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AN OVERVIEW OF THE ROLE OF EDIBLE INSECTS IN PRESERVING BIODIVERSITY

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In this discussion the principle is adopted that factors tending to increase food and/or income for economically marginal rural families, while decreasing pressure for land-clearing, pesticides and intensive agriculture, will tend to favor the preservation of biodiversity and a sustainable future. The great diversity of habitats of insect species that serve as traditional foods presents an almost endless diversity of situations in which recognition and enlightened management of the food insect resource can result not only in better human nutrition but simultaneously aid in maintaining diversity of habitats for other forms of life. Approaches include: 1) Enhancing forest conservation and management by acting on the desire of local populations for protection of traditional insect foods (i.e., caterpillars in Zambia and Zaire); 2) Reducing poaching in parks and wildlife preserves by allowing sustainable use of the food insect resources by the local people (i.e., caterpillars in Malawi); 3) Reducing pesticide use by developing more efficient methods of harvesting pest species that are traditional foods (i.e., grasshoppers); 4) Increasing environmental and economic efficiency by developing dual product systems (i.e., silks and silk moth larvae/pupae, honey and honey bee brood); 5) Reducing organic pollution by recycling agricultural and forestry wastes into high-quality food or animal feedstuffs (i.e., fly larvae, palm weevils). Other relevant considerations are that some edible insect species enhance their local environment in various ways (i.e., leafcutter ants in S. America) or create additional diversity of species within the habitat (i.e., termites in Africa). Some, as shown in studies with crickets exhibit considerably higher food conversion efficiency than beef cattle when fed diets of similar quality. Finally, there is need for research on industrial scale mass-prodution of edible insects, for increased recognition of the nutritional and environmental importance of insects by national governments, and for increased involvement of Western media and academia in dispelling unfounded cultural biases in the Western World toward insects as food.

KEY WORDS: biodiversity, edible insects, entomophagy, food ecology, food insects

Insects are among the traditional foods of many cultures around the world, and they have played an important role in the history of human nutrition. They are a good source of protein, fat (and thus calories and energy), unsaturated fatty acids, important minerals such as iron and zinc, and vitamins such as thiamin and riboflavin (DeFoliart, 1992). They are sold in village markets, and a few of the favorites in urban restaurants, so they are not only a source of nutrition but a source of income for economically marginal rural populations. In approaching this subject, the precept is adopted that policies, principles and practices that tend to increase food and/or income for economically marginal rural families, and thus may decrease the pressure for land-clearing, intensive monoculture agriculture and/or pesticides will favor the preservation of biodiversity. Economic incentives are inextricably linked to successful conservation effort and are included in the ensuing discussion.

A Large Number of Insect Species, Representing Great Taxonomic Diversity, are Used as Food

Worldwide, the number of insect species used as a food probably totals well over 1000, with 20 or 30 or more species being part of the cuisine in many individual countries. These insect species represent a great diversity of habitats ranging from arid to rainforest to aquatic. The total numbers of edible insect species used in selected countries are shown in Table I. These are very conservative estimates. Only those species were counted which could be assigned, from the available published information, to a specific genus, family and order. For example, the 32 species tabulated for Zimbabwe include only six species of Lepidoptera (caterpillars) although 12 to 15 vernacular names, mostly Shona names, have been recorded for caterpillars by four different investigators in that country. For China, the total of 46 species listed in Table I includes one species each in the hymenopteran families Apidae, Vespidae and Scoliidae, but Xiaoming (1990) states that in Yunnan Province, larvae and pupae of five species of bees and wasps belonging to those three families are eaten by minority nationalities. The 27 species tabulated for Japan include only one species of Cicadidae, a

TABLE I
The numbers of edible insects reported from selected countries.

Country	Number of each taxon			
	Orders	Families	Genera	Species
Asia				
Burma	7	14	17	17
China	10	30	36	46
India	7	17	22	24
Indonesia	8	15	20	25
Japan	11	19	22	27
Philippines	6	13	17	21
Thailand	10	31	69	80
Vietnam	8	18	20	24
Australian Region				
Australia (indigenous)	7	22	39	49
Papua New Guinea	11	22	31	34
Africa/Madagascar				
Congo	7	15	25	30
Madagascar	7	15	22	22
South Africa	7	16	32	36
Zaire	5	21	47	62
Zimbabwe	7	14	25	32
Western Hemisphere				
Brazil	7	14	19	23
Colombia	8	20	36	48
Mexico	10	42	99	136*
USA (indigenous formerly)	10	27	53	69

* Now known to total more than 200 species.

fried cicada (*Graptopsaltria nigrofasciata*) known as *semi*, which is found on menus of a type of restaurant that specializes in foods of the Japanese Alps (Pemberton and Yamasaki, 1995). On the other hand, Remington (1946) stated that among the very popular foods eaten in Japan are all species of Cicadidae. Some countries which obviously use as many edible insect species as those countries in Table I are not included because of inadequate taxonomic information for placement in the table. For example, one observer in Cameroon stated that (in addition to other insects consumed) 21 species of caterpillars are eaten by the Pangwe of southern

Cameroon; a worker in Zambia gives 18 vernacular names of caterpillars consumed in that country.

