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N Senthilkumar
Scientist F & Head, Department of Chemistry and Bio-Prospecting Division, Institute of Forest Genetics and Tree Breeding, Coimbatore, Tamil Nadu, India

P Nithya Jeniffer
Michael Job College of Arts and Science for women, Coimbatore, Tamil Nadu, India

Corresponding Author:
Scientist F & Head, Department of Chemistry and Bio-Prospecting Division, Institute of Forest Genetics and Tree Breeding, Coimbatore, Tamil Nadu, India

Entomoforestry: An overview of a novel concept on insect prospecting

N Senthilkumar and P Nithya Jeniffer

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Abstract
Entomoforestry is the practice of combining trees (Forestry) and insects (Entomology), as in the raising of stick-lac, bees for honey production, silkworm for silk production, pollination services by bees and other insects, insects for decomposition and nutrient recycling, insects for ecological monitoring as indicators of landscape and climate changes, insects as food and medicine and for aesthetic values. Host plants of these insects are trees in natural stands and plantations as well. Hence trees for insects and their byproducts of great utility warrants the emergence of new discipline, Entomoforestry. This article gives an overview of Entomoforestry opportunities in India.

Keywords: Entomoforestry, entomophagy, pollinators, insects for nutrient recycling, insects as bio-control agents and ecological indicators

Introduction
Entomoforestry may be defined as the deliberate interventions to manipulate trees for the sake of insects, especially multipurpose insects, and their integration with other land-use management schemes (Schabel, 2010) [6].
Approximately 80 percent of animal species on earth are insects, 99 percent are invertebrates. We share a large proportion of our genetic material with all life on earth down to the simplest worms. Insects provide natural services that we often take for granted. They are the pollinators, undertakers, leaf litter sweepers, garbage collectors, soil conditioners and natural fertilizer producers of nature.

1. Insects for Pollination
About 80% of the flowering plants on Earth are pollinated by insects. Flower color, shape and scent have evolved to attract their insect pollinators.
Examples: bumble bees, solitary bees, squash bees, beetles, butterflies, flies and ants.

2. Insects for decomposition and nutrient recycling
Insects and their arthropod relatives are responsible for much of the nutrient cycling, conditioning and aeration of the soil. The value of nutrient cycling in terrestrial ecosystems is estimated to be over $3 trillion per year. Insects and related arthropods make up half the animal biomass in some tropical forests.
Examples of reducers and recyclers: Dung beetles, Flies, Millipedes, Ants termites.

3. Insects as food for human and wildlife
Many different kinds of animals eat insects making them essential parts of the food chain.
Examples: amphibians, reptiles, birds, fish, arthropods and other invertebrates, mammals (primates including humans, insectivores focus almost exclusively on insect prey.

4. Insects as predators, parasites and predators for crop protection
Some insects provide natural population control of other insects, arthropods and vertebrates.
Examples: Ladybird Beetles, Lacewings, Parasite Wasps.
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5. Insects used in Medicine

Insects have been invaluable as research models to discover key scientific principles.

Examples:

- **Genetics:** Fruit flies, Madagascar hissing cockroaches
- Bioprospecting sources of new pharmaceuticals
- **Anesthesia:** Flies during WWII used to clean wounds
- Insects pollinate the rosy periwinkle plant which was an important drug to treat childhood leukemia
- Sources of bioluminescent chemicals used in medical diagnostics

6. Insects used for basic research

How the world works; flight, miniaturization, neural networks, biomimetics, genetics, population biology.

7. Food and Wood

a. Pollination of commercial crops

Approximately one third of the world's crop production depend directly or indirectly on pollination by insects. The value of pollination in the world, most of it by insects, has been estimated at about $117 billion per year (Costanza *et al*. 1997) [1].

Examples of crops: coffee, tea, vanilla citrus fruits, vegetables, and other tree crops.

Examples of pollinators: The honey bee (Apis mellifera) is responsible for the production of approximately $14 billion worth of agricultural products, however other pollinates are important pollinators as well including bumble bee which are used to pollinate tomatoes and carpenter bees which pollinate wild and domestic tree fruits.

b. Biological control

Natural biological control provided mostly by insects is valued at over $400 billion per year, according to Constanza (1997) [1]. As pests insects can destroy or eat $5 billion worth of domestic crops.

c. Commercial products

- Silk production, the silk worm (Bombyx mori) is the sole sources of commercial silk.
- Cotton (*Gossypium hirsutum*) can self-pollinate but can cross pollinate with services of bees: bumble bee (*Bombus spp*.) and honey bees (Apis mellifera).
- Red cochineal dye for textiles and cosmetics is produced by the scale insect *Dactylopius coccus*
- (Dactylopiidae) native to Mexico and Kermes vermilio (Kermidae) native to Europe.
- Honey is produced by bees and harvested
- Beeswax: candles, cosmetics, soap
- **Shellac:** the scale insect *Laccifer lacca* (Lacciferidae), native to India, is used to make phonograph records and varnish
- **Salt production:** Brine shrimp cleaned salt is better tasting than salt containing the organism that the brine shrimp eat. The price of the salt is affected.

