Hypsipyla Shoot Borers in Meliaceae

Proceedings of an International Workshop held at
Kandy, Sri Lanka 20–23 August 1996

Editors: R.B. Floyd and C. Hauxwell

Australian Centre for International Agricultural Research
Canberra, 2001

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Floyd, R.B. and Hauxwell, C., ed. 2001. Hypsipyla Shoot Borers in Meliaceae. Proceedings of an International Workshop, Kandy, Sri Lanka 20–23 August 1996. ACIAR Proceedings No. 97, 189pp.

ISBN 0 642 45621 6 (print)
ISBN 0 642 45624 0 (electronic)

Editorial management: P.W. Lynch
Production editing: PK Editorial Services Pty Ltd, Brisbane
Typesetting, page layout and illustrations: Sun Photoset Pty Ltd, Brisbane
Printing: Brown Prior Anderson, Melbourne

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Foreword

IT HAS been a most welcome and opportune initiative of CSIRO Entomology and the Queensland Forestry Research Institute (QFRI) to organise an International Workshop on Hypsipyla which was hosted by the Forestry Department of Sri Lanka and supported financially by ACIAR, DFID, AusAID and RIRDC. The papers presented at the meeting and now incorporated in these Proceedings reflect both the current 'state of the art' and the involvement of a great number of national and international institutions and organisations in research on the shoot borers of the Meliaceae. No less than 35 participants from 16 countries, representing 25 institutions and organisations have been involved in the workshop.

The organisers of the workshop are to be congratulated for the intercontinental and participatory approach of the meeting, which provided a binding element in the search for a common solution to a common problem. Hopefully, these contacts can be maintained and perhaps even expanded into effective international collaboration. As it has been more than 20 years since the First Symposium on Integrated Control of *Hypsipyla* was held in Turrialba, Costa Rica, by the Inter-American Working Group on *Hypsipyla*, the Kandy workshop also represents the end of a long period of discontinuity in major international co-operative research on the relationship between the valuable Meliaceae and their most intractable insect pest *Hypsipyla* spp.

The current international need to find a solution to the age-old shoot borer problem is given impetus by the rapid erosion of genetic sources of the Meliaceae in most of the continents. In 1992, during the Earth Summit at Rio de Janeiro, ecologists and biologists predicted that 10–20% of the earth's estimated 10 million species of plants and animals would have become extinct by the year 2020. Of these, 50% were likely to be lost due to disappearing tropical rainforests.

Meanwhile, *Swietenia humilis* and *S. mahagoni* have been listed on Appendix 2 of the Convention on International Trade in Endangered Species (CITES), while the inclusion on Appendix 2 of *S. macrophylla*, currently listed on Appendix 3, was considered. The inclusion of the mahoganies on this list obliges timber companies to formalise the export from the countries of origin and forces the governments of exporting countries to warrant that the species is still adequately stocked in the forests. Trade in these species is not prohibited. However, in a number of Western European countries, a discussion is currently taking place to limit the import of tropical timber species to only those that are produced on a sustained yield basis. That would clearly pose a problem with regard to species of Meliaceae such as the cedars and mahoganies for which, notwithstanding all efforts in the past, no viable silvicultural system exists yet in the countries of origin, not even in Australia.

Fortunately, CSIRO Entomology and the QFRI are taking up the challenge to find a solution for the shoot borer problem in a multidisciplinary approach. A stimulating interaction between disciplines, in addition to motivated Ph.D candidates and post-graduate students, forest nursery facilities, experimental plantation areas and last but not least a mass rearing program, were a few of the key factors that resulted in a high research productivity of the Working Group on *Hypsipyla* at CATIE in Turrialba, Costa Rica. It was most encouraging to learn that research on the shoot borer has again been taken up at CATIE.

Among the important research subjects that remained largely undeveloped after the research in the 1970s and 1980s were silviculture and ecology of the Meliaceae, i.e. soil and site selection, silvicultural systems of line or group plantings in existing wet and dry forests and the degree of heterogeneity of mixed plantations. To determine the place of the Meliaceae within the complex environment of the tropical forest, with its multiple interdependent biological networks, requires long-term research and consequently substantial funding. Researchers as well as funding agencies experience that prospect as a barrier. To pass that barrier the co-ordinated support of several development agencies and sponsors, as well as the close collaboration of Forest Services, might be necessary.

In my home in the Midi-Pyrenees, I still keep a potted plant of Spanish Cedar (*Cedrela odorata*) which is now a little over eight years old. With its long pale green leaves, it has a graceful appearance and reminds me of the time I worked on *Hypsipyla*. Every other winter, when it has become too tall, I cut it back to some 5 cm above the soil and stop watering it until next spring. To be frank, I once hoped that it would grow into a small twisted Bonsai tree. However, every time it revives, it produces several buds on its trunk, which are all eventually suppressed except one that grows into a new long straight leader; a most promising sign. More promising, however, is that a new generation of scientists has found a common basis to work on the strategies and priorities that have been set at the *Hypsipyla* Workshop. I am sure that all my old-time colleagues and fellow-researchers join me in wishing them persistence and resourcefulness to develop a method for reducing shoot borer damage to native Meliaceae to a tolerable level.

Pieter Grijpma

Hypsipyla Shoot Borers of Meliaceae in Sri Lanka

D. Tilakaratna[1]

Abstract

Although the forest industry plays a relatively minor role in Sri Lanka's economy, its forests (covering 31% of the land area) play an important role in environmental stability and sustenance of the hydropower generation in the country. The plantation forest estate consists of 131 309 ha, with about 3400 ha planted annually. There are three native species of sub-family Swietenioideae in Sri Lanka. Two are small trees used mainly for fuel wood and have a limited occurrence in mangrove swamps. The third is a minor cabinet timber. Out of five introduced species of subfamily Swietenioideae, two are very important (*Swietenia macrophylla* King and *Khaya senegalensis* (Desr.) A. Juss.). *Swietenia macrophylla* has been a successful plantation species since the 1890s and local foresters have developed good silvicultural practices. Although *Hypsipyla robusta* (Moore) attacks occur, damage can be avoided by maintaining shelter in young plantations. *Khaya senegalensis* is a recent introduction and is gaining popularity, especially due to its suitability for drier areas. *Toona ciliata* M. Roem. is grown mainly as a shade tree in tea plantations at higher elevations. It is also specifically planted to produce valuable timber. Presently an unidentified disease threatens its continued use. *Swietenia mahagoni* (L.) Jacq. and *Cedrela odorata* L. are also planted but have not gained popularity since their introduction. The very limited work in the past on *H. robusta* is largely due to it not being a major problem in Sri Lanka when mahogany is raised using enrichment planting as practised by the Forestry Department. However, it is a serious problem in plantings on open sites as practised by the private sector and research to find a control technique is important. Future research on *H. robusta* in Sri Lanka will be directed mainly at silvicultural control and tree improvement.

THE forest industry plays a lesser role relative to other industries in the economy of Sri Lanka. This is indicated by the industrial production figures given in Table 1. Wood products come mainly from man-made plantations and home gardens, as logging in natural forests has been banned. The total forest cover in 1994 was about 31% of the land area (Conservator of Forests 1994). Forests provide shelter for wildlife and a source of other natural products such as medicinal plants, rattans etc. Maintenance of environmental stability, soil conservation and protection of biodiversity are other indirect benefits of forests. Forests in the catchment areas of rivers and reservoirs help regulate stream flow and water levels and thereby contribute to the maintenance of hydroelectric power production and to the entire industrial production in the country. The area planted to the principal plantation species is shown in Table 2 with *S. macrophylla* representing the fourth largest area.

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Importance and success of Meliaceae sub-family Swietenioideae tree species

Xylocarpus granatum Koen., *X. moluccensis* (Lam.) M. Roem. and *Chukrasia velutina* Roem. are the only species of sub-family Swietenioideae that are native to Sri Lanka (Triman 1974). *Xylocarpus* species are found in mangrove swamps and are harvested in very limited quantities, mainly by local communities for firewood. The present rate of harvesting is not sustainable as mangrove areas are being converted to other land use types and demand for firewood is increasing. *Chukrasia velutina* is used as a cabinet timber. The area planted to various Meliaceae species is presented in Table 3 and discussed in the following text.

***Swietenia macrophylla* King**

Swietenia macrophylla has been planted in Sri Lanka over the past 100 years with the first plantation established in 1897 (Streets 1972). It is a high value species in the local market fetching around 300–500 rupees per cubic foot. Presently, about 7314 ha of mahogany plantations have been planted in Sri Lanka and it represents an important component of the plantation forest estate**.** Easy establishment, relatively fast growth and ability to regenerate naturally under existing plantations has made it an attractive tree species for producing high value hardwood. *Swietenia macrophylla* is a high priority species for planting in the intermediate and wet zones with, respectively, an average annual rainfall of 1500–2000 mm and 2000–5000 mm. It is unable to grow in the drier areas in Sri Lanka.

Table 1. Value of industrial production 1991–1995 (Rs. million). Source: Central Bank of Sri Lanka (1995).

Categories	1991	1992	1993	1994	1995
1. Textiles, wearing apparel and leather products	33 854	53 020	70 057	78 211	89 944
2. Food, beverages and tobacco	30 003	34 157	30 700	45 054	54 927
3. Chemical, petroleum, rubber and plastic products	20 140	23 817	28 876	34 017	38 321
4. Non-metallic mineral products	8 181	10 582	12 351	14 580	16 740
5. Fabricated metal products, machinery and transport equipment	5 093	5 948	5 915	7 122	7 977
6. Paper and paper products	2 214	2 586	3 438	4 066	4 595
7. Wood and wood products	802	1 005	1 230	1 601	1 929
8. Basic metal products	1 264	1 424	1 497	1 909	1 736
9. Products not elsewhere specified	2 373	2 658	3 402	4 083	5 271
Total	103 924	136 106	166 475	190 643	221 440

Table 2. Area of forestry plantations in Sri Lanka. Source: Conservator of Forests (1995).

Tree species planted	Present area planted (ha)	Projected rate of planting (ha/year)
Tectona grandis Linn. f.	46 060.80	500
Pinus caribeae Morelet.	17 964.70	0
Eucalyptus camaldulensis Dehn.	15 774.30	0
Swietenia macrophylla King	7 314.50	400
Acacia auriculiformis Cunn.	5 964.00	175
Eucalyptus grandis Hill ex Maiden	4 827.95	250
Azadirachta indica A. Juss.	3 420.90	300
Eucalyptus microcorys F. Muell.	910.50	75
Acacia mangium Willd.	890.10	450
Eucalyptus tereticornis Smith	852.60	0
Artocarpus heterophyllus Lam.	438.90	0
Other species	26 889.90	1250
Total	131 309.15	3400

Table 3. Native and exotic tree species of Meliaceae subfamily Swietenioideae planted in Sri Lanka.

Tree species	Native/ introduced	Present area planted (ha)	Rotation (years)	Present planting rate (ha/yr)	Planting status[1]	*Hypsipyla* attack
Swietenia macrophylla King	Introduced	7314	40	400	A	YES
S. mahagoni (L.) Jacq.	Introduced	6.8	40	0	D	YES
Khaya senegalensis (Desr.) A. Juss.	Introduced	70	40	50	A	YES
C. odorata L.	Introduced	Not known	40	0	C	NO
Toona ciliata M. Roem.	Introduced	43.6	40	20	A	YES

[1] A – ongoing and successful; B – ongoing but having limited or variable success; C – preliminary or experimental only; D – terminated

Mayhew and Newton (1998) have reviewed the silviculture of *S. macrophylla* with special reference to Sri Lanka. Most of the *S. macrophylla* plantations in Sri Lanka have been established as mixed plantations with teak (*T. grandis* L.) and Jak (*Artocarpus integrifolia* Linn. f). *Swietenia macrophylla* is successful in these mixtures but teak and Jak are unable to compete effectively (Mayhew and Newton 1998).

The interim management plan prepared by the Forest Department proposes three methods of establishing *S. macrophylla* plantations (Sandom and Thayaparan 1995). These are enrichment by underplanting, enrichment by block planting and enrichment by block planting with a nurse crop. Current planting practices are enrichment planting in degraded secondary forests and underplanting of *Pinus* plantations for conversion to broad leaf species, while research is being conducted on the use of nurse crops (Mahroof 1999). Enrichment planting consist of 2 m wide lines spaced at 5 m intervals in secondary scrub forests with trees planted 3 m apart. Planting stock is obtained by uprooting seedlings (striplings) about 1 m tall from under older plantations. Underplanting is carried out by removing alternate rows of pine trees and striplings are planted along the opened lines at 3 m spacing. After planting, patch weeding and climber cutting is carried out for 3 years. Underplanting of *Pinus* with *S. macrophylla* has been researched and reviewed by Weerawardane (1996).

During the establishment phase of mahogany there are problems due to damage by wild animals such as porcupine, wild boar and rabbits. Termite damage to the root system also causes considerable mortality. Some mortality is due to drought. Sporadic incidents of *Hypsipyla robusta* (Moore) attack can be found but do not pose a major threat under the present planting practices of planting under partial shade. *Hypsipyla robusta* becomes a serious problem when mahogany is planted in open sites. Damage by wild animals is considered the most important hindrance to growth, followed by termite damage, *H. robusta* attack and mortality due to drought.

Khaya senegalensis (Desr.) A. Juss.

This species is a recent introduction to Sri Lanka from Africa. Two mature stands (0.5–1 ha) have been established in the intermediate rainfall zone. Several trees in these stands are producing seeds and growth has been very satisfactory. Recent investigations have shown its suitability to drier regions (Tilakaratna and Weerawardane 1992) and it is now considered a priority species for the dry zone. It requires more light than *S. macrophylla* and is increasingly used for reforesting open sites in the intermediate and dry zones, where forest cover is more sparse.

Studies are continuing on provenance testing and planting methods. Planting is continuing, using locally collected seeds and commercial seed-lots procured from external sources. *Khaya senegalensis* is planted mainly as pure stands or mixed with other local species in open areas. It is also used for underplanting of *Pinus caribaea* Morelet. plantations. *Khaya senegalensis* has become popular in social forestry and roadside planting.

The most important hindrance to growth is elephant damage in some districts. In the existing plantations and trials, multi-stemming and heavy branching has been observed. Sporadic incidents of *H. robusta* attack have been observed in plantations but the incidence of attack is so limited that it does not pose a major threat at this time. It may become a serious problem if incidence of attack increases in the future.

Toona and *Cedrela* species

There is confusion in the proper taxonomic identity of the *Toona* and *Cedrela* species planted in Sri Lanka with determinations including *T. ciliata* M. Roem., *C. chinensis* and *C. serrata*. It appears that both Cedrela spp. are probably *T. sinensis* (A. Juss.) M. Roem. *Toona ciliata* and *Cedrela* spp. have been planted at elevations between 1000 m and 1800 m principally in tea plantations. *Cedrela odorata* has been planted in a trial in the low country intermediate zone and appears to be growing well at present. No further work on this species has been done.

Currently, the Forest Department is using *T. ciliata* as one of the species in mixed plantations in the up-country. It produces good wood for furniture and construction. It has been planted in tea estates primarily as shade trees, but also in water catchments and protective reserves in and adjacent to tea estates. This species is naturalised and regenerates well such that it can be seen growing in natural forests and homesteads.

The greatest threat to *T. ciliata* is from dieback of the trees which may be due to a pathogen. High mortality of trees, including large mature trees, can be seen in many areas. Shot-hole borer (*Xyleborus* sp.) is found in dead and dying trees and is thought to be the vector for a suspected pathogen causing dieback. The beetle makes galleries in the sapwood of living trees. Brownish discolouration can be seen in the sapwood around the insect galleries. This problem has become a very serious hindrance to growing *T. ciliata* in Sri Lanka. A detailed study on this problem is necessary to understand and design control strategies. Damage by *H. robusta* is also a considerable problem because the sites in which this species is planted are typically open (Beeson 1941).

Swietenia mahagoni (L.) Jacq.

As this is a slow growing mahogany species, it is not popular in areas where *S. macrophylla* can be grown. However, *S. mahagoni* can be grown in the dry zone of Sri Lanka. Open planting and enrichment planting have been tested in trials. Initial plantings have shown some success but slow growth and high susceptibility to fire have resulted in this species no longer being planted.

Some studies on the yield and growth of *S. mahagoni* have been done for the preparation of management plans (Sandom and Thayaparan 1995) with the assistance from the Overseas Development Administration of the United Kingdom. Two types of single-tree volume tables have been prepared. These are single entry volume table with diameter at breast height (dbh) as the predictor variable and double entry volume table with dbh and top height as the predictor variables (Mayhew *in press* a). Site index curves have been produced using dominant height measurements from temporary sample plots in Sri Lanka (Mayhew *in press* b).

Hypsipyla robusta research results and future directions

Results on research on *H. robusta* in Sri Lanka have been published in a Masters thesis (Mahroof 1999). Results suggest that attack can be successfully avoided by planting mahogany under shade provided by a nurse crop that is pruned and managed for competition. Since *H. robusta* is a major threat to growing Swieteniodeae in the open, future research will be directed at finding control measures for reducing attack on open sites. Emphasis will be placed on silvicultural methods and natural resistance rather than the use of pesticides.

Current researchers

The Prof J. Edirisinghe and Ms R. Mahroof of the University of Peradeniya in Kandy and Dr C. Hauxwell of the University of Edinburgh (UK), in conjunction with the Forestry Department, have conducted research on management of nurse crops and shade for control of *H. robusta* during establishment of *S. macrophylla* (Mahroof 1999). Funding from the UK Department for International Development supported this project. At the Forestry Department, Mr D. Tilakaratna, Research Officer, is studying variation in susceptibility to *H. robusta* attack in different provenances of *S. macrophylla* from Sri Lanka and Nicaragua. Mr S. Thayaparan, Assistant Conservator of Forests, is studying silvicultural treatments for control of *H. robusta* damage.

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Hypsipyla Shoot Borers of Meliaceae in India

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Abstract

The shoot borer, *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) in India is a serious pest of meliaceous forest trees such as the exotics, *Swietenia macrophylla* King and *S. mahagoni* Jacq. and the native *Toona ciliata* M. Roem. Although *Swietenia* spp. are grown in plantations in many States, the establishment is difficult because of shoot borer attack during the sapling stage. Once past the sapling stage, *Swietenia* spp. are almost free of major pest problems. Information on the extent of mahogany plantations in a few States is available, but not for the country as a whole. Several studies have generated data on the biology and natural enemy complex of *H. robusta*. Recommendations for silvicultural management of the pest include providing overhead and side shade during establishment. However, this method has not been experimentally tested in field conditions. In the absence of a reliable management system for *H. robusta*, forest managers generally prefer tree crops which are more easily managed and less susceptible to pests. Thus *Swietenia* spp. are not favoured species for plantations. The past work done in India on *H. robusta* is reviewed and the need for a collaborative effort to develop a pest management system, incorporating silvicultural and biological methods is stressed.

ONE OF THE long-standing pest problems in forestry in India is that of the shoot borer, *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) which attacks most species belonging to the family Meliaceae, subfamily Swietenioideae. It is a serious pest of the native *Toona ciliata* M. Roem. and *Xylocarpus moluccensis* (Lam.) M. Roem., and the exotics, *Swietenia macrophylla* King and *S. mahagoni* Jacq. Plantations of *Swietenia* spp. and *T. ciliata* have been established in many parts of the country but have not succeeded due to severe damage caused by *H. robusta*.

Forestry is an important industry in India with about 13 million hectares of forest plantation in 1990 and the target of about 17 million hectares in 1995 (Rao 1994). The most important plantation tree species are *Tectona grandis* Linn. f., *Eucalyptus* spp., *Acacia* spp., *Casuarina equisetifolia* J.R. & G. Forst. and *Dalbergia sissoo* Roxb. The total area under meliaceous species is relatively small and precise data are not available. In addition, India has 64.2 million hectares of native forest of various types (Lal 1989), some of which is commercially harvested.

This paper summarises existing information on various aspects of the ecology and control of *H. robusta* and identifies and sets priorities on major research needs.

Biology and Impact of *Hypsipyla robusta*

A reasonably detailed account of the biology of *H. robusta* in India was presented by Beeson (1941) and is summarised below. The female moth, which is larger than the male, lays hundreds of eggs which are deposited on the young shoots. Young larvae bore into the shoots and grow to a length of about 30 mm. Pupation occurs within the cocoon usually inside the larval tunnel or in some other parts of the host plant. The duration of the life cycle varies from 1 to 6 months in northern India where it overwinters as a fourth instar larva. In tropical climates, breeding is continuous throughout the year with overlapping generations of about 2 months in length. Under laboratory conditions the larvae tend to be cannibalistic (Ramaseshiah and Sankaran 1994) and a semi-synthetic diet for rearing *H. robusta* has been developed (Achan 1968).

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The life history and phenology of *H. robusta* varies depending on the host plant and climatic conditions. In temperate and subtropical regions, five generations have been reported with different generations feeding principally on flowers, fruit or shoots (Beeson 1941). In Southern India, the population is more or less continuous with overlapping generations (Mohandas unpublished). Incidence of the pest is confined generally to younger plantations while older trees are almost free from attack. This may be because adult moths are poor fliers and may find it difficult to reach tall trees for oviposition. The difference in the chemical composition of the shoots of mature and young trees may also affect the moths oviposition preference. General observations indicate that borer incidence is greater during the monsoon season. However, data on the incidence of the pest in relation to environmental factors have yet to be generated. Detailed investigation of the population dynamics of *H. robusta* under different climatic zones is also required.

Heavy damage to young saplings of *Swietenia* spp. in plantations has been caused by larvae of *H. robusta* boring into the tender shoots. Larvae have also been recorded feeding on the inflorescences and fruits of *T. ciliata* with distinct shoot, flower and fruit feeding generations. The larvae usually feed under the protection of a loose silken network. It is noted that a single larva can bore into more than one shoot during the course of its development.

H. robusta damage is heaviest in young plantations. Older trees are generally free from attack. Although *H. robusta* attack rarely causes death of saplings, tree growth and form can be severely affected. Repeated attacks on the terminal shoots will cause forking and result in crooked stems. *H. robusta* can also cause considerable loss of seeds in *T. ciliata* and *X. moluccensis* (Sen-Sarma 1981). Reliable, quantitative data on the severity of damage and resulting growth loss are not available.