The Number of Insect Species used as Food has Been Greatly Under- reported for Most Countries

Despite the totals shown in Table I, more field studies supported by expert taxonomic input are needed before we will begin to fully appreciate the number and taxonomic diversity of insects used as food. The taxonomic identity of fewer than 20 species was known in Mexico prior to the early 1970s when Ramos-Elorduy (formerly Conconi) launched her intensive studies. Her studies, published in a long series of papers (see Conconi *et al.*, 1984, for example), have revealed the use of more than 200 edible species in various parts of Mexico. Similarly, the intensive study of edible caterpillars in southern Zaire by Malaisse and Parent (1980) more than doubled the number of edible species with known taxonomic identity in that country. Marais (1995) in Namibia has noted that "different tribes and ethnic groups in the same environment do not necessarily make use of the same resources."

The findings in two studies conducted in Colombia, are compared in Table II; the first by Ruddle (1973) on insect foods of the Yukpa in the northeastern part of the country, the second by Dufour (1987) on insect foods of the Tukanoans in southeastern Colombia. Samples from both studies were examined by taxonomists at the U.S. Department of Agriculture's Insect Identification Laboratory, Beltsville, Maryland. The results suggested that at least 25 species are included in the diets of the Yukpa and at least 20 species are used by the Tukanoans, but there was virtually no overlap in species recorded from the two areas. Wide departures are evident, for example Ruddle finding seven or more species of grasshoppers used by the Yukpa while Dufour did not observe grasshopper use by Tukanoans. Conversely, Ruddle did not observe use of termites, while Dufour observed the use of three species of termites. The only overlap occurred in the Formicidae where the leafcutter ants, *Atta* spp., reported by Ruddle undoubtedly include one or more of the three species of *Atta* reported by Dufour.

TABLE II

Comparison of edible insect species used by the Yukpa in northeastern Colombia (Ruddle 1973) and by the Tukanoan (Tatuyo) in southeastern Colombia (Dufour 1987).

Taxons	Yukpa (Ruddle)	Tukanoan (Dufour)
COLEOPTERA (beetles, weevils)		
Bruchidae	*Caryobruchus* spp.	
Buprestidae		*Euchroma gigantea*
Cerambysidae		*Acrocinus longimanus*
Curculionidae	*Anthonomus* spp.	*Rhynchophorus* spp.
Passalidae		Genus?
Scarabaeidae	*Podischnus agenor*	*Megaceras crassum*
HYMENOPTERA (ants, bees, wasps)		
Formicidae	*Atta* spp.	*Atta cephalotes* *Atta laevigata* *Atta sexdens*
Meliponidae	*Trigona clavipes* *Trigona trinidadensis*	
Vespidae	*Mischocyttarus* spp. *Polistes canadensis* *Polistes pacificus modestus* *Polistes versicolor* *Polybia ignobilis*	*Apoica thoracica* *Poliybia rejecta* *Stelopolybia angulata*
LEPIDOPTERA (caterpillars)		
Hesperiidae		Genus?
Lacosomidae		Genus?
Noctuidae	*Laphygma frugiperda* *Mocis repanda* Genus? (2 spp.)	Genus?
Notodontidae		Genus?
Saturniidae		Genus?
ORTHOPTERA (grasshoppers)		
Acrididae	*Aidemona azteca* *Orphulella* spp. *Osmilia flavolineata* *Osmilia* spp. *Schistocerca* spp. *Tropidacris latreillei*	
Tettigoniidae	*Conocephalus angustifrons*	
DIPTERA (fly larvae)		
Stratiomyidae	*Chrysochlorina* spp.	

(Continued)

TABLE II (*Continued*)
Comparison of edible insect species used by the Yukpa in northeastern Colombia (Ruddle 1973) and by the Tukanoan (Tatuyo) in southeastern Colombia (Dufour 1987).

Taxons	Yukpa (Ruddle)	Tukanoan (Dufour)
ISOPTERA (termites)		
Termitidae		*Macrotermes* sp. *Syntermes parallelus* *Syntermes snyderi*
NEUROPTERA (dobsonflies, etc.)		
Corydalidae	*Corydalus* spp.	
TRICHOPTERA (caddisflies)		
Hydropsychidae	*Leptonema* spp.	