8. Ecological monitoring

Insects are excellent indicators of ecosystem health. The numbers of species and kinds of species of insects can tell scientists if a particular ecosystem is healthy or disturbed.

9. Human and livestock health

Arthropods as vectors of disease insects weaken or kill 200 million people per year.

Examples:

- Mosquito borne diseases: malaria, yellow fever, dengue, West Nile virus, some forms of encephalitis.
- Tick borne diseases: lyme disease, erlichiosis, tularemia, Q fever, Colorado tick fever, Rocky
- Mountain spotted fever, relapsing fever and more
- Flea borne diseases: plague, typhus

10. Aesthetics

The fluttering beauty of butterflies

The sound of crickets.

The flash of fireflies

Fish baits, paper weights with impregnated insect specimens.

Jewels in insect models

Importance of insects in Bioprospecting

Silkworm (Lepidoptera) -Sericulture

Mulberry silk: *Bombyx Mori* on *Morus alba*

Muga silk: *Antheraea assamensis* on *Machilus bombycina* and *Litsaea polyantha*

ERI silk: *Samia cynthia* on *Ricinus communis and Ailanthis grandis*

Tassar silk: *Antheraea mylitta* and *Antheraea proylei* on *Terminalia* spp and *Shorea robusta*

India is the only country producing all four types of silk *viz*., mulberry, eri, tasar and muga with mulberry alone accounting for about 90 per cent of the total silk production, a report said. The estimated annual silk production in the country is 18,000 tonne. With domestic demand at 25,000 tonne per annum, most of it is met through imports from countries like China and Brazil. The Central Silk Board notes sericulture had better prospects in developing rather than advanced countries. However, in India, sericulture enjoyed good prospects due to tropical climate enabling the farmers to raise about four to six crops in a year. According to a recent analysis, the total demand for silk in the country by the end of 2011-2012 was assessed as 39,300 tonne. This required domestic raw silk production of 28,000 tonne as against the current 18,000 tonne. Hence there is scope for increasing sericulture in India with bioprospecting values.

Honey bee (Hymenoptera) - Apiculture

Apis indica - Indian Honey bee.

Apis floria - smallest Indian honeybee.

Apis dorsata- Wild rock honey bee (largest Indian honey bee)

Hosts: Many flowering plants

Honey bees are one of the important primitive social insects as well as a rich source of honey. Honey has been traditionally used in various diet preparations, medicines, cosmetics, ointments, candles and house-hold bee-wax items, besides Ayurvedic drug preparations. The propolis of the bee hive is used in lip balms and tonics, whereas royal jelly is used to strengthen the human body, for improving appetite, preventing aging of skin, leukaemia and for the treatment of other cancers. On an estimate, about 80% of honey is used directly in medicines and 10% is used in Ayurvedic and pharmaceutical production. Honey bees during foraging for pollen and nectar from flowers of different plant species enhance agricultural productivity to the tune of 30–80% annually through cross-pollination. Five species of honey bees are found all over the world, namely *Apis florea*, *A. cerana*, *A.*

dorsata, *A. mellifera* and *Trigona iridipennis*. However, *A. cerana* and *A. mellifera* are reared in hives in India. India produces about 70,000 tonnes of honey
every year of which 25–27,000 tonnes is being exported to more than 42 countries, including the European Union, Middle East and the United States. The major honey-producing states are Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. Honey, an NTFP is an important source of livelihood for tribals, who have constituted women's SHGS handling honey as commodity from forest. In South India the hilly areas of Western Ghats *viz* Nilgiris, Coorg, Hassan, Shimoga, South Canara, North Canara, Goa and Konkan areas are the major producers of honey. The role of Apiculture is very important for the upliftment of economy and for providing employment mainly to rural population settled in hilly and forest areas. Indian honey has a good export market. With the use of modern collection, storage, beekeeping equipment, honey processing plants and bottling technologies the potential export market can be tapped.