Methods of Control

Attempts to control *H. robusta* using conventional insecticides have been made in the past (Beeson 1941). Screening of new insecticides, especially systemics, is being conducted for short-term control (Mohandas unpublished). The hidden nature of the insect is an obstacle for effective management through chemical means. Although chemical control may become useful in extreme circumstances, its scope for large-scale application under operational conditions is limited.

H. robusta has a rich natural enemy complex (Browne 1968; Rao and Bennet 1969; Ramaseshiah and Sankaran 1994). Initial studies were made in India by the Commonwealth Institute of Biological Control (CIBC now IIBC) at Bangalore. Nearly 50 parasite species belonging to the orders Hymenoptera and Diptera have been reported (Rao and Bennet 1969). Some of the most important parasites are *Trichogrammatoidea robusta* Nagaraja, *Aptesis latiannulata* (Cam.), *Tetrastichus spirabilis* Wtstn. and *Antrocephalus destructor* Wtstn. A survey of *H. robusta* parasites in southern India revealed *Apanteles stennos* Nixon and *Agathis* sp.nr. *corphye* Nixon to be effective parasites (Ramaseshiah and Sankaran 1994). A nematode parasite of the genus Hexamermis has also been recorded from different locations. The highest level of parasitism was noticed during the monsoon season. It appears that many of the naturally occurring parasites can limit the pest population to some extent. No microbial pathogens have been recorded so far, although, the suitability of *Beauveria tenella* (Delacroix) as a pathogen of *H. robusta* has been reported by Kandasamy (1969). A more intensive search for pathogens would be worthwhile.

A number of silvicultural control options have been suggested from field observations. It has been found that saplings naturally regenerating under the shade of mother trees incur very little *H. robusta* damage. Thus, providing overhead and lateral shade has been suggested as a silvicultural method to reduce *H. robusta* incidence. Pest incidence also appears to be higher in monocultures than in mixed plantings, and higher in open rather than the shaded conditions. These observations and hypotheses need to be tested through field experiments.

Research Needs and Future Directions

A summary of the research effort into various aspects of the biology and control of *H. robusta* in India is given in Table 1. Given that *H. robusta* is a limiting factor for successful establishment of *Swietenia* spp. plantations, the following research priorities are suggested:

- studies on *H. robusta* incidence and damage in relation to the age of the crop to assess the economic impact;
- field trials in different locations to establish the effectiveness of shade and mixed planting as a possible silvicultural management method to reduce pest incidence;
- studies on the pheromones of *H. robusta* for monitoring and mass trapping;
- pathogens associated with *H. robusta*; and
- detailed studies on the population dynamics of *H. robusta*.

Table 1. Summary of current and past research effort on various aspects of *Hypsipyla robusta* (Moore) biology and control.

Area of study	Current research	Historical research
Biology		
Taxonomy	–	*
Life history	*	**
Ecology in natural stands	–	*
Ecology in plantations	–	*
Population dynamics	–	*
Natural enemies	*	**
Other	–	–
Control		
Biological control	–	*
Chemical control	–	–
Silvicultural control	–	*
Provenance trials	–	–
Pheromone studies	–	–
Genetic engineering	–	–
Other	–	–

– none; * minor; ** major

Conclusions

Studies of *H. robusta* in India show that it is a serious pest both on native and exotic Meliaceae. Measurements of the loss of timber production caused by *H. robusta* and the relative impact of *H. robusta* on plantations of native and exotic species of Meliaceae are required in order to assess the need for control. The observations that shaded and mixed plantations appear to be less prone to *H. robusta* attack need to be tested experimentally.

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Hypsipyla Shoot Borers of Meliaceae in Bangladesh

M.W. Baksha[1]

Abstract

In 1993–1994, more than 350 000 ha of forestry plantation had been established in Bangladesh with new plantings amounting to nearly 17 000 ha per year. *Toona ciliata* M. Roem. and *Chukrasia tabularis* A. Juss. occur in natural stands but have not been harvested since 1989. Meliaceous species including *T. ciliata, C. tabularis*, *Swietenia macrophylla* King and *S. mahagoni* Jacq. have been planted in Bangladesh. The main hindrance to growth of these species has been damage by the shoot borer, *Hypsipyla robusta* (Moore). Even though *H. robusta* is considered to be the main problem in growing mahogany, to date, no major research has been conducted on this pest. The Government of Bangladesh has now given top priority to research on *Hypsipyla* and a new research program is being established to study the biology and ecology of the pest and to devise suitable pest management techniques.

BANGLADESH is located between 20° and 27° N and has a total area of 14.3 million ha, comprised of 0.93 million ha of waterways, 8.5 million ha of cropland, 2.67 million ha of uncultivable land and 2.2 million ha of ‘forests’. Of the ‘forest’ area, 40% is under tree cover and the remainder consists of denuded grassland, scrub and encroached lands. Village groves, estimated to be 0.27 million ha, are composed of woodlots of multipurpose fast growing trees, bamboo, rattans and shrubs. Even though this represents only 10% of the government forest area, it supplies 70%–80% of sawlogs and 90% of fuel wood and bamboo consumed in the country. The forestry sector contributes 3.3% of the gross domestic product of Bangladesh (Table 1).

The total area under forestry plantations in Bangladesh is just over 350 000 ha (Table 2) and is spread across various parts of the country (Figure 1). The current rate of planting is about 17 000 ha per year and consists of a wide range of species. An exact breakdown of plantation area by tree species is not available.

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Table 1. Relative contribution of the forestry sector to the gross domestic product (GDP)[1] of Bangladesh in 1993– 94 market prices.

Primary production sectors	Million taka[2]	GDP (%)
Crops	187 653	18.2
Livestock	36 091	3.5
Fisheries	48 405	4.7
Forestry	33 739	3.3

[1] Anon. Ministry of Planning (Bangladesh Bureau of Statistics) 1995

[2] 1 million taka = US$22 000

Economic Importance and Performance of Swietenioideae Species

Bangladesh has two native species of Meliaceae subfamily Swietenioideae (hereafter referred to as Swietenioideae) of potential economic importance. *Toona ciliata* M. Roem. and *Chukrasia tabularis* A. Juss. are present in some areas of native forest in the hill country but have been subject to a harvesting ban imposed in 1989 in an effort to stop the depletion of the meagre forest resources of the country.

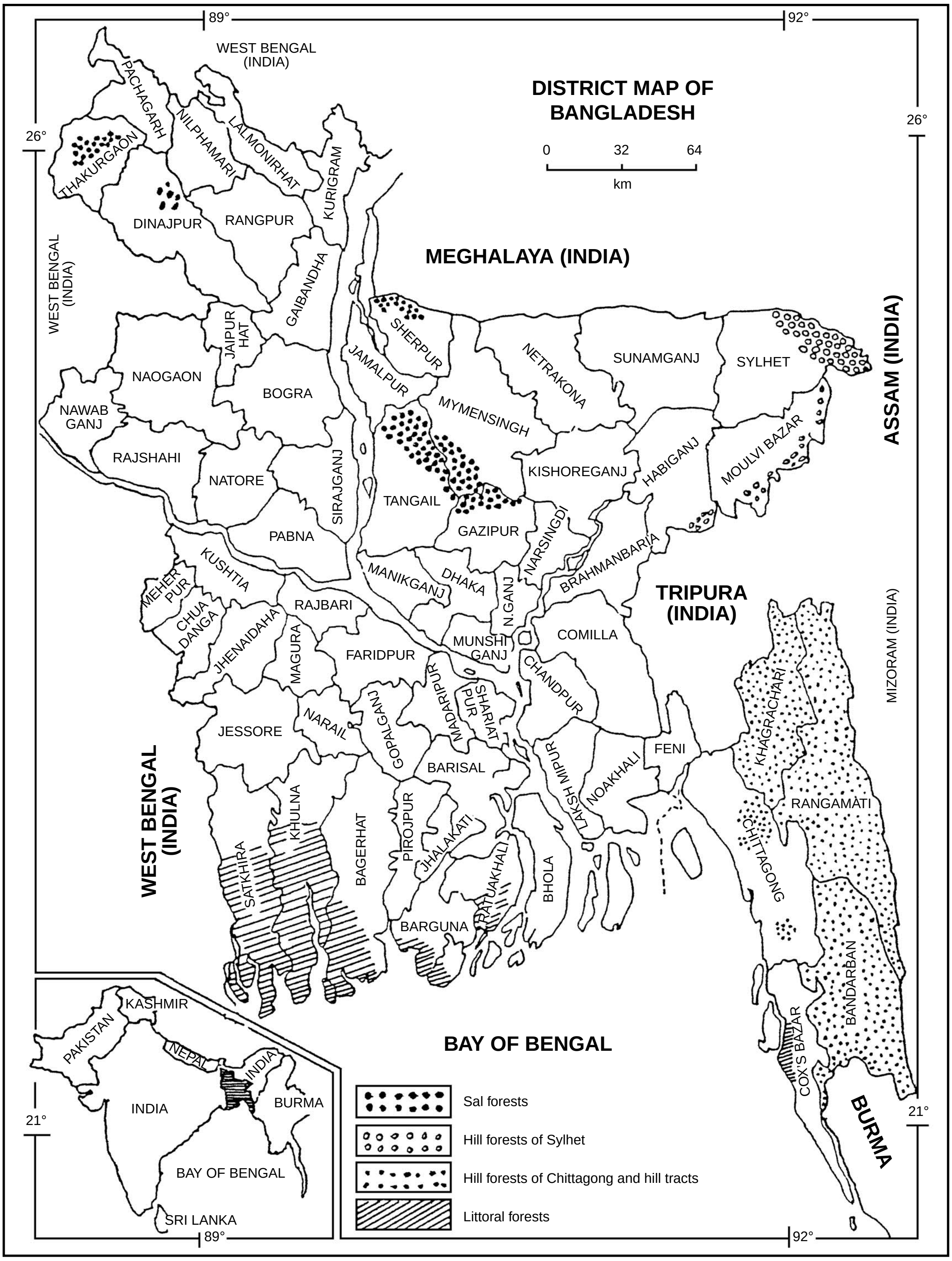

Figure 1. Location of major forest areas in Bangladesh.

Table 2. Area of forestry plantations in Bangladesh categorised by plantation type and tree species, up to 1993–1994.

Plantation types	Tree species	Plantation area (ha)	Rate of planting (ha/year)
Coastal plantation	*Sonneratia apetala* Buch. Ham. *Avicennia officinalis* Linn. *Excoecaria agallocha* Linn.	120 521	3936
Hill plantation	*Tectona grandis* Linn. f. *Dipterocarpus turbinatus* Gaerth. *Syzygium grande* (Wt.) Wall. *Swietenia macrophylla* King *Toona ciliata* M. Roem. *Chukrasia tabularis* A. Juss. *Hopea odorata* Roxb. *Lagerstroemia speciosa* Pers. *Artocarpus chaplasha* Roxb.	95 205	3971
Sal plantation	*Albizia procera* Benth. *Acacia auriculiformis* Cunn. *Acacia mangium* Willd. *Eucalyptus camaldulensis* Dehn.	31 141	4141
Unclassified state forest plantation	*Gmelina arborea* Roxb. *Anthocephalus chinensis* (Lam.) Rich ex Walp. *Pinus caribaea* Morelet. *A. procera* *Samanea saman* Merr. *Paraserianthes falcataria* (L.) Nielsen	56 587	1394
Village groves a. strip plantation	*Acacia nilotica* (L.) Willd. *S. macrophylla* *Dalbergia sissoo* Roxb. *Leucaena leucocephala* de Wit *Terminalia arjuna* (Roxb.) Wt. Arn. *Melia azaderach* Linn.	20 550	1731
b. block plantation	*A. procera* *S. macrophylla* *E. camaldulensis* *A. auriculiformis*	26 038	1646
Total		350 042	16 819

Table 3. Native and exotic tree species of Meliaceae subfamily Swietenioideae planted in Bangladesh.

Tree species	Origin	Plantation area (ha)	Planting rate (ha/year)[1]	Planting type	Optimal rotation length (yrs)	Program status[2]	*Hypsipyla* damage
Swietenia macrophylla King	Introduced	Not known	141.30	Open block or strip plantings	40	B	Major
S. mahagoni Jacq.	Introduced	Not known	Not known	Open block or strip plantings	40	B	Major
Toona ciliata M. Roem.	Native	Not known	Not known	Enrichment social forestry	40	C	Minor
Chukrasia tabularis A. Juss.	Native	Not known	34.82	Mixed species open block planting in hill forest	40	B	Minor

[1] Source: Huq and Banik (1992)

[2] A. Ongoing and successful; B. Ongoing but having limited or variable success; C. Preliminary or experimental only; D. Terminated.

The only harvesting of Swietenioideae in the foreseeable future will be from plantations. Native (*T. ciliata* and *C. tabularis*) and exotic (*Swietenia macrophylla* King and *S. mahagoni* Jacq.) species of Swietenioideae are being planted in plantations in the hill country and also in village groves (Tables 2 and 3). *Swietenia* spp. are the most commonly planted meliaceous species and are often established in open spaced areas as block plantings or as strip plantings along highways, railway lines, roadsides and embankments. In block plantings, they are usually planted in monoculture while in strip plantings they are mostly in mixtures with other species. *T. ciliata* is planted both in forest and in village groves, whereas *C. tabularis* is exclusively planted in the hill forests.

Severe damage caused by the shoot borer, *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) has been the major hindrance to growth of species of Swietenioideae. However, the incidence of the collar borer, *Pagiophloeus longiclavis* Marshall (Coleoptera: Curculionidae) has also been observed in some plantations of Bangladesh. The larva of the latter tunnels in the cambium and sapwood causing swelling and cracking in the collar region of the host plant.

No data have been collected on the growth, yield or economic performance of species of Swietenioideae in Bangladesh.

Hypsipyla robusta Research and Future Directions

In Bangladesh, no research on *H. robusta* has so far been conducted apart from the work of Beeson (1919, 1941) which covered many parts of the then British India (now India, Bangladesh and Pakistan) and the adjoining countries. Table 4 summarises the adequacy of knowledge of various aspects of *H. robusta* ecology and management. In spite of the paucity of data on this pest, it is considered a major problem in *Swietenia* spp. plantations in Bangladesh (Baksha 1990, 1993; Baksha and Islam 1990). Baksha provided brief notes on the pest and its control measures. Beeson's earliest work recorded *H. robusta* infesting *T. ciliata* and *Swietenia* spp. in the southern Asian region (Beeson 1919) and was followed by his monumental synthesis of all available information on this pest (Beeson 1941). However, he did not mention specifically the occurrence of this pest from anywhere in the territory now known as Bangladesh. This could be due to the fact that *Swietenia* spp. were not planted extensively in Bangladesh until the independence of the country in 1971, following which plantation establishment gained momentum.

Table 4. Summary of current and past research effort on various aspects of *Hypsipyla robusta* (Moore) biology and control.

Area of study	Current research	Historical research
Biology		
Taxonomy	–	–
Life history	**	*
Ecology in natural stands	–	*
Ecology in plantations	**	*
Population dynamics	**	–
Natural enemies	*	–
Other	–	–
Control		
Biological control	*	–
Chemical control	**	–
Silvicultural control	**	*
Provenance trials	–	–
Pheromone studies	–	–
Genetic engineering	–	–
Other	–	–

– none; * minor; ** major.

A detailed description of the biology and ecology of *H. robusta*, based on various published sources including Beeson (1941) is presented in Griffiths (these Proceedings). However, a number of specific aspects of the pest's biology and impact on host plants that have been recorded in the southern Asian region are now outlined. In India, the length of the insect's lifecycle varies from one to six months depending upon the season and it usually overwinters as a fourth instar larva. In equatorial climates, breeding appears to be continuous throughout the year, with overlapping generations. Larval feeding can cause considerable seed loss, particularly in *T. ciliata*, but its importance lies mainly with its activity as a shoot borer (Browne 1968).

Hypsipyla robusta passes through three distinct generational feeding phases in *T. ciliata* in northern India and Myanmar. The first generation feeds on the flowers, the second on the fruit, and the third, fourth and fifth on the shoots. In the flower and fruit generations, pupation occurs in sheltered places, whereas in the shoot generations, a pupal chamber is formed in the larval tunnel. In southern India and Sri Lanka, *H. robusta* only feeds on shoots.

Infestation is heaviest on young, vigorous trees growing in full sun. The host is rarely killed; however, retardation of growth in early years is serious. Plantations in their second and third years are generally most heavily attacked. Heavy infestation with repeated destruction of terminal buds results in crooked and highly branched stems.

A range of management strategies including avoiding alternative host plants, close spacing, provision of shade, mixed species plantings, pruning affected shoots, thinning and sack banding have been recommended by Beeson (1941) but have not been very successful. In Bangladesh, heavy damage has been sustained in plantations of *Swietenia* spp. raised in block and strip plantations and around private homesteads. Consequently, the Government of Bangladesh has attached top priority to further research on *H. robusta*. The research work is to study the biology and ecology of the pest and to devise suitable pest management techniques.

Current Research

Hypsipyla research in Bangladesh is being conducted only at the Bangladesh Forest Research Institute, Chittagong. Two scientists, M.W. Baksha (Project Leader) and M.R. Islam (Associate), are currently involved in this research. No other person in Bangladesh is involved in research on this pest.

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Hypsipyla Shoot Borers of Meliaceae in Philippines

E.B. Lapis[1]

Abstract

The Philippines in 1992 had 125 513 ha of forestry plantations of which nearly 13 000 ha were planted to *Swietenia macrophylla* King. The current aim is to plant about 200 000 ha of plantation per year till 2015 and *S. macrophylla* is the third most popular species. One native species of Meliaceae subfamily Swietenioideae, *Toona calantas* Merr. & Rolfe is harvested on a small scale and has been experimentally planted. It has not been recorded to be damaged by the shoot borer, *Hypsipyla robusta* (Moore). *S. macrophylla* plantations have been significantly affected by *H. robusta* and another lepidopteran stem borer of the family Cossidae. Very little research has been conducted on *H. robusta* in the Philippines, which is partly due to the moratorium on the planting of *S. macrophylla* in the 1970s as a result of *H. robusta* damage.

THE forestry industry is very important to the Philippine government, as shown by the following indicators. A total of 31 schools nationwide offer forestry courses with a total enrolment of 3740 students in 1994. The 1991 Annual Survey of Establishments reported a total of 1242 large establishments manufacturing wood and wood products, including furniture and fixtures. Average employment in these establishments totalled 76 046 people. The revenue realised from forest charges on logs was estimated to be about US$21 million in 1994. Additionally, non-timber forest products generated about US$0.44 million in forest charges, mainly attributed to rattan poles.

In 1994, the contribution of the forestry sector to the gross national product (GNP), at constant 1985 prices, amounted to about US$114 million or 0.37% of national GNP, ranking third among all agriculture and fisheries activities. The combined gross value added (GVA) of the agriculture and fisheries sector was also ranked third behind the industry and service sectors.

The Master Plan for Forestry Development of the Philippines government set a target for the establishment of 3 million hectares of forest plantations from 1991 to 2015, planting an average of 200 000 ha/year. From 1991 to 1995, 202 000 ha of government and private sector plantations have been established.

According to the Forestry Sector Program of the Department of Environment and Natural Resources (DENR) (PCARRD 1992), the principal species of trees planted in reforestation areas as of 1992, were: *Gmelina arborea* Roxb. (65 508 ha), *Pterocarpus indicus* Willd. (16 535 ha), *Swietenia macrophylla* King (12 969 ha), *Acacia auriculiformis* Cunn. (12 720 ha) and *Acacia mangium* Willd. (4053 ha). The area planted to minor species totalled about 13 728 hectares in 1992. These species include *Albizia procera* Benth., *Casuarina equisetifolia* J.R. & G.Forst., *Pentacme contorta* (Vid.) Merr. & Rolfe, *Terminalia cattapa* Linn., *Alnus japonica* (Thunb.), *Eucalyptus deglupta* Bl., *Samanea saman* Merr., *Gliricidia sepium* Steud., *Agathis philippinensis* Warb., *Tectona grandis* Linn. f., *Delonix regia* Raf., *Triplaris cummingiana* Fisch. & May., *Bauhinia monandra* Kurz, *Shorea astylosa* Foxw., *Vitex parviflora* Juss., *Cassia fistula* Linn., *Anisoptera thurifera* (Blanco) Blume, *Piliostigma malabaricum* Roxb., *Parkia roxburghii* G. Don, *Diospyrus philippinensis* A. Dc., *Calophyllum inophyllum* L., *Hopea foxworthyi* Elm., *Paraserianthes falcataria* (L.), *Intsia bijuga* (Colebr.), *Lagerstroemia speciosa* Pers., *Pinus kesiya* Royle ex Gordon, *Senna spectabilis* (DC) I.&B. (Spreng), *Melia dubia* Cav., *Toona calantas* Merr. & Rolfe, *Aleurites moluccana* Willd., *Dracontomelon dao* Blume and *Eucalyptus camaldulensis* Dehn.

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Economic Importance and Performance of Swietenioideae Species

The only native species of the family Meliaceae, subfamily Swietenioideae (hereafter referred to as Swietenioideae) that is being harvested in the Philippines is *T. calantas*. It is being harvested from natural forest as a species in association with other commercial species. Harvesting is usually undertaken on a small scale and is considered sustainable. Statistics on the current volume of harvesting and its value are not available.

Experimental plantings of *T. calantas* have been established on a very small scale. Even though the wood quality and uses of this species is comparable to that of the exotic *S. macrophylla,* and the optimal rotation period of 25 to 50 years for sawn timber is also similar to *S. macrophylla*, no large plantations have yet been established. *T. calantas* is found naturally in species-diverse, thick forest, yet the current experimental plantings have been in the open and in pure stands. Currently, the silvicultural requirements of *T. calantas*, in terms of soil type, light, spacing, etc., have not been identified.

According to the 1992 report of the Forestry Sector Program of the DENR, 12 969 ha of *S. macrophylla* have been established in the Philippines (PCARRD 1992). It is expected that the area planted to this species has increased tremendously since that time as it is one of the most commonly planted species for reforestation and tree plantations by private individuals. *S. macrophylla* is usually planted in the open as pure stands, or as pure stand blocks in combination with *G. arborea* and other species. It is also a favoured species in social forestry programs and agroforestry projects in the uplands.

