

Diversity of Moths (Insecta: Lepidoptera) Supported by Sandalwood (*Santalum Album* L.) in South India

S Padma

Institute of Wood Science and Technology

N Kavya

Institute of Wood Science and Technology

K N Manjula

Institute of Wood Science and Technology

R. R. Shanbhag

Institute of Wood Science and Technology

R Sundararaj (✉ rsundariwst@gmail.com)

Institute of Wood Science and Technology

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Abstract

The evergreen and perennial Royal tree, *Santalum album* L., is an eco-conservator because it houses a wide variety of organisms. One such group is moths. Intensive surveys were conducted in sandalwood plantations in south India to understand the diversity of moths supported by sandalwood. A total of 56 species of moths belonging to 15 families were found in sandalwood, and the record of 27 moths forms the first report on sandalwood. Out of 15 families, the family Erebidae is dominant with twenty-one species, followed by Geometridae with eight species and Psychidae with six species each. The remaining moths include three species each of Cossidae and Limacodidae; two species each of Crambidae, Eupterotidae, Lecithoceridae, Noctuidae and Tortricidae; and a single species in each of the remaining 5 families. Further, the pruned plantations showed a significantly negative impact on the diversity of moths and greatly influenced the level of their infestation on the trees.

Implications for insect conservation:

Our analysis provides an effective groundwork for addressing the principle of conservation for not only target insect species but also in general. Further, immediate action is specified for the protection of vegetation and proper maintenance of structural integrity of trees, which directly influences the distribution and habitats of insects.

Introduction

Insects are the largest and most diverse group of species on earth. Among the different groups of insects, lepidopterans are the second largest and most diverse, including both butterflies and moths, with around 160,000 described species in more than 120 families (Pawell 2009). Both moths and butterflies elicit a wide range of feelings in us with their magnificent beauty (Rao et al. 2022). Moths alone constitute 85% of all known lepidopterans, and from the Indian subcontinent, over 12,000 species belonging to 41 families have been reported (Chandra 2007). It is cosmopolitan in distribution and seen as associated with plants as feeding its caterpillars. They play a significant role economically and ecologically as a primary food source for vertebrates and insectivores, as pollinators and pests of plants, and as model organisms in scientific study (Common 1990; Roe and Just 2009; Mac Gregor et al. 2015). Some of these functions have a direct influence on the food chain. They are potential indicators of ecosystem health and biodiversity across a wide range of landscapes (Rao et al., 2022).

Several factors such as rapid urbanization, habitat loss, artificial light, agricultural intensification, pesticide application, decrease in resource availability, extreme weather, and a lack of conservation policies gradually resulted in a decline in the diversity and abundance of moths around the world (Dennis et al. 2019) and they are rarely considered for conservative assessment (Hallmann et al. 2020). In addition, because of the monoculture practice of plantation forests, they are poor in biodiversity, and often control operations are engaged against these insects. The use of pesticides and loss of habitat due to unfavorable conditions created by unscientific methods of plantation resulted in either a complete loss

of insect species or an outbreak of pest populations. Though caterpillars are voracious feeders, their individual damage is negligible. Also, pruning trees implies an unavoidable loss of ecosystem services like nutritional resources to pollinators and predators, and inappropriate pruning causes deterioration of tree condition (Clark and Metheny 2010; Fini et al. 2015; Sundararaj et al. 2020; Sundararaj et al. 2023). The immature stages are the best-known stage to study host associations and their life histories (Wagner et al. 2021) since adults are potential pollinators that forage on different flora.

In contrast to most monoculture plantations, sandalwood being hemiparasitic in nature, cannot be grown under monoculture arrangements as it requires a host (Lu et al. 2020; Qin et al. 2023). For the growth and survival of sandalwood primary and secondary hosts are much needed, thus providing the ideal different strata of vegetation needed for the moths to survive. Moreover,

sandalwood is the medicinal tree generally used in Ayurvedic medicines (Rajsmitha and Keshavamurthy 2019), local decoctions, and other homemade preparations. The presence of toxic residues of pesticides in raw materials makes them unfit for further processing and use (Gahukar 2018; Pan et al. 2023). Hence, integrated pest management strategies with the use of botanical-based chemicals or natural enemy complexes are practiced in sandalwood plantations (Gahukar 2018), thus rendering a favorable environment for moths to thrive. The present study deals with the findings of the surveys conducted to document the moth diversity supported by sandalwood plantations in south India.

