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Edible insects as minilivestock

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Many species of insects (probably 1000 or more) have served as traditional foods among indigenous peoples, especially in warmer climes, and the insects have played an important role in the history of human nutrition. As part of the hunter-gatherer style of life, the main criteria for selection of these traditional species appears to be medium-to-large size and easy availability, i.e., abundance, as noted by Dufour and others. Thus it is not surprising that many insects considered as crop pests in modern agriculture have served as important food sources. Locusts and grasshoppers, which often occur in swarms, are good examples, and these insects have been included in the diets of almost every culture with any history of food-insect use.

Keywords: edible insects; entomophagy; insects as food; microlivestock; minilivestock

Introduction: the nutritive value of insects

The insects (Class Insecta) are high in protein, especially in the dried form in which they are frequently stored or sold in the village markets of developing countries; some are high in fat (and thus, energy) and many are rich sources of important vitamins and minerals. DeFoliart (1992) provided a brief general overview of the nutritional quality of edible insects. Studies that provide nutrient analyses for a number of species in specific countries include Quin (1959) in South Africa, Oliveira and colleagues (1976) in Angola, Malaisse and Parent (1980) in Zaire, Gope and Prasad (1983) in India, Sungpuag and Puwastien (1983) in Thailand, Conconi and colleagues (1984) and Ramos-Elorduy and Pino (1989, 1990) in Mexico.

Domesticated edible insects

A dictionary definition of 'livestock' is 'domestic animals kept for use on a farm or raised for sale and profit'. Although insects harvested from the wild are widely sold for profit in tropical countries, very few insects meet the criterion of being domesticated. The most thoroughly domesticated insect is probably the silkworm or mulberry silk moth, *Bombyx mori* (Order Lepidoptera: Family Bombycidae). It has been cultivated for so long, 5000 years in China, that it bears little resemblance to its ancestral species and it probably would not survive in the wild state. The reared larvae are fed leaves layered in open trays and Peigler (1993) notes that 'the caterpillars of *B. mori* cling to branches poorly and would fall off if placed on a mulberry tree'. Because of the ready availability of silk moth pupae as a by-product of commercial silk production, it is not surprising that the pupae have been widely used as food and/or animal feed in nearly all of the countries of Eastern and Southeastern Asia.

There are numerous published references to the preparation, marketing and popularity of silkworm pupae. They are eaten boiled, steamed, baked, fried or roasted, depending on locality and preference. Ghosh (1924), in Burma, states: 'It was delightful to see the little children come begging for [boiled] pupae from the Indian reelers'. Hoffmann (1947) saw roasted pupae in food stalls in the silk districts of South China, and mentions that 'One gets a pleasant odor of food being cooked as he passes through a reeling laboratory'. According to Bodenheimer (1951), also in China, pupae from baked cocoons are 'more delicious' and liked better than those pickled with salt. For eating, the pupae are softened in water and then fried either with chicken eggs in the form of an omelette or simply fried with onion and sauce. Hyde (1984) noted that stir-fried pupae at a Chinese commune added a protein-rich supplement to a predominantly vegetarian diet. Canned silkworm pupae are exported from South Korea to the United States where they can be purchased in Asian food shops. The price was US $1.59 per 100 g in 1990 in Madison, Wisconsin, where, according to the shopkeeper, the pupae are a favourite of the local Korean community.

In Thailand, Vara-asavapati and colleagues (1975) state that silkworm pupae are a popular food and quite expensive in the markets. Pupae can be prepared in many ways, one of which is to fry and then grind them. The ground pupae may be included in soup, curry or other kinds of food. Watanabe and Satrawaha (1984), state that the pupae are 'very popular' in Thailand and are sold steamed for 5 baht per five scoops or 25 baht per kg. The Nutrition Division of the Thai Ministry of Public Health (1987) included silkworm pupae among the local foods that can be used in supplementary food formulae it developed for malnourished infants and pre-school children. Sungpuag and Puwastien (1983) have provided nutrient analyses (proximate, vitamins and minerals) of the pupae and for 12 other edible species in Thailand.

Kiuchi and Tamaki (1990) mention that *B. mori* pupae are fed to fish and chickens in Japan and India. Not only the pupae, but waste material from the reeling factories is used as fish food in pond fish culture in China (Hoffmann, 1947; Hyde, 1984). Even more extensively used as fish food is the waste from silkworm rearing (faeces, dead worms and mulberry leaves).

The pupae of *B. mori* have been experimentally evaluated in India and Sri Lanka as a high-protein replacement for various levels of fishmeal in poultry and egg production. Chopra and colleagues (1970) analysed 33 samples of feed ingredients from various parts of India and found that de-oiled silkworm pupae meal from Mysore (the only insect product tested) was the highest in crude protein (76.0%, with free amino acids removed) and highest in the amino acids lysine, histidine and arginine. In chick feeding trials (white leghorn up to 8 weeks of age), Ichhponani and Malik (1971) found that half of the fishmeal and half of the groundnut cake in the ration can be replaced by de-oiled silkworm pupae and corn-steep liquor (a by-product of the corn (maize) starch industry), with no reduction in final weight or feed/gain ratios. The authors pointed out that the annual production of silkworm pupae meal in India was 20 000 te and that of corn-steep fluid was 8000 te, making them significant sources of protein. Saikia and colleagues (1971) tested the effect on egg production of using several agricultural and industrial waste products in Assam as substitutes for yellow maize and fishmeal which are very costly. The experimental layer mash containing silkworm pupae cost the least, gave the lowest feed-to-egg conversion ratio, and the lowest cost per dozen eggs produced. In addition, the pupae-fed pullets (white leghorn) suffered the lowest mortality (nil), produced the largest eggs, thickest shells, light yellow yolks and were graded AA. In feeding trials in Sri Lanka, Wijayasinghe

and Rajaguru (1977) also found that silkworm pupae could successfully replace the local fishmeal in poultry rations, both for growth and egg production.