The Desire by Local Populations for Protection of Traditional Food Resources is Favorable for Good Forest Management

In Zambia, late burning during the dry season (when it is very dry) can severely damage regeneration of the *miombo* woodland that dominates the country. Some trees are killed, regrowth is reduced and erosion is increased. The best way to prevent this damage is by early burning. In part of this territory, there is a saturniid caterpillar (called *mumpa* in the local language) which is a highly appreciated relish and is important both as a source of nutrition and source of income. The *mumpa* caterpillars feed on *Julbernardia paniculata* and several other common trees in the *miombo* woodland. One person can pick about 20 liters per day if the bush is rich in caterpillars. Seven days' picking will earn, if all are sold, the equivalent of a month's salary for a general worker in Zambia. It is not strange, therefore, that people travel 200–300 km to pick caterpillars, and traders come from Lusaka and the Copperbelt (900 km) to buy the foodstuff and then to sell it at a much higher price on their return.

In 1985, an agroforestry researcher, Stein Holden (1991), noticed that there were very few late bush-fires in the areas where the *mumpa* caterpillars are found. In fact, on one occasion when Holden was traveling with Zambian companions in caterpillar territory and a late bush-fire was seen, his companions said,"A stupid guy has put it on fire, he wants to destroy our caterpillars."

In areas where the *mumpa* caterpillars are found, the people are careful to burn early to protect the caterpillars. The caterpillars provide the incentive for people to burn early, thereby protecting the caterpillars and enhancing woodland regeneration.

In another example, several years earlier, in Zaire, a territorial administration in the Kwango District of southwestern Zaire commissioned a study (Leleup and Daems, 1969) to determine whether fluctuations and reduced tonnage of the most economically important caterpillars might be caused by badly timed burning. Optimum times for burning that would minimize caterpillar destruction were determined. One of the species involved was *Cirina forda*, one of the most widely eaten caterpillars in Africa. In addition to optimum times for burning, recommendations from the study included: 1) enforce the ban on felling trees in order to harvest the caterpillars; 2) forbid the increasing practice of harvesting pupae; 3) encourage resowing attempts on a massive scale by collection of eggs prior to burning; and 4) create reserves of some small wooded savannas in which all harvest for purposes of consumption would be forbidden.

Opening National Parks and other Wildlife Preserves to Controlled Sustainable use by Local Populations can Reduce the Problems of Poaching

A study conducted in Malawi's Kasungu National Park (2316 km^2) and in human settlements adjacent to its eastern boundary (Munthali and Mughogho, 1992) demonstrates the advantages of introducing economic incentives that integrate biological conservation with economic development for the rural people. Prior to the study, management practices for Kasungu and other protected areas stressed non-consumptive utilization through ecotourism and law enforcement. For neighboring rural people, however, most of them families and their descendents who were resettled outside the Park when it was established in 1930, outdoor recreation is of low priority in their hierarchy of needs, and the cost of entry to parks and reserves is more than they can afford. Further, as the money from ecotourism goes into the central treasury, rural people view the management policies as favoring the most affluent rather than addressing their own socio-economic dependence on wildlife. They manifest their antagonism through illicit encroachment into protected areas.

In 1990, Malawi's Department of National Parks and Wildlife allowed 173 families (about 10% of all households around the Park) to harvest caterpillars in the Park, and simultaneously initiated modern bee-keeping in the Park in order to diversify the rural communities' income base and to win their support for wildlife conservation programs. The caterpillars involved are two species of emperor moth (Saturniidae), *Gonimbrasia belina* and *Gynanisa maia*, which occur abundantly, the larvae being in season from about mid-October to December every year. Formerly, 100% of families practiced beekeeping and utilized saturniid caterpillars and other products of the forest such as game animals, small mammals, medicine, mushrooms, firewood and poles. Now, only 33% practice beekeeping outside the Park, the main reason given by those who do not, being lack of bee forage. Caterpillars are non-existent outside the Park because of the absence of forage tree species. According to the investigators, extensive agriculture (tobacco estates, and maize, beans and ground nuts grown by smallholder farmers for subsistence and cash) is the main cause of the rapid dwindling of Malawi's rich biodiversity, even though 22% of its total area is legally protected as national parks, wildlife and forest preserves.

It was found during the study that significantly greater caterpillar yields were obtained from plots that were burned early every year (similarly to the situation in Zambia), followed by no burn and with lowest yield from late burn which obviously is destructive to the eggs and larvae as well as the foliage on which the caterpillars feed. Yields also varied significantly with forage tree height, with highest yield from height class 1–3 meters. The authors therefore recommend a rotation burning policy that promotes both good caterpillar yield and vegetation coppicing with more stems in the 1–3 m class. This height class has the added advantage that it puts the caterpillars within easy reach for harvesting. Relative to beekeeping productivity, both honey and wax yields were found to ascend from years 1 through 5, then decline, thus requiring modest investments in new hives and other equipment in year 1 and after the fifth year.