Materials and Methods

Study area and collection method:

Extensive surveys were conducted in sandalwood plantations in different regions of South India (Table 1; Fig. 1) for a period of two years from July 2020 to June 2022. Every nook and corner of the plant, starting from branches, flowers, fruits and even the barks was observed for the presence of caterpillars. An active searching method of roving survey was adopted and damaging stages of the moths, i.e., larval stages were handpicked and brought to the laboratory. Then they were reared in insect-rearing boxes by providing leaves of sandalwood. Each stage was photographed and recorded with the help of the camera Canon SX540s. After the completion of the life cycle from larva, pupa and adult, the adult specimens were pinned and preserved in an insect mounting box and deposited in the Department of Forest Protection Division, IWST campus. Identification and confirmation were done with the help of experts and using the butterfly image database created by the National Bureau of Agricultural Insect Resources (NBAIR 2023).

From the data, further analysis of the effect of pruned and unpruned plantations was done by categorizing all the species collected in sandal plantations into two group's viz. species collected from pruned plantations and species collected from unpruned plantations. The student "t" test was performed using Microsoft Excel 2017.

Result and Discussion

Fifty-six species of moths belonging to 15 families were found inhabiting different parts of sandalwood (*Santalum album* L.) in southern India (Table 2). Out of 56 species of moths collected, 27 were new reports on sandalwood. These 56 species belonged to 15 different moth families, with the family Erebidae being the dominant one with 21 species (38%), followed by Geometridae with 8 species (14%) and Psychidae with 6 species (11%). The remaining families were Cossidae and Limacodidae each with 3 species (5%); Crambidae, Eupterotidae, Lecithoceridae, Noctuidae and Tortricidae were represented with 2 species (4%) each; and the other 5 families, Hepialidae, Lasiocampidae, Nolidae, Pterophoridae, and Sphingidae were represented by single species (2%) (Table 3; Fig. 3). The observed moths were predominantly feeding on the leaves of sandalwood, but some prefer to feed on fruit and floral buds at some stages of their life span with the exception of *Indarbela quadrinotata* and *Polyphagozerra coffeae* which feed on the bark and stem, respectively.

The findings illustrate that the family Erebidae is widely distributed and abundant which corroborates the findings of Dar et al. (2021) who reported the dominance of Erebidae moths in the Aravalli Hill range of Rajasthan. A study on moth diversity in three different vegetative habitats namely forest, agriculture, and urban areas in south Goa by Rao et al. (2022) revealed a uniform dominance of the Erebidae family. Also, the checklist of the moths of Kerala included a maximum of 264 species of moths of this family (Valappil 2020).

The results further depicted a huge difference in the distribution of moth species between healthy unpruned and severely pruned sandalwood plantations. Pruned sandalwood plantations recorded significantly less diversity of moths compared to unpruned sandalwood. Unpruned healthy sandalwood plantations recorded 56 species under 18 families whereas pruned sandalwood recorded only 6 species under 4 families which include *Artaxa* sp., *Orgiya* sp., *Hyposidra talaca*, *Olena mendosa*, *Macroplectra nararia* and *Kophene cuprea*. The Two-tail "t" Test also statistically confirmed ($P(T \leq t) = 0.0241362$) the significant difference in the overall species distribution in pruned and unpruned sandalwood (Fig. 4 and Fig. 5). It indicates that the lateral branches and the original evergreen nature of sandalwood play a vital role in the diversity and inhabitation of moth species. However, the unpruned plantations recorded a vast diversity of moth species; the impact of feeding is negligible compared to pruned plantations.