The success of *S. macrophylla* plantations is, however, restricted by the occurrence of the shoot borer, *Hypsipyla robusta* (Moore), particularly in the Mindanao and Visayas region, and by another species of a stem borer, presumably *Zeuzera coffeae* Nietner (Lepidoptera: Cossidae) in the Luzon and Mindanao regions (Lapis 1995). Another hindrance to growth, though isolated, is poor site suitability. *S. macrophylla* does not grow well in sites with relatively thin top soil and in rocky areas, but in good soil can reach a height of 6 m in three years (Weidelt 1976).

No economic analyses of the associated plantation costs of these species of Swietenioideae are available. Estimates of plantation costs (Table 1) are based on general estimates for several fast-growing premium tree species planted with a spacing of 2 × 3 m for a 100 ha ‘contract reforestation’ scheme, for a period of 3 years. The cost of protection may well be higher if the tree species was *S. macrophylla* and *H. robusta* attack was severe and persistent. There have been no studies on productivity, yield or growth of *T. calantas*. A yield prediction model has been developed for *S. macrophylla* (Revilla et al. 1976). This model shows that on average to good sites, trees would be 5–7 m high at 5 years of age and reach about 30–40 m after 50 years.

Table 1. Estimated costs over three years for reforestation of 100 ha planted with premium tree species at 2 m × 3 m spacing.

Activity	Estimated cost (US$)
Survey, mapping, and blocking	673
Nursery operations	13 750
Plantation establishment	12 820
Maintenance	15 846
Protection	5 865
TOTAL	48 954

Source: PCARRD 1992

Hypsipyla robusta Research and Future Directions

It is sad to note that research on *H. robusta* in the Philippines is lacking. Past research on the ecology of *H. robusta* in plantations is fragmented and unpublished. It is based on field trip observations on the seasonal abundance of the pest in nurseries and small plantations. These observations suggest that *H. robusta* is most abundant during January–February in Bukidnon, Mindanao. In general, as observed in other regions, abundance of *H. robusta* coincides with the flushing period of *S. macrophylla* when young and succulent shoots become available. Research on other biological aspects is completely lacking.

A research project initiated in 1985 by the then Forest Research Institute (now the Ecosystem Research and Development Bureau of the DENR) on silvicultural control of *H. robusta* was prematurely terminated due to some social problems in the area. The project aimed to determine the effect of planting espacement and of mixed planting on the incidence and severity of *H. robusta* attack and damage on *S. macrophylla*. The research was supposed to have a seven-year observation period. Preliminary observations, however, indicate that closer spacing and mixed planting have lower damage and attack levels.

The current absence of any research on *H. robusta* can be traced to the time when planting of *S. macrophylla* in the reforestation project areas of the then Bureau of Forest Department (now Forest Management Bureau) in the Mindanao region was stopped in the early 1970s due to severe damage by

H. robusta. From that time onwards, research on *H. robusta* was thought to be irrelevant and unimportant. However, in the later part of the 1980s, when the Department of Environment and Natural Resources (DENR) implemented its wide-scale reforestation and afforestation programs, *S. macrophylla* was included as one of the five most commonly planted species. This was largely due to the exceedingly heavy demand for plantable seedlings, the availability of *S. macrophylla* seedlings, and was without due consideration of the probable consequence of *H. robusta* infestation.

However, now that *S. macrophylla* is the third most commonly planted species in both government and private reforestation programs and plantation establishments, and *H. robusta* and another borer that appears to be *Zeuzera coffeae* are still the most limiting factors in the maintenance of the health of nursery and young plantations of *S. macrophylla*, research leading to the development of pest management strategies should be revived and intensified.

Proposed future research directions will include research into:

1. the biology and ecology of *H. robusta*;
2. biological control of *H. robusta* using parasites and microbial pathogens;
3. silvicultural control using nurse crops, spacing and mixed planting;
4. chemical control for nursery and newly established plantations; and
5. provenance trials.

Current Research

There is currently no research being done on *H. robusta*. in the Philippines. The Ecosystems Research and Development Bureau, which is the research arm of the DENR and has a mandate to conduct research on problems in forestry (among other things) with national impact, has still to come up with a comprehensive research program on *H. robusta* management and to coordinate with local and regional research institutions all over the country.

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Hypsipyla Shoot Borers of Meliaceae in Vietnam

Nguyen Van Do[1]

Abstract

Meliaceous species do not constitute much of the 300 000 ha of forestry plantations in Vietnam. *Chukrasia tabularis* A. Juss. is an important native species of great value for high-grade timber but has now been banned from logging. Small areas of the exotic species, *Khaya senegalensis* (Desr.) A. Juss. and *Swietenia macrophylla* King have been planted. *C. tabularis* and *Toona sureni* (Blume) Merr. seedlings in nurseries have been damaged by shoot borers, presumably *Hypsipyla robusta* (Moore) and a number of other species. No research on *H. robusta* has been conducted in Vietnam.

VIETNAM extends from 6°N to 23°N and is located in the Southeast Asian monsoon region. Due to its central location in Southeast Asia, the flora of Vietnam is characterised by a number of endemic species as well as many species from the nearby Indian, Chinese and Himalayan regions. Although an inventory of the flora of Vietnam has not been completed, more than 7000 species from 1850 genera and 267 families have been recorded. Among the 1000 species that can produce wood and timber, only a few species yield sufficient quantity and quality of timber to be commercially important. However, forests in Vietnam are of great environmental importance since they contribute towards regulation of stream flow and reduction of soil erosion in a country with more than 60% of the land area classified as mountains, hills or sloping land. Many forests also have scientific and tourism values.

Until 1943, forest covered more than 40% of the total land area of Vietnam. The following period of the resistance wars and post-war period resulted in a large area of the forest being removed for war supplies, country reconstruction and raw materials for the rapidly expanding population. In this period, the forest resources were overexploited, leading to severe degradation. This led to a strong emphasis on forest plantation establishment, native forest conservation and regulated logging of native forest.

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In Vietnam, there are about 1.6 million ha of plantation forests which are increasing in both the rate of planting and quality. Many species have been planted, including indigenous (e.g. *Styrax tonkinensis* Pierre**,** *Manglietia glauca* Blume) and exotic species (e.g. *Pinus merkusii* Jungh. & de Vriese, *Pinus massoniana* Lamb., *P. caribaea* Morelet, *P. oocarpa* Schiede, a wide range of *Eucalyptus* spp., *Acacia mangium* Willd., *Acacia auriculiformis* Cunn.). Some valuable commercial species such as *Chukrasia tabularis* A. Juss., *Talauma gioi* Chev., *Tectona grandis* Linn. f., *Hopea odorata* Roxb. have been planted to create a resource base for the developing wood peeling and veneer industries. Table 1 lists the area of plantation of the most important tree species. Plant breeding for higher wood production has become a leading concern for forest researchers and practitioners.

Importance of Swietenioideae Species

Chukrasia tabularis is no longer harvested from native forest due to a government ban in 1985, although some illegal logging still occurs. This species has high economic value (US$1000 per m^3) and has been used to make fine furniture and other commodities.

Only a small area has been planted to species of Swietenioideae. The native species, *C. tabularis* has been used in enrichment plantings in Nghe An and other provinces with a total of 569 ha planted. Planting of *C. tabularis* is ongoing and proving successful and is expected to have an optimal rotation length of 50 to 60 years. The Forestry Ministry has decided, as part of its program, to develop afforestation of high economic value tree species, to include three native species of Swietenioideae (*C. tabularis*, *Toona sureni* (Blume) Merr., *T. sinensis* (A. Juss.) M. Roem.) in the development of seed production areas. Some exotic species have been planted with *Khaya senegalensis* (Desr.) A. Juss. used mainly as an ornamental tree along streets and *Swietenia macrophylla* King established in small plantings in some areas.

Table 1. Area of forestry plantations in Vietnam.

Tree species planted	Present area planted (ha)
Eucalyptus camaldulensis Dehn.	94 674
Pinus merkusii Jungh. & de Vriese	62 333
Casuarina equisetifolia J.R. & G. Forst	25 906
Aleurites montana Wils. and *Thea sasanqua* Pierre	21 175
Pinus kesiya Royle ex Gorden	16 468
Anacardium occidentale L.	16 216
Melaleuca cajuputi Powel. and *Rhizophora* sp.	13 252
Styrax tonkinensis Pierre	12 692
Manglietia glauca Blume	12 230
Pinus massoniana Lamb.,	11 889
Acacia auriculiformis Cunn.	6 347
Dipterocarpus sp. and *Tectona grandis* Linn. f.	5 818
Cinnamomum cassia Blume. and *Illicium verum* H.	4 131
Cunninghamia lanceolata (Lamb.) Hook	1 558
Melia azedarach Linn.	1 022
Chukrasia tabularis A. Juss.	569
Catanopsis spp.	398
Madhuca pasquieri H. Lec.	229
Total	306 907

There have been some reports of insect pests on *C. tabularis* seedlings in nurseries. Local workers have reported leaf eating caterpillars and shoot borers but their identification has not been verified.

Hypsipyla robusta Research and Future Directions

There has been no research into *Hypsipyla robusta* (Moore) in Vietnam. Even though the dominant species in some natural forests belong to the Swietenioideae and they have high economic value, studies on their insect pest, especially *H. robusta*, have not been carried out for a number of reasons.

Firstly, there are no funds available for basic research on forest insect pests of tree species that are not widely planted. Instead, the limited funds are directed towards applied studies on control of the main insect pests of plantation species that have already been planted (e.g. *Pinus* spp., *Eucalyptus* spp., *Manglietia glauca*, *Styrax tonkinensis* and cashew).

Secondly, species of Swietenioideae have usually been established in mixed species or forest enrichment plantings and have not incurred destructive levels of insect damage. However, if species of Swietenioideae are to be planted widely and in open plantings, their insect pests are very likely to become a problem. It has been reported that *H. robusta* destroyed young *Toona sureni* (Blume) Merr. in nurseries in central and southern Vietnam. However, shoot borers collected from *T. sureni* in these areas in a subsequent year were identified as *Zeuzera* sp.

Research directions in the future include:

- surveying the insect pests of Meliaceae, particularly species of high economic value that are being used in new forestry projects;
- participating in a regional network to exchange findings, experimental approaches and techniques in order to improve our knowledge of the biology of *H. robusta* and measures for its control;
- collaborating with entomologists in Vietnam and overseas to carry out studies on insect pests of Meliaceae;
- ensuring that the knowledge and experimental techniques for the study of *H. robusta*, as discussed at this workshop, will be properly applied in Vietnam.

Hypsipyla Shoot Borer of Meliaceae in Lao PDR

Xeme Samontry[1]

Abstract

The forestry sector plays a very significant role in national economic development. In 1994, forest product exports were valued at US$49.2 million and were expected to reach approximately US$70 million in 1995. There are a number of native tree species which are very important for sustainable plantation development, that belong to the subfamily Swietenioideae of the family Meliaceae such as *Chukrasia tabularis* A. Juss. and several species of *Toona*. However, shoot borers, presumably *Hypsipyla robusta* (Moore), often damage young trees and have discouraged plantation development using Meliaceous species in Lao PDR.

THE Lao People's Democratic Republic (Lao PDR) is located between China in the north, Cambodia in the south, Vietnam in the east and Thailand and Myanmar in the west. The country has an area of 23.68 million hectares and a population of 4.5 million people. Eighty five percent of the people live in the rural area and rely on forestry and agriculture for their livelihood.

Lao PDR is very rich in natural resources, especially forestry resources. There are approximately eight million hectares of existing forests, which cover more than 33% of the country's total land area. Benefits derived from these forests make a major contribution to the national economy through timber production, non-wood forest products and quality water supply for hydroelectricity generation. Other important benefits are related to social and environmental quality. In 1994, forest product exports totalled US$49.2 million and were expected to reach approximately US$70 million in 1995. These products included sawn timber, logs, plywood and other wood products.

Plantation Development

Plantation establishment in Lao PDR has been carried out since the early 1940s and is mainly undertaken by the government. The main species planted are *Tectona grandis* Linn. f., *Pterocarpus macrocarpus* Kurz, *Dalbergia* sp., *Xylia kerri* Craib. and Hutch. Due to a lack of funds for establishment and proper maintenance, the area planted each year is irregular and relatively small and survival and growth rates are less than desirable.

Since 1986, the government has adopted an open economic policy by welcoming both national and foreign companies and individuals to invest in tree plantations and related wood-based industries in various parts of the country. Huang Fat Hong have established a three line production plywood factory and a chipwood plant in Thakhek, and DAFI, a state enterprise, has installed an integrated wood processing plant at Pakse, Champasack Province. These facilities have created a new phase of plantation development.

During the past 4 years, there has been an increase in interest by farmers, companies and the Department of Forestry, through the development of a forest policy to create a large viable plantation estate in the country. The government plantation establishment program has been increased from 3000 ha in 1990 to 10 000 ha in 1995 and over 20 000 ha in 1996 (Department of Forestry 1995).

Importance of Swietenioideae Species

Like other tropical forests in Southeast Asia, the flora of Lao PDR is very rich in tree species that provide many wood and non-wood products and are vital to the living conditions of local people. Among

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them are species of the subfamily Swietenioideae of the family Meliaceae such as *Chukrasia tabularis* A. Juss. and *Toona* spp. *Swietenia macrophylla* King is an exotic species which was first introduced into the country in the early 1940s for roadside planting in the main cities.

These species are very important and have great potential for a sustainable plantation program in Lao PDR, but shoot borers, presumably *Hypsipyla robusta* (Moore), often damage young trees and have discouraged plantation development using species of Swietenioideae. Research on the insect problem has not been carried out because the Lao Department of Forestry does not have a forest entomologist.

Hypsipyla robusta Research and Future Directions

CSIRO Forestry and Forest Products in collaboration with Vietnam, Thailand, Lao PDR and Malaysia has developed a project proposal for a regional ACIAR project to develop a domestication strategy for indigenous tree species in Southeast Asia using *C. tabularis* as an example. As part of this project, surveys monitoring the incidence and extent of insect damage in the field trials will be conducted (Applegate and Samontry 1996).

Acknowledgments

Thanks are expressed to the Department of Forestry for enabling the presentation of this information and to CSIRO and the Australian Centre for International Agricultural Research who provided the assistance necessary to attend this workshop.

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Hypsipyla Shoot Borers of Meliaceae in Thailand

Supachote Eungwijarnpanya[1]

Abstract

Several species of the Meliaceae subfamily Swietenioideae have been grown commercially in Thailand and virtually all have experienced some damage from *Hypsipyla robusta* (Moore). Native species of Swietenioideae include *Chukrasia tabularis* A. Juss., *Toona ciliata* M. Roem., *T. sureni* (Blume) Merr. and *Xylocarpus moluccensis* (Lam.) M. Roem. while exotic plantation species include *Swietenia macrophylla* King and *S. mahagoni* Jacq. *Swietenia* spp. and *T. ciliata* in plantations have been observed to be seriously damaged by *H. robusta*. A recent trial of meliaceous species showed that *T. ciliata* was much more susceptible to *H. robusta* damage than the exotic *Cedrela odorata* L. The number of private plantations of *T. ciliata* is increasing throughout the country, although the problem of *H. robusta* attack on species of Swietenioideae in Thailand has not been solved.

HYPSIPYLA robusta (Moore) is known to feed almost exclusively on plants of the subfamily Swietenioideae of the family Meliaceae, of which there are seven species from three genera (*Toona, Chukrasia* and *Xylocarpus*) endemic to Thailand (Mabberley et al. 1995). Several exotic species belonging to the genera *Swietenia, Khaya* and *Cedrela* have been planted in Thailand for timber production. Species of the genera *Swietenia* and *Toona* have been recommended by the Royal Forest Department (RFD) for plantations in Thailand because of their beautiful wood and use for various purposes such as furniture, musical instruments, boats and paper pulp. However, some plantations have incurred serious damage from the *Hypsipyla* shoot borer.

Mr Dumrong Chaiglom, a forester in the RFD, reported that the shoot borer of *Swietenia* spp. and *Toona ciliata* M. Roem. was *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) (Chaiglom 1972). Other native hosts of *H. robusta* include *Chukrasia tabularis* Jacq. and *Xylocarpus moluccensis* (Lam.) M. Roem. (Hutacharern and Tubtim 1995).

The larvae bore into shoots and feed inside stems, pupate and then emerge as an adult moth. The damage causes the shoot to wilt and die and as a consequence, the tree becomes highly branched. *Swietenia* spp. and *T. ciliata* are not only attacked by *H. robusta* but also by another stem borer, *Pagiophloeus longiclavis* Marshall (Coleoptera: Curculionidae). Hutacharern and Choldumrongkul (1985) listed five important insect species that attack *T. ciliata*; *H. robusta, P. longiclavis*, *Aristobia approximator* Thom. (Coleoptera: Cerambycidae), *Zeuzera coffeae* Nietner (Lepidoptera: Cossidae) and *Sinoxylon* sp. (Coleoptera: Bostrychidae).

From 1981 to 1994, the Royal Forest Department did not recommend *Swietenia* spp. and *T. ciliata* as plantation species due to the likelihood of severe insect damage. However, since 1994, the government has launched a project to subsidise private growers for afforestation plantings and *Swietenia* spp. and *T. ciliata* are included in the recommended species list.

Economic Importance and Performance of Swietenioideae Species

Native species of the Swietenioideae belong to the genera *Chukrasia, Toona* and *Xylocarpus. Chukrasia* spp. are sparsely distributed in mixed deciduous forest in the northern, northeastern, eastern and southern parts of Thailand (P. Wasuwanich, RFD, pers. comm.). The biggest tree of *C. tabularis* is found in Kanchanaburi with girth at breast height (GBH) of 20 m and height of 65 m.

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T. ciliata grows in dry deciduous forest and can be found in many parts of Thailand such as Lampang, Uthaithani, and Songkhla provinces. *Xylocarpus* sp. is a mangrove species naturally distributed in the eastern and southern parts of the country. None of these species are harvested from native forest since logging concessions were terminated in 1988. *Hypsipyla robusta* has been recorded to attack each of these native species of Swietenioideae.

A number of native and exotic species of Swietenioideae have been planted in plantations. *Chukrasia* sp. has been planted in small areas (0.5–1 ha) for experimental purposes in Tak Province.

T. ciliata was recommended 15 years ago by the RFD for planting in the government plantation. *H. robusta* caused severe damage to the shoots resulting in the trees being very bushy and stunted. Control of *H. robusta* was not attempted and after two to three years of consistent damage, the RFD ceased to recommend *T. ciliata* for planting. However in 1994, because of its fast growth and good quality timber, *T. ciliata* has again been recommended by the RFD for afforestation projects. The government subsidises planting at the rate of 19 000 baht (US$730) per ha.

The total area of plantings of *T. ciliata* is about 15 ha and most trees are less than 3 years old. Many growers are currently interested in planting *T. ciliata* from seed provided by Mr Chumnong Thesagate, a forester who has collected seed from trees that were planted 14 years ago. He has 3 mother trees with GBH of approximately 175 cm. Mr Chumnong has planted about 3.2 ha of *T. ciliata* in a mixed species planting. In July 1996 it was found that 50% of the *T. ciliata* aged between one and two years were damaged by *H. robusta*. Trees that were damaged at a height of less than 1.5 m produced bushy tops and were sold as shade trees or ornamentals for commercial recreation areas such as resorts and golf courses. Trees that had 2.5 m of clear bole before being attacked were retained for timber production. Since 1995, Mr Chumnong has produced many *T. ciliata* seedlings and has distributed them for planting in many provinces such as Ratchaburi, Suphanburi and Prachuabkhirikhan. At one location in Ratchaburi Province, a plantation as large as 8 ha (C. Thesagate, RFD, pers. comm.) has been established. Many more growers have ordered seedlings from him for planting in 1997. Many of these plantings are being damaged by *H. robusta*.

Swietenia sp. was planted in government plantation, however, due to serious damage by *H. robusta* it was no longer recommended. As a result of the early plantings, about 0.5 ha of 40–50 year-old *Swietenia* sp. remains in Trang Province and 0.8 ha in Phuket Province (S. Bunyavejchewin, RFD, pers. comm.). Together with some more recent plantings (4–5 years old) in southern and northeastern Thailand, the total area of *Swietenia* sp. plantings is about 6 ha.

Hypsipyla robusta Research and Future Directions

T. ciliata is known to be very susceptible to infestation by *H. robusta*. Dr Chaweewan Hutacharern, a forest entomologist in the RFD, has established an insect resistance trial where a plantation of mature *Tectona grandis* Linn. f. was underplanted using seed of *Cedrela odorata* L., *C. augustifolia* Sesse & Moc., and *T. sureni* (Blume) Merr. obtained from Indonesia, and *T. ciliata* from Thailand.

In these experimental plots in Lumpang Province, *H. robusta* caused greater damage to *T. ciliata*, (100% damage), than to *C. odorata*, (2% damage). Both species were also infested by *P. longiclavis* causing 56% and 5% damage respectively (Choldumrongkul and Hutacharern 1985). Both insects also caused damage to *T. sureni* and *C. augustifolia* but was not able to be compared to the other species because of the low survival of seedlings. All trees were removed from the trial plots and substituted by other species because of the heavy damage caused by both insect pests.

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Hypsipyla Shoot Borers of Meliaceae in Malaysia

Khoo Soo Ghee[1]

Abstract

Exotic species of the family Meliaceae subfamily Swietenioideae such as *Swietenia* spp. have been planted in Malaysia for more than 100 years but have incurred severe damage from *Hypsipyla robusta* (Moore) on various occasions. *Khaya* spp. were introduced from the late 1950s. The level of damage varies with location and planting type, with recent interplantings of *Khaya ivorensis* A. Chev. in a rubber plantation being free of damage. Emphasis on the exotic Swietenioideae has tended to overshadow the potential of the indigenous species such as *Chukrasia tabularis* A. Juss., *Toona sinensis* (A. Juss.) M. Roem. and *T. sureni* (Blume) Merr. as timber trees suitable for plantation forestry. Although these species are all attacked by *H. robusta*, there appears to be a distinct preference for *T. sureni* over the others, just as there is a preference for *Swietenia* over *Khaya* or *Cedrela* among the exotic species. However, trial plantings of *C. tabularis* and *T. sinensis* in urban areas in Peninsula Malaysia were free from attack by *H. robusta*. *H. robusta* does present a serious problem in the reforestation of logged-over forests. Mixed plantings of different meliaceous species are proposed to determine whether a preferred species can successfully act as a trap crop in order to protect a less susceptible species from attack. Close surveillance and chemical or biological control measures may then be directed at the preferred species.