Munthali and Mughogho (1992) used gross margin analysis (defined as output minus the variable associated costs expressed in money terms) as a measure of each enterprise's economic efficiency. Caterpillars and beekeeping had more than twice to several times the gross margin values of maize, beans and ground nuts. These wildlife-based enterprises not only produced earnings that exceed those from agriculture, but they did not directly compete for labor with the existing agricultural enterprises. Most families affirmed that they would have time to practice beekeeping and/or to harvest caterpillars even during crop season. Of added importance, of the small-holder families in the study area, 50% run out of food stocks by November, which is, coincidentally, when caterpillars and honey are in season.

Munthali and Mughogho (1992) conclude that the utilization of honey and caterpillars by the rural people in the Park is an important turning point in the history of wildlife management in Malawi. While taking full cognizance of the Park's primary purpose of preserving the country's representative biotic communities, they indicate that "The DNPW needs to take full advantage of the rural people's willingness to be allied with wildlife management programmes and consolidate it through the validation of sustainable land use practices."

Reducing Pesticide use by Harvesting Pest Species that are Traditional Foods

According to Pemberton (1994), rice-field grasshoppers, primarily *Oxya velox*, called *metdugi*, were formerly a common food ingredient in Korea, but their use as food declined as insecticide use increased during the 1960s and 1970s. *Metdugi* ceased being found in the Seoul markets whereas silkworm pupae (*Bombyx mori*) are almost always present. In Chahwang Myun (a district in Sanchung County) insecticide spraying began to decline in 1981, allowing *metdugi* populations to begin increasing. In 1982 some *metdugi* began to be collected and sold again in the local market at Sanchon.

Pemberton states: "The decline in insecticide use and the desire of some Koreans to eat pesticide-free rice led to the development of organic rice farming in Chahwang Myun. This was economically viable because the yields of rice were the same in unsprayed fields as in sprayed fields, and organic rice sold (and still sells) for higher prices." In 1989, the Chahwang Agricultural Cooperative began buying dried *metdugi* from farmer-collectors. In 1990, more than 600 families sold 1744 liters of *metdugi* to the Cooperative at 5000 Won per liter (US $6.98). The Cooperative sold them for 6500 Won per liter (US $9.08); much of the 1990 sale went to a supermarket company in Pusan which divided the *metdugi* into 0.2 liter packages and sold these for 3000 Won (US $4.19). By 1992 the Cooperative was paying US $9.91 per liter for *metdug*i and selling it at bulk rate for US $12.03 per liter. In addition to selling to the Cooperative, farmers sell *metdugi* at the local five-day markets (open one day every five days) and on the street.

Metdugi are most commonly collected by older women, and usually from mid-October to early November. The collected *metdugi* are steamed or boiled, then dried in the sun for one day and in a room for two more days. As to food preparation of dried *metdugi*, they are sometimes eaten dried without seasoning, but they are usually pan-fried with or without oil after the legs and wings have been removed. Pemberton describes further preparation as follows: "During or after cooking, they are flavored with sesame oil and salt, or sesame oil and sugar, or soy sauce with or without sugar. I have also seen live ones fried whole. These turn red like shrimp as they cook. Many of these preparations produce a product with good snack food essence. They are bite-sized, crispy, crunchy, and salty and/or slightly sweet...." According to Pemberton, many Koreans consider *metdugi* to be a health food, and, for older Koreans, it brings nostalgia—a taste of the past.

A one-liter package of *metdugi* purchased from the Cooperative was found to consist of three species, *Oxya velox* (84.5%), *Oxya sinuosa* (14.8%) and a single *Acrida lata*, a large species not expected to be found in *metdugi* although it is one of the species eaten in Korea.

According to Litton (1993), grasshoppers are a favorite food in many parts of the Philippines and therefore they are not sprayed with chemical insecticides. They are also fed to chickens raised on pasture. These pastured chickens are not fed commercial feed; they have a delicious taste and are sold at a much higher price than chickens which are fed commercial feed. Insecticidal sprays were used recently, however, during a 1993–1994 outbreak of *Locusta migratoria*, although with little success according to Philippine newspaper accounts (DeFoliart, 1995a). A movement began in some areas, apparently partly farmer-instigated and partly government-instigated, to harvest the insects for sale as food for humans and as animal feed supplements, primarily for cattle and fish (tilapia). Some farmers began using commercially available nets to catch locusts, and netting to provide protective cover for high value crops. In Nueva Ecija, the provincial board appropriated additional funds to pay for locusts caught by residents in affected towns. According to one report, "Locusts are selling like hotcakes in San Antonio where the insects are considered a gourmet's delight." In Zambales, the locust task force sponsored a locust cooking contest among housewives. In some areas, however, there was criticism that lack of community involvement by some local government officials hampered the campaign to harvest locusts for use as food and feed.