Sandalwood is a perennial plant with bright, glistening, dark green leaves throughout the year. Hence, it is natural for insects to get attracted to and take shelter under the shade of this marvelous plant. Sundararaj et al. (2006) recorded 1049 species of insects representing 119 families under 13 orders from sandalwood-dominated ecosystems of south India, in which Lepidoptera stands as the third most diverse group of insects with 67 species under 23 families, with the highest being the family Arctiidae with 9 species. Subsequently Sundararaj et al. (2011) reported 159 insect species as phytophagous on sandalwood, of which Lepidoptera are the second most diverse group with 31 species representing 15 families. Moths display an immense mutual association with sandalwood by being nocturnal pollinators and, in return, getting food and shelter from sandalwood. Sandalwood is a self-incompatible, cross-

pollinating flower that blossoms twice a year (Ananthapadmanabha et al., 1991) and is predominantly pollinated by insects belonging to the orders Hemiptera, Diptera, Hymenoptera and Lepidoptera (Bhaskar 1992; Balasubramanian et al. 2011; Krishnakumar et al. 2018; Efloraofindia 2020) in which the role of moths as a potential pollinator is hardly recognized as they are nocturnal pollinating agents (Macgregor et al., 2015). Lepidopterans spend longer on flowers compared to Diptera and Hymenoptera (Herrera 1989), accounting for 98% of nocturnal pollination only by adult moths and their role is understudied (Waring and Townsend, 2017; Macgregor et al., 2020). Species belonging to Erebidae and Sphingidae are cited as key pollinators for the Himalayan ecosystem (Holloway 2003). The association of plants and invertebrates is an integral part of the development and maintenance of pollination networks and ecological services. Increasing the availability of nectar and pollen resources through proper plantation and habitat restoration can contribute to the conservation of efficient pollinators like moths and increase the population size of threatened plants (Benton et al. 2003; Klein et al. 2007; Maia et al. 2019).

Vegetation-based community supports the diversity and abundance of moths (Highland et al. 2013) and sandalwood plantations play a major role in maintaining the diversity and abundance of these moths. In south Goa, Rao et al. (2022) reported a rich diversity of moths in both forest and agricultural areas of 51.96 and 29.8% abundance, respectively, compared to urban anthropogenic areas of only 19.23% abundance. Rapid urbanization and deforestation lead to habitat loss for both larval and adult moths. Ectothermic insects such as moths are least appreciated as sensitive ecological indicators for determining the quality of the environment, especially in forest ecosystems (Intachat et al. 2005; Thomas 2005; Wirooms 2005; Lomov et al. 2006; Gerlach

et al. 2013). They are abundant and yet diverse, with a high reproductive rate and a short generation time. They are sensitive to habitat fragmentation and anthropological activity; loss of vegetation leads to alteration in development, dispersal, and reproduction and directly affects their population growth (Bale et al. 2002; Andersen et al. 2004).

The association of insects with the crop or forest plant is a natural phenomenon; as long as the tree species is healthy, the situation of an artificial method of management of insects is unlikely to arise. The vegetation plays a vital role in their survival and mating and also determines certain suitable microclimates (Dover et al. 1997). Thicker and healthier vegetation positively supports and invites natural enemies, which in turn keep the pest population under control. Many of the reported moth caterpillars in this study are voracious feeders but caused negligible damage in healthy unpruned sandalwood plantations. In contrast to this, the pruning of the branches caused more severe damage to the living tree than the mere feeding by the larvae. Thus, trees with no pruning or less pruning had an insignificant range of damage by moths in spite of having a large number of associated species. In severely pruned sandalwood plantations, the nutritional resources of defoliators are virtually removed, leaving few leaves, and hence the impact of feeding by a few species of moths shows a visible impact. Apart from the external damage caused by pruning, immense invisible internal damages are made, which make the tree species vulnerable to a small infestation of insects (Sundararaj et al. 2018). The impact of pruning is masked by the infestation of insects, but in reality, the pruned, energy-starved trees are the first to get

affected by the insect infestations and fungal infections as they have lost the ability to resist (Laca 2013). Padma and Sundararaj (2021) have conducted a detailed study on the role of vegetation in the occurrence of natural enemies, especially spiders. They reported 17 individuals of three species in pruned sandalwood plantations and 45 individuals of 28 species in unpruned plantations, and they concluded that due to the loss of a conducive environment by pruning, the occurrence of natural enemies is negatively affected. It not only affects the distribution of natural enemies but also affects the other mobile ecosystem servicers like pollinators from making their colonies and drastically affecting their foraging ability (Sundararaj et al. 2020). This could be the possible reason for the sudden outbreak of single moth varieties as pests and their severity of infestation in the pruned plantations of sandalwood. In addition, Sundararaj et al. (2018) stated that insect pests and natural enemies documented from more diversified areas of sandalwood showed less severity of infestation and did not require insecticidal application. This indicates that nature's scientific

approach towards sandalwood plantations is more encouraged for the better co-existence of pests and predator populations and the pest populations can be managed without any impairment to the sandalwood.

