Chapter 11
Insect Bioprospecting Especially in India

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Abstract Bioprospecting has been an important phenomenon involving discovering new drugs and has occurred since the dawn of civilization. The Convention on Biological Diversity (CBD) Secretariat defines bioprospecting as the exploration of biodiversity for commercially valuable genetic and biochemical resources. In the early stage, bioprospecting was focused on plants and various plant-based drugs were discovered. However, insects were also explored, and are of special interest to India. In a broader sense, bioprospecting is the collecting and identifying of biological samples (plants, animals, microorganisms) and the amassing of indigenous knowledge to help in discovering genetic or biochemical resources. Bioprospecting is intended for economic purposes e.g., new drugs, crops, industrial products. However, studies suggested that the value of bioprospecting is higher if it is based on the knowledge of local people because the wisdom that indigenous people have regarding bioprospecting is embedded in their belief system and their culture. Insects as a food play an important role in the new insect focus. Ants, bees, termites, caterpillars, water bugs, beetle larvae, flies, crickets, katydids, cicadas, and dragonfly nymphs are among a long list of edible insects that provide nutrition for the people of Asia, Australia, Africa, South America, the Middle East, and the Far East. Insects represent an important food source for a wide variety of other animal species. By weight, termites, grasshoppers, caterpillars, weevils, houseflies and spiders are better sources of protein than beef, chicken, pork or lamb. Insects are also used as medicine by traditional healers. Chemicals produced by insects for self-defense can be used for antibacterial and anticancer drugs. In the present chapter, contributions that insects make to diets/food security are discussed in detail. Legal regimes and concepts of bioprospecting are described. Information on insects as (a) medicine, (b) natural dyes, (c) food, (d) animal feed, and (e) aesthetic value are assessed. A discussion on the constraints of bioprospecting is provided as are suggestions to promote insect bioprospecting. The nutritional and economic value of edible insects is of much importance and we should further encourage their collection and commercialization, given the benefits to the environment and human health. It is an interesting concept, managing pest insects by developing them into a delicacy and

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medicine. The chapter will attract the attention of farmers, entrepreneurs, scientists, research workers, the media and the decision-makers to explore insects for the future need of society.

11.1 Introduction

People worldwide have revered insects for millennia as they have been (a) considered sacred, (b) celebrated in art and literature, (c) used as pollinators, (d) nutrient recyclers, (e) carcasses and dung decomposers and (f) human food. They have also been feared as predators and parasites. Insects are fundamental in all terrestrial and aquatic food chains and provide us with silk, honey, waxes, medicines and dyes. Exploitation and utilization of insect resources are broadly classified into four different categories, the (a) insects of edible and therapeutic purposes. This includes the utilization of various stages and forms of insects; (b) utilization of insects for industrial resources. This level includes the utilization of silk worms, honeybees, lac insects, dye insects and aesthetic insects; (c) use of insects in forensic investigation. By analyzing the stages of succession of insects, rough estimations of the post mortem intervals can be achieved and (d) insects of ecological importance. As biomass recyclers, house fly larvae are used to recycle organic wastes to produce protein and fat. Dung beetles recycle cattle dung as organic manure. Insects are also used as bio-indicators to assess the cumulative effects of environmental stressors such as pollutants. Many insect species act as potential predators and parasites of destructive insects. Despites these fascinating benefits, insect resources are often neglected due to limited documentation, expertise, and advance commercial enterprises in these fields (Zhang et al. 2008).

11.2 What Is Bioprospecting?

Bioprospecting has been an important phenomenon involving discovering new drugs and has occurred since the dawn of civilization. The Convention on Biological Diversity (CBD) Secretariat defines bioprospecting as the exploration of biodiversity for commercially valuable genetic and biochemical resources (UNEP/CBD/COP/5/INF/7 2000). However, its definition varies in different countries, with some defining bioprospecting narrowly to include only the search for valuable genetic materials, whereas others encompass the development and application of such materials. For example, the New Zealand Biodiversity Strategy defines bioprospecting as ‘the search among biological organisms for commercially valuable compounds, substances or genetic material (Slobodian et al. 2011). The South African Biodiversity Act defines bioprospecting as any research on, or development or application of, indigenous biological resources for commercial or industrial

exploitation, and includes the systematic search, collection or gathering of such resources, or making extractions from such resources for purposes of such research, development or application. Hence, the commercialisation aspects of bioprospecting and potential profitability remain the critical impasse regarding its legal definition. Article 136 of the United Nations Convention on the Law of the Sea (UNCLOS) states that 'The Area and its resources are the common heritage of mankind'. The CBD includes conservation and sustainable use as well as access and benefit sharing obligations with regards to biological diversity. However, it is not clear that these obligations apply to bioprospecting given its low estimated environmental impact and lack of proprietary states, or peoples in the domains where common pooled resources are found. The Global Commons specifically refers to domains which do not fall within the jurisdiction of any one nation, thus all states have legal access. The CBD imposes a general obligation on parties to cooperate in conserving and sustainably using biodiversity in areas beyond national jurisdiction. In the early stage, bioprospecting was focussed on plants and various plant-based drugs were discovered (Taylor 2000). However, insects and algae were also explored (Kumar and Tarui 2004).

In a broader sense, bioprospecting is the collecting and identifying of biological samples (plants, animals, microorganisms) and the amassing of indigenous knowledge to help in discovering genetic or biochemical resources. Bioprospecting is intended for economic purposes e.g., new drugs, crops, industrial products (Srivastava et al. 2009). However, studies suggested that the value of bioprospecting is higher if it is based on the knowledge of local people (Martin 2001), because the wisdom that indigenous people have regarding bioprospecting is embedded in their belief system and their culture.