In Thailand, "Deep-fried, crispy grasshoppers are very well-liked by a lot of people" (Vara-asavapati *et al.*, 1975). According to Gorton (1988), villagers in northeast Thailand have been able to stem the insect damage to crops by "turning foe into food," a notable example being the grasshoppers or "flying shrimp" which feed on corn seedlings, sugarcane, rice and banana leaves. Government spraying programs involving "massive amounts of chemicals" became less and less successful while "being expensive and hazardous to health." Villagers sometimes ate insects dead from pesticides, and as recently as 1986, there were stories of villagers dying or being seriously injured by chemicals ingested along with the insects. "Large cross-province shipments of grasshoppers killed by pesticides, then fried to a crisp in cooking oil were a lucrative business for some." Gorton reports that, as a result of information from news reports and health officials, some districts and villages gave up the spraying in favor of grasshopper catching competitions. Health and culinary experts gave demonstrations on the best way to clean and prepare the grasshoppers. Gorton notes that, "Those who can catch the insects in mass quantity are able to sell them on the village roadside or become involved with the lucrative 'export' trade to Bangkok."

Similarly, the November 13, 1983 edition of the *National Review*, published in Bangkok, described a campaign launched by local officials in which villagers in the Province of Prachinburi collected more than 10 tons of pest grasshoppers for use as food. The program was launched because chemical control efforts had been unsuccessful. The article stated: "Fried and crispy grasshoppers are, according to many people, delicious snacks and many food shops in Prachinburi and other provinces served them for their customers. For beer and whiskey drinkers, fried grasshoppers are marvelous. Grasshoppers have now become one of the exporting items of Prachinburi which has a long list of orders from traders who buy them at six baht a kilo… Grasshoppers have become a favorite dish for many people…"

Anon. (1992) described the Thai grasshopper-collecting initiated in 1983 in more precise economic terms. The price of grasshoppers rose from US 12 cents per kg in 1983 to US $2.80 per kg in 1992. At local restaurants, once they are deep fried, they cost about US $6/kg. A small farmer can earn up to US $120 per half-acre, twice as much as he can from corn. The trade in grasshoppers now averages about US $6 million per year. Because of the obvious benefits in containing the grasshopper population, the Thai government has publicized a number of grasshopper recipes.

Multiple-Product Food Insect Systems can Increase Economic and Environmental Efficiency

The silkworm or mulberry silk moth, *Bombyx mori* (Lepidoptera: Bombycidae), furnishes an edible byproduct, the pupa, that has long been considered a food delicacy in many parts of Asia. In some countries it has also been used as a high-protein animal feedstuff, especially in pond fish culture. In addition, there are more than a dozen species of "wild silk" producers in Asia and Africa (Lepidoptera: Lasiocampidae, Notodontidae and Saturniidae) from which the pupae (or in one genus the larvae) likewise are available as a food byproduct (DeFoliart, 1995b). For the tribal peoples in northeastern India, the pupa of the eri silkworm, *Samia ricini,* is so highly regarded as a food delicacy that the cocoon is regarded more or less as a byproduct (Chowdhury, 1982). Ericulture is carried on as a cottage industry involving about 40,000 families (Peigler, 1993). It is also a cottage industry in Nepal, and although the pupae are not eaten, there is interest in using them for feed for poultry and pond fish.

Neupane *et al.*, (1990) investigated the rearing biology of *S. ricini* in Nepal and found that six generations per year are produced when the caterpillars are grown on castor leaves, although rearing is not recommended during the cold months, November to April, because the life cycle is much longer. This species is an excellent example of a multiple-product insect and of sustainable agriculture practice. The castor plant grows on poor soils, helping to prevent 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.

Honeybees (Hymenoptera: Apidae) are another multiple-product insect group. In addition to their immense importance in pollination, modern products of the hive include honey, beeswax, pollen, propolis, royal jelly, venom (for treatment of severe sting allergies) and brood (larvae and pupae). The brood is not only relished as food in many indigenous cultures, but has proven nutritional value in the feeding of non-human animals, particularly songbirds. In the form of drone powder, brood has proven valuable in rearing certain insectivorous predators used in biological control programs (Schmidt and Buchmann, 1992).