Conclusion

Phytophagous insects and plants coevolved together, and sandalwood being an evergreen tree, supports the survival of various insect species, including phytophagous insects, potent pollinators, and effective predators and parasitoids. The present investigation exhibited the importance of healthy plantations for the co-existence of these organisms without affecting the health and growth of sandalwood. In the natural growth of sandalwood, it develops dropping and erecting lateral branches that support all these groups of organisms, but pruning of the lateral and side branches causes the loss of habitat and food resources and mutualisation between insects and tree species. Such imbalances often lead to the outbreak of phytophagous insects in the absence of natural enemies and pruning-induced loss of virulence in trees. Hence, it is recommended to nourish the sandalwood plantations in harmony with nature and the biodiversity they support.

Declarations

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Ethical Approval

Not Applicable

Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

Author Information:

Authors and Affiliation

Institute of Wood Science and technology, Malleswaram, Bangalore- 560003, India

S Padma, N Kavya, K N Manjula, R. R. Shanbhag and R Sundararaj.

Authors contribution:

S Padma, N Kavya and K N Manjula carried out the field survey and collection of different stages of moth species from sandalwood plantation. S Padma prepared draft of the manuscript, assisted in identification of moth species and analysis of data. R R Shanbhag and R Sundararaj have guided in preparing the manuscript and analysis of data. R Sundararaj also guided and assisted, in every step like, designing and execution of the work and finalizing the manuscript. All authors read and reviewed the final manuscript.

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Availability of data and materials:

The data collected were analyzed and student t test was performed using excel sheet (Excel- 2017).

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Tables

Table I Details of the locations of the sandalwood plantations surveyed in south India.

Sl. NO	State	District	Place	Latitude-Longitude
1.	Karnataka	Bangalore	IWST, Malleshwaram	13°00'42.1"N 77°34'12.3"E
2.		Chikkaballapur	Bagepalli	13°48'10.9"N 77°48'16.3"E
3.			Sevapura- Tarikere	13°42'12.8"N 75°49'28.2"E
4.			Bikkaemanae	13°15'38.6"N 75°45'51.7"E
5.		Chitradurga	Pitlali	13°54'00.0"N 76°41'48.6"E
6.		Davanagere	Hanumanahalli	14°09'17.6"N 75°43'44.5"E
7.		Kolar	Bhatrahalli	13°11'21.6"N 78°28'02.3"E
8.	Kerala	Idukki	Marayoor- Forest Sandal Reserve	10°16'27.6"N 77°09'12.6"E
9.	Tamil Nadu	Coimbatore	Karumathampatti	11°07'46.2"N 77°09'17.6"E
10.			Ayyampalayam	10°58'23.4"N 7°12'37.0"E
11.		Namakkal	Ichampalaya	11°24'56.5"N 78°16'08.8"E
12.		Thoothukudi	Pudhukulam	8°26'16.8"N 77°52'24.0"E
13.		Salem	Machinanickenpatti	11°42'45.1"N 78°01'58.8"E
14.		Kallakurichi	Kalvarayan Hills	11°54'04.8"N 78°30'11.1"E
15.	Telangana	Rengareddy	Shadnagar	17°03'06.1"N 78°12'50.8"E
16.		Mahbhuagar	Damakanur	16°37'11.2"N 77°50'17.0"E
17.		Mahbhuagar	Nagarkurnool	16°28'44.6"N 78°17'42.4"E
18.	Andhra Pradesh	Ananthapur	Kottacheruru	14°13'13.5"N 77°44'56.9"E

Table II: Species diversity of moths in sandalwood plantations

Sl.No	Family	Species
1.	Erebidae	21
2.	Geometridae	8
3.	Psychidae	6
4.	Limacodidae	3
5.	Cossidae	3
6.	Crambidae	2
7.	Eupterotidae	2
8.	Lecithoceridae	2
9.	Noctuidae	2
10.	Tortricidae	2
11.	Hepialidae	1
12.	Lasiocampidae	1
13.	Nolidae	1
14.	Pterophoridae	1
15.	Sphingidae	1

Table III: Species of moths supported by Sandalwood (*Santalum album* L.)