11.3 Legal Regimes and Concepts

1. Open-access regime: refers to the system of law in which no sovereign state controls the resource or area in question, yet they are free to exploit and profit from these resources/areas if they adhere to generally accepted principles and obligations of international law.
2. The Global Commons: also known as 'the Commons', is a term used to describe domains where common pooled resources are found. The Global Commons specifically refers to domains which do not fall within the jurisdiction of any one nation, thus all states have legal access.
3. Common Heritage of Mankind (CHM): this legal concept dictates that certain resources/areas are the communal property of all humankind. Hence, no person or state has exclusive legal rights to these resources/areas, in so far as all uses and benefits must be shared equally for the benefit of current and future generations.
4. Access and benefit-sharing (ABS): commonly describes legal regimes that seek an equitable right to developed and developing states regarding the exploitation

and any derivate benefits from scientific research and commercial development of biological resources.

5. Precautionary Principle: an approach which dictates that in the absence of adequate scientific evidence, decision-makers must err on the side of caution and adopt laws/policies that prevent suspected risks of harm to the environment or human health.

11.4 Insect as a Source of Medicine/Zootherapy/ Entomotherapy

Insects have been used in traditional medicine since time immemorial (Srivastava et al. 2009). The therapeutic application of honeybee venom (bee venom therapy) has been used to treat diseases such as arthritis, rheumatism, back pain, cancerous tumors, and skin diseases. Traditional healers use insects as medicine. Chemicals produced by insects as a result of their self-defense mechanisms can be used for antibacterial and anticancer drugs. In addition, silkworm pupae were traditionally used as medicine in countries such as China, Japan, Korea, India, and Thailand (Talukdar 2009 and Mishra et al. 2003). The waste liquor containing sericin yielded through the process of degumming silk fiber, is a raw material for the production of sericin powder which is used in various applications including medicine (Zhu 2004).

In many parts of New South Wales, Australia, people use medico-entomological drugs daily (Cambell et al. 1994). Costo neto (2003) coined the term "entomotherapy" for the use of insects for therapeutic purposes. Other accounts include Antonio (1994); Alexiades (1999); Zimian et al. (1997); Green (1998); Namba et al. (1988); Maya (2000) and Padamanbhan and Sujana (2008). Gallnuts of commercial value are produced on various species of oaks and other trees by certain *Eurasion cynipid* wasps. It is also called Allepo, Mecca, Chinese or Turkey galls and the best grades, containing more than 50 % tannic acid, come from Iran, Turkey and Syria. These are used in making dyes and medicine (Quijano and Vergara 2007). A list of insect preparations of use in Zaire is provided in Table 11.1.

One of the most commonly used insects for medicinal purposes is the blow fly (*Calliphoridae*) larvae. During World War II, military surgeons noticed that wounds which were left untreated for several days, and were infested with larvae, healed better than treated and non infested wounds. It was later discovered that the larvae secreted a chemical called allantoin which had a curative effect (Maya 2000). The use of traditional knowledge could be extended further in modern medicine systems by identifying the proactive biomolecules with pharmacological action (Anonymous 2009; Hider 1988; Werner 1970 and But et al. 1991).

The therapeutic application of honeybee products has been used in traditional medicine to treat various diseases e.g. diarrhoea, tuberculosis, impotency, asthma, exophthalmic goiter, and mouth galls (Maya 2000). The practice of using honeybee

Table 11.1 Some examples of traditional medicinal uses of insects in Zaire. These are provided only to give examples of traditional use and have no valid scientific basis. The author of the review and the editors do not recommend using these methods

Name	Local name	Used for the treatment	Method of treatment
Praying mantis	Kayakua	Epilepsy	A healer places the whole mantis in a pot with boiled aromatic leaves, and washes the entire body of the patient. The patient also drinks the preparation. Duration of treatment is 1 week.
Builder/worker caterpillar	Kenbul Mpiak	Haemorrhage during childbirth or during pregnancy	A healer crushes the caterpillar nest, the caterpillar, and the red earth, and the preparation is called largile nkol. The mixture is solubilized which the woman drinks.
Termite	N'zo Musien	Internal haemorrhage	The specialist removes the bark of the *Muton* tree (which produces red bark) and these are placed in a pot with a nest of termites. The patient drinks a little of this solution.
Glowworm	Nkwazeb	"Chasing the spirits/boogey-men from an infant having nightmares"	The healer takes several glowworms, mixes them with ash from a cooking fire near to where the infant resides. The patient drinks a small quantity in water. The same mixture is rubbed on the forehead, head, ears and nape of the infant.
Bee	Ngobo	Stuttering	The healer places several bees in a *calabasse* (gourd-bowl) of palm wine which the patient drinks.
Domestic cricket	Mpayenzo	Stuttering	The patient eats the cricket.
Butterfly	Kenguapob	Illnesses of the ears	The healer puts the nymph and cocoon in a cone made from wild leaves. The aromatic plant *Losaal Nzian (aile de Dieu;* wings of God) is added, and it is a lit on hot coal. The smoke is blown on the ears of the patient.
Tse-tse fly	Kebty	To avoid sleeping sickness after having been bitten by the tse-tse fly	Tse-tse fly is crushed and rubbed on the skin, and an incision made on the skin.
Aquatic bee	Ngundumugun and Kender Maza	Cure heavy menstruation	The healer places the bee in a pot with a piece of clothing from the woman which are burned to make ash. These are applied to the reproductive part after bathing.
Soldier termites	Mbwiidi	Revive a syncope/blackout/fainting fit	Soldier termites are placed in a container containing the sap of tobacco leaves/tobacco. The live insects are absorbed into this substance. This is placed them on the body of the patient, when the termites bite the patient, he awakens.