Lac insect (Hemiptera) – Lac culture

Laccifer lacca or *Tachardia* lacca is the Indian lac insect.
Host: Palas *(Butea monosperma)*, Ber *(Ziziphus mauritiana)* and Kusum *(Schleichera oleosa)*

Lac is a natural, biodegradable, non-toxic, odourless, tasteless, hard resin and non-injurious to health. Lac is, in fact, a resinous protective secretion of tiny lac insect, *Kerria lacca* (Kerr.) which belongs to the family Tachardidae in the super family Coccoidea of the order Hemiptera. The lac insect is a pest on a number of plants both wild as well as cultivated. It is the only resin from animal origin lending itself to diverse applications e.g. as a protective and decorative coating in the form of thin films, adhesives and plastics. It makes a small but significant contribution to the foreign exchange earning of the country, but the most important role that the lac plays in the economy of the country is that roughly 3-4 million tribal people, who constitute the socioeconomically weakest link of Indian population earn a subsidiary income from its cultivation. India is the major producer of lac, accounting for more than 50% of the total world production. Today an average of about 20 -22 thousand tons of stick lac (raw lac) is produced in the country per year. Most of the lac produced in India is from homestead land and wasteland. The main lac producing states in India are Chhattisgarh, Jharkhand, Madhya Pradesh, West Bengal, Uttar Pradesh, Orissa, Maharashtra and Gujarat. The cultivation of lac is at present mainly confined to the conventional lac hosts trees of Palas *(Butea monosperma)*, Ber *(Ziziphus mauritiana)* and Kusum *(Schleichera oleosa)*. At present total annual average production of stick lac in India is approximately 20-22 thousand tons which forms the raw material for lac industries. Chhattisgarh ranks 1st among the states followed by Jharkhand, Madhya Pradesh Maharashtra and West Bengal. These five states contribute around 95% of the national lac production. Nearly 75-80% of the finished product is exported and only a small portion nearly 20 to 25% is consumed within the country. Lac is one of the Non Wood Forest Product (NWFP) of great economic importance to India.

Insects as food- Entomophagy

Insect eating may be frowned upon in the west but termites, mealybugs, dung beetles, stink bugs, leaf cutter ants, paper wasps, even some species of mosquitoes are all relished by someone, somewhere, suggests the study. Eighty grasshopper species are regularly eaten; in Ghana during the spring rains, winged termites are collected and fried or made into bread. In South Africa they are eaten with a maize porridge. Chocolate-coated bees are popular in Nigeria, certain caterpillars are favoured in Zimbabwe, and rice cooked with crunchy wasps was a favourite meal of the late Emperor Hirohito in Japan. So far, says the UN, more than 1,900 species of insects have been identified as human food, with insects forming part of the traditional diets of possibly 2 billion people. The most consumed insects are the beetles (468 species), followed by ants, bees and wasps (351), crickets, locusts and cockroaches (267), and butterflies, moths and silkworms (253).
UN also reported that the best way to feed the 9 billion people expected to be alive by 2050 could be to rear billions of insects like crickets, beetles, bees, wasps, caterpillars, grasshoppers, termites, ants and common houseflies on an artificial diet and grind them up to use as animal feed. This would reduce the pressure on the Earth's forests and seas as food sources. As a nutrient-rich food source, certain insects can contribute to a balanced diet and thus have the potential to promote human health, while improving food and income security, especially among economically disadvantaged populations. Dependence on and appreciation of insects as valuable food sources will also enhance environmental awareness and help to foster positive conservation attitudes. The consumption of insects would also provide business and export opportunities for poor people in developing countries, especially women, who are often responsible for collecting insects in rural communities.

Table 1: Insects being eaten by tribes in India (Alemla AO and Singh, 2004; Oudhia, 2002)

Coleoptera	**Lepidoptera**
Cerambycidae (long-horned beetles)	Bombycidae (silkworm moths)
Coelosterma scabrata – Larva	*Bombyx mori* - pupa
Curculionidae (weevils, snout beetles)	Saturniidae (giant silkworm moths) *Antheraea assamensis*- pupa
Rhynchophorus ferrugineus larva	*Antheraea paphia*- pupa
Scarabaeidae (scarab beetles)	*Antheraea roylei* - pupa
Oryctes rhinoceros larva	*Samia ricini* -pupa
Hymenoptera	**Isoptera**
Anthophoridae (carpenter bees) *Xylocopa* sp., adult Apidae (honey bees) *Apis dorsata* Fabr., larva, pupa Bee brood Formicidae (ants) Red ant	Winged termites Termite queens Odontotermitidae *Odontotermes feae* Termitidae *Termes* sp.