Pupae are also a food by-product from wild silk production. Peigler (1993) lists 23 species of wild silk producers belonging to the Lepidoptera families Lasiocampidae, Notodontidae, Pieridae and Saturniidae, with the last family being the most important. The pupae (or in one case, caterpillars) of at least a dozen of the species listed by Peigler have been reported as food and, considering the constant search for protein among tropical populations, it is probable that all or most of them have been so utilized, at least as animal feed. Of *Antheraea pernyi* (Lepidoptera: Saturniidae), Bodenheimer (1951) states:

> In Shantung, people of certain hilly districts cultivate [this species] on oak trees . . . the pupae are generally prepared by frying with onion and sauce, and not with eggs as is done for ordinary silkworm pupae. Since the pupae of this species are rather rare, but of large size, they are especially valued. Farmers who have these pupae may give them to their friends or relatives as a special gift.

According to Peigler (1993), thousands of acres of oak are under cultivation in China today for tussah production (the silk produced by this moth); tussah production fluctuates, but 75 000 te were produced in 1980 and 50 000 te each year from 1987 to 1989.

Another saturniid of wild silk importance in Asia is *Samia ricini*. This moth, known as the eri silk moth, has been domesticated for centuries in India, China and Japan, and Peigler (1993) says that it is so domesticated that, like the mulberry silk moth, it cannot exist in the wild state. Chowdhury (1982) reported that for the tribal peoples in Northeastern India, 'the eri chrysalid [pupa] is a delicacy and the cocoon is more or less a by-product'. The production of eri cut cocoons in Assam and six other states in Northeastern India was estimated at about 183 te in 1979. Ericulture involves about 40 000 families and is carried on as a cottage industry. Neupane and colleagues (1990) investigated the rearing biology of *S. ricini* in Nepal where ericulture is also a cottage industry, and found that six generations are produced per year when the caterpillars are grown on castor leaves. However, they do not recommend rearing during the cold months (November–April) because the life cycle requires 114–126 days for completion compared with 38–61 days from March to November. The pupae are not eaten in Nepal, but there is interest in using them as feed for poultry and pond fish. It offers a nearly ideal example of sustainable agriculture: the castor plant grows on poor soils, helping to prevent soil erosion; castor bean oil is sold for medicinal and industrial uses; excess leaves are fed to the caterpillars which produce silk and a pupa that is a high-protein food or animal feedstuff, and the caterpillar frass and other rearing residue can be used for pond fish culture.

The pupa of a third Asian saturniid, *Antheraea assamensis*, the producer of muga silk, has been experimentally investigated as a high-protein substitute for fishmeal in chick diets (Bora and Sharma, 1965). Weight gains to 4 weeks of age were not significantly different between chicks fed a basal ration +7% fishmeal (the control diet), and those fed the basal ration +4.67% silkworm pupal powder (protein content equivalent to 7% fishmeal) +2% limestone +1% bone meal. According to Peigler (1993), the Indian government is actively promoting the development of mugaculture with research aimed at producing varieties better suited for indoor rearing and yielding larger cocoons.

From among wild silk producers in the family Lasiocampidae, *Gonometa postica* pupae are a food of the Pedi in South Africa (Quin, 1959), and *Borocera cajani* pupae are used in Madagascar (DeCary, 1937). In 1894, in fact, a dish of *Borocera* pupae prepared in a

bechamel sauce (white sauce with cream) was served at an official meal in the French residence in the capital, Tananarive. According to Peigler (1993), *Borocera* sericulture is at low ebb today while *G. postica* is being studied for its sericulture potential by workers in Africa and India.

The other wild silk producers of commercial interest in Africa belong to the family Notodontidae. At least four species, all in the genus *Anaphe*, are used as food, *A. infracta, A. venata* and *A. reticulata* in Nigeria and *A. panda* in Congo, Tanzania and Zaire. In this genus, the larvae are eaten. The larvae are gregarious and the large communal nests in which they spin individual cocoons and pupate may be more than 30 cm in length. It is the silk from the bag nests that is used commercially; the larvae are collected prior to pupation. They are prepared by roasting them in hot dry white sand (Ashiru, 1988) or they may be fried dry and eaten as such or used in preparing soup just as dried lobsters are used (A.E. Akingbohungbe, Obafemi Owolowo University, personal communication, 1988). The larvae have high energy value with 611 kcal 100 g^{-1} dry weight (Ashiru, 1988). Because *A. venata* is univoltine and its host tree, *Triplochiton scleroxylon*, is an important timber species, Ashiru concludes that mass-rearing would be necessary to enhance its value as a supplementary protein source in rural areas.