(continued)

Table 11.1 (continued)

Name	Local name	Used for the treatment	Method of treatment
Salivating insects	Bentiey	Stop exaggerated salivation	The insects are cooked with the meat of the Ntambien gourd which are eaten for a week.
Water bug/lion bug	Kenzi & Nziie	Used to cure in insanity	The patient eats the insects mixed with mud from the same river.
Lion-ant	Munkuuk	Used to relieve and cure high fever	The lion ant is made to bite the patient.
Trembling red ant *Solenopsis invicta*	L.nkaam	Muyeem (bronchitis)	The sticky saliva of the ants is thought to help recover normal respiration. The entire ants are used. The healer places the ants in a bowl made of forest leaves; he mixes it with pure and clear water and gives it to the patient to drink. Duration of treatment is up to 1 week. These insects also have a common name meaning "child-birth aid".
Grasshopper	Mpaylaar	Violent headaches	The healer crushes the dry grasshoppers into ash. The ash is mixed with a little organic salt. An incision is made on the nape and front of the patient and then the solution is applied.
Worker wasp	Ngankoy	Strengthens weak infant	The nest of the wasp is crushed in a glass of water, and is drunk by patient. Also, it is rubbed into the skin. The nest of the worker wasp has a acetylcholine-like substance, which is thought to cause the effect.
Cockroach	Kembaar	Scabies/mange	Cockroaches are burnt to ashes and are mixed with palm oil. It is rubbed on the body after each bath until the scabies is cured.

products for medicinal purposes is known as Apitherapy. One of the major peptides in bee venom, called melittin, is used to treat inflammation in sufferers of rheumatoid arthritis and multiple sclerosis. Melittin blocks the expression of inflammation genes, thus reducing swelling and pain (Maya 2000). The therapeutic application of bee venom therapy has been used as a traditional medicine to treat a variety of conditions, such as arthritis, rheumatism, back pain, cancerous tumors, and skin diseases (Padamanbhan and Sujana 2008). Bee venom contains at least 18 active components, including enzymes, peptides, and biogenic amines, which have a wide variety of pharmaceutical properties. It was reported that melittin inhibited the DNA binding activity of NF-kB, a critical transcriptional factor regulating inflammatory gene expression, by inhibiting IkB phosphorylation (Faulkner 1992). Bee venom also has anticancer activity: Several cancer cells including renal, lung, liver, prostrate, bladder, mammary cancer cells and leukemia cells are targets of melittin (Lazarus and Attila 1993; Park et al. 2004 and Liu et al. 2005). Pharmaceutical companies are currently funding extensive research into the potential of venom as the next generation of cancer fighting drugs (Moon et al. 2006). Honey has been used traditionally in various medicine preparations (Cao et al. 1996). The propolis of the bee hive is used in lip balms and tonics, whereas royal jelly is used with the intention to strengthen the human body, for improving appetite, preventing ageing of skin, leukemia and for the treatment of other cancers. About 80 % of all honey by weight is used directly in medicines and 10 % in traditional Ayurvedic medicine and pharmaceutical production. Thus, pharmaceuticals from bees can be cited as a spectacular example of medicinal insects. There may be many such insects having similar or superior medicinal properties.

Cantharidin is a medicine obtained from the blister beetle, *Cantharis vesicatoria*, an insect belonging to the order Coleoptera, family Meloidae. Its medical use dates back to Hippocrates (460–377 BC) (Moon et al. 2006). It was administered as a diuretic and to alleviate epilepsy, asthma, rabies, and sterility. The eggs of red ants, *Solenopsis invicta* are said to be used as a constituent of medicine for the control of malaria. An extract of cocoons of mulberry silkworm is believed to check profuse menstruation and chronic diarrhoea (Sharma et al. 2006). Pierisin, a protein from pupa of the cabbage butterfly, *Pieris rapae*, exhibit cytotoxic effects against human gastric cancer. Extracts of the body fluids of other cabbage butterflies, *P. brassicae* and *P. napi*, also contains pierisin (Davis 1918). Tang et al. (2008) proposed that antimicrobial molecules from insects may serve as significant sources of antibiotics as revealed from the Chinese traditional medicine made from edible housefly larvae of *Musca domestica.*

Traditional healers in Chhattisgarh, India have used the green coloured larva Jatropha leaf miner, *Stomphosistis thraustica*, as a medicinal insect for many decades (Srivastava et al. 2009). The larvae collected just before pupation, are considered optimal for effectiveness. The larvae are dried in shade and are converted into a dry powder. The traditional healers use this powder internally with lukewarm water in order to increase the flow of milk in lactating women. Many healers use it boiled in water and drank to obtain better effects. The traditional healers of Southern Chhattisgarh use the larvae in the treatment of fever. For the preparation of medi-

cine, they dry the larvae in moonlight and powder it, which is taken internally in combination with other herbs, mainly Kalmegh (*Andrographis paniculata*) (http://botanical.com 2012).

A common practice in North Gujarat is to feed animals which fail to come into heat with two or three grasshoppers (*Hieroglyphus niegrorepletus*) along with chapatti (bread) or fodder. It is believed that animal comes into estrous within 15 days after this treatment. A single treatment is enough to obtain the desired result. The grasshopper is locally called titighodo. It is generally found during the rainy season on cactus (*Euphorbia* sp) and akada *(Calotropis* sp) and it has yellow and greenish stripes on the body (Patel and Patel 1995). Natives of Sambar Village of Chhattisgarh, India use the common agricultural pest Kambal Keeda (*Diacrisia oblique*) in case of dog bite. The patients are advised to eat freshly laid eggs in order to reduce the rabies effect caused by the virus that attacks the central nervous system. It is also applied externally on affected parts. It is a promising treatment as they have used it for generations, apparently with success. Bhavri Keeda (*Gerridae*) an aquatic insect commonly known as water striders, is used in other villages of the Bagbahera region, for the treatment of dog bite and rabies (http://botanical.com 2012). However, all these practices require scientific validation.

