate in large numbers along a running stream to filter their food. The study was carried out in three areas of Mae Ab Nai village – a rice field and two streams (designated Stream 2 and Stream 3). The last stage of the larval instar was noted. The rice field, which had a different habitat from both streams, possessed only one species of black fly, namely, *Simulium aureohirtum*, while 11 species were detected in the stream habitats. The temperature and pH level differed only slightly among the three habitats. In addition, the number of last-stage larval instar at the rice field exceeded Stream 2 several-fold in each month during 2004 and 2005. However, the number of black flies in Stream 3 was twice that of Stream 2 in each month. Black fly larvae could be found throughout the year, occurring most frequently during the rainy season. It was deduced that adult female black flies, which bite humans, should also be found in large numbers as well (Leksawasdi and Srisuka 2007)

Topic 9: bamboo borer

Omphisa faseidentalis, Family Pyralidae, Order Pipidoptera, has been promoted by the mass media and is the best known edible insect in Thailand. Bamboo borers or *nae* (*Omphisa* spp.) are abundant in the mountains of northern Thailand. The larvae develop inside the stems of bamboo. They are collected and sold by local people and preyed upon by woodpeckers. Forty-seven local people were interviewed about their knowledge of the borer; the market value quoted by hilltribe people was 80-120 baht/kilogram. Frying was the favourite cooking method. Experiments were in progress that involved rearing borers in the mountains. The adult and egg stages are 5 to 14 days during August. Larvae bore a hole in the bamboo stem (*pai hok*), destroying the inner pulp. Then the larvae bore through the internodes moving upwards within the stem. External evidence of their presence includes holes in the stem, shortened internodes and stiffened sheaths. The larval stage is 280 to 304 days, August to May. When almost mature, larvae migrate back down the stem into the old segment where they initially bored in. The pupal stage is 30 to 40 days. Moths emerge from the entrance hole. Collection by humans, rather than predation by woodpeckers, is the most important factor limiting bamboo borer populations (Leksawasdi 1995).

Topic 10: bamboo borer workshops

The author realized that the bamboo borer was a suitable subject for edible insect training workshops, based on natural husbandry. Such training was developed and conducted from 2005 to 2008. Training was intended to stimulate alternative income for some farmers in mountainous areas. This was the last phase of the bamboo borer project that studied this insect as food. Local people have considered the bamboo borer to be a delicacy for a long time. Earlier research focused on detailed information about this insect; subsequently efforts were made to extend the knowledge acquired to the general public by holding training workshops for collectors on bamboo borer husbandry. Since 2006, this activity has extended workshop training to villagers in eight provinces of northern Thailand on ten occasions. Evaluation results indicated that the training was well-received and the participants ranked the training highest on the satisfaction scale. Research on income derived by representative bamboo borer collectors from the Lahu tribe was done by grouping them into four work units: (1) two males, (2) husband and wife, (3) single male and (4) single female. These units were evaluated with respect to the quantity of insects collected as well as the corresponding income. Insects collected amounted to 29, 22, 15 and 13 kilograms, respectively; this represented income of 3 500, 2 637, 1 791 and 1 600 baht. On average, the quantity of insects collected and income were 13 kilograms and 1 588 baht per person. Fifty-six percent of the households in the surveyed villages were bamboo borer collectors (Leksawasdi and Sununta 2008).

Conclusion

The topics presented in this paper summarize an array of studies carried out on edible insects in northern Thailand. Information on nine insect species is summarized. The popularity of food insects and indigenous rearing practices demonstrate the potential for further development of this food resource.

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Edible products from eri and mulberry silkworms in Thailand

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*At least 194 species of edible insects are reported in Thailand. There are 81 species of edible forest insects. In general, insect foods are well-known as a protein source in the country, especially in the north and northeast. Of the edible insects, Coleoptera represents the major group (61 spp.), followed by Lepidoptera (47 spp.), Orthoptera (22 spp.), Hymenoptera (16 spp.), Hemiptera (11 spp.), Homoptera (11 spp.), Odonata (4 spp.), Isoptera (2 spp.) and others. Cooking methods and recipe development are derived from indigenous knowledge of provincial insect consumers. Mulberry silkworm (*Bombyx mori *L.) pupae are popularly consumed as a by-product from silk yarn reeling. Recently, a cultivated wild silkmoth (eri silkworm,* Samia ricini *D.) was introduced into the northeast where cassava (*Manihot esculenta*) is its main host plant. This silkworm has other diverse host plants found generally in the region such as castor bean (*Ricinus communis*), the Ceara rubber tree (*Manihot glaziovii*) and variegated cassava (*Manihot esculenta *var.* variegata*). It is reared easily under northeastern conditions. Because of high protein content (66 percent), eri food products have been developed using more than eight recipes, which have been registered as intellectual property. Eri silkworms are safe "green" edible insects because no chemicals are used in the rearing process. Moreover, eri products could generate supplementary income for farmers. Publicity campaigns should provide more information for consumers. The eri silkworm has the potential to support government food security policies in the context of supplying edible insects as protein sources for communities in Thailand.*

Keywords: *Bombyx*, edible insects, protein, recipes, *Samia*, silk by-product

Introduction

Insects account for the greatest species diversity and the largest numbers of all of the world's fauna. They have been used as human food for millennia. At least 194 species of insects are reported to be edible in Thailand. Among them, Coleoptera is the major group (61 spp.), followed by Lepidoptera (47 spp.), Orthoptera (22 spp.), Hymenoptera (16 spp.), Hemiptera (11 spp.), Homoptera (11 spp.), Odonata (4 species), Isoptera (2 species) and others. Insects as food are most popular in the northern and northeastern parts of Thailand. Cooking methods and recipe development of edible insects were derived mostly from indigenous knowledge of provincial insect consumers. Generally well-known edible insects are sugar-cane white grubs, dung beetles, giant water bugs, bee larvae, red ant eggs (*Oecophylla smaragdina*), wasp

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larvae, crickets, grasshoppers, sugar-cane stem borer pupae, banana leaf rollers, mole crickets, diving beetles, water scavenger beetles, adult termites, green weevils and mulberry silkworm larvae and pupae. The mulberry silkworm is an industrial insect, which has been reared for a long time and can be produced year round. Farmers raise this insect for the weaving of high value textiles. A by-product from yarn reeling is the pupa, a popular food in Thailand, especially in the northeast. Mulberry silkworm rearing is either a principal or alternative economic activity. These activities give rise to silk products that generate income; this amounted to 1 675.28 million Thai baht[3] in 2004 (Chuprayoon 2005). Approximately 136 884 households, mostly in the northeast, raise the silkworms, which account for about 80 percent of the country's production. Thai silk is a well-known product worldwide.

Edible insects in general and silkworm pupae in particular, are low in price, taste good and are high in protein content and nutritional value (Table 1). Produced throughout the year, they are always available on the market, fresh or as processed food. Recently, the wild silkmoth or eri silkworm has become well-known in Northeast Thailand, where cassava, its major host plant, is cultivated extensively.

Eri silkworm is a species of wild silkmoth, which can produce commercial quantities of silk. The eri silkworm in Thailand has been studied for rearing and silk production by several local scientists (Sirimungkararat *et al*. 2005a, 2005b, 2001, 2000, 1994; Attathom *et al*. 1992; Wongtong *et al.* 1980). Other major host food plants of eri silkworm are castor bean, papaya (*Carica papaya*), *kesseru* (*Heteropanax fragrans*), *Evodia fraxinifolia*, *Ailanthus excelsa*, *Sapium* spp. and *Jatropha curcas* (Jolly *et al.* 1981; Sengupta and Singh 1974). Wongtong *et al.* (1980) studied eri culture in the highlands of northern Thailand and used castor bean leaf as the principal food plant. Attathom *et al*. (1992) reported on eri silkworm rearing using different food plants and various cassava varieties. Cassava leaf is suitable for eri silkworm culture. In addition, the research group of Khon Kaen University reported for the first time that the Ceara rubber tree and variegated cassava were new food plants for eri silkworm (Sirimungkararat *et al*. 2005b). Silk yarn production from reeling machines using indigenous knowledge was reported initially by the same research group (Sirimungkararat *et al*. 2005a).

Eri silkworm production provides not only silk yarn but also by-products such as pupae, fertilizer from faeces and sericin from wastewater in the reeling process. Eri larvae and pupae fed with cassava leaf were nutritionally analysed by Sirimungkararat *et al*. (2004b). Results showed that larvae and pupae contained high amounts of protein, approximately 66 percent (Sirimungkararat *et al*. 2004a), which is higher than mulberry silkworm (53-54 percent) and very low content of hydrocyanic acid (6.21-50.47 mg/kgDM) (Sirimungkararat *et al*. 2004b). These favourable properties led to exploitation of eri silkworm as animal feed, aquarium fish food and also as human food. Rearing focused on low cost and applicable techniques for encouraging eri culture as a secondary activity among cassava growers. Removal of up to 30 percent of cassava leaves, used as the sole food of eri silkworms, significantly increased the cassava tuber yield in the northeast (Sirimungkararat *et al*. 2002). Given its high protein content, a simple rearing process that does not use chemicals and a wide range of host plants, eri food was developed as a sustainable high protein food source. It is a safe food with diverse cooking preparations and is ideal as high-protein food for schoolchildren, rural dwellers and local communities.

[3] US$1.00 = 33 Thai baht (October 2009).