IN 1992, the forestry sector was only exceeded by petroleum and natural gas in terms of value of export earnings from primary commodities, and contributed about 10% of Malaysia's total export earnings of RM103.49 billion (approx. US$40 billion). Log production in 1992 was 43.5 million m^3 but has decreased since then.

The major forest tree species planted in Malaysia are shown in Table 1. About 90% of the area planted to forestry plantations, excluding tree crops such as *Hevea brasiliensis* Muell. Arg. (rubber), *Elaeis guineensis* Jacq. (oil palm) and *Theobroma cacao* L. (cocoa) (indicated by * in Table 1), is planted to *Acacia mangium* Willd., *Gmelina arborea* Roxb. and *Paraserianthes falcataria* (L.) Nielsen for production of general purpose timber. Tree crops as listed above are generally not included in statistics on forestry plantations even though in recent years rubber logs comprised between 10% and 14% of total log production and have been important in furniture manufacture. Recently, there have been trial plantings of rubber clones suitable for timber production and also the interplanting of timber trees among young plantings of rubber and oil palms by the private sector.

In Peninsula Malaysia, most of the forest plantations are established by the government forest departments, but in Sabah, they are established mainly by the private sector. With the introduction of incentives for the establishment of forestry plantations, it is likely that there will be greater participation in Peninsula Malaysia by the private sector. Rising labour costs are also encouraging the conversion of rubber estates into mixed timber plantations. Presently, *Tectona grandis* Linn. f. and *Azadirachta excelsa* (Jack) Jacoby are being actively promoted for forest plantations by the Forest Research Institute Malaysia (FRIM).

Economic Importance and Success of Swietenioideae Species

Statistics on the economic importance of species of the family Meliaceae, subfamily Swietenioideae, hereafter referred to as Swietenioideae, are difficult to obtain since harvesting of native species is usually

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Table 1. Area of forestry plantations and current rate of planting in Malaysia.

Tree species	Area planted (current or recent)	Current rate of planting
Pinus spp.	5681 ha (Peninsula Malaysia) 1030 ha (Sabah 1991) negligible in Sarawak	Discontinued in late 1980s in Peninsula Malaysia
Acacia mangium Willd. *Gmelina arborea* Roxb. *Paraserianthes falcataria* (L.) Nielsen	54 189 ha (Peninsula Malaysia 1994) 90 000 ha (Sabah 1995) 10 000 ha (Sarawak 1995)	188 000 ha to be planted in Peninsula Malaysia by 1995 but halted temporarily in 1992 due to heart rot problems. Moratorium lifted in 1994.
Tectona grandis Linn. f. High-quality timber trees including *T. grandis*	1918 ha (Peninsula Malaysia 1994) 3624 ha (Sabah 1995)	Planting currently being promoted
Swietenia macrophylla King	587 ha (Peninsula Malaysia 1994) 340 ha (Sabah 1992)	Depending on availability of planting material (Peninsula Malaysia)
Khaya ivorensis A. Chev.	≈200 ha	Depending on availability of planting material
T. grandis *K. ivorensis* *Azadirachta excelsa* (Jack) Jacoby	1187 ha (Peninsula Malaysia 1995)	Private sector, increasing
*Hevea brasiliensis** Muell. Arg.	1 807 000 ha (1992)	Declining
*Elaeis guineensis** Jacq.	2 167 396 ha (1992)	Slight increase in 1993
*Theobroma cacao** L.	388 700 ha (1992)	Declining
Total	168 576 ha (excluding*) 4 531 672 ha (including*)	

included in the general category of ‘mixed light hardwood’. However, the available data on native species of Swietenioideae in Malaysia and their significance to forestry in natural forests have been summarised in Table 2. *Toona sureni* (Blume) Merr. and *Chukrasia tabularis* A. Juss. are probably the native species of most economic importance. Table 3 summarises the forestry significance and success of plantings of native and exotic species of Swietenioideae.

Limits to Growth of Plantings of Swietenioideae Species

Damage caused by *Hypsipyla robusta* (Moore) is the most serious limit to economical growing of species of Swietenioideae in Malaysia. The severity of damage varies with species and the type of planting, and some tree species have also been attacked by other species of insects. Limits to growth will be described for each of the species of Swietenioideae planted in Malaysia.

Cedrela odorata L. has only been planted in small experimental open plantings, and from these very restricted trials only slight attack by *H. robusta* has been observed.

C. tabularis has been planted in open plantings in urban areas and has been performing quite well. There have been no positive or negative records of *H. robusta* damage.

Two species of *Khaya* have been planted in Malaysia. *K. ivorensis* A. Chev. has been planted in enrichment plantings or interplanted with rubber while *K. senegalensis* (Desr.) A. Juss. is only used in urban forestry. *K. senegalensis* has not been observed to be attacked by *H. robusta* but is occasionally attacked by a defoliator, *Attacus atlas* Linnaeus (Lepidoptera: Saturniidae). *K. ivorensis* planted in enrichment plantings in Sabah has incurred some damage from *H. robusta*. However, this damage was not as severe as for *Swietenia macrophylla* King planted in similar situations. Enrichment plantings of *K. ivorensis* in Peninsula Malaysia have also incurred a small amount of *H. robusta* damage while interplantings in rubber plantations have been free of attack. Another stem borer, *Zeuzera coffeae* Nietner (Lepidoptera: Cossidae), and a bark borer have occasionally caused damage to trees while *Xylosandrus compactus* (Eichhoff) (Coleoptera: Scolytidae) and some other scolytids have caused severe damage to seedlings of *K. ivorensis* in nurseries.

Table 2. Economic importance of native tree species of the subfamily Swietenioideae (Meliaceae) in natural forests of Malaysia.

Tree species	Amount harvested	Scale of operation	History of harvesting and planting
Chukrasia tabularis A. Juss.	Total export production from all native Meliaceous species in Sabah in 1992 was 92 m^3 valued at US$33 000	Small scale local or community harvesting	
Toona sinensis (A. Juss.) M. Roem.	No information		See below for *T. sureni*
Toona sureni (Blume) Merr.	34–40 m^3 in 1956 and 1957	Small scale local or community harvesting of mixed light hardwoods. Recently, 8000 seedlings of *Toona* spp. were used in mixed planting by a state governments in Peninsula Malaysia (Noraini pers. comm.)	Currently promoted together with *T. sinensis*, for planting on degraded lands (Noraini 1993; Noraini et al. 1992; Noraini and Hanim 1996)
Xylocarpus granatum Koen.	No information		
Xylocarpus moluccensis (Lam.) M. Roem.	No information		
Xylocarpus rumphii (Kostel.) Mabb.	No information		

Table 3. Plantation forestry using species of Meliaceae subfamily Swietenioideae in Malaysia.

Tree species	Origin	Present area planted (ha)	Present planting rate (ha/year)	Planting type	Optimal rotation length (yrs)	Planting status (A/B/C/D)[1]	*Hypsipyla* damage
Cedrela odorata L.	Exotic	Negligible	–	Open planting (experimental)	–	C	Slight
Chukrasia tabularis A. Juss.	Native	Not available	–	Open planting in urban areas	?	C	No information
Khaya ivorensis A. Chev.	Exotic	Less than 200 ha	Erratic	Enrichment planting or interplanting with rubber	25–30 yrs	A	Sabah — moderate, Peninsula Malaysia — low, no damage when interplanted with rubber
Khaya senegalensis (Desr.) A. Juss.	Exotic	Not available	–	Urban forestry	–	A	No information
Swietenia macro-phylla King	Exotic	Few hundred hectares	Erratic	Mixed species plantings	33–36 yrs	B	Some severe
Swietenia mahagoni Jacq.	Exotic	Negligible	–	Mixed species with other Meliaceae	–	D	Very severe
Toona sinensis (A.Juss.) M. Roem.	Native	Not available	–	Open plantings in urban areas and also mixed plantings with *T. sureni*	?	C	Not attacked in mixed plantings
Toona sureni (Blume) Merr.	Native	Not available	–	Open plantings in urban areas or mixed plantings with *T. sinensis*	?	C	Severe

[1] A. Ongoing and successful; B. Ongoing but having limited or variable success; C. Preliminary or experimental only; D. Terminated.

S. macrophylla and *Swietenia mahagoni* Jacq. have been grown in small areas in mixed species plantings and have both been severely attacked by *H. robusta* with *S. mahagoni* being more severely attacked. *S. macrophylla* is not always severely attacked but the circumstances leading to attack are not well understood. Trees can also be severely damaged by bark feeding squirrels. In nurseries, weak seedlings may also be attacked by scolytid borers and the collar borer, *Pagiophloeus longiclavis* Marshall (Coleoptera: Curculionidae).

The native species of *Toona*, *T. sinensis* (A. Juss.) M. Roem and *T. sureni*, have been established in open plantings in urban areas or in mixed plantings with each other. *T. sinensis* has grown quite well, while *T. sureni* has suffered severe attack by *H. robusta*.

Growth and Productivity of Swietenioideae Species

Some growth data have been collected but no economic analysis of plantation operations has been performed.

The growth rate of *S. macrophylla* has been described in brief accounts of trial plantations at FRIM, Kepong (Barnard and Beveridge 1957; Streets 1962; Ng and Tang 1974; Appanah and Weinland 1993) while Hashim et al. (1989) compared the growth rate at FRIM with that from other parts of Peninsula Malaysia. In general, the early growth is very variable and this is believed to be due to soil factors. At 9 years, the mean annual increment in diameter of selected dominant trees was 1.5 cm. A 24-year-old tree growing on a moist site in well drained, sandy soil at FRIM had a height of 23.5 m, clear bole height of 8.2 m and a diameter of 66 cm. In Malacca, a 33-year-old tree under open conditions on poor lateritic soil had a height of 25 m and a diameter of 54 cm. *S. macrophylla* trees in Malaysia rarely have straight clear boles longer than 9.2 m.

Brief data on growth rates for *K. ivorensis* are given in Ng and Tang (1974), Darus et al. (1990), Hashim (1990) and Appanah and Weinland (1993). The mean annual increment in height was 1.0 m and in diameter was 1.9 cm for a 26-year-old tree in Kedah (Darus et al. 1974).

Noraini et al. (1994a, b) and Noraini and Hanim (1996) made some studies on the establishment and initial growth rates of some of the native Swietenioideae (*Toona* spp. and *C. tabularis*) while Ng and Tang (1974) reported a 33-year-old tree of *C. tabularis* with a clear bole of 15.5 m and a diameter of 58 cm.

Hypsipyla robusta Research and Future Directions

A summary of the extent of current and historical research into *H. robusta* in Malaysia is presented in Table 4. Overall, there has been very little previous research conducted on *H. robusta* in Malaysia except for reports on its attack and some attempts at chemical or silvicultural control. Current research is still at an early stage and mainly comprises preliminary observations on the biology of the species.

Experimental trials on the management of *H. robusta* have been delayed pending the establishment of new plantings. Past reports on the attack of *H. robusta*, as well as the current observations on the extent of attack at different sites and on different plant species, have provided an insight into the biology and possible present occurrence of the pest. These observations have helped to determine the direction of future research and also to assess the planting potential of some species of Swietenioideae.

Table 4. Summary of current and past research effort on various aspects of *Hypsipyla robusta* biology and control.

Area of study	Current research	Historical research
Biology		
Taxonomy	–	–
Life history	**	–
Ecology in natural stands	–	–
Ecology in plantations	**	–
Population dynamics	**	–
Natural enemies	**	–
Other	–	–
Control		
Biological control	**	–
Chemical control	*	*
Silvicultural control	**	*
Host resistance	*	*
Pheromones	**	–
Genetic engineering	–	–
Other	–	–

– none; * minor; ** major.

Swietenia mahagoni was introduced into Malaysia in 1876 and *S. macrophylla* in 1886 and again in 1892 (Burkhill 1936). Both species were attacked by *H. robusta* although the attack was more severe on *S. mahagoni*, which is no longer being planted except for comparative experimental trials.

Some good specimens of *S. macrophylla* established in these early plantings have survived as ornamentals in the larger towns and also as a small group of plantings in Bukit Bruang Forest Reserve in

Malacca. However, no plantations were established (Barnard and Beveridge 1957). Small experimental plantations were set up in the FRIM grounds in 1928 and 1931–1933 using the seeds from trees in Malacca.

In the 1950s and onwards, more plantings were carried out on unused land and also as enrichment plantings in logged forests. In the 1930s and 1950s (Anon. 1932, 1933, 1934, 1956–1959) there were reports of attacks by *H. robusta* and also by a weevil stem/collar borer (*Pagiophloeus* sp). These attacks by *H. robusta* intensified with the removal of overhead cover. There were also unsuccessful attempts in 1958 to control *H. robusta* using dieldrin.

According to Barnard and Beveridge (1957), *S. macrophylla* grows well throughout the country but Mitchell (1962) cautioned against large-scale planting of mahogany. In 1962 it was reported that enrichment plantings of *S. macrophylla* in Malacca suffered no attacks from shoot borers or squirrels whereas in Selangor the attacks by these two pests were quite severe. Recent line plantings of *S. macrophylla* in Sabah have also suffered severe damage from *H. robusta* shoot borers.

Other exotic species of Swietenioideae include *K. ivorensis* which was introduced into the country in the late 1950s and early 1960s (Hashim 1990) and *K. senegalensis* which was introduced in the late 1980s for urban planting. *K. ivorensis* in Peninsula Malaysia is relatively free from serious pests except for an isolated attack by *Hypsipyla* shoot borer on potted seedlings in a nursery in Kedah (Darus et al. 1990). In Sabah, *K. ivorensis* suffers from attacks by *Hypsipyla* but not as severe as on *Swietenia* spp (unpubl. report, Luasong Forestry Centre 1991).

Chukrasia and *Toona*, the indigenous genera of Swietenioideae, have not attracted much attention, although *C. tabularis* has been established as plantations in India and elsewhere (Day et al. 1994). *T. sureni* and *T. sinensis* are not only suitable for sustainable timber plantation trials but also for rapid reforestation and gap regeneration projects, particularly on poor soils and where soil stabilisation and water catchment management are priorities (Edmonds 1993). *T. sureni* and *T. sinensis* are currently being promoted for planting by Noraini (1993) and Noraini et al. (1994a, b). *C. tabularis* and *T. sinensis* have also been recommended for urban planting by Noraini and Hanim (1996).

Currently, the planting of *S. macrophylla* and *K. ivorensis* in Peninsula Malaysia has been on a small scale, mainly to reforest idle land or land damaged by illegal logging. There was a serious attempt at establishing line plantings of *S. macrophylla* in a logged forest in Sabah but unfortunately the plants were heavily attacked by *Hypsipyla* shoot borers. As a result, there is now a serious attempt to study the biology and ecology of *H. robusta*. The research is, however, in its early stage and there are plans for various trials on the management of the pest.

From the initial records of infestations by Luasong Forestry Centre, and also from preliminary observations in Sabah, it appears that *H. robusta* attack is most severe on *S. mahagoni* followed by *S. macrophylla* while *K. ivorensis* and *C. odorata* are less heavily attacked in that order. Attacks on *T. ciliata* var. *australis* appears to be more serious than that on *C. odorata*. *H. robusta* attack occurs both in the open and in the forest, although the infestations may be earlier in open plantings than in the forest. The presence of a highly susceptible plant species seems to be able to reduce the attacks on nearby less susceptible species. *K. ivorensis* at 4.5 months of planting did not suffer from *H. robusta* attack in the presence of *S. mahagoni* and *S. macrophylla*.

In Peninsula Malaysia, an experimental interplanting of *T. sureni* with *T. sinensis* (Noraini unpubl.) showed the former species severely damaged by *Hypsipyla* shoot borers while the latter was free from attack.

It is known that certain plant species which are susceptible to *Hypsipyla* sp. of one region may not be severely attacked when they are planted in another region (Grijpma 1974). The exception seems to be plants of the genus *Swietenia* which seems to be attacked by *Hypsipyla grandella* (Zeller) in its native home as well as by *H. robusta* elsewhere. However, some species seem to be more susceptible, regardless of location (e.g. *S. mahagoni* and *S. macrophylla* are more susceptible than *K. ivorensis*; *T. sureni* is more susceptible than *T. sinensis*).

Is this a case of plant resistance resulting from increased larval mortality as in *T. ciliata* var. *australis* against *H. grandella*? Or is it a case of a greater attraction of the adult moths to a particular plant species which perhaps can then function as a 'trap crop' when interplanted among the less susceptible species of Swietenioideae? The effectiveness of the 'trap crop' would depend also on the density of the pest as well as on the density and phenology of the plant itself. Hence a study on the population dynamics of the borer, plant phenology and also on host selection by the adult moths will greatly help in developing appropriate strategies for the management of the pest.

In a rubber estate in Peninsula Malaysia, *K. ivorensis* (age 1.5 years) interplanted with young rubber plants (age 2.5 years) showed no signs of attack by *H. robusta*. A single plant of *S. macrophylla* that was present in the same area was also free of attack. Currently in urban areas, new plantings of *S. macrophylla, K. senegalensis, C. tabularis* and *T. sinensis* do not appear to be attacked by *Hypsipyla* shoot borers. Even on FRIM grounds, exposed seedlings of *K. ivorensis* and *S. macrophylla* have not been observed to be attacked by *H. robusta*. It is possible that the urban areas and some of the large rubber plantations are now far away from the natural habitat of *H. robusta* and that the threat to the planting of mahogany and other Swietenioideae no longer exists in such areas. There is a need to assess the situation through trial plantings in rubber estates which represent a vast area for future conversion to timber or mixed mahogany/rubber plantations.

If there is an intention to plant high-quality timber trees of the subfamily Swietenioideae in logged-over forests, it is important to select species that are resistant or seemingly less attractive to *H. robusta*, or to plant a mixture of species, using one as a trap crop with close surveillance and if necessary control measures implemented.

Concerning the biological control of *H. robusta*, it would be interesting to study the effectiveness of predatory ants like *Oecophylla smaragdina* (F.) of infestations by *Hypsipyla* shoot borers. *O. smaragdina* has been observed locally to be effective in reducing damage to fruit by fruit flies (*Bactrocera* spp.) or in preventing attacks by *Helopeltis* sp. on cocoa fruits. In agriculture, the use of such ants is not a pleasant proposition because of their bites. In forest plantations, however, the situation is quite different because, by the time of complete canopy cover, both the ants and the borer would no longer be a problem. Apart from the study of *H. robusta*, it is also necessary to look into the silvicultural aspects concerning the planting of mahogany so as to improve the form of the tree and also to shorten the period when damage by *H. robusta* is most critical.

Current Researchers

Currently there is a joint research project by Forest Research Institute Malaysia (FRIM), Japan International Research Center for Agricultural Sciences (JIRCAS) and Rakyat Berjaya Sdn. Bhd (RBJ) on *Hypsipyla* shoot borers of Meliaceae at the Luasong Forestry Centre in Sabah where more than 300 ha of mahogany have been severely attacked by *H. robusta*.

Dr S.G. Khoo of FRIM is studying the biology and host preference/selection of *H. robusta* and also the role of predatory ants (*O. smaragdina*) in *Hypsipyla* shoot borer control.

Dr Kazuma Matsumoto of JIRCAS is currently based at Luasong Forestry Centre. Dr Matsumoto arrived in Sabah in December 1995 and is currently studying the ecology and population dynamics of *H. robusta*, in addition to carrying out various trials on possible control measures, the latter being dependent on establishment of new plantings.

Mr James Rubinsin Kotulai of RBJ, a subsidiary of Innoprise Corporation Sdn. Bhd. in Sabah is working closely with Dr Matsumoto on the biology of the borers.

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Hypsipyla Shoot Borers of Meliaceae in Indonesia

Oemijati Rachmatsjah[1] and F.R. Wylie[2]

Abstract

In Indonesia, *Hypsipyla robusta* (Moore) has been recorded from the native *Toona sureni* (Blume) Merr. and several introduced species, principally *Swietenia macrophylla* King. Impact has been severe, particularly on the mahoganies, trees aged three to six years and two to eight metres tall being the most heavily damaged. In Java, *H. robusta* completes its life cycle in about five weeks, peak flight activity occurring around dusk in the early rainy season (October). Several methods have been tested to control the insect, including form pruning, closer spacing at planting, the use of nurse, barrier and mixed plantings, and insecticide application. However, effective management of *H. robusta* has not yet been achieved.

THE SHOOT BORER *Hypsipyla robusta* (Moore) is known to feed on most tree species of the subfamily Swietenioideae in the family Meliaceae. In Indonesia, its most noticeable impact has been on the mahoganies, *Swietenia macrophylla* King and *S. mahagoni* (L.) Jacq., introduced into the country in the late 1800s and extensively attacked by the mid-1920s (Morgan and Suratmo 1976). These species are favoured for planting because of their high value timber. When young, they are often attacked by *H. robusta*, resulting in highly branched trees of inferior value due to a large reduction in straight bole length and timber volume. Several other species of Swietenioideae have been trialed, mainly in Java, but most have been attacked by the shoot borer.

Biology of *Hypsipyla robusta*

Hypsipyla robusta appears to be very widespread in Indonesia, being recorded from the islands of Java, Sumatra, Kalimantan, Sulawesi and Maluku. It is found in an altitudinal band ranging from the lowlands through to 1100 m above sea level (Suharti and Santoso 1990).

Following on early work by Kalshoven (1926), the morphology and biology of *H. robusta* in Java have been studied in some detail by Indarwati (1980), and its host preferences by Morgan and Suratmo (1976). Light trap catches and observations by the latter authors in West Java showed that, while generations are continuous throughout the year, the moth is most active during the period early September to early December. Flight activity of the adult is greatest around dusk in the early rainy season (October) and copulation and egg-laying occur during the night. Indarwati (1980) found that individual female *H. robusta* can produce up to 472 eggs, with an average incubation period of seven days. Newly hatched larvae bore through the epidermis of the growing shoot and mine in the twig. There are four or five larval instars occupying about 19 days (Morgan and Suratmo 1976). Usually, each shoot contains only one larva. Pupation is mostly within the twig mines or in silken cocoons in the foliage, and takes 10 days. The adult lives on average four days. The life cycle of *H. robusta* in Java is thus about five weeks (Morgan and Suratmo 1976).