Hemiptera	Orthoptera
Belostomatidae (giant water bugs)- adults *Lethocerus indicus* Lep. & Serv., Gerridae (water striders) *Gerris spinole* Pentatomidae (stink bugs) *Coridius nepalensis* *Erthesina fullo* Homoptera Cicadidae (cicadas) *Cicada* sp.	Acrididae (Short-horned grasshoppers) - adults *Acrida gigantea* *Locusta mahrattarum* *Mecapoda elongata* *Schistocerca gregaria*) Locusts/qrasshoppers Gryllidae (crickets) *Gryllodes melanocephalus* - adult Gryllotalpidae (mole crickets) *Gryllotalpa africana* Tettigoniidae (long-horned grasshoppers, katydids) *Holochlora indica*

Insects as medicine

Like plants, insects also possess medicinal properties. Though insects were widely used throughout history for medical treatment on nearly every continent, relatively little medical entomological research has been conducted since the revolutionary advent of antibiotics. Heavy reliance on antibiotics, coupled with discomfort with insects in Western culture limited the field of insect pharmacology until the rise of antibiotic resistant infections sparked pharmaceutical research to explore new resources. Arthropods represent a rich and largely unexplored source of new medicinal compounds. Medicinal significance of entomological products is important for value addition and benefit sharing for economic upliftment and poverty alleviation of local communities and indigenous people. The information available on the medicinal use of insects in NE India is presented below. Based on the sources availabe, it is indicated that there is a tremendous scope for entomological prospecting with special reference to medico entomological drugs.

Table 2: Insects are being used as medicine/medicinal products in India (Senthilkumar *et al*., 2008)

Taxon	Scientific name	Common Name	Stages used	Medicinal uses
Coleoptera	*Batocera rubra*	Long-horned beetles	Larvae	Wounds
	Coelosterna scabrata.	Long-horned beetles	Larvae	Burns
	Neocerambyx paris	Long-horned beetles	Larvae	Expectorant
	Xysterocera globosa	Pink wood borer	Larvae	Antiseptic
	Rhynchophorus ferugineus	Palm weevil	Larvae	For bronchial catarrh
	Oryctes rhinoceros	Scarab beetles	Larvae	Dissipates clots and bruises
	Zonabris pustulata	Blister beetles	Larvae	Problems in urino genital system
	Cantharis strygosa	Spanish fly	Larvae	Skin disorders, kidney and Urethra, Cauterizes tissues to control toxin spread (esp. used in rabid dog bites).
Dictyoptera	*Hierodula coarctata*	Mantid	Adult	Resolves bruises and clots
	Hierodula westwoodi	Mantid	Adult	Strengthens kidneys and relieves convulsions
	Eupolyphaga sinensis	Cockroach	Adults	Stop bleeding and heal bone fractures, swelling
	Blatta orientalis	Cockroach	Adults	Asthma and tuberclosis and use as local anesthesia and for internal feverish-chills", "for breaking up retained bloodclots", and as a "galactogogue" (milk inducer
Diptera	*Musca nebulo*	Housefly	Adult	> 15 diseases e.g., cold fever and used as a dye the hair black, eye and digestive system
	Phaenicia sericata	Blow fly larvae	Larvae	Wound healing (larvae secreate an excretion called "allontoin," It is used to prepare antiseptics and antibiotics. Allontoin now is used to treat osteomyelitis, an infectious inflammatory disease)
Hemiptera	*Dolycoris indicas*	Bamboo bug	Adult	Paralysis
	Bagrada picta	Sting bug	Adult	Goiters
	Coridius chinensis	Sting bug	Adult	Urino genetal disorder
	Coccus cacti	Cacti insect	Brood	Whooping cough
	Cimex lectularis	Bed bug	Adults	Epilepsy, piles, Urinary disorder, snake bite and hair growth. Headaches, constipation, ulcers, arthritis to baldness
Homoptera	*Cicada verides*	Cicada	Adult	For skin eruptions and ulcers, urticaria, and for deafness with running pus from ear, eye growths after smallpox, for indigestion and vomiting and clear lungs.
	Pellis cicadae	Cicada	Parasitized by the fungus *Cordyceps soboliferea*	For infantile convulsions, tetany and tetanus; for night-crying and fear
	Nephotettix nigropictus	Green leaf hopper	Adult	Stop bleeding, asthma and gonorrhea
Hymenoptera	*Cerana indica*	Honey bee	Bee sting, venum Bee wax	Arthritis Rheumatism
	Apis mellifera	Honey bee	Egg, larva, pupa Bee hives	Spleen and stomach disorders. Relieves flatulence, counteracts toxicity and kills worms