Table 1. Nutritional value of edible insects per 100 grams of fresh weight compared to commonly eaten livestock

Insect/livestock	Energy (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)	Iron (Fe) (mg)	Calcium (Ca) (mg)	Phosphorus (P) (mg)	Potassium (K) (mg)	Vitamin (mg)		
									B1	B2	Niacin
Grasshoppers (large)	95.7	14.3	3.3	2.2	3	27.5	150.2	217.4	0.19	0.57	6.67
Grasshoppers (small)	152.9	20.6	6.1	3.9	5	35.2	238.4	237.4	0.23	1.86	4.64
True water beetles	149.1	21	7.1	0.3	6.4	36.7	204.8	197.9	0.31	3.51	6.85
Mole crickets	125.1	15.4	6.3	1.7	41.7	75.7	254.1	267.8	0.20	1.89	4.81
Red ant eggs (a mix of eggs and pupae)	82.8	7	3.2	6.5	4.1	8.4	113.4	96.3	0.15	0.19	0.92
Silkworm pupae	98	9.6	5.6	2.3	1.8	41.7	155.4	138.7	0.12	1.05	0.89
Giant water bugs	162.3	19.8	8.3	5.5	13.6	43.5	225.5	191.7	0.09	1.50	3.90
Chicken	110	20.8	2.4	0	1.2	11	214	-	0.15	0.16	7.90
Beef (without fat)	150	20	7.2	0	3	9	171	-	0.07	0.34	6.70
Pork (without fat)	376	14.1	35	0	2.1	8	151	-	0.69	0.16	3.70
Pork (with fat)	457	11.9	45	0	1.8	7	117	-	0.58	0.14	3.10

Source: Nutrition Division (1978).

Life cycle of the eri silkworm

The eri silkworm reared in northeastern Thailand completes its life cycle in 47 to 59 days. There are four development stages: egg: 7-8 days; larva: first to fifth instar, 18-24 days; pupa: 15-19 days; and adult: 7-8 days (Plate 1).

Plate 1. Life cycle of the eri silkworm (*Samia ricin*i D.)

Source: Sirimungkararat (2003).

Development of eri food products

Rearing of larvae, prepupae and pupae of eri silkworm was reported by Sirimungkararat *et al.* (2002). Various eri food recipes were developed using late fifth instar larvae, prepupae and pupae as the principal raw materials, combined with herbs, vegetables and spices. The recipes developed by Sirimungkararat *et al.* (1992) were registered as intellectual property in the form of a patent. These recipes comprising larvae, prepupae or pupae are: crispy basil flavour, herb flavour, spicy salad flavour, traditional spicy flavour, *tom yam* crispy flavour, chili paste flavour, original flavour and classic flavour.

Analysis and contents of processed eri food products

Nutritional value and other major constituents of eri processed foods were analysed using the same raw materials employed in the study of eri food product development. The analysed larvae (Duan-KKU) and pupae (Sab-KKU) had good nutritional value and contained high amounts of protein, about 76.22 and 67.64 percent in processed larvae and pupae, respectively. Ash, crude fibre, ether extract, nitrogen free extract and moisture values are given in Table 2. These findings are similar to a previous study by Sirimungkararat *et al.* (2004a, Table 3). Compared to other food insects, the eri silkworm is one of the highest protein producers and a “green” product.

For these reasons, it is suitable for exploitation as a protein source (Jolly *et al*. 1981). In addition, the general characteristics, colour, odour, taste and texture are considered good to very good. The moisture content of Sab-KKU (13.13 percent) was similar to Duan-KKU (13.30 percent), which gives it a smooth texture (Table 3). Regarding micro-organism contamination, there was a low concentration of 1.4 x 10^3 cfu/gram and 1x10^2 cfu/gram in analysed larvae and pupae, respectively (Table 3). These concentrations in the pupae product were one-tenth of the Thai Community Product Standard (TCPS)’s limit for cricket products, which is not more than 1 x 10^3 cfu/gram. Moreover, the processed eri products were safe in terms of toxic substances (Table 4). Results revealed the quantities of such toxic substances as hydrocyanic acid (HCN), heavy metals (Pb, Hg, Cd), arsenic, benzoic acid and sorbic acid (Tables 3 and 4). The allowable levels used here were defined by the TCPS for other products, because the standards for eri foods are still not available and need to be developed. The safe level of HCN was previously reported by Sirimungkararat *et al*. (2004b).

Table 2. Analysis of processed eri silkworm larvae and pupae

Chemical composition	Processed material	
	Larvae (Daun-KKU)	Pupae (Sab-KKU)
Moisture (%)	5.325	6.025
Ash (%)	2.72	2.30
CP (crude protein, %)	76.22	67.64
CF (crude fibre, %)	4.621	1.860
EE (ether extract, %)	10.967	16.494
NFE (nitrogen free extract, %)	0.143	6.381

Source: KKU analysis.

Table 3. Evaluation of processed foods of eri silkworm compared to the TCPS

Item	Processed material		Method
	Larvae (Daun-KKU)	Pupae (Sab-KKU)	
Aerobic plate count (cfu/g)	1.4×10^3 EAPC	1×10^2 EAPC†	BAM 2001 (Pour plate methods)
Yeast and mould (cfu/g)	27	3	BAM 2001 (Pour plate methods)
Moisture (g/100 g)	13.30	13.13	AOAC‡
Benzoic acid (mg/kg)	46.91	<5	In-house method based on HPLC¶
Sorbic acid (mg/kg)	ND	ND	In-house method based on HPLC

†EAPC = estimated aerobic plate count; ‡AOAC = Association of Analytical Chemists; ¶HPLC = high performance liquid chromatography. ND = not detectable

Source: KKU analysis.

Table 4. Analysis of HCN and heavy metals from processed eri silkworm food

HCH/heavy metals	Processed material	
	Larvae (Daun-KKU)	Pupae (Sab-KKU)
HCN (ppm)	<2.068	<2.0
Pb (mg/L)	ND	ND
Cd (mg/L)	0.199	0.261
Hg (µg/L)	NA	ND
As (µg/L)	3.008	5.836

ND = not detectable
NA = not analysed

Source: KKU analysis.

Consumer evaluation of eri foods

Eri products derived from larvae (Duan KKU) and pupae (Sab-KKU) with classic flavour were evaluated with regard to consumer preference, compared to other edible insects sold in the markets of Amphoe Muang District, Khon Kaen Province from October 2007 to February 2008. Based on interviews with retailers, the most popular edible insects are bamboo caterpillars, Bombay locusts, white crickets and mole crickets. Comparing price after processing, the most expensive were bamboo caterpillars, white crickets, Bombay locusts and mulberry silkworm (pupae), in descending order (Table 5). Random visitors/buyers were tested, interviewed and their reactions evaluated using a questionnaire. The results showed that there was a distinct difference between the types of consumers.

Farmers prefer to eat giant water bugs, predacious diving beetles/water scavenger beetles, mulberry silkworm (pupae), eri pupae, white crickets, mole crickets, Bombay locusts, short-tail crickets or giant crickets, bamboo caterpillars and eri silkworm (larvae), in descending order. Reasons given for preference related to familiarity with native edible insects, low price, as a main ingredient cooked with rice and other usage. Least popular were bamboo caterpillars and eri larvae because of the unpleasant appearance of the larvae, which inspires disgust. Giant water bugs were the most popular because of their pleasant cooking odour; true water beetles ranked second.

Farmers' preferences were almost totally different to urban dwellers or those living nearby, including university students and schoolchildren. In this group, 50 percent favoured Bombay locust, eri pupae, mulberry silkworm (pupae) and white crickets. Other insects such as eri silkworm (larvae), mole crickets, crickets, bamboo caterpillars, giant water bugs and true water beetles were preferred by 37.5, 25, 25, 25, 12.5 and 0 percent of those interviewed, respectively (Table 6). In this group, the reasons for preference were: delicious taste, crispiness, ease of buying and availability year round. Disliked were giant water bugs and true water beetles because of their odour and hard body, respectively.

One of the largest edible insect dealers in Thailand related that the most widely distributed insect was the bamboo caterpillar, which is regarded as a delicacy. This correlated with the overall frequency evaluation of international testers who participated in the Chiang Mai edible forest insect workshop – that the most popular edible insects were bamboo caterpillars, white crickets and Bombay locusts, in descending order.

Table 5. Insects sold in the Khon Kaen market during November 2007 to February 2008

Common name	Scientific name	Vernacular name[†]	Preference[†](%)	Price (baht/kg)[‡]		Family
				Fresh	Processing	
Giant water bugs	*Lethocerus indicus*	*Maeng-dah*	12.5	2-4 baht/piece	5 Baht/piece	Belostomatidae
Mulberry silkworm (pupae)	*Bombyx mori*	*Dak-dae-mai*	37.5	100-150	400-600	Bombycidae
Mole crickets	*Gryllotalpa africana*	*Maeng-gi-son*	50	120	400	Gryllotapidae
Predacious diving beetles, Water scavenger beetles	*Cybister limbatus* *Hydrous cavistanum*	*Maeng-tab-tau*	0	100-120	300	Dytiscidae, Hydrophilidae
White crickets	*Acheta domesticus*	*Maeng-sa-ding, Jing-reed-khao*	50	100-180	600-1,000	Gryllidae
Short-tail crickets orGiant crickets	*Brachytrupes portentosus*	*Ji-pom*	37.5	100-120	400-600	Gryllidae
Bamboo caterpillars	*Omphisa fuscidentalis*	*Rod-duan*	50	190-500	1,000-2,000	Pyralidae
Bombay locusts	*Patanga succincta*	*Tak-ka-taen-mo*	50	260-700	700-800	Acrididae

[†]Interview with the sellers.
[‡]US$1.00 = 33 Thai baht (October 2009).