Damage to Meliaceae

In Indonesia, *H. robusta* is known to feed on the native *Toona sureni* (Blume) Merr. and the introduced *Carapa guianensis* Aubl., *Cedrela odorata* L., *Chukrasia tabularis* A. Juss., *Khaya anthotheca* (Welw.) C.DC., *K. grandifoliola* C.DC.,

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K. senegalensis (Desr.) A. Juss, *S. macrophylla* and *S. mahagoni*. Ardikoesoema and Dilmy (1956) report that while *K. senegalensis* is heavily attacked, *K. grandifoliola* and *K. anthotheca* are little affected. Surveys by Morgan and Suratmo (1976) of shoot borer attack on *S. macrophylla* in West Java showed that trees aged three to six years and two to eight metres tall were most heavily damaged, and trees over 15 m tall and aged 13 years or more were only slightly damaged or not damaged at all. Further results from that same study showed that degree of infestation decreased with increasing age and height of the host; infestation being 90% for trees aged three years or 2.5 m high decreasing to less than 5% for trees older than 14 years or taller than 13 m (Suratmo 1977).

Management of *Hypsipyla robusta* in Indonesia

Much of the research on *H. robusta* management has been done as thesis work and remains unpublished. A number of student projects at the Faculty of Forestry, Bogor Agricultural University, have studied parasitoids of *H. robusta* eggs and larvae. Ibrahim (1974) reported that eggs were parasitised by *Trichogramma* sp. (Hymenoptera: Trichogrammatidae), while Kadarusman (1984) records the braconid *Megacentrus* sp. as a larval parasitoid.

Effective management of *H. robusta* has not been achieved even though a number of approaches have been investigated or suggested. Kalshoven (1926) attempted to prune the damaged shoot to produce a new leading shoot but considered the method to be unsatisfactory. Suratmo (1977), following his West Java studies reported above, suggested that protection of trees older than 14 years or over 13 m is unnecessary but that control measures should be applied to trees younger than eight years or under seven metres high. Closer spacing (1×2 m or closer) was advocated to encourage height growth and reduce the period of susceptibility to *H. robusta*. In south Sumatra, it has been demonstrated that weeds left uncut around *S. macrophylla* plantings could be a physical barrier against attack by the shoot borer until the height of the trees exceeded that of surrounding weeds (Sutomo 1987, cited in Matsumoto et al. 1997).

In subsequent studies by Matsumoto et al. (1997) in the same region, two experimental plantations of *S. macrophylla* enclosed by *Acacia mangium* Willd. trees were not attacked by the borer for three years (unfortunately the control plots for this experiment were destroyed by fire and further work is necessary to confirm the effectiveness of this protection method). Extracts of neem, *Azadirachta indica* A. Juss., leaves and seed have been tested in the laboratory against the shoot borer in Java and repelled and killed the insects (Suharti et al. 1995). The same authors report that interplanting of neem in *S. macrophylla* plantations in East Java, particularly in an uneven planting design, reduced the attack of the insects. Based on their host preference studies of *H. robusta* in Java, Morgan and Suratmo (1976) suggested the use of *Paraserianthes falcateria* (L.) Fosberg as a nurse crop. Ibrahim (1974), Barlian (1974) and Haryadi (1986) concluded that application of organophosphate insecticides was the most effective method of control of *H. robusta*.

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Hypsipyla Shoot Borers of Meliaceae in Papua New Guinea

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Abstract

Papua New Guinea is largely covered with forest (78% of land area) of which 3% has been commercially logged and about one-third is inaccessible to conventional logging techniques. Forestry accounts for 20% of the Nations export earnings. Two species of *Toona* (*T. ciliata* M. Roem. and *T. sureni* (Blume) Merr.) are harvested in a sustainable manner from native forests with less than 800 m^3 of each species extracted each year. None of these species are grown in plantations. No exotic species of Meliaceae are grown in plantations in Papua New Guinea, largely because of the presence of *Hypsipyla robusta* (Moore). No research is currently being undertaken on this pest.

PAPUA NEW GUINEA is well forested with more than 78% of the total area dominated by natural forest. Of the forest area, only about 3% has been influenced by industrial logging operations. However, because of the extremely mountainous terrain which is typical of most of the country, it is probable that no more than 42% could be harvested by conventional techniques. The total accessible area of forest is about 12.6 million ha, of which 3.75 million ha is not productive and a further 0.88 million ha is a buffer area around productive forest areas. Therefore, the total area of accessible productive forest is about 7.97 million ha with an estimated gross volume of about 170 million m^3. The best current estimate of annual sustainable yield is 4.9 million m^3. Harvesting operations will leave sufficient advanced growth to enable an equivalent volume to be harvested at the end of a 35-year cutting cycle.

Forestry has recently assumed a much greater level of importance to the national economy. Throughout the 1980s and the early 1990s, forestry contributed an average of less than 100 million kina (PGK) in annual export earnings. This represented around 6%–8% of the nations total export earnings. Howeve,r this has increased markedly due to the significant rise in the price of timber in 1993, with forestry contributing an anticipated 20% of the export earnings in 1994 (approximately 512 million PGK). The value of forest products exceeded all other agriculture and fisheries exports by more than 50% and was second in export revenue only to the non-renewable resources sector of oil and minerals (Figure 1). The total volume exported during 1994 was 3.1 million m^3 of sawn timber valued at 5.9 million PGK which was exported mainly to Australia and New Zealand. Woodchip sales to Japan amounted to 4 million PGK.

While Papua New Guinea is ninth among tropical countries in terms of forest area, its timber output is relatively low due to the large areas of inaccessible forest. Currently, the main consumers of logs are Japan (68%), Korea (22%) and Hong Kong (5%).

Relatively small but significant areas of plantations are found in several localities (Table 1). The most important is the 13 000 ha of government owned and managed plantations of *Araucaria cunninghamii* Aiton ex D. Don and *A. hunsteinii* Schumann in the Wau/Bulolo area. These support a plywood mill and associated processing industries at Bulolo. In the Madang area, 11 000 ha of privately owned hardwood plantations of predominantly *Acacia mangium* Willd. contribute to the wood supply for a chip mill. Other significant areas of industrial plantations are at several localities in New Britain where 17 600 ha of plantations (mainly *Eucalyptus deglupta* Blume) have been established and are approaching maturity.

Plantation establishment rates are not expected to exceed the present target of 4000 ha per year for the foreseeable future. Lack of funds and the risks associated with land tenure security are significant problems in expanding the plantation resources.

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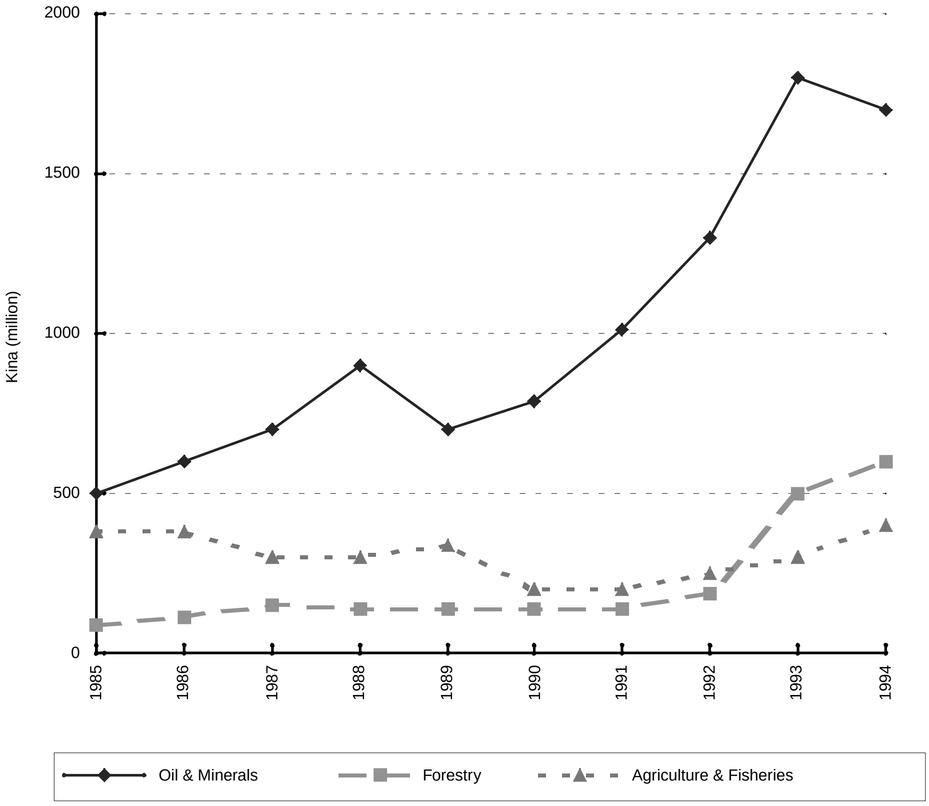

Figure 1. Contribution of the three major export sectors to Papua New Guinea total exports.

Economic Importance and Success of Swietenioideae Species

Two species of the subfamily Swietenioideae of the family Meliaceae, *Toona ciliata* M. Roem. and *T. sureni* (Blume) Merr. occur in native forest in Papua New Guinea. These scattered trees are harvested by large private companies, producing a total of less than 800 m^3 per year of timber. The exact amount harvested of each species is not known since both species are harvested under the trade name of 'Toona'. The current rate of harvesting of these species from native forest is considered sustainable. There are no commercial plantations of *Toona* spp. or any other species of Swietenioideae in Papua New Guinea due to the severe damage caused by *Hypsipyla robusta* (Moore).

Hypsipyla robusta Research and Future Directions

There is no current research into *H. robusta* in Papua New Guinea and only limited research has been undertaken in the past year because the focus has been on harvesting *Toona* spp. from native forest rather than growing these and related species in plantations.

In the Bulolo area (Morobe Province) in 1974, three line plantings of *T. ciliata* were established (3 m between lines) for experimental purposes on an area of open grassland dominated by *Imperata cylindrica* (L.) Beauv. Trees were established from cuttings treated with indole-acetic acid and indole-butyric acid (Merrifield and Howcroft 1975) since seedlings were unavailable. The trial was aborted

Table 1. Major plantation areas and tree species in Papua New Guinea.

Project	Province	Ownership	Total area (ha)	Species (% of area of major species)
Brown River	Central	Customary	1200	*Tectona grandis* Linn. f. (100%)
Bulolo/Wau	Morobe	Government	13 000	*Araucaria hunsteinii* Schumann (50%) *A. cunninghamii* Aiton ex D. Don (50%)
		Customary	?	*Pinus merkusii* Jungh. & de Vriese (80%) *P. caribaea* Morelet
Gogol Valley	Madang	Private	11 000	*Acacia mangium* Willd. (100%)
		Government	1200	*Eucalyptus deglupta* Blume (60%) *Terminalia brassii* Exell
Fayantina	Eastern Highlands	Government/Customary	500	*Pinus patula* Schldl. and Cham. (100%)
Kainantu	Eastern Highlands	Government	1000	*P. patula* (100%)
Kaut	New Ireland	Government/Customary	250	*E. deglupta* (100%)
Keravat	East New Britain	Customary	1900	*T. grandis* (80%) *E. deglupta* *Ochroma lagopus* Sw.
Kuriva	Central	Government	600	*T. grandis* (100%)
Lapegu	Eastern Highlands	Government	3200	*P. patula* (100%)
Open Bay	East New Britain	Private	9200	*E. deglupta* (90%) *T. brassii* *A. mangium*
Madang North Coast	Madang	Government	900	*E. deglupta* (48%) *A. mangium* (48%) *T. brassii*
Stettin Bay	West New Britain	Private	8400	*E. deglupta* (80%) *Octomeles sumatrana* Mig. *T. brassii* *A. mangium*
Ulabo	Milne Bay	Government	1500	*T. brassii* (80%) *E. deglupta* *A. mangium*
Waghi Valley	Western Highands	Government	2100	*E. grandis* (49%) *E. robusta* (49%) *P. patula*
Ialibu	Southern Highlands	Government	900	*P. patula* (96%) *E. robusta*

after the first couple of years due to very severe attack by *H. robusta* resulting in the trees being of shrubby form and less than 1 m high.

Swietenia macrophylla King and *Toona* sp. were planted in a plot of less than 1 ha in the Gogol Valley (Madang Province) in the mid 1970s at a 10 m × 10 m spacing as an enrichment planting following clear felling. Both these species were severely attacked by *H. robusta* virtually ever since planting which has resulted in the *Toona* sp. appearing as very bushy small trees. In contrast, the *S. macrophylla* has managed to grow through the damage and is showing very promising form and growth.

A few line plantings of *S. macrophylla* and *Cedrela odorata* L. have also been established at Bulolo in 1959 at a spacing of 2.4 m as a minor component of a plantation of *A. cunninghamii and A. hunsteinii*. The site was previously clear felled and logged. At Kuriva in the mid 1980s, a few line plantings of *S. macrophylla* were established on an old nursery site. At both locations, the trees have been attacked by *H. robusta* but have produced trees of good height and form. These results suggest that these exotic species of Swietenioideae may be successfully grown at low densities in mixed species plantings.

Khaya anthotheca (Welw.) C.DC. and *K. nyasica* Stapf. ex Baker were planted at Brown River (Central Province) in the 1950s or 1960s as line plantings in a reforestation project (Skelton 1981). Current information is not available and land has reverted back to the customary landowners.

In 1975 at Bulolo, 25 organophosphate and carbamate insecticides were screened for systemic activity in *T. ciliata*. The most highly systemic insecticides were aldicarb, dimethoate, isolan, phosphamidon, propoxur and trichlorfon. It was proposed to then test these chemicals against *H. robusta*. However, these studies have not been reported.

Presently there is no active research into *H. robusta* or growing of species of Swietenioideae in Papua New Guinea. However, the Papua New Guinea Forest Research Institute has recently established a new program on the domestication of indigenous tree species into which *T. ciliata* could be included if damage from *H. robusta* could be controlled. Hence, these Proceedings and resolutions of this workshop will assist greatly in determining the future directions of research at the Institute.

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Hypsipyla Shoot Borers of Meliaceae in Solomon Islands

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Abstract

Hypsipyla robusta (Moore) is a major pest in the tropics including Solomon Islands. In 1996, there was about 3545 ha of *Swietenia macrophylla* Jacq. plantation and the status of the pest needs to be seriously considered. There are a number of experimental trials of *S. macrophylla* in which *H. robusta* is being studied. It is necessary to research potential biological control of this pest, as chemical control measures are highly uneconomical to implement in plantations. Treating *H. robusta* in the nursery using a systemic insecticide, Orthene, is currently an accepted treatment in Solomon Islands. *Cedrela odorata*, another of the Meliaceae, is also planted and is only minimally attacked by *H. robusta*.

SOLOMON ISLANDS lies in the Southwest Pacific between latitude 5° and 12°S and longitude 155° and170°E and has a total land area of 28 300 km with a population of 412 902 in 1996. The economy of Solomon Islands relies heavily upon fishing, agriculture and forestry. The cultural heritage and economic development of Solomon Islands is dependent on forests. Benefits from the forest include poles, fuelwood, medicinal plants and a range of customary uses.

Overview of Forestry Industry

Solomon Islands is an independent state and relies mostly on its natural resources for its revenue. The forest and its people are almost inseparable and thus the forest is highly valued. Some of the fundamentally important aspects of forests in Solomon Islands are:

- part of the nation's cultural heritage and future economic development;
- environmental and the ecological stability of the islands is conditioned by the protective covering of the forest;
- forests cover more than 80% of the land area and supports the timber industry;
- generate significant amounts of government revenue;
- provide employment for 4% of the national workforce;
- earnings from log royalties by resource owners; and,
- provide fuelwood, poles, food and a variety of customary uses including medicinal herbs.

Revenue earned from log exports in the late 1990s has been the largest for any industry in the country. Estimates of production and revenue earned are shown in Table 1. However, the sustainability of these logging practices is currently a controversial issue.

Table 1. Volume of timber and revenue earnt from logging in Solomon Islands.

Year	Volume (m^3)	Revenue ($ million)
1993	591 100	73.9
1994	627 952	76.6
1995	733 817	79.3
1996	431 755 (Jan-June)	48.9

The national inventory carried out in 1995 by the Solomon Island Forest Resources Inventory Project, funded by AusAID, found that only 8 million ha of forest remains and is likely to be exhausted in four to five years. There are many foreign logging companies operating in Solomon Island with a combined annual quota of 642 000 m^3 (Table 2).

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Table 2. Foreign companies logging in Solomon Islands and their annual quotas in 1996.

Company	Annual quota (m^3)
Kalena Timber	160 000
Allardyce Lumber	42 000
Dalsol Ltd	30 000
Pacific Timber	50 000
Hyundai	75 000
Intergrated Forest Industry	72 000
Kayuken Pacific	50 000
Eagon Forest Development	93 000
Levers Solomon	40 000
Marvin Brothers	30 000
TOTAL	642 000

Government planting on logged-over crown land started in 1967 and through till 1996, about 26 000 ha had been planted to various indigenous and exotic species. Initially, enrichment planting was the dominant method. Planting material was then mostly from wildings of major commercial indigenous species (e.g. *Terminalia brassii* Exell, *Campnosperma brevipetiolata* Volk., *Eucalyptus deglupta* Bl.) and *Swietenia macrophylla* Jacq. imported from Papua New Guinea and Fiji. Currently, six major tree species are recommended for large-scale plantations in Solomon Islands. Table 3 lists these species and gives their recommended espacement.

Table 3. Tree species and espacement recommended for plantation forestry in Solomon Islands.

Species	Espacement
Cedrela odorata L.	5 m × 3 m
Eucalyptus deglupta Bl.	5 m × 3 m
Gmelina arborea Roxb.	4 m × 3 m
Swietenia macrophylla Jacq.	10 m × 3 m
Tectona grandis Linn. f.	4 m × 3 m
Terminalia brassii Exell	5 m × 3 m

Following the Government Structural Adjustment Policy on Privatisation in 1995, all government plantation establishment ceased. Large scale forestry planting is now done by private companies only. The net planted area from 1967–1995 is as shown in Table 4.

Economic Importance and Success of Swieteniodeae Species

The only indigenous species belonging to the subfamily Swietenioideae of the family Meliaceae in Solomon Islands is *Xylocarpus granatum* Koen. This is a mangrove species and of little commercial value. Fruit of *X. granatum* has been destroyed by feeding of larvae of *Hypsipyla robusta* (Moore) (Bigger 1988) while shoot feeding has not been recorded. Two exotic high-value species of Swietenioideae, *Cedrela odorata* L. and *Swietenia macrophylla* Jacq., have been grown in Solomon Islands and are among the most important plantation species in Solomon Islands. *C. odorata* is minimally attacked by *H. robusta* while *S. macrophylla* is generally heavily attacked (Bigger 1988). *S. macrophylla* has been widely planted in Solomon Islands and by the end of 1995 the Forestry Division has planted 3545.5 ha.

Hypsipyla robusta Research and Future Directions

Hypsipyla robusta is a major pest of species in the Swietenioideae which includes *Swietenia* spp. and *Cedrela* spp. *H. robusta* is found in the South Pacifc in Australia, Papua New Guinea and Solomon Islands but does not extend to Vanuatu or Fiji (Bigger 1988). Early specimens from Solomon Islands were identified at the British Museum of Natural History as *Hypsipyla pagodella* Ragonot in 1969 while specimens in 1970 were identified at the Commonwealth Institute of Entomology as *H. robusta*. *H. pagodella* is a junior synonym of *H. robusta* (Horak, these Proceedings).

The presence of shoot borer is quite noticeable as the shoot tips above the larval entrance hole rapidly die and turn black. The presence of larvae is also indicated by quantities of frass ejected from the entrance holes. In other countries, it has been reported that *H. robusta* attacks leaves, flowers and shoots (Bigger 1988). In plantations of *S. macrophylla* in Solomon Islands, the only parts of trees that have been observed to be attacked are the shoots of young plants (Wilson 1986a). The first reported attack of *H. robusta* in Solomon Islands was in 1959 when the Mt Austen trial plot of *Toona ciliata* M. Roem. was virtually destroyed and *S. macrophylla* was also severely distorted.

The most serious pest of *S. macrophylla* in nurseries is *H. robusta*, on occasions affecting a high proportion of seedlings (Wilson 1986b). The seedlings usually survive but develop multiple shoots, making them not acceptable material for planting. An insecticide that can be used to effectively control *H. robusta* in nurseries is the systemic insecticide, Orthene, which was applied to foliage using a knapsack sprayer. Chemical application in the field is not recommended as it is too expensive and the whole operation would be uneconomical.

A nursery trial has been established to determine if attack of *H. robusta* can be reduced by randomly mixing seedlings of *S. macrophylla, C. odorata* and *Tectona grandis* Linn. f. After 2 months, no attack was noted on any of the seedlings. It is still too early to conclude whether shoot borer damage has been reduced.

Field experience indicates that closely spaced *S. macrophylla* are highly susceptible to *H. robusta* and wide spacing leads to invasion of the crown of the trees by the climbing vine, *Merremia peltata* (L.) Merr. The current recommendation is spacing at 10 m × 3 m since damage from *H. robusta* was considered a greater risk than competition from *M. peltata*. A nurse crop was considered to be a better strategy to overcoming both these problems.

A plantation of alternate rows of *S. macrophylla* and *Terminalia calamansanai* (Blco.) Rolfe was established in 1984. This trial was not successful due to different growth rates leading to different harvesting time and the *S. macrophylla* being suppressed by the fast growing *T. calamansanai*. Another mixed species trial was established using *S. macrophylla* and *Schleinitschia novo-guinensis* (Schn). Again in this trial, the nurse species grew faster and suppressed the *S. macrophylla*.

Another nurse crop trial has been established with a different nurse crop species (*Securinega flexuosa* (Muell. Arg.)). The data from the trial had not yet been analysed but it appeared that there was a difference in both growth and *H. robusta* attack when line planted *S. macrophylla* are compared with those planted under a nurse crop. There is also some indication that small black birds while feeding on *S. flexuosa* fruit may also feed on *H. robusta* larva on the mahogany. This idea is yet to be experimentally tested.