A different kind of domesticated insect is the honey bee, *Apis mellifera* (Hymenoptera: Apidae). In industrialized nations apiculture is practised primarily for honey production, with other commercial products of the hive being beeswax, pollen, propolis, royal jelly and venom (used for treating people with severe sting allergies) (Schmidt and Buchmann, 1992). Throughout the tropical world, however, human populations relish not only the honey produced by bees but also the bee brood (larvae and pupae). In fact, honey bees might be thought of as the invertebrate equivalent of dairy cows, which are valued not only for their milk but also as meat.

The honey and brood of many species of wild bees are used, and some of these will be mentioned later under the family Apidae. Here, we reflect on the possibility of incorporating the brood of *A. mellifera* as a marketable product of the hive in Europe and North America, where insects are not yet generally thought of as food. Because of the uncertainty of winter survival of honey bee colonies in the Prairie Provinces of Canada (Alberta, Manitoba and Saskatchewan), the bees are killed in the fall and restocked in the spring. Hocking and Matsumura (1960) estimated that 132 te of bee brood could be harvested each year from these killed colonies. The bee pupae contain 18% protein (fresh weight basis) and are a rich source of vitamins A and D. Hocking and Matsumura report that when brood was prepared by shallow frying in butter or deep-fat frying in vegetable cooking fat and presented to a taste panel:

> Most reactions were favourable and some were eulogistic; initial prejudice proved easier to overcome than we had expected. When tasters were asked to compare the material to some more familiar foods, those most commonly mentioned were walnuts, pork crackling, sunflower seeds, and rice crispies.

DeFoliart (1989) suggested that the honey bee, because of its excellent public image, could be a valuable tool in reshaping attitudes towards insects as food in the USA. It is associated with such pleasing activities as flower-visiting, nectar-gathering, pollination, honey and candle wax production, and is super-clean compared with many of the animal foods that we eat. And, because of its enormous importance in the pollination of crops and non-cultivated plants, it possibly represented the most environmentally harmonious food

production system in the realms of agriculture. In attempting to develop colony-management practices for dual honey/brood production, several points should be kept in mind. Only the pupae and pharate or pre-pupae should be harvested because hymenopterous larvae do not void the gut contents until 2–3 days before pupation. Also, as drone pupae are three times heavier than worker pupae, research should be done to determine to what extent drone pupae production can be maximized without reducing honey production or stressing adult bee replacement. In drone foundation comb, the cells are larger than in worker foundation comb. Through 'compensatory egg-laying' the queen bee responds to whatever comb cell size is available to her, thus the proportion of drone pupae can be controlled somewhat by the proportion of drone foundation comb provided in the colony. Research is needed to develop an efficient method for uncapping the domed drone cells prior to removal of pupae from the comb. If marketing interest can be stimulated among beekeepers and honey producers' associations, already in place, research could probably soon solve the problems of harvesting, including the harvesting of capped brood.

Schmidt and Buchmann (1992) summarized several potential market demands for bee brood and discussed some of the problems in production and marketing. Noting its excellent nutritional properties, that it is higher in protein and lower in fat than beef and has no crunchy cuticle as is the case with some insects used as food, it could become an interesting high-priced gourmet delicacy. Brood has proven nutritional value in the feeding of non-human animals, particularly songbirds; thus there is a potential demand in pet and zoo animal markets. In the form of drone powder, brood has proved valuable in rearing certain insectivorous insect predators used in biological control programmes. Among the problems, methods devised so far for extracting brood from the comb are labour-intensive or destructive, and there are no established marketing techniques and networks.

Brief survey of some major orders and families

Insects reportedly used by humans as food number many hundreds, representing at least ten orders, more than 90 families and more than 370 genera, and the number actually used has undoubtedly been greatly under-reported. Space limitations permit discussion of representatives of only five of the orders and eight families. Major orders not discussed below include the Diptera (true flies), Hemiptera (true bugs) and Homoptera (cicadas, etc.). Although the term 'microlivestock' has been, and continues to be, widely used for insects exploited for food or animal feed, increasingly they are called 'minilivestock' (Hardouin, 1994).

ORDER COLEOPTERA (BEETLES, WEEVILS)

Species representing more than 100 genera in 17 families are used as food. Major families, in addition to those discussed below, include the Buprestidae (metallic woodborers) and Dytiscidae (predaceous diving beetles).

Cerambycidae (long-horned beetles)

Representatives of at least 30 genera in this family, primarily the larvae, are used as food. They are woodborers in living and dead trees, fallen logs and stumps, and have long life

cycles of a year or more. Species of *Batocera* are among the most widely eaten, being reported from Indonesia, Philippines, Sri Lanka and Papua New Guinea. Mercer (1993) mentions being offered a large cerambycid grub which appeared to be a *Batocera* sp., cooked in coconut milk as the centrepiece of a celebratory feast at Ahora, near Gona, in Papua New Guinea. He also has watched villagers in the Gabensis logging area near Lae collecting grubs of *Hoplocerambyx severus* in large numbers from under the bark of felled *Anisoptera polyandra* trees. If logs are left in the forest for any length of time, they become riddled with holes; he was able to extract nearly 100 grubs from a single log in a little more than 15 min. The high regard for these grubs is indicated by the fact that collectors from the village must climb 1000 metres to reach the logging area.