Source: Questionnaire survey.

Table 6. Preference evaluation of eri food compared to other edible insects bought by urban dwellers

Common name	Vernacular name	Family	Preference (%)
Mole crickets	*Maeng-gi-son*	Gryllotalpidae	25
Giant water bugs	*Maeng-dah*	Belostomatidae	12.5
White crickets	*Maeng-sa-ding*	Gryllidae	50
Predacious diving beetles, Water scavenger beetles	*Maeng-tub-tau*	Dytiscidae, Hydrophilidae	0
Mulberry silkworm(pupae) Short-tail crickets or Giant crickets	*Duk-dae-maiJi-pom*	Bombycidae Gryllidae	5025
Bombay locusts	*Tak-ka-taen-mo*	Acrididae	50
Bamboo caterpillars	*Rod-duan*	Pyralidae	25
Eri silkworm (pupae)	*Sab-KKU*	Saturniidae	50
Eri silkworm (larvae)	*Duan-KKU*	Saturniidae	37.5

Source: Questionnaire survey.

Eri recipe contest

Because of the high potential of eri silkworm larvae and pupae for diverse cooked dishes, an eri recipe contest was organized at the Annual Silk Festival in Khon Kaen Province. It had already been confirmed that eri silkworm was a potential industrial insect. Eri silkworm breeders were delighted to take part and demonstrated an excellent ability to develop their own recipes, based on indigenous knowledge of edible insects. This activity served to inculcate the need to promote this high protein source for the community and as a food security resource in the minds of contestants and observers, especially as it represents a green product.

The final results revealed that the three winners with larval recipes were: crispy fried larvae with citrus hystrix (wild lime) leaves; fried larvae with *koki* powder (ginger rhizome?) and tofu stuffed with larvae. The three winners for pupal recipes were: pupae fried with hot chilies, traditional flavour mixed with pupae and pupae fried with basil leaves.

Future prospects for eri food

Eri silkworm has been recognized as an edible insect, especially in Northeast Thailand, for 17 years. To introduce eri food widely to potential consumers, it is necessary to provide them with satisfactory information via displays, tasting opportunities and education. One of the most successful efforts was the eri food recipe contest. Promotional selling of eri food products also allows more people to become familiar with and appreciate this edible insect.

The public sector is an important driving force to promote food safety. One such effort is the One Tambol (subdistrict) One Product (OTOP) campaign. OTOP was developed to increase productivity in districts, subdistricts and provinces. Public universities and government policies support OTOP. Eri food was developed by Sirimungkararat *et al.* in 2006 and was further improved through better processing techniques and improved quality, to achieve a high-quality product. Two eri food products have been nominated as outstanding OTOPs, as shown in Plate 2.

Plate 2. Outstanding OTOP – eri silkworm pupae (Sab-KKU), developed by Sirimungkararat and collaborators in 2006 ***(Courtesy the authors)***

Discussion and conclusion

Rearing eri silkworms is relatively easy and can be practised throughout the year in Thailand, including the northeast, using techniques and equipment similar to those employed in mulberry silkworm rearing. Eri silkworms can be fed leaves of the host cassava plant, without any chemical use, thus yielding a green product (Sirimungkararat *et al*. 2002). This silkworm produces thermal property silk yarn, along with high protein larvae and pupae (Sirimungkararat *et al*. 2004a). Most countries in the world are facing rising costs for cereals and other foods. This global situation provides a timely opportunity for the eri silkworm. Due to its high protein content, eri food has excellent potential as a protein source and security food for schoolchildren and people in rural areas. Eri food will become better known when both the private and public sectors provide long-term promotional support. Eri food and eri products should be quickly and widely promoted through consumer publicity campaigns. In this way, the potential of the eri silkworm can be realized to support government food security policies and to broaden the availability of edible insects as commodities in Thailand. The eri silkworm represents one of the potentially commercial wild silkmoths in Thailand and is being promoted in the northeastern region.

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Edible insects in Thailand: nutritional values and health concerns

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Edible insects should be considered not only for their nutrient content, but also for their nostalgic value to consumers. In the past, insects were commonly eaten by people in the north and northeast of Thailand. Nowadays, they are even eaten by urban dwellers throughout the country. In general, there are three main groups of insect eaters: (1) indigenous consumers from the northern and northeastern provinces (some of whom have migrated to other parts of the country); (2) consumers in urban areas who learn about and later develop a taste for insect foods; and (3) foreign tourists attracted by different insects prepared and sold in tourist spots.

Although over 50 species of insects are reported to be commonly eaten in Thailand, not all of them have had their nutritive values determined. The Institute of Nutrition at Mahidol University has analysed the nutrient contents of only those insects that are most commonly eaten. These include groups of ants, bees, beetles, bugs, cicadas, crickets, locusts, moths and termites. Edible insects are good sources of protein, fat, calories and micronutrients. The amino acid score of silkworm pupae reaches 100, followed by bamboo caterpillars (77.5), house crickets (68.7), wasps (59.4), Bombay locusts (55.8) and scarab beetles (34.2). Insects having an optimal ratio of fatty acid are house crickets, short-tailed crickets, Bombay locusts and scarab beetles.

Methods of preparation play a part in determining the nutritional values of insects for consumers. In Thai cuisine, there are 13 techniques for cooking insects, grouped into singeing (precooking), cooking in oil (frying, sautéeing) and oil-free cooking (paste, soup, curry, poaching, steaming and hot salad. Recently, insect fritters, burgers and sandwiches have become popular and in high demand among non-indigenous consumers, especially in urban and tourist centres. These new methods possibly increase the caloric intake of consumers. Excessive consumption of insects may fill the stomach with chitin and chitosan, protein and fat, which carry the risk of urinary tract stone formation and development of chronic degenerative disease.

Keywords: chitin, chitosan, cuisine, nutritive value, protein, stone diseases, traditional food

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Introduction

Insects are commonly used and consumed in a variety of ways: (1) as part of regular diets; (2) as famine or survival foods; (3) for medicinal purposes; (4) for ritual purposes; and (5) as novelties (Sutton 1995). In hunter-gatherer societies, insects are recognized as food. In modern agricultural societies, insects are generally viewed negatively. But in many cultures in Africa, Asia and Oceania and Latin America, pests such as locusts and grasshoppers are important food items (Defoliart 1999). Eating insects is not simply the result of poverty or of protein deficiency. In many parts of the world, eating insects is a matter of preference and tradition (Jach 2003; Pemberton 1999). Worldwide, insects have formed part of the cuisine of 113 entomophagous countries, with almost 1 500 known species of edible insects being consumed by over 3 000 different ethnic groups (MacEvilly 2000). In Thailand, approximately 164 species are edible (Lewvanich *et al.* 2000) and over 50 species are commonly eaten (Watanabe and Satrawaha 1984).

This paper focuses on insects and their role in human nutrition. Grivetti (1997) provides four principles influencing individual food patterns. First, availability of foods, either on a seasonal or regular basis, providing a variety of food supplies to consumers. Second, humans perceive a food item to be edible and become familiar with it. However, familiarity does not necessarily correlate with nutritional quality. Third, individuals select food based upon their personal preferences as to whether they like or dislike it. These are based upon sensory evaluation of past experience with such food. If foods are tasted and liked, consumption is likely to be repeated. The body's reactions and perception of the taste and aroma of food provide valuable indications about whether or not a specific food should be eaten. The crunchy exoskeleton of insects offers a wonderful taste and induces the consumer to eat it in considerable quantity. But not all potential items identified as fit for consumption are selected. Lastly, expectation follows from exposure, that is, taste (sweet, sour, salty, bitter), colour (hue, intensity), texture (smooth, coarse) and odour (pleasant vs. unpleasant). Besides the nutrient content, the nutritional values of edible insects are confounded by eating patterns and behaviours, which are complicated issues. Therefore, this paper is not limited to only nutritive value; the aforementioned principles are also applied. Information presented here was obtained from rapid assessments, observations carried out over several years and published sources.

Edible insects: a contribution to economic empowerment

On average, the monthly household income of a Thai farmer is approximately 9 639 Thai baht[2] (National Statistics Office 2007). Selling insects could improve the economic status of poor farmers. Unlike other agricultural or food products, there are no national data collected on the contribution of insects to the economic status of Thai farmers. As an income source, bamboo caterpillars and silkworm pupae are popular and are normally expensive. A few decades ago, Watanabe and Satrawaha (1984) reported that silkworm pupae sold for 25 baht per kilogram in rural markets. Nowadays, their market price has increased to 200 to 250 baht per kilogram for bamboo caterpillars and 120 to 150 per kilogram for silkworm pupae.

[2] US1.00 = 33 Thai baht (October 2009).

As a primary occupation, selling edible insects can be attractive. One of the pioneers of edible insect selling, Mr Nusu T., who has been in this business for 16 years, related that selling edible insects is a job that can be handled singly. It does not need many labourers. Purchasing insects wholesale requires an investment of about 4 000 baht per day for 13 species. Net profit is approximately 1 200 baht per day (or 30 percent). Mr Nusu T, reported that he sells 70 to 80 tonnes of insects per year, and he estimates that the country's demand may be 2 000 tonnes (Department of Industrial Promotion 2004).