Table 4. Net area of plantation established in Solomon Islands from 1967 to 1995.

Year	Area planted (ha) for each tree species										Total Area (ha)
	AGAM	CAMB	CEDO	EUCD	GMEA	SWIM	TECG	TERB	TERCAL	MINOR	
1967		47.0									47.0
1968		173.7									173.7
1969		279.2									279.2
1970		177.7							55.0		232.7
1971		498.3							442.4		940.7
1972		543.1							394.2		937.3
1973		75.7						14.9	39.6		130.2
1974		778.9						265.0	92.0	297.6	1433.5
1975		721.8							159.5		881.3
1976		1045.4			69.0			69.0	212.3		1395.7
1977	128.4	688.0		468.6				217.3	27.0		1529.3
1978	528.9	1733.8		827.9		58.0			285.3		3433.9
1979	583.7	1416.2		400.5		70.0		28.8	258.6		2757.8
1980	66.5	281.0		133.8				774.9	388.9		1645.1
1981	72.6	36.5			15.3			74.3			198.7
1982	18.1	223.1			64.9	175.8		26.0		7.0	514.9
1983	129.3	192.3			65.5	395.5		88.7	55.5	87.3	1014.1
1984		175.4			66.2	384.3	18.2	92.9	133.4	47.8	918.2
1985		140.4	193.5		100.7	460.1	50.9	166.9	34.1	81.1	1227.7
1986		36.5	119.9	45.6	62.0	198.4	86.5	232.1	160.2	16.6	957.8
1987		31.6		70.1	184.5	445.9	137.5	250.4			1120.0
1988			106.5	15.0	357.0	359.0	173.9	26.4			1037.8
1989			209.8		230.4	518.4	358.1				1316.7
1990			56.3		319.5	65.1	160.2	30.1			631.2
1991			21.6		71.4	23.9					116.9
1992											0.0
1993			4.2		211.3	40.3	52.3				308.1
1994			91.1		286.3	202.9	115.2				695.5
1995			95.0		285.8	147.9	57.7				586.4
Total	1527.5	9295.6	897.9	1961.5	2389.8	3545.5	1210.5	2357.7	2738.0	537.4	26 461.4

ACAM – *Acacia mangium* Willd.; CAMB – *Campnosperma brevipetiolata* Volk.; CEDO – *Cedrela odorata L.*; EUCD – *Eucalyptus deglupta* Bl.; GMEA – *Gmelina arborea* Roxb.; SWIM – *Swietenia macrophylla* Jacq.; TECG – *Tectona grandis* Linn. f.; TERB – *Terminalia brassii* Exell; TERCAL – *Terminalia calamansanai* (Blco.) Rolfe

Future research is required to extend this work on nurse crops, particularly using *S. flexuosa* which can be thinned for house poles. Other species of cover crop have also been suggested, including *Glyricidia* spp and *Paraserianthes falcataria* (L.) Nielsen (Morgan and Suratmo 1976).

Conclusion

The planting of *S. macrophylla* in Solomon Islands is economically a highly attractive venture and needs to be properly monitored and managed. Unfortunately, this species is often severely damaged by the shoot borer, *H. robusta*, both in plantations and in the nursery.

The attack in the nursery can be easily monitored and treated.

Future research will concentrate on identifying a suitable and effective nurse crop for *S. macrophylla*. Clearly, *S. macrophylla* is a high-value species and has potential in Solomon Islands and thus needs to be properly researched.

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Hypsipyla Shoot Borers of Meliaceae in Australia

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Abstract

Red cedar, *Toona ciliata* M. Roem, has been a highly favoured timber species in Australia since the time of European settlement. Rapid and indiscriminate felling during the 1800s led to concern about the future supply of this timber, and various attempts were made to grow the tree in natural forests and plantations. Some of the first silvicultural work on any species in Australia involved experimental plantings of young trees into former cedar areas in the late 1800s and early 1900s. These early plantings were unsuccessful, with the failure attributed primarily to damage caused by the tip boring moth, *Hypsipyla robusta* Moore (Pyralidae, Phycitinae). The Queensland and New South Wales forest services have tried to identify the conditions that minimise *H. robusta* damage and therefore allow successful production of *T. ciliata.* However, damage from *H. robusta* remained a problem, and only a few plantings produced trees with good overall growth rates and form. The outcomes of these trials are summarised in this paper. Despite the early recognition of the critical role of *H. robusta* in limiting growth of *T. ciliata,* until recently there have been few attempts to investigate the taxonomy, biology, ecology or life history of *H. robusta* in Australia. Work undertaken to date is described, and directions for future research are identified.

Overview of the Forest Industry

THE forest industry is an important part of the Australian economy, comparable with the barley, cotton and sugar industries in terms of gross value of production (Table 1). The industry comprises approximately 4% of the total gross value of production for farming, forestry and fishing.

Australia is a net importer of forest products. In 1994–1995, Australia imported forest products valued at AU$3 billion, while exports for the same period were valued at AU$1 billion, or 5% of the value for the rural sector (ABARE 1996b). In 1994–1995, the forestry and logging industries employed 12 000 people, accounting for 3% of the workforce employed in agriculture, forestry and fishing, and 0.15% of the total industrial workforce (ABARE 1996a). Forest products industries employ an additional 61 000 people (ABARE 1996b).

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Table 1. Estimated gross value of production in selected primary industries. [a] ABARE (1996a); [b] Sar (1993); [c] ABARE (1995) – average gross value 1992–93 to 1994–95.

	Gross value of production (AU$ millions)			
	1991–92	1992–93	1993–94	1994–95
Crops[a]				
Wheat	2097	2894	2867	1958
Barley	693	802	845	572
Sugar	590	805	947	1257
Cotton lint	862	665	631	804
Livestock[a]				
Beef	3802	3839	4353	3960
Wool	2980	2569	2459	3264
Fisheries products	1376	1493	1686	1745
Forestry	712[b]	738[b]	967[c]	967[c]
Total	23 474	24 658	26 280	26 302

Australia's forestry resource base comprised approximately 41 million ha of native forests and 1.1 million ha of plantation forests at March 1995 (ABARE 1996b). The majority of plantations were of softwood species, predominantly the exotic *Pinus radiata* which occupied approximately 726 000 ha (Table 2). Approximately 14% of plantation land was occupied by broadleaf species, of which 97% was under *Eucalyptus* spp. (Table 2). In 1995, the total plantation area was expanding at a rate of approximately 21 000 ha/year, with the greatest increase being in hardwood species. A number of programs initiated by the Commonwealth Government (National Afforestation Program, Farm Forestry Program, Community Rainforest Reforestation Program) supported the expansion of Australia's plantation resource base.

Table 2. Area of forestry plantations in Australia classified by tree species and land ownership (ABARE 1996b).

Tree species	Plantation area in March 1995 (ha)	Area planted for year ending March 1995 (ha)
Coniferous		
Pinus radiata D. Don	725 731	8 606
Pinus elliottii Englem.	69 170	0
Pinus pinaster Bess.	30 853	540
Pinus caribaea Morelet	57 539	0
Other exotic species	33 880	235
Total exotic	917 173	12 348
Araucaria spp.	46 700	601
Total coniferous	963 873	12 949
Broadleaved		
Eucalyptus spp.	150 703	1 184
Populus spp.	1 048	0
Other	3 199	32
Total broadleaved	154 950	11 216
Total	1 118 823	20 597
Public ownership	759 332	13 833
Private ownership	359 491	13 034

Economic Importance of Native Swietenioideae Species

Four species of Swietenioideae (a subfamily of Meliaceae) are native to Australia; *Toona ciliata* M. Roem., *Xylocarpus granatum* Koen, *X. moluccensis* (Lam.) M. Roem., and *X. rumphii* (Kostel.) Mabb., of which only *T. ciliata* is commercially harvested. *Toona ciliata* has been an important tree in the history of the Australian timber industry. Harvesting of this species commenced along the Hawkesbury River, New South Wales, in 1792, shortly after European settlement (Baur 1962). The search for new stands of *T. ciliata* led to the exploration and eventual settlement of much of the Queensland and New South Wales coastline. Extensive logging and land clearing resulted in the virtual disappearance of *T. ciliata* from many regions (Grant 1989; Newport 1904; Volck 1971) which led to a dramatic reduction in the quantity of timber harvested. In 1878, 2797 m^3 of timber was harvested from the rainforests of north Queensland alone (Vader 19887), while in 1995 less than 200 m^3 was harvested from the entire State (Table 3). Similarly, harvesting of *T. ciliata* in New South Wales declined from an average of 1585 m^3/year in 1910–1917, to 570 m^3/year in the 1940s (Grant 1989) and ultimately to less than 100 m^3/year in the 1990s (A. Signor, State Forests of New South Wales (SFNSW), pers. comm.; R. Ainley, New South Wales Forest Products Association (NSWFPA), pers. comm.). The harvesting of *T. ciliata* from publicly owned lands effectively ceased in 1982 in New South Wales and 1994 in Queensland. Most logs of *T. ciliata* now come from windfalls and power line clearing, with a very small quantity from plantation harvesting.

Table 3. Removal of *Toona ciliata* from public and private lands in Queensland since 1991. Compiled from QDPI – Forestry, Production Division Statistics.

Year	Public land (ha)	Private land (ha)	Total (ha)
1991	41	63	104
1992	135	120	255
1993	393	41	434
1994	138	171	309
1995	5	194	199

Small quantities of timber are harvested from privately-owned lands. Much of this timber is cut for specific users and does not come onto the open market. Almost 200 m^3 of timber was removed for sale from private lands in Queensland during 1995 (Table 3) while about 20m^3 was harvested in New South Wales (R. Ainley, NSWFPA, pers. comm.). In addition, logs confiscated from illegal logging on private property, forestry reserves, or national parks are sold when seized.

The value of *T. ciliata* is difficult to gauge due to its rarity on the market. Recent estimates put the value between \$500 and \$1000/m^3 for logs, and up to \$3000/m^3 for sawn timber (G. Palmer, QDPI – Forestry, pers. comm.; R Ainley, NSWFPA, pers. comm.). Thus, *T. ciliata* is currently one of the most valuable timbers in Australia, comparable only to white beech *Gmelina leichhardtii* (F Muell.) F. Muell. ex Benth (Verbenaceae).

Success of Exotic Species of Swietenioideae Planted in Australia

A wide variety of introduced species of Swietenioideae have been trialed in Queensland and New South Wales (Table 4). Despite recognition of the potential of these species, plantings have been experimental and small scale (details in Tables 5, 6, 7). At present only 16.2 ha in Queensland are planted with introduced species of Swietenioideae, of which 14.3 ha are planted with *Cedrela odorata* L. (Source: QDPI Forestry, Plantation Register, Hunted Compartments Report July 1996).

Many of the introduced Swietenioideae species were damaged by *H. robusta* (Table 4). *Swietenia macrophylla* King has been consistently and heavily damaged, *C. odorata, C. lilloi* C. DC. and *Chukrasia tabularis* A. Juss. were less damaged, while *Khaya senegalensis* (Desv.) A. Juss. and *K. nyasica* Stapf. ex Baker received very minor damage. Damage invariably commenced within five years of planting, but was not always systematically recorded. The absence of recorded damage cannot, therefore, be assumed to indicate low damage levels. Greater damage has been reported on *T. ciliata* than on *S. macrophylla*, *C. odorata*, *C. lilloi*, and *C. tabularis* when grown in mixed species plantings or growing nearby.

Many species of Meliaceae, especially those in the genera *Swietenia* and *Khaya*, tend to develop multiple leaders and heavy branching. Although damage from *H. robusta* contributes to this, poor form has also been attributed to wind, frost, poor soils and damage from browsing animals. In particular, many species are susceptible to frost, leading to the failure of many plantings in southern areas and at higher altitudes. Trees do not readily shed lateral branches in plantation situations, so pruning is required to improve form. Even heavy and frequent pruning has failed to produce reasonable log lengths in many plantings.

There have been many small trial plantings of exotic species of Meliaceae with mixed success, some of which are very promising. Exotic species of Meliaceae have been divided into three categories; species that have been grown with some success (Table 5), species that have not been adequately assessed (Table 6), and, species that have been trialed and abandoned due to poor performance (Table 7). Trials for species in each category are summarised in the following sections.

Species grown with some success (Table 5)

Cedrela odorata

Cedrela odorata is capable of very rapid early growth in open plantings on good sites, achieving mean annual increment (MAI) of height generally above 1.0 m over 8 years and up to 4.0 m during the first few years. The early growth of open planted trees has been further improved with the use of protective shelters (Growtubes ™). After one year, trees attained a mean height of 1.7 m in 1 m Growtubes, and 2.3 m in 2 m Growtubes compared to 1.5 m without Growtubes) (Applegate and Bragg 1989). Open plantings on heavy red soils or in drier

Table 4. Exotic species of Meliaceae subfamily Swietenioideae planted in Australia. Source: Queensland: QDPI Forestry, Plantation Register, Hunted Compartments Report July 1996 (current areas); New South Wales: Wyatt 1984 – (areas at time of planting – 1952–1958).

Tree species	Current area of planting[a] (ha)	Current rate of planting (ha/year)	Optimal rotation length (yrs)	Status[1]	*Hypsipyla* damage
Cedrela lilloi C. DC.	0.3	Nil		C	Slight
C. microcarpa C. DC.	Negligible	Nil		D	None recorded
C. odorata L.	14.4	Negligible		B	Slight/variable
Chukrasia tabularis A. Juss.	Negligible	Nil		C	Moderate/variable
Khaya anthotheca (Welw.) C. DC.	0.1	Nil		D	None recorded
K. grandifoliola C. DC.	Negligible	Nil		B	None recorded
K. ivorensis A. Chev.	Negligible	Nil		C	None recorded
K. nyasica Stapf. ex Baker	1.1	Negligible	~30	B	Slight
K. senegalensis (Desv.) A. Juss.	0.3	Nil		B	Slight
Entandrophragma utile (Dawe & Sprague) Sprague	0.1	Nil		D	None recorded
Swietenia macrophylla King	0.2	Negligible		B	Moderate
S. mahagoni (L.) Jacq.	0.1	Nil		C	None recorded
S. macrophylla × *mahagoni*	Negligible	Nil		D	None recorded

[1]A – ongoing and successful; B – ongoing but having limited or variable success; C – preliminary or experimental only; D – terminated.

Table 5. Description of on-going experimental plantings of exotic species of Swietenioideae having some success. Mean annual increments (MAI) in height are provided for trees at approximately 5 years age (or nearest available measuring date). MAI for diameter at breast height (DBH) are those from the last measure available.

Experiment	Species	Type of planting	Planting date	Seed source	Planting density (sph)	Height		DBH		Survival (%)
						Age (yrs)	MAI (m)	Age (yrs)	MAI (cm)	
ATH120/1	*Cedrela odorata*	Underplanting - thinned *Araucaria cunninghamii* plantation (18 yrs)	02/1953	local – Atherton	946	4.2	0.7	–	–	high
ATH139	*C. odorata*	Enrichment planting - silviculturally treated rainforest	02/1954	Puerto Rico	1111	4.2	0.2	8.0	0.2	24
ATH140	*C. odorata*	Rainforest enrichment	03/1954	local – Atherton	–	1.5	0.4			13
ATH162/24	*C. odorata*	Interplanting – *Toona ciliata*	03/1955	Ecuador	772			19.1	1.5	
ATH206/135	*C. odorata*	Increment plot – grown under rain forest shelterwood	07/1927	local – Imbil	–			25	1.8	39
ATH399	*C. odorata*	Open planting – mine rehabilitation	1972			3.3	1.6			
ATH704/5	*C. odorata*	Open planting – provenance trial – red earth	02/1987	Coyote, Honduras	1234	4.6	0.5			
ATH704/6	*C. odorata*	Open planting – provenance trial – red earth	02/1987	Taulabe, Honduras	1234	4.6	0.6			
ATH704/7	*C. odorata*	Open planting – provenance trial – red earth	02/1987	Chameleon, Honduras	1234	4.6	0.5			
ATH704/8	*C. odorata*	Open planting – provenance trial – red earth	02/1987	Matagalpa, Nicaragua	1234	4.6				0
ATH704/9	*C. odorata*	Open planting – provenance trial – red earth	02/1987	local Atherton	1234	4.6				0
ATH708/5	*C. odorata*	Open planting – provenance trial, ex rainforest site – kraznozem	02/1987	Coyote, Honduras	1234	4.6	2.7			
ATH708/6	*C. odorata*	Open planting – provenance trial, ex rainforest site – kraznozem	02/1987	Taulabe, Honduras	1234	4.6	2.4			
ATH708/7	*C. odorata*	Open planting – provenance trial, ex rainforest site – kraznozem	02/1987	Chameleon, Honduras	1234	4.6	2.5			
ATH708/8	*C. odorata*	Open planting – provenance trial, ex rainforest site – kraznozem	02/1987	Matagalpa, Nicaragua	1234	4.6	2.1			
ATH709/1	*C. odorata*	Growtube trial – control		unknown		1	1.5			
ATH709/2	*C. odorata*	Growtube trial – 1 m		unknown		1	1.7			
ATH709/3	*C. odorata*	Growtube trial – 2 m		unknown		1	2.3			
HWD354	*C. odorata*	Open planting – site of clearfall *Pinus elliottii* plantation (34 yrs)	12/1987	unknown	1111	1.8	1.6			
HWD355	*C. odorata*	Open planting – originally dry sclerophyll; cleared and cultivated	12/1987	unknown	1111	1.8	2.0			
HWD374/324	*C. odorata*	Enrichment planting – dry sclerophyll grassy open forest 20–30 m	12/1987	unknown	1111	1.8	3.0			

Table 5. Continued. Description of on-going experimental plantings of exotic species of Swietenioideae having some success. Mean annual increments (MAI) in height are provided for trees at approximately 5 years age (or nearest available measuring date). MAI for diameter at breast height (DBH) are those from the last measure available.

HWD375/266	*C. odorata*	Enrichment planting - dry sclerophyll grassy open forest 20–30 m	12/1987	unknown	1111	1.8	2.6			
IMB226	*C. odorata*	Yield plot on ex hoop pine scrub	1930/31	unknown	793	20.5		42.7	1.0	
IMB291/1	*C. odorata*	Open planting – single parent study of two high quality parent trees	02/1953	local – Imbil	1540	5.5	1.8	19.5	1.5	31
IMB291/2	*C. odorata*	Open planting – single parent study of two high quality parent trees	02/1953	local – Imbil	1540	5.5	1.8	19.5	1.2	68
IMB302	*C. odorata*	Underplanting – *A. cunninghamii* (0.5 yr) – ex rainforest land	04/1953	unknown	1293	8.5	1.5	23.5	1.4	
IMB319/3	*C. odorata*	Interplanting – *T. ciliata* 2.7 × 2.4m spacing	02/1953	local – Imbil	1543	5.5	1.4	12.5	2.3	
IMB355	*C. odorata*	Open planting – testing seed stock	01/1955	Ecuador, ex Cuba	–	6.8	0.9	14.8	1.3	55
IMBROUTINE	*C. odorata*	Open planting – ex rainforest site	12/1930	unknown	–	61.3		61.3	0.5	
ING459/4	*C. odorata*	Open planting – ex dry sclerophyll forest site	01/1979	unknown	1485	5.3	0.2			
NSW Baur	*C. odorata*	Enrichment planting		unknown		5	0.7			30
G1/9.3.2a	*C. odorata*	Underplanting – *A. cunninghamii* on ex rainforest site, basaltic soil	1953	Cuba	250	5	0.4			
YMN1868/1	*C. odorata*	Open planting – ex *A. cunninghamii* scrub	12/1959	unknown	1543	4.7	0.8	11.7	1.1	78
YMN1868/2	*C. odorata*	Underplanting – *Grevillea robusta* (30 yr), ex *A. cunninghamii* scrub	02/1960	unknown	421	8.5	0.4			11
ATH509/4	*Khaya grandifoliola*	Open planting – mixed species, ex rainforest site	03/1972	Ghana	1074	5.5	1.4	8.5	1.5	94
ATH204/5	*Khaya nyasica*	Open planting – mixed species, arboretum plots	03/1957	Nyasaland	1544	7.0	0.5	18	0.2	3.4
IMB373	*K. nyasica*	Open planting – ex rainforest site (frost free)	04/1956	Tanganyika	1443	5.5	0.8	26.3	0.9	
IMB378	*K. nyasica*	Open planting – ex rainforest site (exposed to frost)	11/1956	ex H.O.	1569	5.0	1.0	20.8	0.8	~100
MTO008	*K. nyasica*	Open planting – ex heavy vine scrub site	01/1957	Nyasaland	1527	5.5	1.3	23.6	1.0	100
ATH159	*Khaya senegalensis*	Enrichment – (refills only) – varying overwoods	04/1956	unknown	varying	–		–	–	0
ATH204/1/11	*K. senegalensis*	Open planting – mixed species, arboretum plots	02/1956	Nigeria	1544	5.3	0.3	19.1	2.2	88
ATH204/2/1a	*K. senegalensis*	Open planting – mixed species, arboretum plots	02/1956	Nigeria	1544	5.3	0.3	–	–	90
ATH399	*K. senegalensis*	Open planting – mine rehabilitation	1972	unknown			1.5			
ATH509/17	*K. senegalensis*	Open planting – mixed species, ex rainforest site	03/1973	Uganda	1111	4.5	0.3			94
ATH509/3	*K. senegalensis*	Open planting – mixed species, ex rainforest site	03/1972	Uganda	1111	5.5	0.7			80
ING511/1	*K. senegalensis*	Open planting – coastal, well drained site	03/1972	unknown	1500	3.3	0.7	6.3	1.0	98
ATH166/3	*Swietenia macrophylla*	Enrichment planting – logged and treated rainforest	05/1956	unknown	347	3.2	0.4	10.3	0.3	
ING459/7	*S. macrophylla*	Open planting – ex dry sclerophyll forest site	01/1970	unknown	1485	5.3	1.1	8.4	1.2	
ATH122	*S. macrophylla*	Underplanting – in *Araucaria cunninghamii* planting (18 yrs)	02/1953	ex Laguna, Philippines	824	5.2	0.9	22.5	1.0	96

Table 5. Continued. Description of on-going experimental plantings of exotic species of Swietenioideae having some success. Mean annual increments (MAI) in height are provided for trees at approximately 5 years age (or nearest available measuring date). MAI for diameter at breast height (DBH) are those from the last measure available.