Pieris rapae, P. brassicae and *P. napi* butterflies produce antibacterial proteins including cecropins, defensins and lysozymes. Cercopin has been reported to be cytotoxic against mammalian lymphoma and leukemia cells. Some butterflies may be a good source of other novel bioactive materials such as anti-bacterial, and anti-cancer drugs. In India, 1501 species of butterflies are found, hence the country has a tremendous potential in butterfly bioprospecting (http://lib.bioinfo.pl). A cockroach, *Periplaneta americana* locally known in Odisha, India as Asarpa, is used for treating asthma, coughs and colds. Local women collect the cockroach and make tea by boiling one until the water is reduced by 50 %, and use it by taking three doses three times a day to cure the ailments. Farmers of the Sonarhi and Terhi villages of Banda district of Uttar Pradesh feed insects hosted on babool tree to their cattle and buffaloes to initiate the estrous cycle. The insect appears to contain a hormone, which induces estrous in the animals (Singh 2003). Soil collected from termite hills is made into a paste with warm water and applied to the wounds of sheep and goats for 2–3 days for healing in the Makarbilli village of Nuapada district in Odisha (Behera 2003). Finally, some examples of traditional medicinal uses of insects in Zaire described by Tango (1994) are provided in Table 11.1. It requires emphasis that these treatments are non scientific and require further research: They are not recommended as treatments by the current author or the editors of the book.

11.5 Natural Dye from Insect

The demand for natural dyes is constantly growing with an increased awareness of the ecological and environmental problems associated with synthetic dyes (Sharma et al. 2006). Producing natural dye in India from insects has been suggested by

Prasad (2007) with a view to exploitation. Currently, the coccid, *Dactylopius coccus* (Hemiptera: Dactylopiidae) is the most important species due to its use for the extraction of carmine acid, a natural red dye used in food, pharmaceuticals, and cosmetics industries (Subramanian et al. 2005). The coccid lives on cladodes of prickly pears (*Opuntia ficus indica*) and dried females are a source of the dyes (Prasad 2007). *D. opuntiae* is another wild species found in Mexico and has a shorter lifespan and reproduction cycle with a larger number of generations per year (Vigueras and Porlillo 2001). The non-dye residuals from extraction can be used to enrich food for avian species or to prepare fertilizers, as they have a high content of proteins and mineral (Mendez et al. 2004).

The female of *D. coccus* is also found in central and South America. The insects are handpicked and dried and 100,000–150,000 insects yield 1 kg of raw cochineal. Total world production was reported to be 150–180 tonnes/year. Peru is the biggest producer accounting for 90 % of cochineal production. However, large scale production of cochineal has emerged in Guatemala. Cochineal was used as a dye by the Aztec and Maya peoples of Central and North America where it was a commodity of much value, comparable to gold (Mann 1969). Cochineal is used to produce scarlet, orange, and other red tints. The production and exploitation method of the dye has been studied by many workers. The insects are killed by immersion in hot water, exposure to sunlight, steam, or dry heat. Each method produces a different colour which results in the varied appearance of commercial cochineal.

Oak galls have been used commercially as a source of tannic acid. It was a principal ingredient in wool dyes and black hair colourants used during the Greek empire as early as the fifth century BC. It is still used commercially in the leather industry for tanning dying and ink manufacture. Tannic acid was obtained from the Aleppo gall found on oak trees (*Quercus infectoria* Olivier) in Asia and Persia. The trees produce gall tissues in response to polyphenolic molecules secreted by the larvae of wasps (*Cynips gallae tinctoriae* Olivier; Hymenoptera: Cynipidae) that infest the trees. Approximately, 50–75 % of the gall's dry weight is composed of tannic acid (Aldama et al. 2005). Gallnuts of commercial value for making dyes are produced on various species of oaks and other trees by certain Eurasion Cynipid wasps. They are also called Allepo, Mecca, Chinese or Turkey galls and the best grades, containing more than 50 % tannic acid, come from Iran, Turkey and Syria (Quijano and Vergara 2007). The aspect of exploring and utilizing natural dye producing insects is uncommon in the India. However, the north-eastern region is a region of high oak cultivation, and there is scope for bioprospecting in this area.

Lac insects (*Laccifer lacca*) are exploited commercially for lac resins and dyes. Lac is the hardened resin secreted by the insects. There are 87 lac insect species reported from the world, representing nine genera, of which 19 species belonging to two genera are found in India (Anonymous 2006). Of the Indian species, *Kerria lacca* is mainly exploited for commercial production of lac. *K. chinensis* in the northeastern states and *K. sharda* in coastal regions of Odisha and West Bengal are also cultivated. Lac resin being natural, biodegradable and nontoxic, finds applications in food, textiles, and pharmaceutical industries in addition to surface-coating, electrical and other fields.

11.6 Insect as a Source of Food

Some of the renowned works on edible insects from different parts of India are those of Singh et al. (2007); Alemla and Singh (2004) and Singh and Chakravorty (2008). The long history of human use of insects as foods indicates that they do not pose any significant health problem (Capinera 2004). This trend toward reducing the bias against insects as food is promising. Despites the benefits, modernization has led indigenous populations around the world away from this traditional food source, without providing nutritionally-equivalent alternatives (Fromme 2005).

