Forest insects as food: humans bite back / Proceedings of a workshop on Asia-Pacific resources and their potential for development

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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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 There is a tendency to think of traditional habits and customs as outdated or primitive.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

Contents

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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.

[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

V.B. Meyer-Rochow[1]

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).

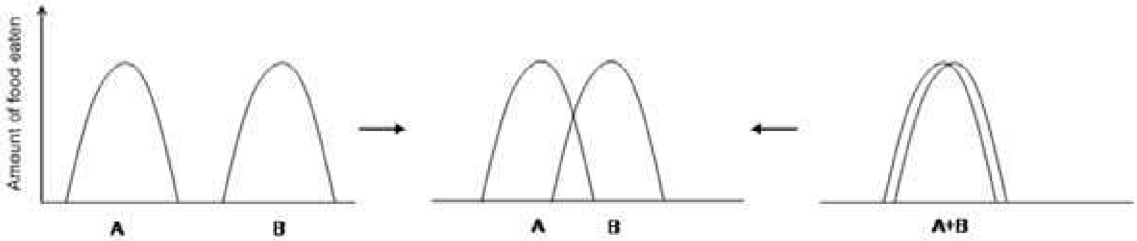

Figure 1. When two species or populations (A and B) encounter an underutilized food source, both will tend to exploit it and move towards the central situation. However, if their food preferences begin to overlap too much and both are competing for the same food (seen on the right), the tendency is reversed.

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).

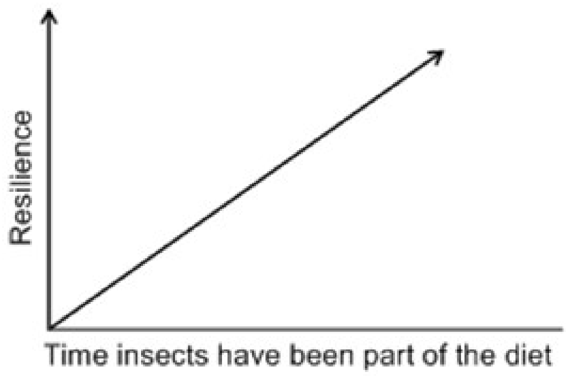

Figure 2. The resilience of a food item increases with the duration it has been part of the established diet.

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).

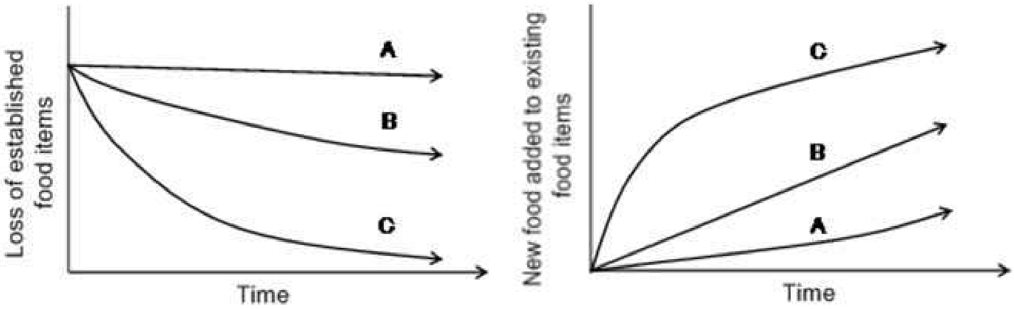

Figure 3. Left: Established food items are given up more easily by societies that are open to outside contacts (C), rather than by those that are more isolated or buffered by surrounding cultures (A). B represents an intermediate situation. Right: New food items are more readily added to existing food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