ATH125/1	*S. macrophylla*	Interplanting – *T. ciliata*, alternate rows	01/1953	ex Philippines	1111	7.5	0.3			58
ATH125/2	*S. macrophylla*	Enrichment	03/1953	ex Fiji	1111	2.6	0.1	–	–	0
ATH204/1/2	*S. macrophylla*	Open planting – mixed species, arboretum plots	02/1956	Puerto Rico	1544	–				0
ATH399	*S. macrophylla*	Open planting – mine rehabilitation	1972	unknown		4.5	1.7			
ATH451	*S. macrophylla*	Enrichment planting – lowland scrub – with *Flindersia brayleyana*	01/1970	ex Sri Lanka	362	7.3	1.6	18	1.5	85
ATH559/2	*S. macrophylla*	Open planting – comparison of parent trees	03/1975	Puerto Rico (dry forest)	1088	6.0	0.2			77
ATH559/4	*S. macrophylla*	Open planting – comparison of parent trees	03/1975	Puerto Rico (wet forest)	1088	6.0	0.6			100
ATH691/1	*S. macrophylla*	Open planting – contour mounded, large mounds on ex open forest site	02/1982	Chore, Bolivia	833					
IMB312	*S. macrophylla*	Interplanting – *A. cunninghamii* (alternate rows)	02/1953	ex Philippines	–	8.7	0.3			48
IMB374	*S. macrophylla*	Open planting	04/1956	Puerto Rico	–	5.5	0.2	9.3	<0.1	11
ING442	*S. macrophylla*	Open planting – coastal area, ex wet sclerophyll forest site	06/1968	unknown	1340	8.8	1.2	20.8	1.2	
ING511/3	*S. macrophylla*	Open planting – coastal, ex dry sclerophyll forest site	03/1972	unknown	1500	3.3	0.5	17.0	0.8	88
NUT058/20	*S. macrophylla*	Underplanting – *Pinus elliottii* planting (16 yrs), dry sclerophyll site	02/1966	unknown	726	6.3	0.5	23.7	0.7	
NUT058/27	*S. macrophylla*	Underplanting – *P. elliottii* planting (16 yrs), dry sclerophyll site	02/1966	unknown	674	6.3	0.2	23.7	0.6	

Table 6. Description of on–going experimental plantings of exotic species of Swietenioideae that do not yet permit adequate assessment of performance. Mean annual increments (MAI) in height are provided for trees at approximately 5 years age (or nearest available measuring date). MAI for diameter at breast height (DBH) are those from the last measure available.

Experiment	Species	Type of planting	Planting date	Seed source	Planting density (sph)	Height		DBH		Survival (%)
						Age (yrs)	MAI (m)	Age (yrs)	MAI (cm)	
ATH120/2	*Chukrasia tabularis*	Underplanting – *Araucaria cunninghamii* planting (18 yrs)	02/1953	local – Atherton	946	4.8	1.0	–	–	high
ATH509/12	*C. tabularis*	Open planting – mixed species, ex rainforest site	03/1973	Batch 1	1111	4.5	0.8			92
HWD374/134	*Cedrela fissilis*	Underplanting – dry sclerophyll grassy open forest 20–30 m	12/1987	unknown	1111	1.8	1.9			
HWD374/267	*C. fissilis*	Underplanting – dry sclerophyll grassy open forest 20–30 m	12/1987	unknown	1111	1.8	1.1			
HWD374/343	*C. fissilis*	Underplanting – dry sclerophyll grassy open forest 20–30 m	12/1987	unknown	1111	1.8	2.6			
HWD374/60	*C. fissilis*	Underplanting – dry sclerophyll grassy open forest 20–30 m	12/1987	unknown	1111	1.8	1.8			
G1/9/2/1	*Cedrela lilloi*	Enrichment planting – moist rainforest	1952	Argentina	1400	11	1.0			100
G1/9.2.2	*C. lilloi*	Enrichment planting – moist rainforest	1957	Argentina	540	6	0.5			
G1/9.2.4	*C. lilloi*	Enrichment planting – dry rainforest	1958	Argentina	1040	5	1.1			
G1/9.2.6b	*C. lilloi*	Underplanting – *A. cunninghamii* ex dry rainforest site	1953	Argentina	100	10	0.4			
G1/9.2.10a	*C. lilloi*	Underplanting – *A. cunninghamii* ex moist rainforest site	1956	Argentina	430	7	0.7			
ATH166/7	*Khaya ivorensis*	Enrichment planting – logged and treated rainforest	05/1956	unknown	412	10.3	0.7	10.3	0.8	
ATH204/1/14	*K. ivorensis*	Open planting – mixed species, arboretum plots	02/1956	Gold Coast	1544	5.3	0.2	18.2	1.3	18
ATH204/2/1b	*K. ivorensis*	Open planting – mixed species, arboretum plots	02/1956	Gold Coast	1544	–		–	–	0
ATH509/5	*K. ivorensis*	Open planting – mixed species, ex rainforest site	03/1972	Ghana	1081	5.4	0.6	8.5	0.8	62
IMB372	*K. ivorensis*	Open planting	04/1956	Gold Coast	–					0
ATH726	*Cedrela augustifolia*	Open planting	02/1988	unknown		1.5	1.4			

Table 7. Description of terminated experimental plantings of exotic species of Swietenioideae. Mean annual increments (MAI) in height are provided for trees at approximately 5 years age (or nearest available measuring date). MAI for diameter at breast height (DBH) are those from the last measure available.

Experiment	Species	Type of planting	Planting date	Seed source	Planting density (sph)	Height		DBH		Survival (%)
						Age (yrs)	MAI (m)	Age (yrs)	MAI (cm)	
ATH691/3	*Entandrophragma utile*	Open planting – contour mounded, large mounds; ex open forest	02/1982	Gregbeu, Ivory Coast	833					
ATH691/2	*Khaya anthotheca*	Open planting – contour mounded, large mounds; ex open forest	02/1982	Sangoue, Ivory Coast	833	7.8	0.2			
ING459/8	*Swietenia mahagoni*	Open planting – ex dry sclerophyll forest site	01/1970	Unknown	1500	5.3	0.7			
ING536/3	*Swietenia macrophylla* × *mahagoni*	Open planting – ex wet sclerophyll forest site (large leaf)	05/1974	Puerto Rico	1111	3.3	1.1	14.8	1.3	
ING536/7	*S. macrophylla* × *mahagoni*	Open planting – ex wet sclerophyll forest site (medium leaf)	05/1974	Puerto Rico	1111	3.3	1.1	14.8	1.5	
ING536/5	*S. macrophylla* × *mahagoni*	Open planting – ex wet sclerophyll forest site (small leaf)	05/1974	Puerto Rico	1111	3.3	0.8			

locations were generally poorer, with MAI for height ranging from 0.2 m to 0.8 m over 4 years. Surprisingly, plantings on mine spoils at Weipa, North Queensland, produced some trees with height MAI of 1.5 m, despite poor soils and dry conditions.

The performance of open-grown trees often deteriorated over time, as trees developed a limby habit and poor form even as early as two to three years of age. Form-pruning of young trees and thinning of mature stems were of little benefit. *Cedrela odorata* showed a tendency to regenerate and coppice vigorously, and in open situations was susceptible to frost and wind-lodging.

Underplanting and enrichment plantings of *C. odorata* have resulted in MAIs of between 0.2 m and 0.7 m during the first few years. One comparison between open planting and underplanting beneath 30 year-old *Grevillea robusta* Cunn. Ex R. Br. produced height MAI after 11 years of 0.7 m (78% survival) and 0.4 m (11% survival) respectively (YMN1868 – details of each trial code are in Tables 5, 6 and 7). Good growth occurred only under more open conditions, either beneath an open forest with a canopy height of 20–30 m (HWD374, HWD375) or following planting at the same time as the companion crop (IMB302). Under these conditions, MAIs exceeding 1.5 m of height were achieved during the early years. Growth beneath a canopy does reduce the multiple branching to which the species is prone, but a heavy canopy cover may restrict growth and may cause high mortality. Some individuals performed better when located in more open positions beneath a canopy, or following thinning of the overhead cover.

Variability in the performance of trees from different seed sources have been noted though not always quantified. In 1986, trials on the coastal lowlands of North Queensland demonstrated variability in the performance of different provenances, including Coyote, Taulabe and Chamelecon in Honduras, and Matagalpa in Nicaragua. The Coyote provenance had the best MAI at 4.6 years of 2.7 m, compared with 2.1 m, 2.4 m, and 2.5 m for other provenances.

In general, *Cedrela odorata* received minor damage from *H. robusta* and in mixed plantings were less damaged and grew better than *T. ciliata*.

Khaya grandifoliola

This species has been planted in one trial on the Atherton Tableland and has performed well. At age 5.5 years, there was 94% survival and trees had a MAI of 1.4 m in height and 2 cm in diameter at breast height (DBH). These growth rates were at least twice those of *K. senegalensis*, *K. ivorensis* and *C. tabularis* at the same site. Despite these very promising results, no further plantings were trialed in the area.

Khaya nyasica

Khaya nyasica has grown well (> 1 m MAI for up to 20 years) in open plantings on frost-free sites in southern Queensland. This species was generally not attacked by *H. robusta* but has a strong tendency to develop multiple leaders and heavy branching while still young, requiring heavy and frequent pruning. Frost damage also increasing the tendency for branching. Some individual trees had better form, indicating potential for genetic selection.

Khaya senegalensis

This species grew best under the dry open forest conditions near Darwin and Weipa (Leggate 1974; Nicholson 1974; D. Riley, Department of Primary Industry and Fisheries, Northern Territory, pers. comm.), responded well to application of fertilisers, especially phosphorous and potassium, and low stocking rates, and was resistant to termite damage (Nicholson 1985). Unfortunately, *K. senegalensis* was prone to develop multiple leaders, heavy branching, and a crooked bole. The reasons for this poor habit are unknown, but site factors, including nutrient deficient soils, seasonality of rainfall and exposure to wind may have contributed. Early form-pruning at approximately 2 m was recommended to improve form (Nicholson 1985).

Khaya senegalensis did not grow well in enrichment plantings in north Queensland, and was generally considered a failure (Keys and Nicholson 1982). In enrichment plantings, mortality was invariably greater than 90% within ten years, and growth rates were poor. In open plantings, mortality was lower but form and/or growth rate were poor. Damage from *H. robusta* was reported at only one site in north Queensland, when trees were 7 years old and approximately 2.6 m high.

Swietenia macrophylla

Growth of *S. macrophylla* has been very variable in Australia. Most underplantings and enrichment plantings were not successful due to poor survival, growth and/or form. In some plantings, trees grew well, producing MAI in height of 0.9 m and 1.6 m during the first few years (ATH122, ATH451). Similarly, many open plantings resulted in high mortality and poor height growth. Among the more successful open plantings was a coastal site originally carrying wet sclerophyll forest (ING442) that produced height MAI of 1.2 m over 8.8 years. Steady growth continued to produce height and DBH MAIs of 1.0 m and 1.24 cm by 20.8 years (Cameron and Jermyn 1991). *Swietenia macrophylla* trees survived well in the hot, dry, conditions of Weipa (ATH399), resulting in trees with MAI of 1.7 m and 0.47 cm at 4.5 years for height and diameter respectively. Unfortunately, form was generally poor with problems including crown breaks at an early age, multiple leaders, heavy lateral branching, and crooked boles.

The success of some plantings in north Queensland led to the establishment of further trials investigating provenance differences (ATH559, ATH691). One trial demonstrated differences in survival and growth rates of young trees from two families from Puerto Rico. Overall, the results were disappointing, possibly due to site degradation following clearing and burning (Cameron and Jermyn 1991). A second trial (ATH691) used seed collected from Bolivia, but results have not been recorded.

Failure of most plantings was attributed to the combined effects of *H. robusta* feeding, cattle browsing and severe competition from grass. Trees were damaged by *H. robusta* in all trials, but damage levels were often low to negligible during the first few years of growth. When planted with *T. ciliata*, damage levels were lower on *S. macrophylla* than on *T. ciliata* and *S. macrophylla* showed better recovery following attack.

Species not adequately assessed (Table 6)

Cedrela augustifolia Sesse & Moc.

An open planting of *C. augustifolia* was established in North Queensland (ATH726). The area was badly affected by frost in the first year, resulting in 53% mortality. The surviving trees showed good growth, with mean height of 2.08 m after 1.5 years.

Cedrela lilloi C. DC.

Experimental plantings of *C. lilloi* were established in subtropical forests of New South Wales between 1952 and 1958 (Wyatt 1984). The species generally grew best in enrichment plantings with height MAI of up to 1.1 m for the first few years. Trees grew less well when under-planted to *Araucaria cunninghamii*.

Chukrasia tabularis

Chukrasia tabularis showed good survival (>90%) and early growth in plantings in North Queensland, achieving MAI in height of 0.8 m to 1.0 m in the first 5 years. However, tree form was poor with heavy branching as a result of repeated damage by *H. robusta*. This species merits further genetic resource trials since some individual trees grew well (Shea 1992).

Khaya ivorensis A. Chev.

The best growth of *K. ivorensis* occurred in an enrichment planting on logged and treated rainforest in North Queensland. After 10 years, MAI of 0.67 m for height and 0.75 cm for DBH were recorded (ATH166). Under these conditions, *K. ivorensis* outperformed *K. senegalensis* and *S. macrophylla*. Open plantings have been less successful, due to high mortality, slow growth and poor form caused in part by frost damage.

Swietenia mahagoni (L.) Jacq.

The growth rate and form of this species was poorer than that of *S. macrophylla*. Damage from *H. robusta* was not recorded.

Species in terminated trials (Table 7)

Entandrophragma utile (Dawe & Sprague) Sprague

An open planting of *E. utile* was established in north Queensland in 1982; however, results of this trial have not been reported.

Khaya anthotheca (Welw.) C. DC.

A single trial of *K. anthotheca* was established in 1982 as an open planting on a silty clay loam cleared of open forest in north Queensland. Very poor survival and growth was reported after 8 years.

Swietenia macrophylla × *mahagoni*

Swietenia macrophylla × *S. mahagoni* hybrids have been planted in North Queensland (ING536). Hybrid trees grew at comparable rates to *S. macrophylla* achieving MAI of 1.1 m in height and 1.4 cm in DBH and after 14 years (Cameron and Jermyn 1991). Despite showing good early growth, the hybrid has not been planted since the early 1970s.

Cedrela microcarpa C. DC.

A single planting of this species near Imbil in south-east Queensland was a failure but the reason for failure was not recorded.

Hypsipyla Research in Australia

Many areas of *H. robusta* biology and control have received some attention in Australia (Table 8).

Table 8. Summary of current and past research effort on various aspects of *Hypsipyla robusta* biology and control. o – none; * minor; ** major.

Area of study	Current research	Past research
Biology		
Taxonomy	*	o
Life history	**	*
Ecology in natural stands	*	*
Ecology in plantations	*	*
Population dynamics	*	*
Natural enemies	*	*
Other	o	o
Control		
Biological control	o	o
Chemical control	o	*
Silvicultural control	*	**
Host resistance	*	o
Pheromones	*	o
Genetic engineering	o	o
Other	o	o

Biology

There have been few attempts to investigate directly the biology, ecology or taxonomy of *H. robusta* in Australia. This is despite the recognition of the critical role of the species in limiting the commercial planting of *T. ciliata*. Early biological observations were made by Froggatt (1923, 1927) and staff of the Queensland and New South Wales forestry services, much of which is contained in unpublished reports. More recent work has been undertaken by Griffiths (1997) and Mo (1996). These studies confirmed that the shoots, fruits and the flowers of *T. ciliata* and the fruit of the closely related *Xylocarpus* mangrove species are fed upon by *H. robusta* in Australia. Infestation of young *T. ciliata* trees was positively correlated with rainfall and, to a lesser extent, temperature. Infestations were concentrated on open-grown trees, trees greater than 1.5 m high, and shoots in the upper canopy. The percentage of shoots attacked per tree decreased as tree size increased.

More than 75% of eggs were laid on leaves. When ovipositing on young trees, *H. robusta* preferred the upper leaf surface to the lower leaf surface, and was least inclined to choose the stem and petiole. When laid on fruits, eggs were often deposited among or close to the frass and borings of previous damage. Losses of both eggs and early instar larvae were high on young *T. ciliata* trees. Initial feeding was concentrated in the terminal foliage with larvae wandering extensively before and in the few days following their first feeding. Feeding bioassays confirmed the existence of feeding stimulants in the ethanol extracts of young shoots.

The number of larval instars ranged from five to seven under laboratory conditions. This developmental polymorphism is also likely to be a characteristic of natural populations. Success of matings was increased by exposure to light and wind. Observations on the patterns of female calling, mating and flight activity indicated that mated females are responsible for host finding.

There are considerable differences in the biology and behaviour of the species in Australia when compared with other regions. For example, Australia and northern India share a similar climate and have the same species of host trees, however, Australian populations lack a distinct sequence of larval generations feeding on different plant parts, have a very low incidence of flower feeding, and have other behavioural and physiological differences in larvae feeding on fruit. These differences call into question the assumption that *H. robusta* is one species.

Biological control

Although there has been some reference to the possibility of obtaining control of *H. robusta* in Australia through utilising natural enemies (Jolly 1914; Queensland Forest Service 1921; K.G. Campbell, formerly of the Forestry Commission of New South Wales, pers. comm.) this possibility has never been addressed. A number of reports have identified insect parasitoids and insect, bird and mammal predators associated with *H. robusta* in Australia (Queensland Forest Service 1921; Girault 1938; Campbell pers. comm.). However, most of these are generalist species and offer little potential as biological control agents (Sands and Murphy these Proceedings).

Chemical control

Chemical control of *H. robusta* has been investigated in Australia since the early 1920s with the initiation of at least 13 insecticide trials utilising 12 different compounds. Most trials failed or were terminated after only one season. The insect has proved difficult to control due to its concealed feeding habit, long period of activity, the tropical climate in which it occurs, low damage threshold of the host, and long protection period required. Many trials have been hampered by logistical problems including a lack of moth attack, severe damage from other insects, equipment failure, and loss of trees to frost, cyclones and hormone spray. In addition, the scheduled spray regimes were frequently disrupted by rain and flooding.

Contact poisons such as DDT and endrin provided reasonable to good control in some trials. However, the required frequency of application, particularly in the tropical north where the period of heaviest infestation coincided with the wet season, rendered their use economically and environmentally unfeasible. Some systemic compounds (e.g. monocrotophos and azinphos methyl) provided limited control but were generally ineffective. For further details refer to Wylie (these Proceedings).

Silvicultural control

Concern regarding the unregulated exploitation of *T. ciliata* in natural forests led to attempts to grow the species in plantations. Most trials have been small scale (less than 0.5 ha), unreplicated, carried out on variable sites, and include treatments that vary during the course of the experiment. In addition, the interval between observations was often long, and records of damage were not consistent. Shoot damage from *H. robusta* represents the major but not the only limitation to growth of *T. ciliata*. Trees were also damaged by the elephant beetle, *Xylotrupes gideon* (Linnaeus) (Coleoptera: Scarabaeidae), especially in northern Queensland and are occasionally seriously defoliated by *Pingasa chlora* (Stoll) (Lepidoptera: Geometridae). The species is very susceptible to frost and generally does poorly in the presence of heavy weed growth. However, it is the high incidence and severity of damage from *H. robusta* that has largely precluded commercial growing of *T. ciliata*.

Natural regeneration

Early observations revealed that *T. ciliata* regenerates rapidly in gaps and clearings that occur naturally in the forest or created during logging operations. Trials encouraging natural regeneration demonstrated that seedling survival rather than seed production or germination was the critical stage in early establishment of *T. ciliata*. Trees require good soils, adequate moisture and ample overhead light, to achieve highest rates of establishment and growth. Growth was fastest in areas receiving both overhead and lateral light following brushing of the undergrowth and opening of the canopy. Heavy thinning of the canopy can lead to higher mortality due to desiccation, mammal browsing, frost, fire and competition from regrowth species.

The timing of silvicultural treatment is critical to the success of natural regeneration. Establishment is likely to be optimised under quite intensive site preparation in two main stages. Firstly, the canopy needs to be opened up well in advance of seed spotting or seed fall to avoid smothering of young plants by falling debris from recently treated overstorey (ATH115). Secondly, brushing and treatment of undergrowth are necessary as soon as possible before seed fall or seed sowing to allow seedlings to establish in advance of the regrowth.

Enrichment plantings

Toona ciliata grew well in enrichment plantings (Haley 1954; Keys and Nicholson 1982; Queensland Department of Forestry 1983a). Planting into relatively small gaps or along cleared lines with lateral shade provided some protection from *H. robusta* damage during early growth. The gaps must be sufficiently large to remain open during the early growth of the tree, but not so large that they increase susceptibility to damage from *H. robusta* or allow proliferation of weeds and regrowth species which may smother young trees. Cleared plots may also be susceptible to falling debris from thinning operations and plantings are likely to require continued canopy management throughout their life.

The high costs associated with enrichment techniques have limited their adoption as general management practice in Australia (Nicholson et al. 1983; Queensland Department of Forestry 1983b). Silvicultural operations opening up the overstory to encourage growth of *T. ciliata* are not only expensive but also risky to the under-plant trees which may be damaged during thinning.

Growth in existing plantations

A number of plantings were established to assess the growth of *T. ciliata* within existing plantations as an interplanted or underplanted species or through natural regeneration.