Curculionidae (snout beetles, weevils)

Species of at least a dozen genera of curculionids are used as food, but several species of *Rhynchophorus* (palm weevils) are by far the most important and widely used. The larvae are greatly esteemed. A modern cookbook on Cameroon cuisine (Grimaldi and Bikia, 1985) describes the recipe for 'coconut larvae' as "a favourite dish offered only to good friends". Coconuts at the half-hard stage are emptied of their milk, refilled with the larvae and condiments, then cooked (capped end up) in water.

The major species are *R. palmarum* in the Western Hemisphere, *R. phoenicis* in Africa, and *R. ferrugineus* and *R. bilineatus* in Southeastern Asia, Indonesia and the Western Pacific. All of these species have long been 'farmed' by indigenous peoples and are an excellent example of how harvests of edible insects from natural populations can be increased by intentional creation of additional breeding sites. Such 'semicultivation' has been reported in Colombia (Beckerman, 1977; Dufour, 1987), Venezuela/Brazil (Chagnon, 1968), Paraguay (Clastres, 1972) and Papua New Guinea (Townsend, 1970; Mercer, 1993), and it undoubtedly occurs elsewhere. Various species of palms are hosts of the weevils. The cultivation and harvest procedures vary slightly from one region to another, but, basically, palms are cut down and the logs left lying in the forest with the expectation that larvae will be ready to harvest from the decaying pith 1–3 months later. The 'heart of palm' is also an important food item in many areas and is harvested at the time the tree is felled.

Dufour (1987) reported a liveweight of 3–16 g for the grubs of *R. palmarum* and a maximum acquisition rate of 2000 g h^{-1} by the Tatuyo in Colombia. In Paraguay, among the Guayaki, the felled trees are considered private property with each man the owner of his larvae bed (Clastres, 1972). The Guayuki are a nomadic people, yet they return to the cultivation area every 2–3 months to harvest the crop of grubs. The flavour of palm larvae is almost as universally admired by Westerners as by indigenous people. Mercer (1993), who studied sago grub (*R. ferrugineus papuanus*) production near Lae in Papua New Guinea describes the flavour as 'tender and sweet with a slightly nutty flavour', and states that it is everywhere considered a delicacy and is the only insect sold regularly in local food markets. They are sold live in aerated plastic bags for 1 kina (about US $1.05) per bag containing about 40 grubs weighing 250 g. Mercer notes that the grubs are bought by both Papua New Guineans and foreigners and they usually sell very quickly.

Palm weevils are also important as destructive pests of palms and, in the Western Hemisphere, as vectors of the nematode, *Rhadinaphelenchus cocophilus*, the causal agent of red-ring disease. 'Trap logs' to attract beetle oviposition is one of the cultural control

methods recommended for use in palm plantations. In view of this, DeFoliart (1990) proposed:

> Palm worms would certainly seem worthy of wider publicizing as traditional cuisine of gourmet quality, the kind of delicacy that could be promoted as tourist and urban fare by the best restaurants throughout the tropics and subtropics, and eventually, maybe, even as an item for export. Could such wider promotion and use create more opportunities for employment and entrepreneurship in the rural countryside? Could, in fact, expanded markets provide a basis for attempting to combine increased palmworm production with more efficient recycling of dead and diseased palms, and as part of reduced-pesticide integrated pest management (IPM) programs and disease control on coconut and other palm species?

Scarabaeidae (june beetles, dung beetles, rhinoceros beetles)

The larvae and/or adults of species representing at least 30 genera are used as food. The widest use and variety of species used is in Asia. Many of the species are used as adults, and are strongly attracted to lights at night and are thus easily captured. Other species frequent and breed in animal dung or in decomposing plant materials. Vara-asavapati and colleagues (1975) note that in some villages in Thailand, signs are placed on certain dung piles to indicate that they are already 'reserved'. After collection the beetles (the adult stage is eaten) are left overnight in a bucket of water to rid themselves of the ingested dung. They are also soaked in water for 2–3 h before cooking.

Probably the most interesting group of scarabaeids is the subfamily Dynastinae or giant rhinoceros beetles, particularly the genus *Oryctes*. *Oryctes rhinoceros*, a major pest of palms, is widespread in coconut growing regions of Asia from Pakistan through Indonesia to Polynesia and other islands in the western Pacific (Bedford, 1980). It has been reported as food in India, Burma, Thailand and The Philippines. The main hosts of the adult beetles are coconut, oil and date palms. The larvae live in a wide variety of dead but not yet decomposed plant material, including the tops of dead standing coconut palms, coconut stumps and logs on the ground, and other types of decaying wood, as well as compost, dung heaps, rotting straw, rotting coconut husks, coffee and cacao pulp waste, and refuse from sugar cane factories, ricemills, sawmills and other types of agricultural processing (Bedford, 1980; Kalshoven and van der Laan, 1981). Depending on temperature, larvae complete development in 2–4 months and attain a length of 6–12 cm. *O. rhinoceros* can be mass-reared on a diet of sterilized cow dung and sawdust, supplemented with bananas (Kalshoven and van der Laan, 1981). Control of rhinoceros beetles is based on sanitation and cultural practices similar to those recommended for *Rhynchophorus* weevils, and DeFoliart (1990) has suggested that *Oryctes* might 'be incorporated into palm IPM programs, recycling an endless variety of tropical wastes into animal protein and fat'.