	Xylocopa violacea	Mason bees	By stings	Arthritis
	Oecophylla smaragdina	Ant	Larva and adults	Resistance to fatigue and sun's heat. Hepatitis B – (~60% efficiency to convert hepatitis B surface antigen (HBsAg) to serum negative compared to ~30% conversion efficiency using interferon)
Isoptera	*Odontotermes feae*	Termite	Adults	Anemia
	Microtermes obesi	Termite	Adults	Antidiarrheal agents
Lepidoptera	*Diacrisia oblique*	Tiger moth	Pupa	Cough, shortness of breath
	Bombyx mori	Mulberry silkworm	Pupa	Relieves flatulence and loosens congestion
	Antheraea assama	Giant silkworm moths	Pupa	Impotence
	Antheraea roylei	Muga silkworm	Pupa	Stomach disorder
	Samia cynthia ricini	Eri Silkworm	Pupa	Back pain
Odonata	*Acisoma Panorpoides*	Darner	Nymphs	Blood purifier
Orthoptera	*Hieroglyphus banian*	Rice grasshopper	Nymphs & adults	Liver disorders
	Acrida exaltata	Grasshopper		Anemia
	Holochlora albida	Long-horned grasshoppers		Ulcer
	Gryllus bimaculatus	Field Cricket		Skin diseases
	Gryllodes sigillatus	Gryllid		Skin diseases
	Teleogryllus saussure	Mole cricket		Eliminates edema.
	Gryllotalpa fossor	Mole cricket		Wound healing
Trichoptera	*Hydropsyche sikkimensis*	Caddis fly	Larvae	Stomach disorder

Biological control agents

Pests and diseases adversely affect crop productivity and the stability of production in the tropics. In India, the annual losses amount to Rs. 45,000 crore. Recently, annual crop loss due to Old World bollworm, *Helicoverpa armigera* in India has been estimated at around Rs. 2,000 crore despite the use of insecticides worth Rs. 500 crore. Because of high intensive agricultural practices and chemicalization of agriculture, the age old ecofriendly pest management practices like sanitation, crop rotation, mixed cropping composting, summer ploughing, green manuring to combat pests are found effective. The pace of development and durability of resistance varieties had been slow. Considering these limitations, there have been growing awareness and increasing demand for biological control approach to guarantee effective and sustainable food and wood production.

Biological control, i.e. conservation, augmentation and introduction of natural enemies, has been accepted as an effective, environmentally non-degrading, technically appropriate, economically viable and socially acceptable method of pest management. It has high export values too.

Indian Biological Control Agents being used in other Countries

Forty-six natural enemies from India have established in other countries and 26 are contributing extensively in improving the economy of the recipient countries on a recurring basis.

e.g.,

1. Braconid parasitoid *Aphidius smithi* introduced into USA and successfully controlled the pea aphid *Acyrthosiphon pisum* in pea and alfalfa fields.
2. The braconid larval parasitoid, *Cotesia flavipes* has successfully established on sugarcane tissue borer, *Diatraea saccharalis* in Florida (USA); Mauritius against *Etiella zinckenella* infesting pigeon pea
3. The encyrtid parasitoid *Neodusmetia sangwani* against the Rhodes grass mealybug, *Antonina graminis* in USA.
4. *Dactylopius ceylonicus* was transferred from India to Sri Lanka, which resulted in the successful control of *Opuntia vulgaris* throughout the island.
5. The parasitoid *Encarsia lahorensis* was introduced in California (USA) where it successfully established on citrus white fly, *Dialeurodes citri.* It was also introduced and established in Georgia (former USSR Republic) on *D. citri*.
6. Introduction of *Aphytis melinu* provided complete suppression of *Chrysomphalus dictyospermi* in Greece, California (USA) and Sicily (Italy) was also satisfactory.
7. *Aphytis melinus* along with several other *Aphytis* spp., *Comperiella bifasciata* and coccinellid beetles, *Chilocorus* spp. were successfully introduced to western Australia for the suppression of *Aonidiella aurantii*.
8. Excellent control of Asian citrus psylla, *Diaphorina citri* was achieved by release of eulophid parasitoid, *Tamarixia radiata* into Reunion Island, the vector of greening disease was nearly eliminated and the disease controlled.

Conclusion

Entomoforestry, the management of trees and forests for the sake of insects still poses numerous ecological, economic, technological and social challenges, and thus will be fertile ground for relevant research for years to come. Rewards in terms of long-term food security, income potential, pesticide reduction and nature conservation are conceivable and thus entomophagy may be in the best interest of sustainable development. Use of Entomoforestry insects may have Access Benefit Sharing (ABS) opportunities for those who care for biodiversity, if appropriate agreements are made with end users, like industries.

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