Because of the remarkable increase in demand, supplies of edible insects are even being brought into Thailand from neighbouring countries. For instance, Cambodian farmers collect locusts and trade them at Rong Kluah Market, a large market on the Thai-Cambodian border. The price is 40 baht per kilogram (Hutasingh 1996). It has been observed that the quantities of edible insects being imported through this market have increased. Intermediaries trade the insects from that point to other outlets including Bangkok and Pitsanulok. Bangkok is reportedly the largest market.

Availability of edible insects

In Thailand, insect eaters can be found in all regions of the country. In the past, indigenous insect eaters were known to reside mostly in the north and northeast. These people were attuned to the climate and geographical situation. In these regions, insects can be collected from paddy fields, upland and forested areas, natural ponds and streams; some kinds of edible insects are available all year round (Yhoung-aree and Viwatpanich 2005). However, there may be variations of species and volumes. Grootaert and Kiatsoonthorn (2003) reported that from April to June (peaking in May), ants, termites and beetles are abundant. In this period insects feed on decayed wood and litter. In years of abundant rainfall, the surplus of insects collected from nature adds to the family income of the collectors. Edible insects are commonly found also in urban areas. For instance, Sarapee (2004) listed six Orders, 13 Families and 21 species of edible insects available in urban areas of Surin Province from June 2002 to May 2003. Currently, large quantities, representing 10 to 15 species, are sold in large food outlets such as Klong Tuey and Dhevej markets in Bangkok.

Edible insects are now increasingly being domesticated. This has been accomplished in a number of countries. In Guangdong, China, water beetles sold in the local markets are hatched locally in special nurseries (Jach 2003). In Thailand, commonly farmed species are crickets and locusts. To promote school nutrition, children are encouraged to raise red ants and giant water bugs. Among the few insects being domesticated, mulberry silkworms and crickets are the most successful (Defoliart 1995), whereas red ants and giant water bugs were unsuccessful for commercial-scale production (Chamjanya *et al*. 2008).

Consumption of edible insects

The consumption of insects has evolved over the past decades. Wara-asawapiti *et al*. (1975) published an account of species of insects used in various local recipes in Northeast Thailand. Nutrition researchers consider these consumed insects as an important source of protein for the native people whose nutritional status is poor (Sirichakwal and Sungpuag

1982). Sungpuag and Puwastein (1983) analysed their nutritive values and documented them as an unconventional protein source because they are consumed by native dwellers only, and are not accepted by the Thai people in general. Due to their palatability and status as a delicacy, edible insects have been marketed increasingly in public places. More than 50 species were reported to be eaten in the northeastern region (Watanabe and Satrawaha 1984).

Because of socio-economic developments, rural people are increasingly migrating to urban areas and bringing their food habits along. Not surprisingly, edible insects have been included. Furthermore, the migrants gradually introduce edible insects as delicacies to people in the new setting. As can be observed, the edible insect is accepted and becomes popular, especially in poor urban communities where insect-eating migrants reside. As a result, Yhoung-aree *et al.* (1997) propose that edible insects should no longer be considered unconventional.

Currently, Yhoung-aree and Viwatpanich (2005) divide insect eaters into three groups: (1) indigenous insect eaters, who may reside either in their native areas or have migrated to new locations. (The latter are observed to be deeply attached to insect dishes, considering them to be nostalgic food.); (2) the new insect eaters – people who belong to families of insect-eating migrants and have been introduced to insect-eating customs by their parents or relatives (It was observed that young family members more easily accept insect dishes prepared by frying and frittering because they are more delicious.); and (3) many migrants from neighbouring countries and tourists scattered around various parts of the country. The former are known to be indigenous insect eaters and the latter are traditional insect eaters as well as new consumers.

Cooking methods and recipes

Collected insects die and spoil quickly and are therefore generally prepared live. Preparation and cooking methods vary with the cultural group (Sutton 1995). In traditional Thai cuisine, indigenous knowledge relates that edible insects should be prepared without using oil. Especially in the northern and northeastern regions, people eat sticky rice as a staple food. In this instance, oil-free dishes are prepared because they are most compatible with their standard meal. Traditionally, oil-free insect recipes include roasting, smoking (or baking), steaming (or *homoke*), poaching, with chili paste, as a hot salad (half cooked) and uncooked/raw. Typically, among the rural poor, insects are incorporated into a ragout or vegetable dish as well as an ingredient in plain or spicy soups (Yhoung-aree *et al.* 1997).

Oil-cooking of insects, including frying, sautéeing and frittering, is considered to be modern Thai insect cuisine, because these cooking techniques have been recently introduced. In addition, they have been disseminated to non-indigenous insect eaters through markets. The oil-based recipes make insect dishes tastier resulting in their becoming more popular in urban areas and tourist destinations. These cooking methods are also commonly used in other cultures as well (Ramos-Elorduy *et al*. 1997).

Culinary efforts in the preparation of new insect recipes are directed toward modifications to overcome prejudices against insects. Frittering is a new form of cooking in Thailand and creates a pleasant aroma. Among younger generations of Thai insect eaters, frittering helps to banish the squeamish feelings of the consumer. Flavour is one of the essential determinants by which insects are considered most edible (MacEvilly 2000). Fried and frittered insects are further improved by sauces that enhance their delicacy and palatability, especially when they go well with beverages like beer or wine. In addition, edible insects are being prepared in the form of sandwiches, burgers and pizza in order to serve westerners who are familiar with and appreciate these styles of cooking.

It is evident that insect dishes available in Thailand are not only prepared using traditional but also western styles. However, traditional styles such as soup, paste, steaming, etc. are still used for main meals. The western style of preparing edible insects is directed more towards their being consumed as snacks.

Nutritional values of edible insects

Data on the nutritive values of insects are important, for they inform consumers about the quality and quantity of their intake. For international comparison, a common yardstick to assess the nutritional value of food is the weight of food, along with its nutrient content (Grigg 1995). Because food analysis is costly, the available data on the nutritive values of edible insects in Thailand have focused on those species which are most commonly eaten.

Nutritive values of insects vary depending upon species, habitats, the growth stage of the insects and methods of cooking. Characteristics of consumers such as gender and food habits contribute to their preferences. Many publications state that edible insects are rich in protein, fat and calories, as well as being good sources of minerals such as iron, calcium and vitamins A, B_1, B_2 and D. Ramos-Elorduy *et al*. (1997) conducted protein analysis of 78 species of edible insects. On a dry weight basis, protein content was determined to be 15 to 81 percent. Protein digestibility varied from 76 to 98 percent. Wasps had the highest protein content.

Jongjaithet *et al* (2008) collected samples of seven common edible insects sold in various public markets in Bangkok (Klong Tuey and Dhevej), Khon Kaen and Sakaew (Rongkuah). These markets are well-known as large insect outlets. The results showed high protein content in bamboo caterpillars, silkworm pupae and wasps (Table 1).

Qualitatively, the protein of insects such as silkworm pupae has been analysed and found to be safe for human consumption (Zhou and Han 2006). The contribution of protein to overall human intake varies with the stage of the insect eaten and the time period of its availability. In the palm weevil, the mature stage has higher protein content than when it is immature (Omotoso and Adedire 2007). In the northwest Amazon, insects provide approximately 5 to 7 percent of total protein intake during the year. Their contribution increases to 12 to 26 percent during May to June when availability peaks (Dufour 1987). This period coincides with the mature stage of insects. Sutton (1995) studied gender differences in insect consumption and found that men consumed more insects than women, contributing to more than three times the protein intake (men: 69 percent, women: 31 percent).

In relation to protein quality, the amino acid profile of edible insects is relevant. Some species may contain enough amino acid to provide the requirements of an adult, such as Mexican

Table 1. Calories, protein and fat content in common edible insects by cooking methods

Vernacular name	English name	Scientific name	100 g raw(1)			100 g blanched(2)			100 g fried(2)			Per 100 g paste(3)		
			Cal Kcal	Prot. G	Fat G	Cal Kcal	Prot. G	Fat G	Cal Kcal	Prot. G	Fat G	Cal Kcal	Prot. G	Fat G
Mang tub-tao	Predaceous diving beetles	*Cybister limbatus* F.				180	21.0	7.1	301	24.3	18.6			
Mang ki-noon	Scarab beetles	*Holotrichia* sp.	98	18.1	1.8	98	13.4	1.4	215	15.5	12.9			
Jing-rheed	House crickets	*Acheta testacea* Walker	133	18.6	6.0	134	12.9	5.5	465	14.9	17.0	79	4.6	1.3
Ji konke	Short-tailed crickets	*Brachytrupes portentosus* Licht	188	17.5	12.0	125	12.8	5.7						
Mangkachon	Mole crickets	*Gryllotalpa africana* Beauvois				136	15.5	6.3				101	11.7	4.3
Mang-dana	Giant water bugs	*Lethocerus indicus*				182	19.8	8.3	303	22.9	19.8	90	4.3	1.3
Patunkka	Bombay locusts	*Patanga succincta* L.	157	27.6	4.7	169	20.6	6.1	221	16.6	14.8			
Tukkatan E-moh	Spur-throated grasshoppers	*Chondracris roseapbrunner* Uvarov				105	14.3	3.3	290	23.8	17.6			
Rod-duan	Bamboo caterpillars	*Omphisa fuscidentalis*	231	9.2	20.4				644	25.5	55.3			
Mod daeng	Red ants	*Oecophylla smaragdina* F.							231	16.1	15.0			
Non-mhai	Silkworm pupae	*Bombyx mori* L.	152	14.7	8.3	127	12.2	7.0	241	14.1	18.5			
Toh	Hornet grubs	*Vespa* sp.	140	14.8	6.8	140	14.8	6.8				108	12.1	2.6

(1) Jongjaithet *et al.*: http://nutrition.anamai.moph.go.th/temp/main/view.php?group=3&id=120
(2) Institute of Nutrition, Mahidol University, Food Composition Database for INMUCAL Program, 2002.
(3) Yhoung-aree and Viwatpanich (2005).