Apis mellifera is by far the most widely distributed honeybee, but three species of wild *Apis*, *A. dorsata, A. florea* and *A. indica* are important sources of honey, wax and brood in southeast Asia. Elsewhere, many species of stingless bees (subfamily Meliponinae) are important. In Mexico, the honey and brood of *A. mellifera* and at least eight species of Meliponinae belonging to the genera *Melipona, Trigona, Partamona* and *Lestrimelita* are used as food. The stingless bees are cultivated in small clay jars kept near the walls of houses (Conconi, 1982). Nine species, *A. mellifera* and eight species of stingless bees are semi-domesticated or to some extent manipulated by the Kayapo in the State of Para, Brazil who recognize 56 species of bees mainly on the basis of ecological niche and behavioral characteristics (Posey, 1983; Posey and Camargo, 1985). The brood as well as the honey of seven of the manipulated species (genera *Trigona, Oxytrigona, Scaptotrigona* and *Tetragonisca*) are used as food. Bees, including stingless species, are also important in Africa. Although apiculture is not practiced in southern Shaba in Zaire, villagers are very fond of the brood and it is harvested with the honey. In addition to *Apis mellifera adansonii* which is domesticated elsewhere in Zaire, Parent *et al*., (1978) 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.

It has been suggested that *Apis mellifera*, because of its good public image, might be a valuable tool in reshaping attitudes toward insects as food in the U.S. (DeFoliart, 1989). Initially, at least, honey producers' associations could provide a ready-made marketing network. DeFoliart (1995b) has discussed the advantages of drone pupae production, but research would be needed to develop efficient harvest procedures.

Reducing Organic Pollution by Recycling Agricultural and Forestry Wastes Directly into High-Quality Food or Animal Feedstuffs

Throughout the tropics, palm weevil larvae (Curculionidae: *Rhynchophorus*) are widely regarded as a delicacy. There are three major species, *Rhynchophorus palmarum* in tropical America, *R. phoenicis* in Africa, and *R. ferrugineus* in Asia. Indigenous people have long "farmed" the larvae, collecting them from palm logs and felling palms in the knowledge that larvae would develop to harvest size within two to three months. Mercer (1994) has described in detail the present-day production of sago grubs (*Rhynchophorus ferrugineus papuanus*) in Papua New Guinea. These insects are damaging pests of palms, and in the Western Hemisphere, *Rhynchophorus* is the vector of the red-ring disease nematode, *Bursaphelenchus cocophilus*. Although insecticides have been used for control, emphasis is on cultural methods including elimination of breeding sites by reducing physical injury to palms, control of *Oryctes* beetles, destruction of infested, injured or decaying trees, and trapping of adult weevils (Hill, 1983).

In view of the above, DeFoliart (1990) discussed the use of trap logs for increasing larval production and proposed: "Palmworms 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 of 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?"

Although not as universally admired as palm weevils, palm rhinoceros beetle larvae (Scarabaeidae: mainly genus *Oryctes*) are widely eaten by indigenous populations in Asia and Africa. Cultural methods similar to those for *Rhynchophorus*, biocontrol methods, and insecticides have been recommended for control. In reference to control, Bedford (1980) states that although there is unanimity in advocating the destruction of breeding sites, "the methods are laborious, expensive, unpopular, and frequently ignored." In Western Samoa, dead coconut trunks were dumped into the sea, in Malaysia and the Ivory Coast they were cut into lengths and stacked for burning, while in Indonesia burying rather than burning was suggested. It should be mentioned that *Oryctes rhinoceros*, widely distributed in Asia and the Western Pacific, breeds not only in standing dead coconut palms, stumps and logs on the ground, but in other types of decaying wood, compost, dung heaps, rotting straw, rotting coconut husks, coffee and cacao pulp waste, and refuse from sugar cane factories, ricemills, sawmills, and other wastes from agricultural processing. Considering the similarity in cultural methods, it seems possible that *Oryctes* could also be incorporated into palm IPM programs, recycling an endless variety of tropical wastes into animal protein and fat.

In situations where poultry and other animal manures are not usable as fertilizer in the immediate vicinity where produced, their disposal poses problems of odor, fly production (which may require insecticide use) and N contamination of soil and water. Various fly species, especially the house fly, *Musca domestica*, (Diptera: Muscidae), have received experimental attention for their ability to recycle these manures into useful feed products for poultry and livestock. To reduce the scope of the subject, further discussion here is limited mainly to poultry.