Three species of *Oryctes*, *O. boas*, *O. monoceros*, and *O. owariensis*, are eaten in Africa. These breed, respectively, in rotting vegetation and manure heaps (but not in rotting wood), dead standing coconut and oil palms in western Africa and in decaying coconut logs in Eastern Africa, and in dead standing oil palm, coconut and *Raphia* trunks.

HYMENOPTERA (BEES, ANTS, WASPS)

The immature stages of many species of hymenopterans are used as food by indigenous populations in Africa, Asia, Australia, South America and Mexico. They are almost universally considered great delicacies. In addition to the Apidae and Formicidae discussed below, the Vespidae (wasps, hornets) is a family of major food importance.

Apidae (bees)

Larvae and pupae, sometimes called 'grubs', are widely eaten and often are as highly prized as the honey. The Kayapó in the State of Para, Brazil, recognize 56 species of bees, mainly on the basis of ecological niche and behavioural characteristics (Posey, 1983; Posey and Camargo, 1985). Nine species, *Apis mellifera* and eight species of stingless bees (subfamily Meliponinae) are semi-domesticated or to some extent manipulated. The larvae and pupae of seven of these species (genera *Trigona*, *Oxytrigona*, *Scaptotrigona* and *Tetragonisca*) are used as food. In Mexico, *A. mellifera* and at least eight species of Meliponinae belonging to the genera *Melipona*, *Trigona*, *Partamona* and *Lestrimelita* are utilized (Conconi, 1982). The stingless bees are cultivated in small clay jars near the walls of houses and in small hollowed trunks placed so that they face East. In Colombia and Venezuela, the Yukpa are avid honey hunters (Ruddle, 1973) and two species of stingless bees, *Trigona clavipes* and *T. trinidadensis* are important sources of both honey and bee larvae or 'brood'. The importance of the former is such that the Yukpa name for it is *wano*, the term also used to describe all types of honey. The component parts of the nests are also used for various purposes.

Bees, including stingless species, are also important in Africa. Apiculture is not practised in southern Shaba in Zaire, but the average annual consumption of honey per adult living in the clear forest is estimated at 15 litres (Parent *et al.*, 1978). Although the practice has been much criticized, honey is still harvested by cutting down the tree. Villagers are very fond of the brood and it is harvested with the honey. In addition to *Apis mellifera adansonii*, which is already domesticated in other territories of Zaire, Parent and colleagues call attention to *Meliponula bocandei* as a candidate for possible domestication and local apiculture. Five species of *Trigona* are also important as a source of both honey and brood in the clear forest of Southern Shaba.

In Thailand and elsewhere in Southeast Asia, three species of wild bees, *Apis dorsata*, *A. florea* and *A. indica*, are important sources of honey, wax and brood. The nests of *A. dorsata*, a large species, may be up to two metres in diameter and are found in the higher branches of large trees (Bristowe, 1932). There may be several nests on a single tree. According to Vara-asavapati and colleagues (1975), *A. indica* hives are found in cavities of tree trunks, and those of *A. florea* in the woods on small tree branches and bamboo. Honey from *A. dorsata* is the most expensive, but that from *A. florea* is most commonly found in the markets. Honey is sold the year-round and is considered 'a wonderful medicine and dessert'. People like to eat the bee grubs uncooked, but they are also sometimes fried or put into soup.

Formicidae (ants)

Of all the edible ants, the leaf-cutting, fungus-growing ants of the genus *Atta* are among the most interesting. This genus is restricted to the Western Hemisphere. The winged females are collected as they swarm from the nest by the thousands on their mating flights during the early part of the rainy season. The part eaten is the abdomen. Two species, *A. cephalotes* and *A. sexdens* are the most widely consumed, being relished across the Northern half of South America. There is a voluminous literature on consumption of the ants in both the rural and urban areas of Brazil, and Wallace (1853) described them as 'furnishing the Indian with a luxurious repast', and, when slightly roasted with a little salt added, being 'generally much liked by Europeans'. In Colombia, Dufour (1987) noted that the female alates of *A. cephalotes* are particularly easy to collect as they leave the nest just

before dawn and can be attracted to a burning flare and caught easily in a basket. Those of *A. sexdens*, on the other hand, have colonizing flights during the day and are collected by handpicking them as they emerge from holes spread over the nest surface. Dufour found the liveweight of *A. sexdens* alates to be 0.6 g and the acquisition rate to be only 200 g hr^{-1} compared with 3200 g hr^{-1} for *A. cephalotes*. The biomass of winged females in a colony was estimated at about 3000 g (fresh weight), of which about half may be collected.

The leafcutter nest is a slightly raised bare mound measuring up to 10–15 m in diameter and with numerous entrance holes (Hill, 1983). Depth extends to 4 m underground and there are many interlinked underground chambers in which the fungus gardens, made of chewed leaf fragments and saliva, are located. More than 50% of the dry weight of the fungus is available as soluble nutrient, and the contribution of the fungus to the ants is the metabolic capability of converting cellulose into carbohydrates which can be metabolized by the ants. As commented upon by Hodgson (1955), feeding on a cultured fungus has achieved for *Atta* a preeminent position among rainforest fauna by allowing it to tap the virtually inexhaustible supply of cellulose in its environment.