Table 2. Amino acid content in common species of edible insects

Common name	Scientific name	Essential amino acid: mg/gram protein									Non-essential amino acid: mg/g protein							
		Isoleucine	**Leucine**	**Lysine**	**Methionine &Cystine**	**Phenylalanine &Tyrosine**	**Threonine**	**Tryptophan**	**Valine**	**Amino acid score**	**Arginine**	**Histidine**	**Alanine**	Aspartic acid	Glutamic acid	Glycine	Proline	Serine
House crickets	*Acheta testacea Walker*	29.8	60.9	46.1	30.9	62.4	29.0	24.4	34.4	68.7	45.1	15.4	78.0	69.2	96.8	47.2	45.2	35.9
Scarab beetles	*Holotrichia* sp.	32.1	51.8	18.8	44.6	49.3	26.9	27.1	29.3	34.2	32.3	16.1	58.3	61.2	97.6	52.8	47.0	31.3
Bombay locusts	*Patanga succincta* L.	32.7	59.5	35.7	20.9	60.0	22.3	17.3	35.6	55.8	36.0	13.5	92.7	48.8	76.4	48.8	48.7	23.9
Bamboo caterpillars	*Omphisa fuscidentalis*	33.9	60.0	56.0	41.7	100.7	34.9	41.1	38.8	77.5	47.9	23.3	37.7	88.2	93.2	32.7	40.7	41.3
Silkworm pupae	*Bombyx mori* L.	46.1	70.6	77.2	36.3	122.0	45.3	19.0	52.2	100	58.8	35.4	39.4	88.9	107.3	29.7	44.4	37.9
Hornet grubs	*Vespa* sp.	42.6	78.5	59.0	20.8	165.0	45.3	10.1	53.7	59.4	41.0	35.3	43.5	79.6	180.6	48.2	56.8	3.8
Scorpions*		21.1	50.0	31.1	24.6	76.5	19.4	22.3	24.4	48.4	41.2	18.8	50.1	52.0	67.6	70.8	26.2	25.8

* The scorpion is not an insect.

Source: Jongjaithet *et al*.: http://nutrition.anamai.moph.go.th/temp/main/view.php?group=3&id=120

edible insects (Ladron de Guevara *et al*. 1995). Jongjaithet *et al.* (2008) published amino acid profiles of six common species of insects eaten in Thailand. Table 2 shows that different species of insects have different profiles of both essential and non-essential amino acids. Among the essential amino acids, leucine is relatively high in all species (50.0-78.5 mg/gram protein). Silkworm pupae contained the most lysine. According to WHO (1985), the amino acid score of silkworm pupae reached 100, followed by bamboo caterpillars (77.5), house crickets (68.7), wasps (59.4), Bombay locusts (55.8) and scarab beetles (34.2).

Fat content: Fat components (crude fat, cholesterol and fatty acids) in edible insects show a similar pattern to protein. Not all edible species of insects are high in fat. Ramos-Elorduy *et al*. (1997) reported on fat in 78 species of insects and found it ranged from 4.0 to 77.2 percent. Ekpo and Onigbinde (2007) document unsaturated fatty acid in termites (*Macrotermis bellicosus*) at 51.02 percent. Jongjaithet *et al.* (2008) determined the fat content of seven sample insect species (Tables 1, 3). Bamboo caterpillars and short-tailed crickets are high in fat, followed by silkworm pupae and wasps. As far as nutrition is concerned, fat intake is interpreted based on the optimal ratio among saturated and unsaturated fatty acids. In principle, the optimal ratio of saturated fatty acid to monounsaturated fatty acid and polyunsaturated fatty acid informs the appropriate fat intake. It is recommended that this ratio should be 1:1:1 for these respective components (Whitney and Rolfes 1999). As such, the study shows that fatty acids in house crickets, short-tailed crickets, Bombay locusts and scarab beetles meet the optimal ratio. Apart from fatty acids, cholesterol was analysed. Cholesterol per 100 gram sample is high in house crickets (105 milligrams), followed by Bombay locusts (66 milligrams), scarab beetles (56 milligrams) and bamboo caterpillars (34 milligrams).

Caloric content: As a result of the protein, fat and carbohydrate contents, caloric values can be determined either by calculation or by direct assessment of insect samples. Insects high in fat provide more calories. This was also demonstrated by Ramos-Elorduy *et al.* (1997) from 78 species of edible insects analysed with caloric content ranging from 293 to 762 Kcal/100 grams. The same patterns were confirmed by Jongjaithet *et al.* (2008). The cooking method plays a role in increasing the caloric content of cooked insects. As noted by Banjong *et al.* (2002), frying insects adds fat to the cooked products, amounting to approximately 13 to 17 grams per 100 grams of insects. Table 1 (columns 2 and 3) shows the remarkable increases of calories in fried insects. It is noted that cooking insects as paste does not contain as many calories because insects are but one of the ingredients in a spicy mix.

Table 3. Fatty acid and cholesterol content in common species of edible insects

Common name	Scientific name	Saturated fatty acid (% fatty acid)	Unsaturated fatty acid (% fatty acid)		Cholesterol (mg)
			MUFA	PUFA	
House crickets	*Acheta testacea*	36.5	30.1	31.1	105
Short-tailed crickets	*Brachytrupes portentosus*	35.0	32.3	29.6	NA
Scarab beetles	*Holotrichia* sp.	33.3	30.0	32.4	56

MUFA: Monounsaturated fatty acid
PUFA: Polyunsaturated fatty acid
NA: Not analysed
Source: Jongjaithet *et al*. (2008, Table 4): http://ora.kku.ac.th/res_kku/Abstract/AbstractView.asp?Qid=634858900/
http://nutrition.anamai.moph.go.th/temp/main/view.php?group=3&id=120

Micronutrients: Insects are also rich in vitamins and minerals such as vitamins A, B_2, C and iron (Banjo *et al.* 2006). Black ants (*Polyrhachis vicina* Roger) are rich in vitamin E and minerals. In the Thailand Food Database (Institute of Nutrition, Mahidol University 2002), when compared to pork and chicken, the groups of beetles, crickets and locusts/grasshoppers have comparable levels of phosphorus, potassium, iron, calcium and vitamins B_1 and B_2. However, the level of these micronutrients varies with the insect species.

Advantages and disadvantages of insect consumption

Despite a positive perception of edible insects as delicacies, and scientific evidence of their nutritive values, edible insects need to be considered in terms of the potential negative consequences of their consumption. In this regard, issues related to the chitin, protein and fat content of edible insects are important.

Chitin is a naturally abundant mucopolysaccharide found in the supporting exoskeletal material of crustaceans, insects, etc. Chitosan is the N-deacetylated derivative of chitin. Chitin and chitosan have a wide range of applications (Majeti and Kumar 2000). Chitin is digested by chitinase. There are two chitinase: acidic mammalian chitinase (AMCase) and chitotriosidase (chit). Chit is a hydrolytic enzyme produced by macrophages. In tropical populations with a higher rate of entomophagy, AMCase activity is high and could confer increasing resistance against parasitic infection (Paoletti *et al.* 2007). Chitin and chitosan also have a protective effect on candida, an infection caused by yeast (Koide 1998). Chitin and chitosan can bind dietary lipids, resulting in the reduction of plasma cholesterol and triglycerides. Consequently, the intestinal absorption of lipids is reduced (Koide 1998). Majeti and Kumar (2000) also confirm that chitosan is a fat trapper in the stomach, thereby preventing the trapped fat from absorption. In contrast, chitosan forms gel and traps lipids and other nutrients including fat-soluble vitamins and minerals. As for long-term effects, chitosan may interfere with and lead to calcium reduction. As a result, bone metabolism and possibly vitamin D absorption may be impaired. In this case, pregnant mothers are at high risk.

There is hearsay among medical practitioners working in hospitals in Northeast Thailand that urinary tract stone diseases may be associated with the consumption of edible insects. The mechanism of urinary stone formation is unclear. At the beginning of the twentieth century the percentage of bladder stones was as high as 90 percent in countries such as China and Thailand. In the last few decades the frequency of bladder stones occurrence has sharply decreased (Hesse and Siener 1997). However, health professionals working in entamophagous provinces observe that urinary stone diseases have persisted, for example in Northeast Thailand.

Urinary stone diseases are a painful and costly medical condition to treat (Curhan *et al*. 1996). About 40 percent of urinary stone sufferers need in-patient treatment, with a relatively high rate of surgery (12.2 percent). Of all urinary tract stones, more than 76 percent consist of calcium oxalate (Hesse and Siener 1997). Most of all, calcium oxalate stones have gained increased importance. Halstead and Valyasevi (1967) reported the urinary stone situation in Ubon Ratchathani Province (the lower northeast) where insects have been eaten commonly. In a sample population of 20 860, 3.8 percent, at one time in their lives, had active urinary stone disease, and 2.6 percent had one or more symptoms suggestive of the disease. The prevalence of urinary stones in urban areas in Ubon Ratchathani was 4.7 per 1 000. Sriboonlue *et al*. (1992) documented the prevalence of urinary tract stones in an administrative subdivision of Khon Kaen Province (the upper northeast) as 3.76 per 1 000. The lower rate does not correspond to an improvement of nutrition in this region.