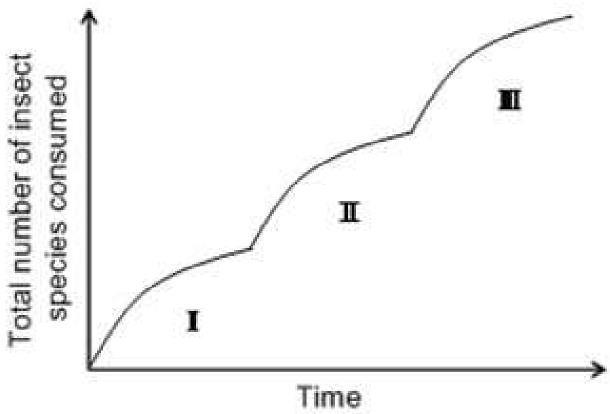

Figure 4. The first insects to be accepted as food (I) were possibly species that had a sweet taste and contained sugary substances. The second group of insects to be accepted (II) were probably fatty, lipid-containing species and finally protein-rich species (III), now constituting the bulk of edible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

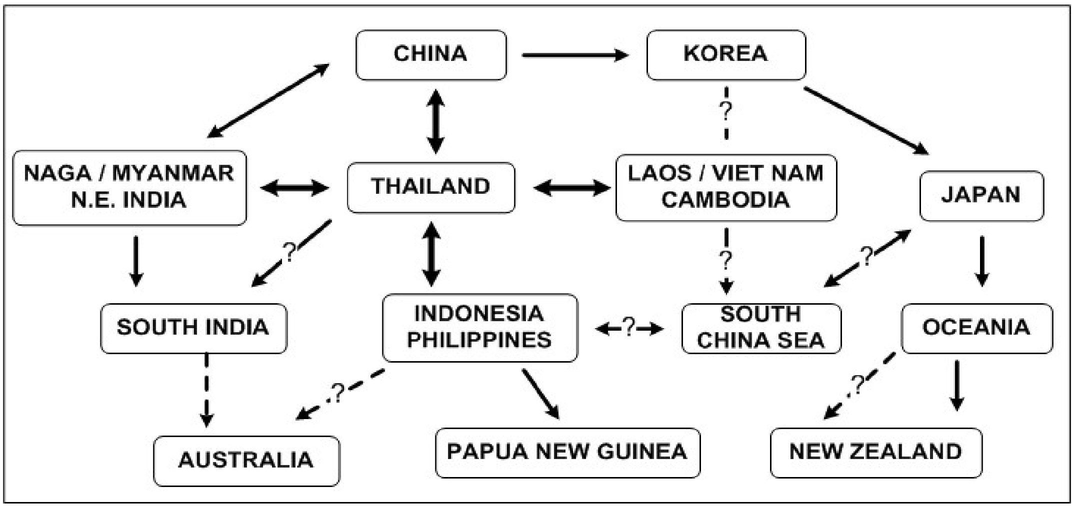

Figure 5. Regions rather than political entities are listed. Insect-eating practices clearly link the Northeast of India via Naga/Myanmar to the Thai region and Indochina. Bilateral exchanges also occurred with China. In other regions of Asia the flow of entomophagous practices seems to have been more 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).

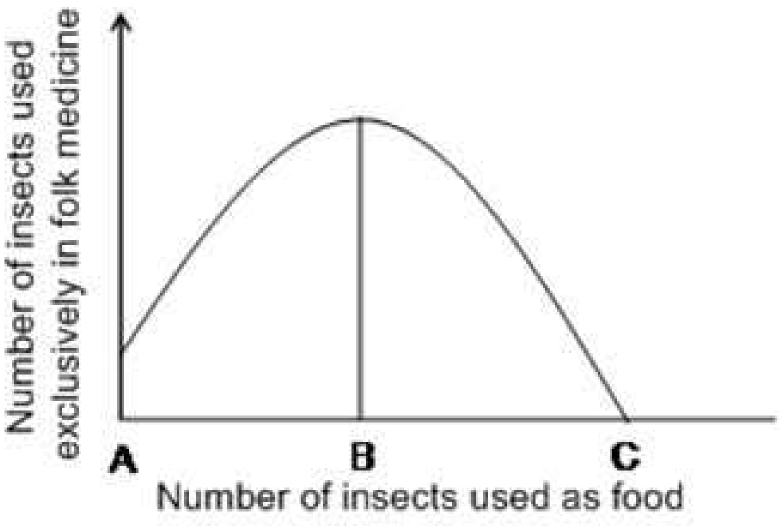

Figure 6. Assuming a culture uses all available insects as food (C), then none is exclusively used for indigenous medicinal practices. On the other hand, in cultures in which insects are no longer used as food (A), some species still find acceptance in folk medicines (e.g. for the treatment of warts,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