Over 1500 species of edible insects have been recorded as being consumed by 300 ethnic groups from 113 countries (Grieve 2009). Human consumption of silkworm pupae has been practiced in China (Zhou et al. 1996) and India by many tribal communities (Arora and Gupta 1979). Indeed, silkworm pupae have been put in the list of "Novel food resources managed as common food" by the Ministry of Health, China (Mishra et al. 2003). Ants, bees, beetle larvae, caterpillars, cicadas, crickets, dragonfly nymphs, flies, katydids, termites and water bugs are among a long list of edible insects that provide nutrition for the people of Asia, Australia, Africa, South America, the Middle East, and the Far East (Grieve 2009). In some ethnic groups, insects provide 5–10 % of animal protein input as well as fat, calories, vitamins, and minerals (MacEvilly 2000) Studies on nutrient analysis for various insects were conducted by many authors in different countries, such as (a) Quin (1959) in South Africa; (b) Oliveira et al. (1976) in Angola; (c) Malaisse and Parent (1980) in Zaire; (d) Gope and Prasad (1983) in India; (e) Sungpuag and Puwastien (1983) in Thailand and (f) Ramos and Pino (1989) in Mexico. Insects generally have higher food conversion efficiency than higher animals. For example, the house cricket (*Acheta domesticus*) when reared at 30° C or more, and fed a diet of equal quality as that used to rear conventional livestock, showed a food conversion twice as efficient as pigs and broiler chicks, four times that of sheep, and six times higher than steer when losses in carcass trim and dressing percentage were counted (Capinera 2004). Protein production from insects for human consumption would be more effective and consume fewer resources than vertebrate protein. Interestingly, increased consumption of grasshoppers and locusts has coincided with decreased pesticides use in Asia and Oceania (Defoliart 1995, 1999).

Native Americans of western North America expended much organization and effort in harvesting insects (Srivastava et al. 2009). Ordinarily, insects are not used as emergency food to ward off starvation, but are included as a planned part of the diet throughout the year or when seasonally available (Srivastava et al. 2015). The *Yukpa* people of Colombia and Venezuela prefer certain traditional insect foods to fresh meat, as do the *Pedi* of South Africa (Ruddle 1973) at least in some cases. When *mopanie* caterpillars (*Gonimbrasia belina* Westwood) were in season, the sale of beef was seriously affected (Quin 1959). According to the Entomological Society of America, termites, grasshoppers, caterpillars, weevils, houseflies and spiders are better sources of protein than beef, chicken, pork or lamb (Srivastava et al. 2009) on a weight basis. Insects are also low in cholesterol and fat and make

some food products more nutritious. According to Ramos (1997), 80 % of the world's population eats insects intentionally and 100 % eat them unintentionally! They have served as traditional foods in most cultures of non-European origin.

At least two billion people include more than 1900 species of insects in their food (FAO 2013) and they are sometimes the only source of essential proteins (amino acids), fats, vitamins and minerals for tribes living in forests. In the Central African Republic, 95 % of forest people are dependent on eating insects for their protein intake. Pupae of *Formica* are often eaten and the optimal time to collect pupae is 1 h after the rays of the sun have contacted the pupae "mound" in the morning and the pupae can be collected just under the surface of the mound at this time. Mexican "caviar" or *ahuahutle*, is composed of the eggs of several species of aquatic Hemiptera; these have formed the basis for aquatic farming in Mexico for centuries (Srivastava et al. 2009).

In parts of Africa, ants, termites, beetle grubs, caterpillars, moths, butterflies and grasshoppers are eaten. Moth larvae are collected and roasted, and may often be bought in the markets. Some insects such as termites are eaten raw soon after catching, while grasshoppers, caterpillars, and young beetles are fried. Ants are eaten raw or ground-up into a paste. Locusts are typically boiled and salted prior to eating and are a particularly important source of nutrition in Africa as they contain protein, fat, vitamins and minerals. In the Congo (Kinshaza) (formerly Zaire), more than 30 species are harvested (see Table 11.1). Some caterpillars are sold not only in the local village markets, but are shipped by the ton from one country to another and there are processing plants where caterpillars are canned in Botswana and South Africa. In the rural countryside, they are usually dried in the sun before being sold in the market. The larvae of the Mopone Emperor Moth are now a cash crop with an annual production of 2,000 tonnes in Southern Africa.

However, termites are most widely used as food in Africa. They are highly attracted to lights, even candlelight, and that is one way they are captured for use as food. The wings are broken off, and the body is fried. The queens are considered a special treat and are often reserved for children or grandparents. *Brachytrupes membranaceus*, a large, fat cricket which is destructive to root crops, is regarded as a particular delicacy and is collected by digging them up from their burrows in the ground. *Gryllotalpa africana* Palisot (mole crickets) adult is used as a food (Fladung 1924). In some cultures, bee nests are collected as much for their bee grubs as for the honey. They are considered a great delicacy. Larvae, pupae and/or adults of many beetles are used as food. The hard parts (wings, legs and head) are removed during preparation for cooking. Walking sticks and leaf insects, *Extatosoma tiaratum* are used as food in Asia and in Papua New Guinea. In Mexico, grasshoppers and other edible insects are sold in village markets and are fried before being eaten. Many are sold in cans as fried grasshoppers, chocolate covered ants, etc. Fried grasshoppers are also canned commercially and sold in supermarkets and local grocery stores. High in protein and low in fat, they may be fried or ground into meal and mixed with flour to make tortillas. Tortillas are served with red and white agave worms in many Mexico city restaurants (Sahagun 1557). *Mopane* (the caterpillars

of a moth species) are a huge industry in numerous African countries. It is reported that tons of the caterpillars are harvested, processed, and sold in markets or by the truckload (Dreyer and Wehmeyer 1982). Ethiopian tribes preserved bugs in salt, as did the Algerians who sell them in their markets. There is a considerable trade in termites in some areas. Sun dried termites are found in the local markets in many East African towns and villages. They are sometimes transported long distances to markets. The Baganda community who live around the northern shore of Lake Victoria in Uganda use termites and fried grasshoppers as snacks between the main meals. In many Bantu speaking parts of the country, boiled and dried termites are on sale in the markets in some seasons of the year. One species in Asia, the giant water-bug, is reported to be exported from Thailand to the Asian food shops in the United States (Pemberton 1988).