A chicken ranch with 25,000 caged layers produces 2500 kg of wet manure per day or 912.5 tons per year (El Boushy, 1991). Dry poultry manure is not, of itself, recyclable as a good feedstuff for poultry because of its low energy and high content of uric acid and non-protein nitrogen, neither of which can be utilized by monogastric animals. The true magnitude of the problem is indicated by the fact that in high production areas such as Georgia, USA, 60,000 hens per house (caged layers) is the preferred house size and most farms have several such houses (Sheppard, 1992). House fly (*M. domestica*) pupal meal produced by biodegradation of poultry manure has been shown in numerous studies to be of high protein quality when fed to chicks (Teotia and Miller, 1973, 1974, and others). In addition, digestion of the manure by larvae reduces its water content and converts it into an odorless, loose, crumbly product that can be easily dried and used as a soil conditioner (Calvert *et al.,* 1970, Miller *et al.,* 1974, and others).

According to El Boushy (1986), poultry in the developing countries produce about 40.3 million metric tons of manure per year (about 26.2 million tons of it from layers and 14.1 tons from broilers). With house fly pupae, based on a yield of 3.2%, a metric ton of manure can be converted to 32 kg of high-protein feedstuff. The 40.3 million metric tons per year could thus be converted to 1.3 million tons of fly pupae. El Boushy (1991) suggests increased consumption of poultry as poultry meat is most palatable and broilers are fast-growing, reaching a weight of 1.5 kg in 7 weeks with a food conversion of 1.8. The total volume of broiler meat produced in developing countries is estimated to be 7 million metric tons per year, providing an estimated consumption of 3 kg per capita per year. El Boushy advocates the development of local industries, as opposed to home slaughter, partly because of better utilization of byproducts such as manure and offal, leading to the establishment of secondary rural industries. As, unfortunately, no practical large-scale method of separating the pupae from the digested manure residue has yet been found, El Boushy (1991) proposed that the most practical procedure is to produce a mixture of pupae and manure residue, thus upgrading the latter to reasonable feedstuff quality.

Studies in Georgia, USA, using the soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae), appear to have solved the problem of efficient harvest of pupae from manure under caged layers (Sheppard, 1992, Sheppard *et al.*, 1992). This non-pest species is proving to be an excellent manure management agent that can produce large quantities of high-quality animal feedstuff, almost completely prevent house fly development and reduce manure residue volume by 50%. Prepupal soldier flies are self-collected as they crawl out of the manure basin seeking pupation sites. They crawl up a 40° slope on one wall of the basin, into a 1/2-inch slit in a 15 cm diameter PVC pipe at the top of the slope, then crawl to a container at the end of the pipe (in the experimental facility, they negotiated a 12-meter length of pipe). The authors estimate that the value of the dried larval feedstuff produced, savings in the costs of insecticide and manure removal and surface application would net a small 20,000 hen egg producer an extra US $7,360. They state that the system should easily adapt to swine waste management, and that soldier flies could be used to degrade many other organic wastes.

In E1 Salvador, Larde (1989, 1990) has conducted a series of studies on the use of fly larvae to recycle coffee pulp which is a noxious waste product with an offensive odor. Although up to 85% of the pulp is disposed of efficiently, the remainder produces flies and other insects and is thus a sanitation problem during the processing season. To avoid this, the pulp is covered with soil, lime, ash, or coffee shells (another byproduct of processing), or sprayed with insecticides or buried in excavations. The two most promising species are *Ornidia obesa* (Syrphidae) and *H. illucens*, but so far, larval yields have been low, mainly because of the formation of anaerobic zones in the pulp beds. Better ventilation of the substrate will be necessary to prevent this problem. According to the author, banana wastes are among other residues that might successfully be used for larviculture of these two species. Relative to larviculture, the size of *O. obesa* and *H. illucens* compared to *M. domestica* is an advantage, i.e., 247 mg, 204 mg, and 11 mg, respectively, on a dry weight basis.

Additional Factors and Considerations

- *Edible insects not only occupy a great diversity of habitats, some create additional habitat diversity.* Termites of many species are widely eaten in Africa. The high termitaria in Shaba in southern Zaire average 3–5/hectare and may cover 4.3 to 7.8% of the *miombo* woodland (Malaisse, 1974). The vegetation of the termite mounds is characteristic and quite different from that of the surrounding *miombo*. The termite hill flora numbers more than 200 species in both Zambia and southern Zaire but differs significantly from one region to another (Malaisse, 1978). Malaisse points out that three species of edible saturniid caterpillars, *Tagoropsis flavinata*, *Urota sinope* and *Gonimbrasia zambesina*, feed only on Shaban termite hill plants. Three other species that feed on termite hill plants also feed on other *miombo* plants.
- *Edible insect species enhance local environments in a variety of ways.* There are many examples, but probably none on a more massive scale than the leafcutter ants (genus *Atta*) of the Western Hemisphere. Two species, *Atta cephalotes* and *A. sexdens* are the most widely consumed, being relished across the northern half of South America. Colonies usually start in a forest clearing, made, for example, by a fallen tree. The leafcutter nest is a slightly raised bare mound up to 15 m in diameter and 4 m in depth (Hill, 1983), with many underground chambers in which the fungus gardens, made of chewed leaf fragments and saliva, are cultured. The fungus converts cellulose into carbohydrates which can be metabolized by the ants, and, as commented upon by Hodgson (1955), achieve 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 nest (Cherrett, 1968). In rainforests their actions remove about 15% of leaf production,

but they turn over and aerate large quantities of soil (Moffett, 1995).