Sl. No	Insect pest species	Family	References/New Record
1	<i>Acanthopsyche moorei</i> Heylaerts	Psychidae	Srinivasan et al., 1992; Sundararaj, 2011
2	<i>Achaea janata</i> (Linnaeus)	Erebidae	Srinivasan et al., 1992; Sundararaj, 2011
3	<i>Acherontia styx</i> Westwood	Sphingidae	Chatterjee, 1935; Sundararaj, 2011
4	<i>Aloa lactinea</i> (Cramer)	Erebidae	Chatterjee, 1935; Sundararaj, 2011
5	<i>Amata passalis</i> (Fabricius)	Erebidae	Chatterjee, 1935; Sundararaj, 2011
6	<i>Archips</i> sp.	Tortricidae	New Record
7	<i>Artaxa</i> sp.	Erebidae	New Record
8	<i>Ascotis selenaria imparata</i> (Walker)	Geometridae	Chatterjee, 1935
9	<i>Asota</i> sp.	Erebidae	Sundararaj, 2011
10	<i>Biston suppressaria</i> (Guenee)	Geometridae	New Record
11	<i>Brunia antica</i> (Walker)	Erebidae	New Record
12	<i>Chiasmia emersaria</i> (Walker)	Geometridae	New Record
13	<i>Clania variegata</i> (Snellen)	Psychidae	New Record
14	<i>Cyana peregrine</i> (Walker)	Erebidae	New Record
15	<i>Darna</i> sp.	Limacodidae	New Record
16	<i>Ectropis bhumitra</i> (Walker)	Geometridae	New Record
17	<i>Erebus macrops</i> (Linnaeus)	Erebidae	Sundararaj, 2011
18	<i>Eumeta crameri</i> (Westwood)	Psychidae	Sundararaj, 2011
19	<i>Euproctis fraterna</i> Moore	Erebidae	Sundararaj, 2011
20	<i>E. geminata</i> Collenette	Erebidae	New Record
21	<i>Eupterote geminata</i> (Walker)	Eupterotidae	Mathur and Singh 1961; Srinivasan et al., 1992
22	<i>E. undata</i> Bianchard	Eupterotidae	New Record
23	<i>Glyphodes</i> sp.	Crambidae	Chatterjee, 1935; Sundararaj, 2011
24	<i>Gonodontis clelia</i> (Cramer)	Geometridae	New Record

25	<i>Homona coffearia</i> (Nietner)	Tortricidae	New Record
26	<i>Hypomecis infixaria</i> (Walker)	Geometridae	New Record
27	<i>Hyposidra talcata</i> (Walker)	Geometridae	New Record
28	<i>Indarbela quadrinotata</i> (Walker)	Cossidae	Sundararaj and Muthukrishnan (2007); Sundararaj, 2011
29	<i>Kophene cuprea</i> Moore	Psychidae	New Record
30	<i>Lantanophaga pusillidactyla</i> (Walker)	Pterophoridae	Sundararaj, 2011
31	<i>Macroplectra nararia</i> Moore	Limacodidae	Srinivasan et al., 1992
32	<i>Mocis frugalis</i> (Fabricius)	Erebidae	Sundararaj, 2011
33	<i>Nola fasciata</i> (Walker)	Nolidae	New Record