The ants forage for distances up to 150 m from the nest, using a number of semipermanent trails leading from the immediate vicinity of the nest (Cherrett, 1968). Cherrett proposed, from studies on *A. cephalotes*, that a 'conservational grazing system' is practised, evening out the grazing pressure around the nest and preventing over-exploitation of the plant resources by providing periods of relief from intense grazing during which vegetation can recover. The clearing of tropical rain forest for agriculture upsets this conservational foraging strategy, concludes Cherrett. Citrus or cocoa, which are commonly planted in newly-cleared forest areas, present a greatly reduced availability of forage, thus increasing the grazing pressure per plant. As leaf-cutters keep returning to a particular tree until it is defoliated, in orchards an individual tree is more likely to be defoliated repeatedly and killed, whereas an individual tree in the forest can recover during the considerable periods between defoliations.

Although *Atta* species can be reared in the laboratory, their expansive nests and extensive foraging behaviour suggest that they cannot be mass-produced economically under controlled conditions. Also, as they are serious pests of many cultivated trees and other crops, nests at the edges of forests adjacent to cultivated areas probably cannot be tolerated. Their presence within the forest, however, and their preservation as a source of food and income for rural people appears to be another matter.

Many other ants serve as food and they are generally considered as delicacies. In Mexico, pupae of two species of *Liometopum*, known as *escamoles* are in great demand and are on the menus of urban restaurants (Conconi, 1982). They have a very delicate flavour and are served fried alone or with black butter or fried with onions and garlic. Rural people who collect *escamoles* by digging them from their underground nests sometimes earn more during the collecting season than most rural workers do during an entire year. Two species of 'honey pot' ants of the genus *Myrmecocystus* are still a sweet treat in Mexico (Conconi, 1982) as are *Camponotus inflatus* and several species of *Melophorus* among Aborigines in Australia (Conway, 1990). When collecting the ants, the nests are only partially dug up in order not to destroy them.

In Southern and Central Africa, the winged sexual stages of *Carebara vidua* are collected as they emerge from their nests after heavy rains. The females are about 2 cm long. The nests are found only in termite mounds. Known as the 'thief ant', the tiny workers enter the termite chamber through tunnels large enough for the ants but too small

for passage of termites, and carry back termite eggs and young. In South Africa, according to Quin (1959), these ants played an important role in the Pedi diet. In Asia, *Oecophylla smaragdina*, known as the red tree ant or green tree ant, is widely eaten in India, Burma, Thailand and in Papua New Guinea; all stages are consumed. In Thailand, they are made into salad, fried with eggs, or put into bamboo shoot soup (Vara-asavapati *et al.*, 1975). It is an aerial insect and any plantation or orchard crop may serve as a host. The main nest (there may also be smaller subsidiary nests) can be 20 cm or more in diameter and is constructed by sewing together with silken threads a mixture of silk, living and dead leaves (Hill, 1983). Their predation on various crop pests outweighs their own importance as an aggressive nuisance during the harvesting of fruit and latex, and colonies are sometimes intentionally established in plantations because of their biological control benefits. Obviously, in situations where the ants are not valued for their predation, their harvest for food use can function as part of IPM programmes.

ISOPTERA (TERMITES)

The most widespread use of termites is in Africa where they are a highly regarded food in practically every country south of the Sahara. They are eaten raw, fried, roasted, or prepared in other ways and are found widely in village markets. R.J. Phelps, former Professor at the University of Zimbabwe, noted to the author (personal communication, 1987) that 'many people of European background eat termites here [Harare], although not in the quantities that the local people do'. Winged termites are a rich source of fat, *M. subhyalinus* in Angola yielding an energy value of 613 kcal 100 g^{-1} (Oliveira *et al.*, 1976), and *M. falciger* in Zimbabwe a value of 761 kcal 100 g^{-1} on an ash-free basis (Phelps *et al.*, 1975).

Reports frequently fail to indicate specific identity, but species of at least ten genera in four families are used. The large winged adults (sexual forms) are collected as they emerge from the nests on their mating flights at the beginning of the rainy season. They are strongly attracted to light and this behaviour is utilized in capturing them. According to Owen (1973) in Uganda and several reports from elsewhere, termite mounds are considered private property in some areas. Soldier termites are also eaten in certain localities and the large termite queens, which can be obtained only when the colony is destroyed, are considered a rare treat.

Termitidae

The fungus-growing termites of the genus *Macrotermes* are the most widely used as food, with reported use of *M. bellicosus* in Nigeria and Congo; *M. falciger* in Zimbabwe; *M. natalensis* in Nigeria, Zimbabwe and Zaire; and *M. subhyalinus* in Angola. All have much wider distributions, *M. subhyalinus*, for example, occurring practically throughout sub-Saharan Africa from Senegal in the west to Ethiopia in the east and south to Namibia and Mozambique, being absent only from South Africa (Ruelle, 1970). Other species, also with wide distributions, have been reported from other countries.

The high termitaria of some species of *Macrotermes* are a spectacular feature of the African landscape. A colony of *M. falciger* in the Upper Shaba of Zaire may contain 2 million individuals (Malaisse, 1978). While the winged adults total only about 60 000 in such a colony they comprise 60% of the dry weight, or nearly 10 kg. Based on an average of four mounds per hectare (3–5 ha^{-1} according to Malaisse, 1974), it can be calculated that

active primary termitaria constitute a regenerative system producing approximately 80 kg ha^{-1} (fresh weight) or nearly 40 kg ha^{-1} (dry weight) per year (winged individuals only) of harvestible high-protein, high energy food.