In the United States, on the menu of some restaurants are interesting dishes such as stir-fried mealworms and caterpillar crunch (a combination of trail mix and fried caterpillars) (Triplehorn and Johnson 2005). In addition to raising your own food-insect supply or catching from the wild, there are numerous stores in various American cities that sell frozen insects from Thailand and other countries in SE Asia. There are already cricket farms in America, which raise these and other insects for the pet trade. They produce tons of insects per week (Anonymous 1991). Processed insects for sale as cocktail snacks, etc., are apparently no longer imported into the United States (Fasoranti and Ajiboye 1993).

However, several processed insects are commercially available in Japan. The most widely eaten is *inago* (the grasshopper, *Oxya velox* F.), which is preserved by boiling in soy sauce. This product appears as a luxury item in supermarkets throughout the country, including Tokyo. There is currently an effort to incorporate several insects that were important in aboriginal diets into the Australian cuisine. In Canada, attempts are under way to apply industrial methods to the production of insects as food (Fasoranti and Ajiboye 1993). Commercially grown insects available to special interest groups (from types of bait and pet foods) in the USA and Europe include the cricket, *Acheta domesticus*, the mealworm, *Tenebrio molitor* L. (a beetle grub), and the greater waxmoth larva, *Galleria mellonella* (L.). A list of insects used as food and methods of prepration in the different parts of world are presented in Table 11.2. More than 80 recipes based on these insects and honeybee pupae (*Apis mellifera*) are included in The Original Guide to Insect Cookery, Taylor and Carter (1976).

Many research teams at universities study insects as human food, using the term *Micro-livestock* to categorize the insects that can be eaten (Srivastava et al. 2009). In some parts of the world it is termed as *Entomophagy*. Some insects such as the mormon cricket, grass hoppers and pandora moth caterpillars yielded a very high energy return for the energy expended in their harvest, often much higher than return rates from seeds or other plant food resources. When dried, the insects can be stored for use as a winter food. Insects contain high value minerals such as potassium, calcium, magnesium, zinc, phosphorus and iron, and vitamins. Due to their high nutritional value, in some regions, flour made from caterpillars is mixed to prepare pulp which is given to children to counter malnutrition. In New Guinea,

Table 11.2 A list of insects used as food and method of use in the different parts of world

Name of the insect	Place	Country	Methods of preparation	Reference
Red ants and termites	Kandhamal, Koraput, Sundergarh, Keonjhar and Mayurbhanj districts of Odisha	India	Roasted. Eaten as snacks or with rice. Termites collected at the time of swarming, while red ants were collected as and when required from the plants where nests of ants were found.	Jishing (2003)
Demta eggs (a red ant on mango trees)	Pithra village, Simdega district, Jharkhand	India	Eggs are found in the curled leaf of mango. They are fried with salt, chilli, spices and mustard oil.	Verma (2003)
Pandora moth caterpillars *Coloradia pandora*	Central Africa	Africa	Caterpillars are harvested. *Piuga* is regarded as a tasty, nutritious food good for sick people. They are collected in trenches dug around the bases of Jeffery pine trees. They are eaten after roasting, by mixing them with hot sand.	Blake and Wagner (1987)
Grasshoppers, crickets, red ants, and larvae of mulberry silkworms	Phek, Dimapur and Kohima districts of Nagaland	India	Grasshoppers are available in the local markets during August and September and usually collected after the harvest of paddy, especially at night. Roasting after removing the wings and legs is the method of cooking.	Srivastava et al. (2009)
Shore flies *Hydropyrus hians* pupae	Nevada border region	California, USA	By drying in the sun and mixing with acorns, berries, grass-seeds, and other articles of food gathered up in the mountains, they make a mixture called *cuchaba*, a type of bread.	Defoliart (1994)
Mormon cricket (*Anabrus simplex*)	Indians, all over the West	India	They are dried, and ground, making a fine flour. Used to make bread, in a manner similar to sugar used in cakes.	Gottfredson (1874)
Jumiles stinkbugs	Oaxaca, Guerrero, Morelos	Mexican states	People frequently cook as a salsa. Also these bugs are eaten live with the traditional *tacos* as they have an aromatic and deep flavor like mint or cinnamon.	Srivastava et al. (2009)
Ant (*Atta cephalotes)* pupae known as escamoles *and* Grasshoppers	Mexico	Mexico	Winged female ants are consumed in the rainy season. Contains 42 % protein. *Escamoles*, are found on the menu in the finest restaurants, served fried with butter, or fried with onions and garlic. Grasshoppers are fried prior to eating.	Srivastava et al. (2009)
Oecophylla	Australia	Australia	Eaten as bush food. People prefer to fry them prior to eating.	Cherry (1991)

(continued)

Table 11.2 (continued)