34	<i>Nyctemera lacticinia</i> (Cramer)	Erebidae	New Record
35	<i>Olene mendosa</i> (Hubner)	Erebidae	New Record
36	<i>Olepa ricini</i> (Fabricius)	Erebidae	Sundararaj, 2011
37	<i>Orgyia postica</i> (Walker)	Erebidae	Chatterjee, 1935; Srinivasan et al., 1992; Swafvan and Sureshan, 2022
38	<i>Orgyia</i> sp.	Erebidae	New Record
39	<i>Orvasca subnotata</i> Walker	Erebidae	New Record
40	<i>Parasa lepida</i> (Cramer)	Limacodidae	Sundararaj, 2011
41	<i>Perina nuda</i> (Fabricius)	Erebidae	New Record
42	<i>Polyphagozerra coffeae</i> Nietner	Cossidae	Stebbing, 1903; Chatterjee, 1935; Srinivasan et al., 1992; Sundararaj, 2011
43	<i>Sahyadrassus malabaricus</i> (Moore)	Hepialidae	Beeson 1941; Srinivasan et al., 1992
44	<i>Scythropiodes</i> sp. 1	Lecithoceridae.	New Record
45	<i>Scythropiodes</i> sp. 2	Lecithoceridae	New Record
46	<i>Semiothisa</i> sp.	Geometridae	Sundararaj, 2011
47	<i>Somena scintillans</i> (Walker)	Erebidae	Chatterjee, 1935; Srinivasan et al., 1992; Sundararaj, 2011
48	<i>Speiredonia suffumosa</i> (Guene)	Erebidae	Sundararaj, 2011
49	<i>Spodoptera litura</i> (Fabricius)	Noctuidae	Mathur and Singh, 1961: Sundararaj, 2011
50	<i>Sterrhopterix</i> sp.	Psychidae	Sundararaj, 2011
51	<i>Strebolte siva</i> (Lefèbvre)	Lasiocampidae	New Record
52	<i>Syntomoides imaon</i> (Cramer)	Erebidae	Swafvan and Sureshan, 2022
53	<i>Thyridipteryx</i> sp.	Psychidae	Sundararaj, 2011
54	<i>Tiracola plagiata</i> (Walker)	Noctuidae	New Record

55	<i>Uresiphita gilvata</i> (Fabricius)	Crambidae	Sundararaj, 2011
56	<i>Xyleutes persona</i> (Le Guillou)	Cossidae	New Record