Halstead and Valyasevi (1967) also determined factors associated with urinary tract stone diseases. As far as nutrition is concerned, symptoms of bladder stones occur at a greater rate in water-deprived villages than in villages with ample year-round water supply (20 per 1 000 and 12.8 per 1 000, respectively). A positive correlation also was found between the abundance of fish and the prevalence of bladder stones. The authors note that the problem was inversely related to economic status. In the better-off villages, the rate of bladder stones is higher than in moderate or poor villages (20.4 per 1 000, 10.4 per 1 000 and 8.6 per 1 000, respectively). Halstead and Valyasevi (1967) also observed that the people in the areas studied ate large quantities of vegetables, which may be rich in oxalate, such as wild spinach (*pak kome*), *pak kadone*, *pak tiew* and the leaves of the naturalized leucaena.

In normal individuals, only small amounts of ingested oxalate (about 6 to 14 percent) are absorbed (Hasse *et al*. 1999). Thus, ingestion of vegetables of high oxalate content in combination with a misbalancing of other nutrients might contribute to the occurrence of the stone diseases. Halstead and Valyasevi (1967), however, do not highlight the quantity of insect intake which has been commonly eaten in the region studied. Not all species of edible insects are high in calcium. Thus, increased dietary oxalate intake (from indigenous vegetables) coupled with low calcium intake leads to a high risk of kidney stone formation (Holmes and Assimos 2004). Moreover, if a person consumes high calcium-containing species, chitosan does not reduce intestinal oxalate absorption (Wolf *et al*. 2006). Curhan *et al.* (1993) ascertained that a high calcium diet is associated with a decreased risk of kidney stone formation. The role of dietary oxalate in calcium oxalate kidney stone formation remains unclear.

The influence of animal protein on the risk of calcium kidney stone formation is uncertain. Robertson *et al*. (1979) report the overall relative probability of forming urinary stones markedly increased throughout the period of high animal protein ingestion. Curhan *et al*. (1993) show a positive association between animal protein intake and kidney stones. Hesse and Siener (1997) found that ingesting high levels of animal protein led to the increased metabolism of phenylalanine, tyrosine, tryptophan and hydroxypyroline. Consequently, oxalate excretion was observed to increase. Age and gender may contribute to urinary stone formation. Taylor *et al.* (2004) found a positive association between animal protein intake and kidney stones in men of 40 to 59; however, no association was found in men over 60. Young women are noted to have a low risk of kidney stones (Curhan *et al*. 2004).

Consuming edible insects that are rich in fat and calories may imply a risk of urinary stone diseases. Overconsumption of fat calories and fat intake leads to obesity, which brings with it the risk of gallstones (Pixley and Mann 1988). Among women, the risk was more than 75 percent greater for those in the highest BMI (Body Mass Index) categories ($\geq$ 32 kg/m^2) (Curhan *et al*. 1998a). Thijs *et al.* (1990) reported that hyperlipidemia is related to gallstones through an elevated triglyceride and cholesterol level. Haffner *et al.* (1990) showed that diabetes carries a risk of gallstones, even if an individual is not obese.

Publications concerning risk of stone formation due to the effects of vitamins are rarely available. Only Curhan *et al.* (1999) published a study that supports the theory that the risk of stone formation rises with increasing vitamin C intake.

To date, urinary stone disease has gained increasing significance due to the changes in living conditions, that is, industrialization and malnutrition (Hesse and Siener 1997). However, an industrialized society does not necessarily influence the lifestyle of people in a negative manner. Curhan *et al.* (1998b) showed that the risk of urinary tract stone formation decreased with the intake of each 240 millilitre serving of beer, wine, coffee, or tea. In contrast, an increase in risk was seen for each 240 millilitre daily serving of grapefruit juice. Taylor *et al.* (2004) discovered that a low risk of kidney stone formation was found in men younger than 60. This group is assumed to be active alcohol drinkers. As observed, fried and frittered insects are commonly eaten with beer or wine. Optimistically, perhaps this food and beverage consumption pattern contributes positively to lower the chance of stone formation. Overall, the genesis of stone diseases is a complex process. No single factor explains an evident apparent cause. Another warning of concern from MacEvilly (2000) relates to insects causing allergies; his study suggested that insects should not be eaten with nuts or shellfish as both have been shown to trigger allergic responses in hypersensitive individuals.

In summary, edible insects are generally viewed as good sources of protein, fat, calories, vitamins and minerals. These nutrients, along with chitin, may imply an influence on urinary tract stone diseases directly or indirectly. Although the mechanism is unclear, metabolic disorders as well as malnutrition could be major contributory factors of urinary tract stone formation.

Conclusion

Eating insects has both advantages and disadvantages. Insects are often incorporated in and cooked with other ingredients. If the recipes are properly prepared, they will increase their total nutritional value. For instance, bees can be part of a balanced diet. While edible insects are perceived as an excellent source of protein, fat and vitamins and minerals, many insect eaters today may disregard them as a source of these nutrients. Rather, they enjoy edible insects to satisfy the preferences of their palates and as a social function. Many are no longer personally squeamish about eating insects when more modern cooking methods (frittering, frying, etc.) are used that add to their taste. The eating behaviour of individuals is influenced by background, cultural traditions and social values. As a result, in general, insect eaters balance the quality of their diet. Well-balanced nutrition is the ideal to strive for. In particular, the nutritional value obtained from insect consumption depends on the species, environmental factors (season, habitat, climate), culture and socio-economics. Unbalanced intake of edible insects possibly brings about obesity, chronic degenerative diseases and urinary stone disease.

In developing countries, agro-ecosystems change rapidly in response to the farmers' perceptions of opportunities and constraints. In most cases, the result of changes leads to apparent vulnerability for environmental abuse. In the past, the insect fauna in Thailand were rich in certain areas such as Na Haew (Grootaert and Kiatsoonthorn 2003), an area of high biodiversity. This was due to the people's indigenous knowledge derived from their local culture to value the environment. They realized that insects could provide not only daily food, but simultaneously aid in maintaining diversity of habitats for other life forms. In return, this helps native people survive and sustain their local environment. In remote areas, insects have considerable potential for alleviating nutritional inadequacies. Moreover, some local people can make use of them to generate income.

Criticisms have been leveled about edible insects playing a somewhat mutually exclusive role in both ecosystems and as human food. The fact is that Thailand imports edible insects from neighbouring countries to satisfy domestic demand and consumption. The edible insect scenario presents one of demand exceeding supply. To a degree, the explanation of the combined issues includes the following: (1) As forests provide shade and habitats to organisms, any reduction of the forest cover poses a threat to the insect fauna. So when forestry areas are destroyed, a normal ecosystem becomes unbalanced. As a consequence, the insect fauna are negatively impacted and their availability is diminished. (2) Overharvesting of insects for economic purposes in order to close gaps brought about by urban demand. (3) In certain more remote forest areas, insects may be abundant; however, there may be a lack of insect collectors because many have migrated to the city.

Edible insect consumption is a good example of the interaction between human nutrition and biodiversity. There will be ongoing future use of insects for human nutrition. The question is: How can we ensure supplies, perhaps through development of economically feasible methods of mass rearing edible insects, in combination with efficient and sustainable harvesting of wild insects? The maintenance of biodiversity is important to human health and nutrition (Wahlqvist and Specht 1998). As proposed by Toledo and Burlinggame (2006), nutrition and biodiversity initiatives provide the very foundation for reducing by half the proportion of people suffering from hunger by 2015 as envisaged in the Millennium Development Goals.

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Filling the plates: serving insects to the public in the United States

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Entomophagy is shunned by most people in the United States, although a growing number of Americans are ready to sample insects that are prepared in the manner of other foods, and without the use of chocolate or similar coatings. Entomophagy has a slowly growing presence in the general culture: insects are eaten on television shows, insect dishes are menu items at a few fine restaurants and many children are able to recognize the facts regarding the environmental impact related to food production. While it is clear that advocating entomophagy means fighting the momentum of American food practices, there are good reasons to be optimistic about the future. The changes and the opportunities for insects as food are discussed.

Keywords: ants, crickets, entomophagy, food practices, insect festivals, microlivestock

Introduction

There is indeed recognizable interest in entomophagy in the United States, and even a small niche market for edible insects in the country. While this paper addresses the status of entomophagy in the United States, other fundamental points will also be made.

Discussion

I am convinced that in addition to research, it will be through our efforts in education and the raising of public awareness on entomophagy – both among the peoples of Southeast Asia and throughout the rest of the world – that we can make the greatest progress. Research and education are like two hands that achieve the most when they work together. I am fundamentally an educator and my focus is the social aspect and how people do and do not perceive insects. These perceptions will have a great impact on the public's willingness to consider insects as a viable food choice. Since 2001, I have served insects to many hundreds of people and in so doing I have planted the seeds of this good idea in people's minds. I give educational seminars at libraries, museums and nature centres. In addition to slide shows and the display of specimens, I serve crickets, silkworm and ant pupae, *Lethocerus*, cicadas and a few other types of insects cooked with rice and vegetables. They are never coated in chocolate.

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Regarding the United States and, I believe, many Western European nations, although commercial demand for edible insects might never compare to the same demand for edible mammals and birds, it is important to note that the current level of demand for these insects already surpasses currently available supply. I would like to see this situation change and I believe that my actions and those of others may well increase this demand in the coming years. In nearly every week of the year, an edible insect event is taking place somewhere in the United States, and people – especially children – are opening their eyes to the logic of entomophagy. Lastly, there is the very real possibility that the mass production of beef, pork, chicken and fish (the standard protein sources for many millions) might not be possible indefinitely. This implies that entomophagy could become a very viable option for meals despite the general cultural resistance to the practice of eating insects.