The leafcutters are serious pests of many cultivated trees and other crops but Cherrett (1968) proposed that, within the forest, a 'conservational grazing system' is practiced which evens out the grazing pressure around the nest and prevents over-exploitation of the plant resources by providing periods of relief from intense grazing during which vegetation can recover. The clearing of tropical rainforest upsets this conservational foraging strategy. 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. Repeated defoliation may kill the plant.

- *Some edible insects exhibit high food conversion efficiency.* The food conversion efficiency of insects varies widely depending on species and type of food consumed (e.g., forbs, grasses, woody plant herbage, wood, organic wastes, etc.) (Slansky and Rodriguez, 1987). Nakagaki and DeFoliart (1991) estimated the food conversion efficiency of the cricket, *Acheta domesticus*, when kept at a temperature of 30°C or higher and fed the high-quality diets used to bring conventional livestock species to market condition, to be about twice as high as those of broiler chicks and pigs, 4 times higher than sheep and nearly 6 times higher than steers when losses due to dressing percentage and carcass trim were taken into account. High fecundity increases the advantage in favor of the insect. Female crickets lay an average of 1200 to 1500 eggs over a period of 3–4 weeks. By comparison, in beef production four animals exist in the breeding herd per market animal produced, thus giving crickets a true food conversion efficiency some 20 times better than for beef.

The Need for Research on Mass-Production of Edible Insects

The widespread use of insects as traditional foods, the diversity of substrates (some of them of low quality) which the insects use as food, and the high food conversion efficiency of some insects when they are fed high-quality diets, when wedded to the idea of industrial-scale mass-production (e.g., Kok, 1983, Kok *et al.*, 1988) offers the possibility of tremendous impact by insects in meeting future world food needs without additional acreage for conventional intensive agriculture. Research is needed.

The Need for Re-education of the Western Public, Government Policy Makers, and Agricultural Researchers about Insects as Food and Insects in General

Mercer (1994), working in Papua New Guinea, concluded that the predicted world protein shortage could be ameliorated by using insect protein, but that an educational program would be necessary "to overcome the taboos currently held in the West." Mercer further stated (1995):

"The majority of my students are keen consumers of a whole range of insects when they return to their villages during vacation time. I have come to the conclusion that it is the West which is out of step in its aversion to insects as food."

Many other researchers and educators who have explored the actual and potential use of insects as food have also targeted the adverse Western attitude as the main problem. Reversing centuries-old cultural taboos is a slow process, but there are indications that the adverse attitude is beginning to undergo significant change and improvement. The BBC Natural History Unit, based in Bristol, England recently completed two programs on insects as food, one on the mopane worm (*Gonimbrasia belina*) in Botswana and one on a variety of insects consumed in Thailand. Producer Rupert Barrington (1995) stated:

"The gratifying thing is that most people react with fascination rather than disgust when they see this footage. We are very much pushing the angle that this is no different than eating Crustaceans, so western attitudes toward eating insects are groundless."

As editor of *The Food Insects Newsletter* for the past eight years, the author has been contacted by more than 300 mass-media organizations—newspapers, magazines, radio and television stations and networks, and film documentary makers and by some of them repeatedly regarding preparation of articles or films. The "tone" of these interviews is quite different now, much more positive than it was 20 years ago when the author also had a period of concentrated contact with the mass-media on this subject. There are also many articles appearing with which this author has had no connection. The point is that the Western public is now getting heavy and favorable exposure to information on the role of insects as food, and the idea is not so strange to people as it was formerly.

While the attitude of the mass-media is important, equally or more important is the fact that edible insects are now finding their way into the U.S. educational system. The author has been contacted by scores of teachers and professors, elementary to university level, who are now including discussion of insects as food in their biology courses, and by scores of students, elementary to university level, doing class papers (including science fair projects) on insects as food.

A number of zoos/insectariums such as in Cincinnati, San Francisco and Montreal, and a number of universities and nature centers hold annual open houses at which insect snacks are offered to the public. It seems also to have become fashionable for Western entomological societies to offer insect snacks or even whole dinners at their annual functions. Educational progress is being made, but continued persistence by interested scientists and educators in providing information and new research will be essential if the current educational momentum is to continue.

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