Figures

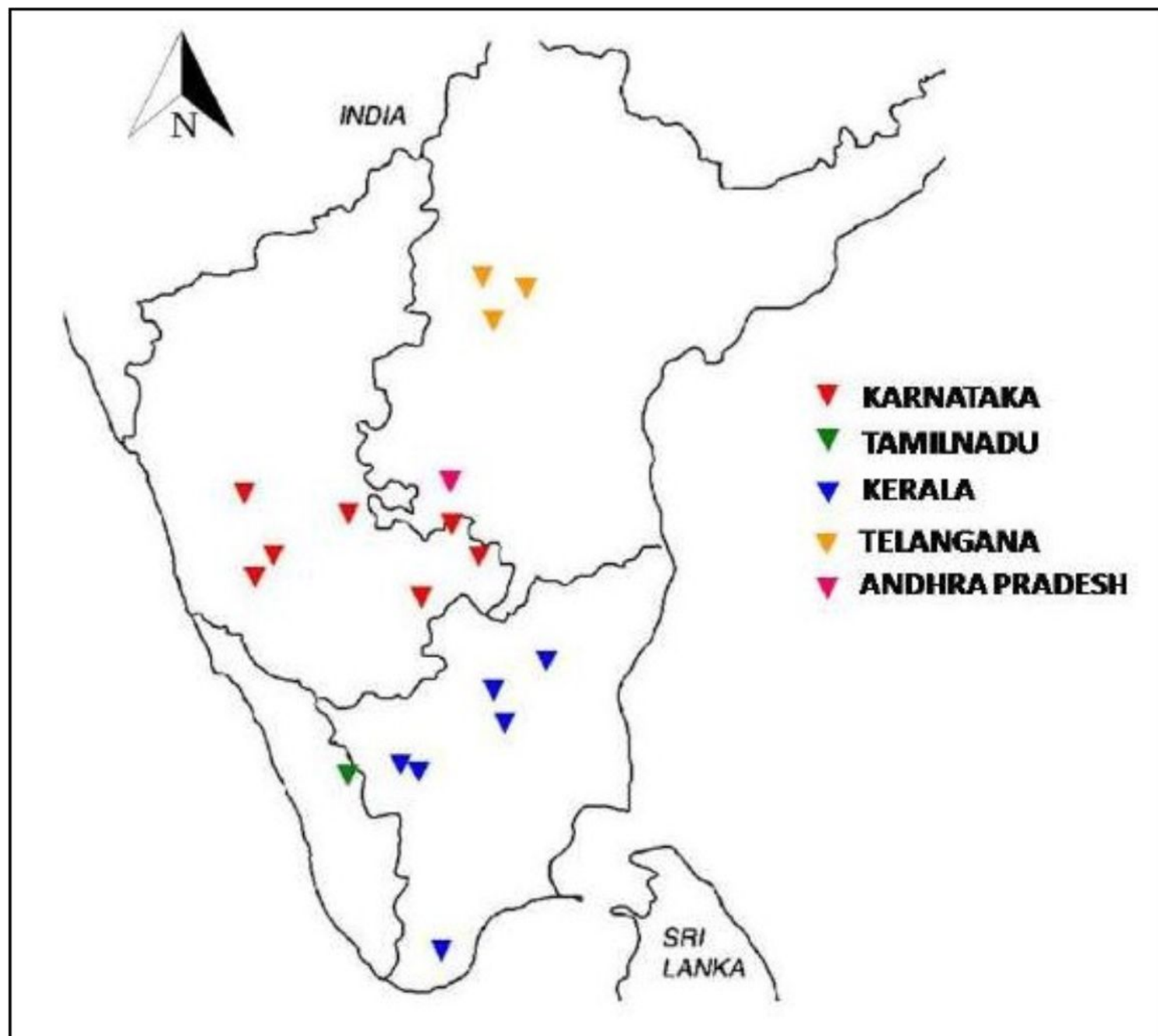


Figure 1

Map of survey area in Southern India

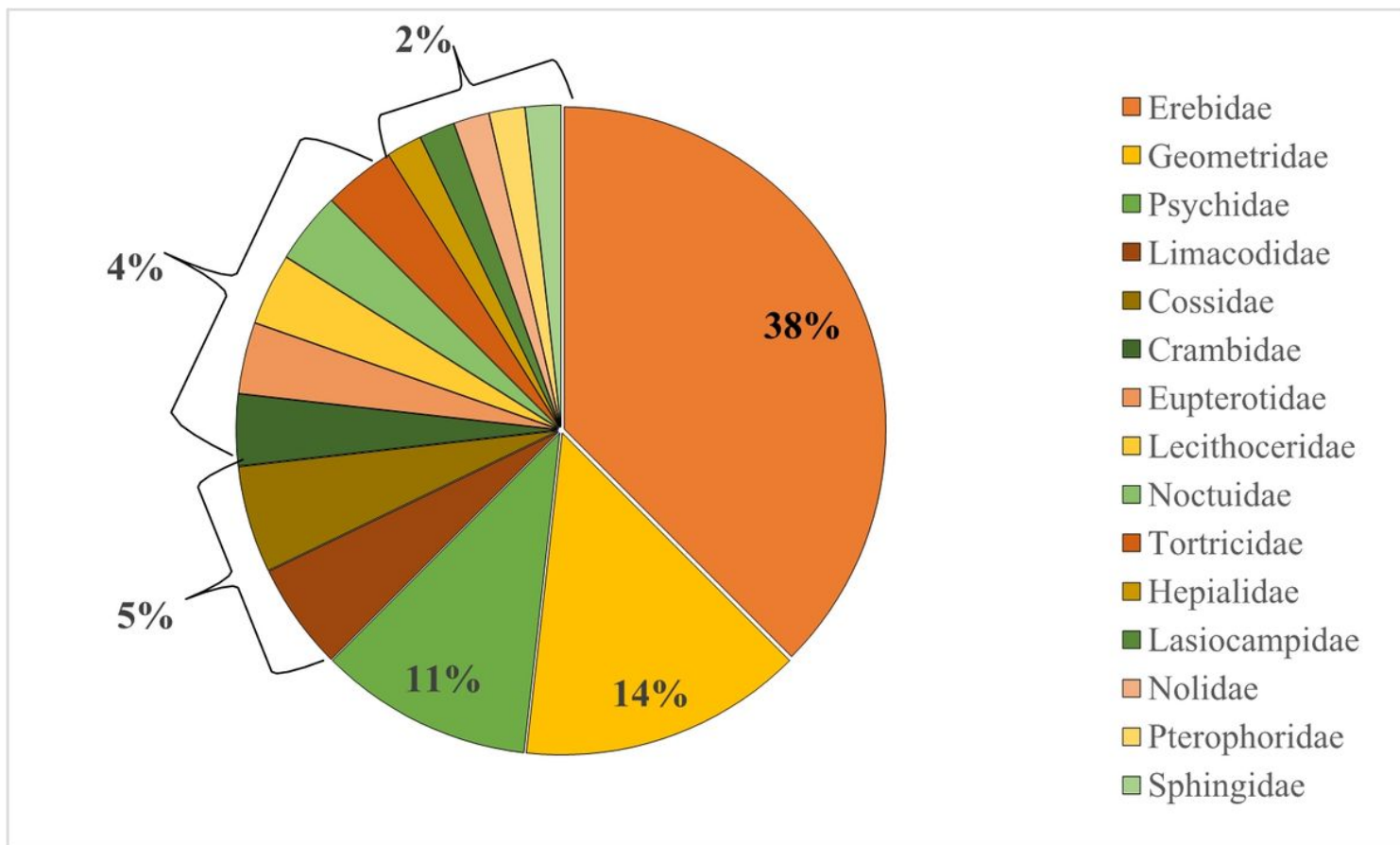


Figure 2

Diversity of moth families supported by sandalwood plantations

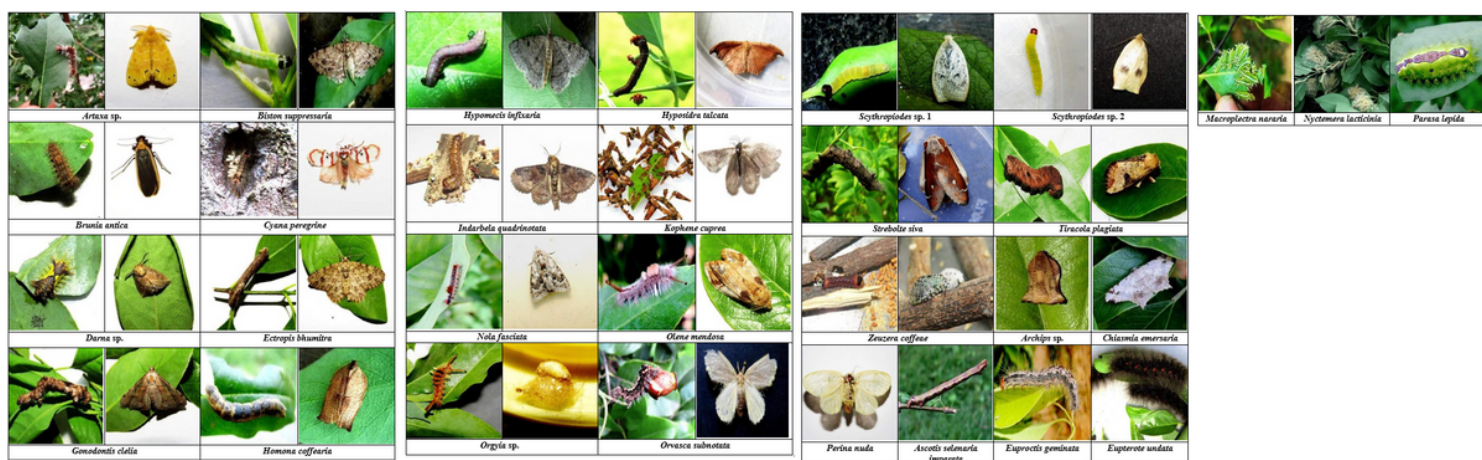


Figure 3

Images of Lepidopteran moth both in Larva (left) and Adult (right) collected from *Santalum album* L.



Figure 4

Images showing Healthy unpruned (a) and Pruned (b) sandalwood



Figure 5

Severe infestation of *Kophene cuprea* in pruned sandalwood