Unfortunately, the future of the high termitaria is dark. Malaisse (1978) reports that in suburban regions and towns, although the mounds persist, their characteristic flora and fauna have been destroyed. They have become the main supplier of brick-clay and a favourable site for maize crops; they are sometimes converted into flower-beds, and near villages they are frequently opened and used as ovens. Malaisse notes that the decay of the termitaria began a long time ago, following the destruction of vegetation that increasingly resulted in a greater number of abandoned and fossil termitaria.

LEPIDOPTERA (BUTTERFLIES, MOTHS)

This is a major order with species of approximately 80 genera in 20 families used as food. For the vast majority of species, the caterpillar is the life stage consumed, although as discussed above, the pupa is used in the case of species valued as silk producers in the families Bombycidae, Notodontidae and Saturniidae. In a few cases, adult moths are eaten after removing the wings, legs and head and singeing off the scales and hairs over a fire. Food use of lepidopterans reaches its maximum in Africa where more than 20 species are consumed in some countries. In southern Zaire, for example, Malaisse and Parent (1980) found that at least 35 species are consumed, 26 of which they were able to determine taxonomic identity after rearing.

Most of the species studied by Malaisse and Parent (1980) are univoltine and show strong 'seasonality', with 20 of the species available only during March and April, corresponding to the 'late rains' in southern Zaire. Fewer species are available in other months, and none from November through January. The season of maximum caterpillar harvest varies considerably, however, from region to region in Africa, with, for example, November–January being the period of heavy harvest in neighbouring Zambia. According to Malaisse and Parent, certain villagers are very knowledgeable about hosts for the edible species and the season when each is ready for harvest. Not infrequently, a branch containing many young caterpillars of an edible species will be cut off, transported to the vicinity of the village and attached to a tree of the same species.

Malaisse and Parent (1980) analysed caterpillars of 23 species (17 Saturniidae, five Notodontidae and one Limacodidae), with samples prepared in a manner identical to that which precedes their culinary preparation, then dehydrated. Crude protein content averaged 63.5%, kcal 100 g^{-1} dry weight averaged 457, and most species proved an excellent source of iron, 100 g averaging (for 21 species analysed for iron) 335% of the daily requirement. Iron deficiency is a major problem, particularly among pregnant women, in Africa.

Saturniidae (giant silk moths)

Probably the best known of the edible African caterpillars is *Gonimbrasia belina*, the famous 'mopanie worm' which is widely eaten in southern Africa. A Botswana-based company, Albert's Mopanie Worms, with retailing centres in Johannesburg, sells the dried, pre-packaged caterpillars and turned a profit in its first year of operation in 1983 (Brandon, 1987). Another company is experimenting with grinding the dried mopanie caterpillars into a protein-rich powder. In Botswana, they can be purchased in the stores in large bags as dried caterpillars and are often roasted. They are exported by the ton to Zambia.

According to Dreyer and Wehmeyer (1982), the South African Bureau of Standards estimates annual sales of mopanie through agricultural cooperative markets at about 40 000 bags, each containing 40 kg of traditionally prepared, dried caterpillars. This amounts to 1600 te entering reported channels of commerce, but does not include those privately collected and consumed or sold. There is a mopanie worm cannery at Pietersburg in the northern Transvaal. In Harare, Zimbabwe, a newspaper reported in 1988 that mopanie had become a feature on the menus of some small city restaurants and the trend appeared to be spreading. A local company had been packaging the caterpillars for 6 years and had 90 tons of them, bought from villagers, on hand at the time.

According to Quin (1959), *G. belina* has one to three generations per year in South Africa. The caterpillars, 8–10 cm in length, grip the host plant tightly and cannot be shaken off; they must be picked by hand. A good picker in an average infestation can collect 18 kg of larvae per h. In areas where they occur in profusion and are bulk-dried they are first eviscerated, the rate of evisceration being about 7.3 kg per person per h. They are roasted for 15 min, then spread out to dry with about 43 h required for the product to become sufficiently dry for storage. According to Quin, all three methods used for evisceration are wasteful as a large proportion of fat is discarded along with the waste. The gut is removed mainly to eliminate the resin-flavoured mopanie leaves that have been ingested. Quin does not say whether it might be possible to reduce the waste of fat by starving the collected caterpillars for a few hours and curing them whole, as is done with saturniid caterpillars in some parts of Africa. Quin noted that the Pedi in South Africa greatly preferred the mopanie caterpillars to fresh beef, and when the caterpillars were available they seriously affected the sale of beef.

In several localities in Africa, efforts have been made to preserve and manage the forest resource better in order to protect the habitat of edible caterpillars. One such area is the Kwango District of Southwestern Zaire which is one of the poorest regions of the country from the standpoint of protein reserves. Caterpillars are not only an important source of protein for local consumption but also a substantial source of income. According to Leleup and Daems (1969), commercialized dried caterpillars in the Kwango District averaged 185 tons per year for the 5-year period, 1954–1958. Adding local consumption and tonnage sold privately to Bapende retailers, the dried caterpillar production was estimated at 280–300 tons per year.