Those who attend my presentations are full of questions. Many come without the intention or willingness to sample insects, yet they try them at the end of the programme. There are several reasons why such people initially resist the practice or why they might change their minds, but they can be explored at another time. One of the questions people often ask is, "If insects are such a perfect food source, why have they been shunned by so many people?" I tend to reply that not so many people actually condemn insects as food, but this does not address the real question: Since we are intelligent beings, why did all of us fail to adopt this most logical food source long ago? I indicate that there are a variety of reasons, none of which include the insects' taste. I also describe society's separation from nature and that our jobs have distanced us from agriculture; our remoteness from the soil and its products has made us ignorant about and suspicious of animals such as insects.

As a teacher I find it helpful to use a variety of rhetorical approaches to introduce the notion of entomophagy to the public. One method is comparative example. The case of the lobster is quite useful. I often show people images of a lobster juxtaposed by a grasshopper, while explaining that one consumes vegetation and the other eats trash and carrion. The answer to, "Which should be the logical food choice?" usually surprises them. Today lobster is both an expensive food item and a carefully regulated harvest, but for much of American history lobsters were condemned as trash, and fed only to pigs and prisoners. How did this change? One reason is that the lobster was "discovered" as a gourmet food for the rich. It became equated with haute cuisine, and that was crucial. Although some might say that this could never happen with insects, this cannot be known for certain.

I cite this example not to suggest that insects should become the food for a society's wealthy citizens, but simply to illustrate that a culture's food perceptions can evolve – and the general perception of insects has been evolving in very positive ways. Insects have always surrounded us, but now they are becoming increasingly present in our culture. The number and variety of insect festivals has risen greatly in the last 20 years, and more zoos now feature insect houses. Also, the amount of insect and arthropod husbandry in the pet industry has expanded considerably. There are even children's books on entomophagy. Most of all we can witness entomophagy on reality TV shows, which are fairly popular in the United States. While it is unfortunate that the people on these programmes are most distressed about eating insects and are doing so only to try to to win money, the practice still exposes entomophagy to the public, and catalyses conversations on the subject. Negative representations are still better than none at all, for they stir a sense of curiosity in some viewers.

Yet it is unlikely that there will be a quick change regarding the acceptance of entomophagy in the United States. Cultural norms are usually slow to change, but they do change like other fashions. In my area there are several small stores that specialize in foodstuffs for Southeast Asian cuisines and they sell frozen insects. I buy these products frequently for my seminars. I have chatted with many of the Thai and Cambodian owners there, either the clerks or other customers, who smile and chuckle when I ask them if they eat these foods. “No, no,” they tell me. “When I was little, back home, we ate this. Not anymore.” I am always tempted to ask them why, and sometimes do, but I get no real answer.

While entomophagy remains a significant component of humanity’s diet, research indicates that the eating of insects may well be declining in many parts of the world, including within societies that have long embraced edible insects as part of their diets. What could be the reason? I have not found any comprehensive studies of this phenomenon, only a host of anecdotal reports and commentary; in this case, educated guesses must be considered at least as a starting point. Gene DeFoliart and others have observed and described how communication technology has influenced a given group’s perception of themselves by showing them how other, seemingly more prosperous people, live. The global spread of television and other media in the last 40 years has meant that nearly everyone on the planet can see how everyone else lives. This becomes important when we consider that tourism, for example, has developed among more industrialized nations and moved towards their lesser industrialized counterparts, in a single direction. Therefore, it is not surprising that citizens of a less industrialized nation might seek to emulate the habits of others, and that various traditions might be discarded in the process.

None of this is intended to suggest that the United States or Western European nations are cultural leaders. Yet the decline in worldwide entomophagy, however slight and gradual it might be, is real cause for concern, and it has been sufficiently commented upon to be taken seriously. If this decline in entomophagy worldwide can be attributed to what might be called *acquired food source bias*, then one way to address this bias would be efforts at its source: among the people of the developed world. This is one of the bases for my work.

Another issue is the possibility that we do not have much time. Though a great many people enjoy the low food prices and other conveniences of our modern world, progress has been causing ever greater threats to our future. While it may be true that the public is generally disinterested in considering these threats, this does not stop my efforts to create positive change. When describing the vast amounts of wasted resources involved in the production of large vertebrate food sources, I tell the public, “Sometimes I hear my four-year-old daughter say that she would like to eat only cake and ice cream. That sounds nice, doesn’t it? After all, these foods are delicious and eating them gives us great pleasure. But we adults know what would happen to someone if he or she ate only cake and ice cream. The person would get fat, and his or her overall health would suffer greatly because vital nutrients – protein, vitamins and minerals in meat and vegetables – would be missing. An individual’s health will improve if he or she eats these foods sparingly.” The same could be said of the impact of large vertebrate food sources on the planet. Just as eating only desserts would harm the body, producing vast numbers of environmentally damaging food species is harming the planet. Anyone who doubts this logic would do well to read *Livestock’s long shadow*, an exhaustive report compiled and published by FAO (Steinfeld *et al.* 2006).

Clearly, vehicle and industrial emissions pose one of the greatest threats to the planet. But immediately behind these concerns are the cumulative effects of our food production. One reason that the mass production of cows, pigs, horses and other animals involves particularly catastrophic environmental impacts is that they are inherently wasteful in their consumption of grain, water and other resources. While many of us enjoy eating beef or pork, we may well sense that the days of consuming these animals are numbered.

A massive and ever-increasing body of research indicates that as global population continues to rise, and as climate and economics continue to change, the demands of food production and resource use will have a major effect on how we feed ourselves. It is distinctly possible that the large animal food sources that we have taken for granted for so long will be impractical to produce. This will make microlivestock, particularly insects, a desirable choice compared to other paradigms. It may well be that many people will embrace insect foods only when their usual food choices become problematic. However, we can do more than to passively wait for this to happen. In the meantime, there are people who see the logic – not only the logic of direct insect consumption, but also of utilizing insects in other forms of agriculture. It is clear that the more humanity is able to use insects in any form of food production, the more we reduce potential damage to the planet. Therefore, it is not an exaggeration to say that our work in entomophagy serves humanity as much as the work of those who seek new methods for attenuating malaria and other insect-borne diseases.

As we have seen, much of the developed world views insects as nothing more than pests. Moreover, even those academics who work with insects are not immune to biases against entomophagy. Many American entomologists appear to be resistant to any research or participation on the subject of entomophagy. Time and again I have approached these professionals for advice or assistance with information and resources for edible insects; few of these attempts have met with success. For this reason, I turn to the international community. While it is true that most of the United States is not ready to accept insects as food, the door is opening slightly, and more can be done. I feel sure that working together, we can make progress not only in Southeast Asia, but all around the world.

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Workshop recommendations: summary

Drawing from the workshop presentations and discussions related to international, regional and country experiences with entomophagy, and specific technical insights, participants conducted extensive deliberations on three main aspects of edible forest insects:

- Taxonomy and ecology;
- Harvest practices and management implications; and
- Postharvest processing, shipping and marketing.

The three working groups each examined their respective topics in relation to three sets of issues: 1) the current status of edible insects in Asia and the Pacific; 2) key constraints to future development; and 3) recommendations for near- and long-term actions.

Key recommendations

The following key recommendations resulted from the working group and plenary session discussions:

Taxonomy and ecology

- Support and provide funding for scientific collection of key insects and the training of insect taxonomists.
- Develop a protocol for recording data on edible insects and establish a centralized database, or establish a collaborative link to an existing database such as the Bureau for Exchange and Distribution of Information on Minilivestock, to aid in species identification and information sharing.
- Conduct further research on the ecology and life cycles of edible insects.
- Carry out further research on the nutritive value of edible insects, possibly including the health benefits of medicinal uses.
- Promote the involvement of local people who eat insects, and therefore capture indigenous knowledge in research and collection.
- Promote a wider acceptance of *entomophagy* and *ethnoentomology* as scientific subdisciplines of entomology.

Harvest practices and management implications

- Conduct research on the management potential of wild edible insects to enhance harvests, to ensure sustainability in nature and to assess potential for rearing of promising species.

- Document consumption, local names and traditional harvest and management practices of edible insects, including any competing uses such as for medicine.
- Establish a mechanism such as a newsletter to share relevant information on these subjects.

Postharvest processing, shipping and marketing

- Enhance promotion, marketing and awareness raising, focusing on human nutritional values and the direct environmental benefits of insect eating.
- Improve public perception of insect eating through education (particularly targeting children), cook books, exhibitions, festivals, articles and interviews.
- Improve quality control (addressing concerns over pesticide residues, parasites, diseased insects and the production processes).
- Improve product appearance, packaging and labeling, provide value-addition.
- Assess the economic feasibility of rearing manageable insects, examining its potential to contribute to rural food stocks and development.
- Promote the adoption of edible insects as an element of government strategy for rural development and agricultural diversification where applicable.

An overarching recommendation was for FAO to strengthen information sharing related to edible forest insects in general, perhaps through a regional newsletter for Asia and the Pacific.

The working groups were structured to deal only with issues surrounding the future development of edible forest insects in general, not with specific insects. Collectively, however, the workshop participants identified a list of the insects considered to be the most important as food in the Asia-Pacific region (Table 1). The workshop recommended that future research and development focus on these priority insects. Among the species listed, highest priority should be given to those that have short life cycles and are therefore most suitable for mass rearing.