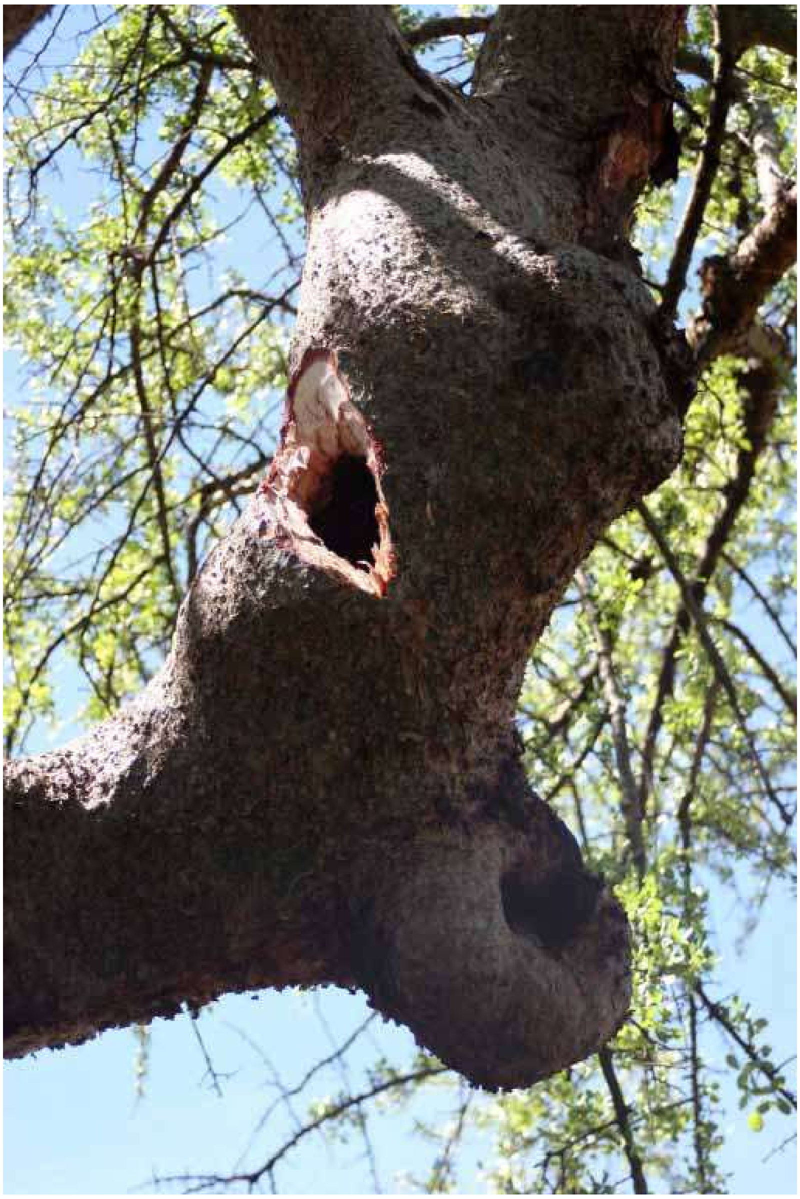

Plate 1. Bee hunting as practised traditionally is often destructive. At least the tree in this case was not cut down in its entirety (Lake Eyasi, Tanzania) *(Courtesy H. Schabel)*

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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