Name of the insect	Place	Country	Methods of preparation	Reference
White beetles *Cyclocephala*, Cerambicid's larvae and Cicadas, Ant	Cotocollao, Quito, Amazonian region	Ecuador	People cook with pork meat and vegetables. People eat the Cerambicid's larvae and Cicadas. Lemon ant and *Hormiga Culona* ants are fried.	Dufour (1987)
Cicada	Irian Java	Indonesia	*Ekagi* people regularly eat caterpillars and grubs as source of protein.	Scholtz and Holm (1985)
Caterpillars, Migratory locust (*Locusta migratoria*); the red locust (*Cyrtacanthacris septemfasciata*); and the desert locust (*Schistocerca gregaria*). Termites *Macrotermes bellicosus, M. falciger*, and *M. subhyalinus*	Central, South and East Africa	Central, South and East Africa Africa, Korea	Collected from forests, eaten as source of protein The termites are eaten raw or lightly fried in their own fat Sometimes they are ground and added to sauces.	Scholtz and Holm (1985)
Honeybee larvae, Lake fly *Chaoborus*, winged termites	Eastern Uganda	Uganda	Larvae are collected as food. Adults of lake fly are used for making cakes as a source of protein. Termites are induced to emerge by beating the nearby ground with sticks. Drumming was observed to induce termite emergence near Namwnda in Bulmogi county of Busoga.	Osmaston (1951)
Giant water bug (*Lethocerus indicus*)	All over Asia	Asia	Gathered at night near water sources. Roasted whole and eaten as a delicacy.	Anonymous (1991)
Ants, beetles, crickets, grasshoppers, katydids, locusts and dragonfly	Philippines	Philippines	Larvae are fried or boiled prior to eating. They are also sauted with vegetables.	Srivastava et al. (2009)
Silk moth	China	China	Workers in Chinese silk factories eat the pupae.	Anonymous (1991)

Termites, palm grubs and ants	Columbia	Columbia	Ants are ground and used as a spread on breads. They are used as ingredients in recipes. It is the ant's larvae and/or pupae that are usually eaten. Roasted leafcutter ant abdomens are sold, instead of popcorn, in movie theatres.	Anonymous (1991)
Sago grubs, larvae of moths, wasps, butterflies, dragonflies, beetles, adult grasshoppers, cicadas, stick insects, moths, locusts and crickets	Papua New Guinea, Korea	Papua New Guinea, Korea	Larvae of a wood-boring beetle are considered a delicacy. The islanders boil the larvae or roast them over an open fire to serve as a main meal. Fried locusts are mostly used in Korea.	Anonymous (1991)
Pupae of the fly *Ephvdra hians*, ants, crickets, mealworms, grasshoppers, larvae of moths and yellow jackets	Western United States	United States of America	Food was called *Koo-tsabe*. Deep fry pieces are eaten.	Triplehorn and Johnson (2005)
Dryopoid beetles	Andes	South America	Tribes dry, grind and uses them as a spicy additive for food flavouring.	Pemberton and Yamasaki (1995)
Candied grasshoppers, known as *inago*, bee or wasps larvae/ pupae	Japan	Japan	As cocktail snack. Canned wasps, and wings are sold.	Pemberton and Yamasaki (1995)
Oak grubs (*Quercus velutina)*	Rome	Rome	A delicacy purposely fattened on flour.	Pemberton and Yamasaki (1995)

Table 11.3 Nutritional content of edible insects and other animals based on a 100 gm serving

Name of the insects and other animals	Energy (Kcal)	Protein (gm)	Iron (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)
Termite *(Macrotermes subhyanlinus)*	613	14.2	0.75	0.13	1.15	0.95
Caterpillar *(Usata terpsichore)*	370	28.2	35.5	3.67	1.91	5.2
Weevil *(Rhynchophorus phoenicis)*	562	6.7	13.1	3.02	2.24	7.8
Beef *(Lean ground)*	219	27.4	3.5	0.09	0.23	6.0
Fish *(Broiled cod)*	170	28.5	1.0	0.08	0.11	3.0

Table 11.4 Nutritive value of different insects

Insect	Protein (gm)	Fat (gm)	Carbohydrate (gm)	Calcium (mg)	Iron (mg)
Giant water beetle	19.8	8.3	2.1	43.5	13.6
Red ant	13.9	3.5	2.9	47.8	5.7
Silk worm pupae	9.6	5.6	2.3	41.7	1.8
Meal worms	20.27	12.72	N/A	13.3	N/A
Wax worms	15.50	22.19	N/A	28.3	N/A
Super worms	17.41	17.89	N/A	12.4	N/A
Fly larvae	15.58	7.81	N/A	87.4	N/A
Dung beetle	17.2	4.3	2.0	30.9	7.7
Cricket	21.32	6.01	5.1	75.8	9.5
Small grasshopper	20.6	6.1	3.9	35.2	5.0
Large grasshopper	14.3	3.3	2.2	27.5	3.0
June beetle	13.4	1.4	2.9	22.6	6.0
Caterpillar	6.7	N/A	N/A	N/A	13.1
Termite	14.2	N/A	N/A	N/A	35.5
Weevil	6.7	N/A	N/A	N/A	13.1

N/A = Not Analyzed

many villagers are currently engaged in the innovative commercialization of the spectacular lacewing butterflies as a source of food. Taiwan exports several hundred million dollars of wild butterfly specimens annually as food. There is a significant trans-border trade in edible insects within central African countries including Sudan and Nigeria. On a smaller scale, they are exported to France and Belgium, which import about 5 and 3 tonnes, respectively of a dried Sapelli caterpillars species (*Imbrasia oyemensis*) annually from the Democratic Republic of Congo (Fasoranti and Ajiboye 1993).