Of the more than 30 species of caterpillars consumed in the Kwango and Kwilu districts, only three (all saturniid larvae) account for most of the exports. The study by Leleup and Daems (1969) was commissioned by the territorial administration to determine whether fluctuations and reduced tonnage of the most economically important caterpillars might be due to badly-timed burning (a widely used management practice in Africa). The three species all pupate underground, but the adult moths emerge and lay their eggs at different times. Although other complicating factors were involved, the investigators were able to determine optimum dates for burning that minimize caterpillar destruction. In addition to optimum times for burning, recommendations included: (i) enforce the ban on felling trees to harvest caterpillars, (ii) forbid the increasing practice of harvesting pupae, (iii) encourage resowing attempts on a massive scale by collection of eggs prior to burning, and (iv) create 'reserves' of some small wooded savannahs in which all harvest for purposes of consumption would be forbidden.

One of the three species in the Kwango study was *Cirina forda*, probably the most widely eaten caterpillar in Africa with reports from Nigeria in the west to South Africa.

A saturniid caterpillar known as *mumpa* is highly relished by local people in *miombo* woodland areas of Zambia and is undoubtedly the most important source of animal protein in the areas where it is found in abundance (Holden, 1991). A person can pick about 20 litres per day if the bush is rich in caterpillars and 7 days' picking, if all are sold, can earn the equivalent of a month's salary for a general worker in Zambia. People, including traders, travel several hundred kilometres to pick or buy the caterpillars. Foresty officials have considered the caterpillars a pest, not so much because of defoliation, but because of the damage done by people collecting them illegally in the national forests. Watchmen are hired to protect forests from this damage. Although there is a picking season regulated by opening and closing dates, usually November 15 and December 15, Holden (1991) notes that it is difficult to enforce the closing date. People find it 'very difficult to stop picking this sweet relish!' The opening date is intended to ensure that the caterpillars are large before picking, the closing date to ensure that there is enough 'seed' for next season.

Holden suggests thast caterpillar husbandry on a communal basis would not only increase the production of *mumpa*, a valuable foodstuff, but have a favourable impact on woodland management. He observed that there are very few late bush-fires in areas where the caterpillars are found. Fires late in the dry season when it is very dry and the trees have started to produce new leaves cause a lot of damage by killing trees, reducing regrowth and increasing erosion. Early burning is the best way to avoid this damage. The caterpillars provide the incentive for people to burn early, thereby protecting the caterpillars and enhancing woodland regeneration. Further, in areas where *mumpa* are now most abundant, there is not much regrown *miombo* woodland left. The bush is mostly 1–3 m high coppicing trees and bushes, and this seems an ideal environment for the caterpillars and for humans harvesting them without any cutting or climbing of trees.

ORTHOPTERA (GRASSHOPPERS, CRICKETS, ETC.)

Edible species are known in more than 50 genera in seven families. In addition to Acrididae, discussed below, Gryllidae (crickets) and Tettigoniidae (long-horned grasshoppers) are important families.

Acrididae (short-horned grasshoppers)

Edible species are known in about 35 genera. There has been increased interest by scientists and governments in some countries in recent years in harvesting pest species as food. In 1983, farmers in Thailand began collecting grasshoppers for sale as an alternative to government-sponsored pesticide spraying that was not effective. Grasshoppers have risen in price from US $0.12 per kg in 1983 to US $2.80 per kg in 1992 (Anon., 1992).

> A small farmer can earn up to US $120 per half acre – twice as much as he can from corn [and] the trade in grasshoppers averages about US $6 million per year. Because of the obvious advantages in containing the grasshopper population the Thai government publicized a number of grasshopper recipes including curried grasshopper and grasshopper sauce.

During recent grasshopper outbreaks in southern Mexico, an extension specialist from Mexico City demonstrated grasshopper recipes (Long, 1993), and freshly-prepared *Sphenarium* could be purchased in local markets for 4000 pesos, or about US $1.25 per 454 g. The grasshoppers are collected in sweep nets and placed in water for 24 h. After being drained, they are placed in boiling water for 30 min with added salt and garlic.

The grasshopper *Oxya velox*, known as *inago*, was once widely eaten in Japan. Post-war

pesticide use reduced its numbers, but stronger regulations regarding pesticide use have allowed the population slowly to increase and it is now found in supermarkets as a luxury item. Mitsuhashi (1984), noting that there are many '*inago* lovers' in Japan and that there is over-production of rice, suggests that, 'Rather than harvesting this excess rice, why not let *inago* feed on the rice so that their population will increase, thereby increasing the yield of animal protein'.

In South Africa Ledger (1987), citing experimental work with industrial vacuum cleaners, proposed that insecticide used against the brown locust, *Locustana pardalina*, could be reduced by harvesting the locusts as food and/or animal feed. As the locusts are too active and skitterish to be approached during the day, the devices would be used at night after the locusts have settled and clustered on vegetation.

Conclusion

From the foregoing discussion, it is evident that there is a great diversity and widespread use of insects as human food. For the most part, these insects are harvested from natural populations. Before insects can make a greater contribution to human nutrition, research is needed to ensure more dependable supplies through development of economically feasible methods of mass-rearing edible species and development of more and better management programmes for efficiently harvesting wild populations.

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