Table 1. Most important edible insects of the Asia-Pacific region†

Common names	Scientific Order, genus and species‡
Bamboo borer caterpillars	Lepidoptera *Omphisa fuscidentalis*
House crickets	Orthoptera *Acheta domesticus*, *A*. spp.
Sago grubs	Coleoptera *Rhynchophorus ferrugineus*
Grasshoppers	Orthoptera *Acrydium* spp.*, Aelopus tamulus,Euconocephalus* spp.*, Patanga succincta*
Dung beetles	Coleoptera *Heliocopris bucephalus*
Cicadas	Hemiptera *Cosmopsatria* sp., *Dundulia* spp., *Pomponia imperatoria*
Giant water bugs	Heteroptera *Lethocerus indicus*
Silkworms, eri silkworms	Lepidoptera *Bombax mori, Samia ricini*
Vespa wasps	Hymenoptera *Vespa* spp. *Vespula* spp.
Weaver ants	Hymenoptera *Oecophylla smaragdina*
Bee brood	Hymenoptera *Apis* spp. *Trigona* spp.

†In no particular ranked order.
‡Does not include all possible genera/species.
Source: Workshop participants.

Bottlenecks

The conference recommendations addressed several bottlenecks to future development, which were commonly identified. First is the lack of information and research, and the need to integrate and document local knowledge that is being lost in many parts of the region. The lack of mechanisms for sharing existing information – which is often in local languages – was also recognized. Second are promotional and educational aspects. Ensuring quality and safety of edible insect products, changing perceptions and raising awareness are continuing challenges in this regard. Food regulatory issues in some countries are also potential impediments that must be taken into account. Finally, moving insect eating from a fringe subject to a mainstream strategy for rural development will require a multifaceted effort. Enhancing the acceptance of *entomophagy* in practice and as a scientific discipline will be an important first step in promoting insects as food in the Asia-Pacific region, as well as on a global scale.

Appendix 1. Internet information sources (listed alphabetically by subject)

Bureau for Exchange and Distribution of Information on Minilivestock (BEDIM). Secretariat: Mrs Goorickx Muriel. FUSA, Bibliothèque Centrale, Passage des Déportés, 2. B-5030 Gembloux, Belgium. E-mail: Goorckx.m@fsagx.ac.be Web site: http://www.bib.fsagx.ac.be/bedim

Beekeeping. Glossary of terms. http://maarec.cas.psu.edu/bkCD/glossary.html

Bee Research. International Bee Research Association. http://www.ibra.org.uk

Butterfly Farming. The Amani Butterfly Project in Tanzania. Web site details for the commercial raising of butterfly pupae. http://www.amanibutterflyproject.org

Caterpillars. Good source of general information on caterpillars, including a database, breeding, etc. http://www.saturniidae-moths.de

Centipedes. Comprehensive information on all aspects of centipedes except food use. http://www.earthlife.net/insects/chilopod.html

Edible insect candy. Butterflies, scorpions and larvae in candy; chocolate covered ants and crickets. McKeesport Candy Co., USA. http://www.mckandy.com

Edible insect snack food and candies. Hotlix Company, USA. Insects in hard candies; chocolate covered insects; fried larvae snacks. http://www.hotlix.com

Edible insects from Thailand. Recipes and other information; spiders included; numerous links. http://www.thaibugs.com

Endangered insects. To determine if an insect may be under threat, it is possible to search the Species of Conservation Concern Database of the UNEP-World Conservation Monitoring Centre. http://www.unep-wcmc.org

Entomology. Information and links on all aspects of the subject. http://www.insects.org

Entomology journals. The Entomology Society of America publishes several journals, including *Annals of the Entomology Society of America*, *Environmental Entomology*, and *Journal of Economic Entomology*. Tables of contents can be viewed at Web site. http://www.entsoc.org

(The) human use of insects as a food resource: a bibliographic account in progress. Prof G. DeFoliart's online book; nearly complete. http://www.food-insects.com

Insect candy. Kathy's Critters Co., USA. Hard candy with insects; chocolate covered insects; fried larvae snacks. http://www.insectcandy.com

Insects. Wonderful world of insects. Information on insect Orders, a glossary of entomology, societies related to insects, etc. http://www.earthlife.net/insects

Insects as food. Most comprehensive Web site for information on insects as food. Site edited by Prof. G. DeFoliart. Site partially updated in October 2006. http://www.food-insects.com

Insects in general. Web site primarily for insect collectors, but with links to broad range of related subjects from how to raise insects to insect-inspired jewelry and T-shirts. http://www.insectnet.com

International Butterfly Breeders Association, Inc. Organization has 134 active members, most in the United States. http://www.butterflybreeders.org

International Centre of Insect Physiology and Ecology, Nairobi, Kenya. Chief research activities are pest management and disease vectors. http://www.icipe.org

International trade in insects. Monitors trade in insects with particular attention to threatened species. http://www.traffic.org

Millipedes. Comprehensive information on all aspects of millipedes except food use. http://www.earthlife.net/insects/diplopoda.html

Scorpions. Current information on all living scorpions and their taxonomy. http://www.ub.ntnu.no/scorpion-files

Spiders and their relatives. Technical information on the Arachnids, including mites and ticks, spiders, tarantulas, scorpions, etc. http://www.arachnology.be

Appendix 2. Taxonomy of insects and their relatives

Phylum	Class	Order	Number of named species
Arthropoda	Insecta or Hexapoda	Odonata: darners, dragonflies and damselflies	5 500
		Orthoptera: grasshoppers and crickets	20 500
		Hemiptera: water boatmen, bed bugs, seed bugs	40,000
		Homoptera: cicadas, treehoppers and aphids	45 000
		Diptera: flies, mosquitoes, midges	120 000
		Coleoptera: beetles	400 000
		Lepidoptera: butterflies and moths	150 000
		Hymenoptera: wasps, ants and bees	130 000
		Ephemeroptera: mayflies	2 100
		Phasmatodea: stick and leaf insects	2 500
		Grylloblattodea: rock crawlers	10
		Dermaptera: earwigs	1 800
		Isoptera: termites	2 300
		Blattodea: cockroaches	3 700
		Mantodea: praying mantids	1 800
		Plecoptera: stoneflies	2 000
		Embiidina: webspinners	150
		Thysanoptera: thrips	5 000
		Anoplura: lice	250
		Phthiraptera: crab louse	3 000
		Neuroptera: lacewings and ant lions	5 000
		Megaloptera: alderflies	180
		Trichoptera: caddis flies	10 000
		Mecoptera: scorpion flies	400
	Arachnida	Araneae: spiders and tarantulas	35 000
		Scorpions: burrowing scorpions	1 300
	Chilopoda	Scolopendromorpha + 4 others: centipedes	2 500
	Diploda	Julida + 13 others: millipedes	10 000

Appendix 3. Insect terminology and definitions

Term	Definition
Adult	Insect in its final adult stage, sexually mature and typically with wings.
Apiculture	Keeping of bees for honey and other products.
Brood	Bees not yet emerged from their cells: eggs, larvae and pupae.
Bug	Insect or other creeping or crawling invertebrate; in entomology, an insect in the order Hemiptera.
Caterpillar	Elongated wormlike larva of a butterfly or moth.
Chrysalis	Pupa of a butterfly.
Egg	First stage in life history of an insect.
Entomology	Study of insects.
Entomophagy	Eating of insects.
Ethnoentomology	Applications of insect life in traditional, aboriginal, or non-industrialized societies.
Frass	Caterpillar or other larvae droppings.
Grub	Soft, thick, worm-like larvae of an insect.
Imago (pl. imagines)	Insect in its final adult stage, sexually mature and typically with wings.
Insect	Any of numerous small invertebrate animals; in entomology, insects in the class Insecta with 3 pairs of legs and 1 or 2 pairs of wings.
Larva (pl. larvae)	Immature insect after emerging from the egg; second stage in life history of many insects.
Maggot	Legless larva, especially of a fly.
Nymph	Immature growing form of an insect such as the grasshopper.
Oviposit	To lay eggs, term used especially for insects.
Ovum (pl. ova)	Egg; first stage in the life history of an insect.
Propolis	Sap or resinous materials collected from trees or plants by bees and used to reinforce the comb; also called bee glue.
Pupa (pl. pupae)	Third stage in the life history of insects like beetles.
Sericulture	Silk production, principally from the moth *Bombyx mori*.
Silkworm	Larvae of Asian moth in the genus Bombyx, and other taxa, which are the source of silk.
Worm	Naked, soft-bodied adult animal; also insect larvae, especially those that are destructive.

Appendix 4. Workshop participants

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Disgusting or delicious?

The idea of eating insects nearly always brings about an immediate reaction. While some people find the very thought of eating a beetle or other insect revolting, others smile and smack their lips, perhaps recalling the roasted grubs their mothers prepared as childhood treats or their favourite deep-fried grasshopper snack that accompanied drinks with friends.

Humans have been eating insects for millennia and, even today, the practice remains far more widespread than is generally believed. Although modern society has largely shunned insects from the dinner table, entomophagy – the practice of eating insects – is getting renewed attention from nutritionists, food security experts, environmentalists and rural development specialists.

Based on contributions from some of the world's leading experts on entomophagy, this publication highlights the potential of edible forest insects as a current and future food source, documents their contribution to rural livelihoods and highlights important linkages between edible forest insects and forest management.

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