The nutritional content of edible insects and other animals based on a 100 g serving is presented in Table 11.3 (William 1991) and the nutritive value of insects is presented in Table 11.4 (Dunkel 1996 and Berenbaum 1996). Research shows that

100 g of insects provide more than 100 % of the daily requirements of the required minerals and vitamins (FAO 2004). Due to their high nutritional value, in some regions of Central African Republic, flour made from caterpillars is mixed to prepare pulp given to children to counter malnutrition. As a treatment for weakness and anemia, termites are prescribed as they are particularly high in iron while red ants are rich in bone building calcium (Srivastava et al. 2009).

11.7 Insects as Animal Feed /Insectivory

Insects represent an important food source for a wide variety of other animal species. Freshwater game fish such as trout, bass and bream feed extensively on aquatic insects such as mayflies, stoneflies, or hellgrammites. Many toads, frogs, turtles, snakes, and lizards also consume insects as a major part of their diet. *Insectivory* is common among land dwelling birds. Purple martins, barn swallows, vireos, warblers, flickers, whippoorwills, and swifts, for example, survive almost exclusively on insects. Other birds such as egrets, quail, geese, plovers, snipes, and bluebirds have a more varied diet, but they still derive a large percentage of their total nutrition from insects. There are some insectivorous mammals such as shrews, moles, bats, armadillos and anteaters. When other food is scarce, even foxes, raccoons, skunks and bears also turn to insects as a source of food (McHargue 1917; Frost 1942). The vast majority of studies in the West have dealt with the nutritional value of muscoid (Diptera) larvae or pupae used to recycle nutrients from poultry manure or other organic wastes as a high-protein source for broiler production (Defoliart 2002). According to Davis (1918), there is no difference in the taste of eggs from grub-fed hens. Cotton and George (1929) also summarized the early use of the meal worm, *Tenebrio molitor* as animal feed. Insect larvae of various kinds are also commonly used as fishing bait (http://www.hobbyandlifestyle.com/fishingbait.html).

11.8 Aesthetic Value of the Insects

Although something of a subjective subject, the beauty of some insects, as well as the graceful flight of butterflies, provides a source of comfort and pleasure to many people. The aesthetic value of insects is phenomenal – many hours could be spent examining the brilliant colours of delicate butterfly wings or the hardened bodies of brightly coloured beetles. Artists, poets, songwriters, and designers have used insects as inspiration for their art, which has brought joy and satisfaction to many admirers (Fig. 11.1). In Japan, some people often keep insects as pets, because their call is believed to be soothing, reminding them of a simple, less hectic life. The diversity of beauty in the insect world is tremendous.

Fig. 11.1 Use of insects for aesthetic purpose

The body colouration, beauty, and mode of life of the insects always attract us. Coloured wing and elytra of many coleopterans are used in jewellery, embroidery, pottery, and basket makings (Cambell et al. 1994). Among the insects of aesthetic value, butterfly attains maximum attention from museums and collectors. For satiating the growing need of butterflies amongst the collectors, numerous butterfly farms have been developed in European countries (Hammond 1995). In such butterfly farms (e.g. Brinckerhoffs), all the pupae are captives, reared exclusively for sale as live insects, which yield $100,000,000 annually (VKRTEX-Tutorials 2009), indicating a source of revenue for bioprospecting. There are many reasons why butterflies and moths are important, both in their own right but also as quality of life indicators. Many countries had developed butterfly parks for conserving butterflies around the world.

Notably, butterfly and beetle species have been used for various aesthetic and decorative purposes. Designs based on insects have been employed in art, jewelry, fashion and other decorative motifs. Thousands of stamps currently display insects(http://itc2.utk.edu). Musical composition has been influenced by insects.

11.9 Constraints

The most serious legal issue facing bioprospecting is the lack of clear rules and guidelines. Various environmental, trade, and geographically-specific agreements currently offer incomplete, ambiguous, or conflicting provisions relating to

bioprospecting activities. Consequently, there are no clear rules on ownership, access, benefit-sharing, and environmental responsibility for bioprospecting in the Global Commons. Lack of clarity and distinct gaps in the existing laws encourages bioprospecting by companies keen to exploit the fragmented legal frameworks and policies for their own commercial benefit. It also obstructs the participation of developing States in exploration and use of the rich biological resources in areas designated as the Global Commons.

11.10 Conclusions

According to UN projections, the global urban population will increase to 66 percent by 2050, from the present 54 % in 2014 (United Nations 2014). This change will be marked in countries like India, which would add 404 million urban dwellers by 2050. Despite this, India would still house the largest rural population. All this will lead to qualitative changes in the requirement of various food commodities. An ever increasing middle-class, elite urban populations and life style changes will stimulate demand for less explored food delicacies. The nutritional, medicinal, aesthetic and other profitable values of insects are often neglected and we should further encourage their collection and commercialization, given the benefits to the environment and human health. It is an interesting concept, managing pest insects by developing them into a sought after delicacy. The collection of edible insects is a good source of income as they require little capital input if gathered by hand. Insects have long been a significant dietary factor and remedies for illnesses in many regions of the world. Their collection, commercialization and mass-rearing needs to be explored by merging traditional knowledge and modern science for the development of rural entrepreneurs. Because of the high protein content, high digestibility, variety in food diets, high conversion efficiency, and great reproductive potential associated with a short life cycle, the useful biomass obtained would be significant when compared to other products. In developing countries, insect food could be helpful in improving livelihoods and nutritional security. To promote insect bioprospecting important suggestions are given below:

- Indigenous knowledge and practices of edible/medicinal insect should be documented.
- Edible/medicinal insect species amenable to farming should be identified including possibilities to increase their nutritional value.
- Institutional mechanisms for promotion and support including capacity building programmes are required for establishment of micro livestock production (edible insects) parks for insect rearing at the village level with greater participation of both genders.
- IT-based network of insect entrepreneurs for exchange of information and consultations should be established.

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