Cover or companion species assessed were:

- *Araucaria cunninghamii* Aiton ex D. Don
  Hoop Pine
- *Grevillea robusta* Cunn. ex R. Br.
  Southern Silky Oak
- *Flindersia brayleyana* F. Muell.
  Queensland Maple
- *Agathis robusta* (C. Moore ex F. Muell.) Bailey
  Kauri Pine
- *Cedrela odorata* L.
  Spanish Cedar
- *Paraserianthes falcataria* (L.)
- *Eucalyptus grandis* Hill ex Maiden
  Flooded Gum
- *Eucalyptus pellita* F. Muell.
  Red Mahogany
- *Eucalyptus saligna* Smith
  Sydney Blue Gum
- *Zea mays* L.
  Maize

Some trials demonstrated that *T. ciliata* performed better when grown beneath a canopy; either levels of *H. robusta* damage were reduced under cover, or the growth response and resultant form of the tree was improved. An overhead canopy also provided protection from frost and hail at some sites. *Hypsipyla robusta* damage was never prevented in any trials and in most sites, trees were damaged within a few years of planting.

The success or otherwise of the various plantings depended on the cover crop species. Tree species with a very dense canopy, e.g. *A. cunninghamii,* failed to allow adequate light to reach *T. ciliata* under-plants, and thus growth was poor. This problem was less severe with more sparsely-crowned species such as *G. robusta, F. brayleyana* and *A. robusta*. Initial growth was generally better, although this often slowed considerably after a few years if no further thinning was carried out. Under a less dense canopy, damage from *H. robusta* was more of a problem. In many trials the density of the overstory of any particular species had little or no effect on tree performance or damage intensity.

Flindersia brayleyana

Toona ciliata grew well under *F. brayleyana* and a mixed stand of the two species was obtained. The technique was not ideal silviculturally because it requires thinning of potentially valuable but currently unmerchantable *F. brayleyana* stems.

Grevillea robusta

The growth of *T. ciliata* under *G. robusta* was highly variable, but often good, particularly under younger *G. robusta* aged 0 to 2 years at the time of planting of *T. ciliata*. Some of these plantings provide the most promising results from underplant trials.

Araucaria cunninghamii

Araucaria cunninghamii has been the most widely tested of the companion species, but has been unsuccessful. Attempts to establish *T. ciliata* under *A. cunninghamii* by planting or through fostering natural regeneration generally failed. *Araucaria cunninghamii* quickly formed a closed canopy, which did not allow adequate light to reach the *T. ciliata* trees. Growth was either suppressed from an early age or trees grew to the nearest canopy gap, resulting in bent and useless stems. The canopy required heavy thinning and the creation of large gaps to allow establishment of underplants. The heavy canopy generally failed to prevent damage from *H. robusta*. When damage was absent, it was probably due to the very poor growth or condition of the plants.

Agathis robusta

Agathis robusta has a much sparser crown than *A. cunninghamii*, allowing better survival and growth of underplants. Under this lighter canopy *T. ciliata* was heavily damaged by *H. robusta* and developed poor form. Initial growth was good under *A. robusta* aged six years but later slowed. Natural regeneration under a planting of *A. robusta* resulted in some useful trees with minimal management, offering potential for further investigation.

Other species

Plantings in New South Wales beneath *E. saligna and E grandis* had some success; however, insufficient information was available to fully assess their potential as cover species. Plantings beneath *E. pellita*, *P. falcataria* and *Z. mays* were unsuccessful. In mixed plantings with *C. odorata, T. ciliata* was consistently the poorer of the two species with respect to height and incidence of *H. robusta* damage.

Open plantings

Open plantings of *T. ciliata* were generally susceptible to damage from *H. robusta*, desiccation, flooding, frost, weed competition and mammal browsing. Despite these problems, a number of open plantings have performed well in the long term and have produced merchantable trees. The establishment phase of these more successful plantings was poorly documented and trees may have received protection in the early stages of growth, either from an interplanted species which subsequently failed, surrounding forest, or the addition of a fast-growing underplant species shortly after establishment.

Improving early growth rates

Toona ciliata grows rapidly under optimal conditions. The choice of good sites, manipulation of the overhead canopy, and use of fertilisers and artificial shelters can improve establishment and further encourage early growth. Such techniques reduce the duration for which trees are exposed to *H. robusta* attack before achieving a straight bole of merchantable length.

A series of fertiliser trials in New South Wales in the late 1950s and early 1960s assessed the impact of nitrogen, phosphorus and potassium on growth of *T. ciliata* and on susceptibility of trees to *H. robusta* (Forestry Commission of New South Wales 1959, 1961). Trees responded well to application of potassium. The increase in tree vigour did not influence the incidence of *H. robusta* damage (Campbell 1966).

The use of artificial growth shelters, comprising UV stabilised polyethylene tubing (Growtubes™) increased growth rates up to five times that of unprotected trees (Applegate and Bragg 1989). Such growth rates were maintained in Growtubes up to 3 m high but the resultant trees were very slender and required continued support after their emergence from the Growtube. By protecting against exposure, stock, browsing animals, herbicide drift, and weed growth, Growtubes could reduce maintenance costs which would offset the high establishment costs.

Growth in areas remote from Toona ciliata

Several plantings of *T. ciliata* have been trialed in sites a long way from existing stands of *T. ciliata* in the hope that isolation will protect them from *H. robusta*. Some of these, most notably those on Norfolk Island (N. Taverner, Administration of Norfolk Island) and around Darwin, Northern Territory (D. Riley, Department of Primary Industries and Fisheries, Northern Territory, pers. comm.), have produced trees of good growth rate and form, which have remained undamaged by *H. robusta* many years after planting. The success of such plantings depends on the careful choice of sites, ensuring isolation from all *H. robusta* hosts, and taking into consideration the soil preferences, moisture requirements and frost susceptibility of the trees. Trees planted on unsuitable sites trees perform poorly regardless of the incidence of *H. robusta*. Successful site selection requires an adequate understanding of the flight capacity and host location ability of *H. robusta* adults.

Host resistance

The existence of naturally-resistant strains or individuals of *T. ciliata* in Australia has been frequently alluded to but little investigated (FAO 1958; Campbell 1966; Entwistle 1967). The species shows great phenotypic variability under natural conditions with variation in the degree of pubescence, growth rates, form, degree of deciduousness, level of anthocyanin in young leaves, and temperature tolerance (Herwitz 1993; Griffiths 1997) Some of these traits are likely to be heritable and have potential to influence damage levels, therefore offering the potential to breed for resistance. Recent trials in southeast Queensland found differences in the level of oviposition by *H. robusta* when comparing *T. ciliata* trees from different regions of Australia planted at a single site (Griffiths 1997). Trees from the most northern collection site (Iron Range: 12°43′S 143°18′E) consistently received fewer eggs than trees from five more southerly collection sites, although the success of early instar feeding did not differ between provenances.

A series of trials undertaken in the 1950s aimed to determine appropriate propagation techniques for *T. ciliata* in the event that a resistant strain was located (Sub-Department of Forestry 1956). Although some success was achieved with both cutting and grafting techniques, the potential of such methods for propagation of resistant trees was never tested. In the majority of experiments, resistance to *H. robusta* was not a criterion for selection of the parent trees. Most experiments were terminated prior to planting out.

Current Researchers

Dr Tom Bellas (CSIRO Entomology) has conducted much work investigating the pheromone blends of numerous insect species in Australia. Tom has undertaken a preliminary analysis of the chemical components present in volatiles collected from female *H. robusta.*

Dr Rob Floyd (CSIRO Entomology) is project leader for the Australian Centre for International Agricultural Research (ACIAR) funded project to review the ecology and control of *H. robusta* in Asia and the Pacific (these Proceedings). His specific research interests are in the areas of host-plant resistance and forest pest management.

Dr Manon Griffiths (CSIRO Entomology) completed her Ph.D. studies addressing aspects of the biology and host relations of *H. robusta* in Australia. Her study highlighted differences in the biology of *H. robusta* in Australia to that described from other countries, confirms the host range of the species in Australia, and investigates interspecific variability in host use. Dr Griffiths contribution to these Proceedings has been funded by ACIAR project FST/95/103.

Dr Marianne Horak (CSIRO Entomology) is a leading taxonomist of the Pyralidae, and is currently undertaking preliminary taxonomic analysis of *H. robusta* in Australia.

Dr Jianhu Mo (Department of Forestry, Australian National University) completed his Ph.D. on the ecology and behaviour of *H. robusta*. Dr Mo investigated temporal and spatial patterns of infestation, temperature-dependant development, feeding behaviour of larvae, reproductive activities and host selection behaviour.

Dr Don Sands (CSIRO Entomology) is assisting in the ACIAR project FST/95/103 to review the ecology and control of *H. robusta* in Asia and the Pacific. He has significant expertise in the biological control of insect pests which he is interested in applying to *Hypsipyla*.

Mr David Spolc (University of Queensland) is currently studying for his Ph.D. by modelling the impact of *H. robusta* damage on form and size of *T. ciliata*. David's work uses a virtual plant modelling system developed at the University of Calgary in Canada and CSIRO Entomology in Australia. The graphical form of the model allows viewers to view the possible responses to pest attack and management practises.

Dr Ross Wylie (Queensland Forestry Research Institute) is assisting in the leadership and direction of the ACIAR project FST/95/103 reviewing the ecology and control of *H. robusta* in Asia and the Pacific. Ross has extensive expertise in the management of forest insect pests, which he is keen to apply to the control of *Hypsipyla*.

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The Forest Resource of Ghana and Research on *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) Control in Mahogany Plantations in Ghana

S.K.N. Atuahene[1]

Abstract

The forestry sector is a major contributor to the national economy of Ghana, employing some 75 000 people and contributing between 6% and 8% of the Gross Domestic Product. Over-exploitation of the timber resource, particularly from the unreserved forests, has led to severe depletion of the highly desirable, traditional mainstays of the Ghanaian timber trade such as *Pericopsis elata* (Harms) van Meeuwan ('Aformosia'*),* *Milicia* spp. ('Odum' or 'Iroko') and the Meliaceae. Previous management policy promoted the sustained supply of forest produce for the timber industry. There are currently 50 000 ha of plantations in Ghana, of which nearly 90% are exotic species, mainly *Tectona grandis* L., *Cedrela odorata* L. and *Gmelina arborea* Roxb. Attempts by the Forestry Department to establish indigenous tree species in open plantations have failed for several reasons, including poor tending operations, poor seed sources, fire, and pests and diseases. Overall success rates in all plantations were poor, ranging from 20–58%, but were particularly so among native Meliaceae, of which only 9% survived, largely as a result of damage by the shoot borer *Hypsipyla robusta* (Moore). With a projected increase in demand for wood and increasing interest in plantation development among individuals and private companies, there is an urgent need for an effective method of control of *H. robusta*. This paper outlines past and current research on *H. robusta* in Ghana, and discusses future research strategies that could help to reduce shoot borer impact on plantations of native Meliaceae in Ghana and the rest of West Africa.

THE HIGH forest of Ghana is located in the south and southwest of the country and covers an area of 82 580 km^2 or 34% of the total land area (Hawthorne 1995). Some 16 340 km^2 of the forest estate has been demarcated as reserves managed by the Forestry Department. Of this area, 7600 km^2 are said to be reasonably well stocked, and have been set aside for timber production. The rest of the reserved forests are either permanent protection areas (3500 km^2) or conversion areas (1220 km^2) where the forest is degraded but could be rehabilitated through natural regeneration and protection over one felling cycle (about 40 years). The remaining reserve area is so degraded that it requires replanting (Aninakwa 1996).

The unreserved forest has been declining at about 750 km^2 per year since the turn of the century. This deforestation has resulted from conversion to agriculture, logging and fuelwood gathering, mining, infrastructure development, and fires (World Bank 1988).

Importance of the Forestry Industry in Ghana

West Africa is home to some of the most valuable timber species in the world. The export trade in timber began in 1891 and initially focussed on the Meliaceae (Taylor 1960). The Meliaceae species of greatest economic importance in Ghana today are species of *Khaya* and *Entandrophragma*, although *Lovoa* species are also harvested (Table 1). Timber from native Meliaceae is extracted from the natural forests.

The forestry sector employs 75 000 people and provides a livelihood to some 2 million people. The sector contributes between 6% and 8% of Ghana's

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Gross Domestic Product, a contribution exceeded only by cocoa and gold. In 1994, exports of forest products amounted to US$244 million or about 18% of total export earnings of that year. Native Meliaceae contributed substantially to these as over 34 000 m^3 of wood, valued at approximately US$20 million were exported, mainly as sawn lumber or sliced veneer, plywood and furniture parts (Table 1).

Like most sub-Saharan countries, Ghana consumes more wood internally than is exported (Forest Products Inspection Bureau 1995). The major domestic markets for timber are the construction industry and fuelwood; thus economic and population growth are key factors leading to increased domestic consumption of wood. Real economic growth rates are currently 3.8% per year and population growth rate is 3.3%. It is estimated that at 3.5% economic growth, future levels of domestic demand of wood would rise from around 0.7 million m^3 in 1995 to nearly 1.0 million m^3 in 2005 (UK Forestry Commission 1995).

Although the annual allowable cut of timber set by the Ghana Forestry Department is 1.0 million m^3, since 1989 the forest has been consistently over cut, with between 1.2 and 2.0 million m^3 harvested per year. As a result, supply of many of the highly desirable, traditional mainstays of the Ghanaian timber trade, such as *Pericopsis elata* (Harms) van Meeuwan ('Aformosia') *Milicia* spp. ('Odum' or 'Iroko') and the Meliaceae, are severely limited (Ghartey 1989).

Internationally, demand for African mahogany is likely to increase as supplies of hardwoods from Southeast Asia and Brazil decline (Elliot and Pleydell 1992). However, supply from natural forests is limited; at current rates of extraction, the resource is likely to be exhausted within 20 years (Alder 1989). The Government has recently taken legal measures to restrict the exploitation and depletion of the off-reserve forests, which will further restrict supply and export revenue.

Forest Plantations in Ghana

As the forest reserves alone are inadequate to sustain a viable timber industry and meet the growing domestic demand for timber, the FAO proposed for Ghana a national forest plantation estate of 59 000 km^2 commencing with the planting of 50 km^2 in 1968 (FAO/UNEP 1981). This figure was later revised downward by a national land use planning committee which targeted an estate of 1000 km^2 to be established over a 10-year period from 1970/71 (Nsenkyire 1992). A plantation program involving indigenous hardwood species including the Meliaceae was widely undertaken in eastern and western regions of Ghana. The annual target was set at 65 km^2 and limited to the forest reserves where the stocking of current valuable species was poor.

Native Meliaceae that have been planted in Ghana include the native species *Entandrophragma utile* (Dawe and Sprague) Sprague, *E. cylindricum* (Sprague), *E. angolense* (Welw.), DC, *K. ivorensis* A. Chev., *K. anthotheca* (Wehu) C.DC, and *K. grandifoliola* C.DC (Table 2). Most native Meliaceae were established in the forest reserves by enrichment planting in previously logged forests or in 'Taungya' systems (Osafo 1970).

Cedrela odorata L. and *Swietenia* spp. from Latin America have also been planted. *Swietenia macrophylla* King and *S. humilis* ZUCC. were planted in experimental pure stands at Pra-Anum Forest Reserve between 1961 and 1967 from seeds obtained from Costa Rica. The oldest *C. odorata* plantation was established at Dunkwa in the Central Region in 1922. Since then, there have been other plantations at Offin Headwaters and Pra-Anum Forest Reserves. *Cedrela odorata* has been planted largely as pure stands, although it has sometimes been included in mixed species plantation established in the Taungya systems (Quaynor 1971).

Enrichment planting was found to be costly to manage and frequently produced poor growth due to

Table 1. Volume and value of native species of the subfamily Swietenioideae of family Meliaceae exported in 1994 and 1995 (Forest Products Inspection Bureau, Takoradi 1996).

Species	Volume m^3		Value (US$)	
	1994	1995	1994	1995
Khaya spp.	17 130	12 753	9 146 969	6 000 407
Entandrophragma utile (Dawe & Sprague) Sprague	6 966	2 855	5 465 827	1 998 354
E. candollei (Harms)	429	470	198 870	213 128
E. cylindricum (Sprague)	4 065	2 877	2 441 543	1 614 440
E. angolense (Welw.) DC	5 186	3 819	2 510 157	1 658 984
Lovoa trichiliodes (Harms)	801	639	399 636	297 101

Table 2. Native and exotic tree species of Meliaceae subfamily Swieteniodeae planted in Ghana (Forest Products Research Institute, Ghana, Annual Reports 1969–1979).

Tree species	Origin	Present area planted (ha)	Present planting rate (ha/Year)	Optimal rotation length (yrs)
K. ivorensis A. Chev.	Native	2400	Planting ceased in forest reserves	Not known
E. utile (Dawe & Sprague) Sprague	Native	2400	Planting ceased in forest reserves	Not known
E. cylindricum (Sprague)	Native	2400	Planting ceased in forest reserves	Not known
E. angolense (Welw.) DC	Native	2400	Planting ceased in forest reserves	Not known
Cedrela odorata L.	Introduced	7900	50	About 40 yrs
Swietenia humilis Zucc.	Introduced	0	Planting ceased	n/a
S. macrophylla King	Introduced	0	Planting ceased	n/a

excessive shade, while the Taungya system restricted the farmers' choice of crops and gave the farmers no stake in the trees, as a result of which tending operations were not well executed. Other reasons for plantation failures include fire, poor seed sources, poor species-site matching, inappropriate choice of species, and pests and diseases.

The main plantation species that have been grown with some success are exotics such as *Tectona grandis* L., *C. odorata* and *Gmelina arborea* Roxb. (Table 3). Overall establishment success of all species was generally poor, however they were particularly so for native Meliaceae, of which only 9 per cent survived.

Table 3. Principal tree species in plantations and survival rate in Ghana (Forestry Department, Planning Branch 1992).

Tree species	Area planted (ha)	Survival (%)
Tectona grandis L.	25 800	34
Cedrela odorata L.	7 900	39
Gmelina arborea Roxb.	6 500	58
Mansonia ultissima A. Chev.	3 000	22
Native *Meliaceae*	2 400	9
Triplochiton scleroxylon K. Schum	100	20
Terminalia ivorensis A. Chev.	150	27
Eucalyptus spp.	2 000	n/a

Although the poor establishment of all species in Ghana was largely due to fire, the particularly high failure-rate of plantations of native Meliaceae has been attributed to shoot borer attack (Ofosu-Asiedu, et al. 1991). Shoot borer also resulted in slow growth and poor form (Britwum 1976). Similarly, planting of the exotic *Swietenia* spp. has been discontinued due to poor fire tolerance and serious shoot borer attack: the trials invariably failed through die-back resulting from shoot borer attack and fire (Ofosu-Asiedu, et al. 1991).

Roberts (1966) lists native and exotic Meliaceae that are susceptible to *H. robusta* in West Africa. The only member of the sub-family Swieteniodeae of which there is no record of attack by the shoot borer in Ghana is the exotic *C. odorata*, which is one of the most successful plantation species (Table 3). In Ghana, *C. odorata* is a fast growing tree and at Pra-Anum, which is in the moist semi-deciduous forest zone with an annual rainfall of 1200–1800 mm, sample plots in a 20-year old plantation had an average height of 39.9 m (Nkansa-Kyere 1974). No pests or diseases of importance have ever been reported on *C. odorata* although the plant is susceptible to attack by ambrosia beetle *Doliopygus condradti* Strohm. (Platypodidae), especially during long, dry periods (Wagner et al. 1991).

Recently, the Forestry Department has recognised the increasing interest of individual farmers and community associations in plantation establishment and is promoting woodlot establishment on private land and farms through the Collaborative Forest Management Unit. In addition, several private companies have embarked on large-scale, commercial planting of exotic species outside the Forest Reserve. However, efforts by foresters to plant indigenous Meliaceae and *Swietenia* species in the various countries of West Africa have been frustrated by *H. robusta* damage and there are currently no plans by the Forestry Department to plant these species in plantations (Table 2). Only one company, the Swiss Lumber Company in the southwest region, has recently invested in planting indigenous Meliaceae.

Hypsipyla Research in Ghana

The research into *H. robusta* in Ghana is summarised in Table 4. The Forestry Research Institute of Ghana (FORIG) have successfully reared *H. robusta* on an artificial diet and described the stages of the life cycle (Atuahene and Souto 1983). The medium used was the McMorran Grisdale Diet (MGD) generously supplied by Prof. G.I. Gara of the College of Forest Resources, University of Washington, USA. The results revealed differences in the life cycle of *H. robusta* from those reported in Nigeria (Roberts 1966) and Ivory Coast (Couillard and Guiol 1980).

A number of parasitoids have been bred in the laboratory from field-collected insects (Atuahene and Souto 1983). Parasitoids collected from *Hypsipyla* spp. in West Africa include Braconids, Eulophids, and Tachinids among others (Roberts 1966, Atuahene and Souto 1983). A parasitic nematode, probably *Hexamermis* sp., is also common in Ghana. The specific names of most of these parasites have not been determined, and their effects on the pest population are yet to be studied.

Table 4. Summary of current and past research effort on various aspects of *Hypsipyla* spp. biology and control.
– none; * minor; ** major.

Area of study	Current research	Historical research
Biology		
Taxonomy	–	–
Life history	*	**
Ecology in natural stands	*	–
Ecology in plantations	*	–
Population dynamics	–	–
Natural enemies	*	*
Other		
Control		
Biological control	**	*
Chemical control	–	–
Silvicultural control	**	*
Provenance trials	*	–
Pheromone studies	–	*
Genetic engineering	–	–
Other		

In the context of developing strategies for integrated pest management of *H. robusta* in Ghana, FORIG has collaborated with the Dept. of Zoology, University of Oxford on the potential use of insect pathogenic viruses to control mahogany shoot borers (Hauxwell 1997). Larvae were collected from the shoots of *K. ivorensis* in FORIG's research nursery at Mesewam in the moist, semi-deciduous forest zone, and from a 5-year-old plantation at the Swiss Lumber Company in Manso Amenfi in the south western moist evergreen forest zone. Larvae were reared on modified tobacco hornworm diet, a general-purpose diet for lepidoptera, emerging adults were preserved for species identification and dead larvae were preserved by freezing and subsequent examination for baculoviruses (Hauxwell 1997).

Research Requirements

In studies involving the use of artificial diets we have observed high incidence of insect mortality (10–70%) among young instar larvae due to non-feeding, a high incidence of infertile eggs, and low pupal widths and weights (Atuahene and Souto 1983). Future research must look into perfecting a diet for rearing *H. robusta*.

The taxonomy of *H. robusta* is still not fully understood in West Africa. Entwistle (1968) states that *H. robusta* probably comprises several races and subspecies. Recent collections from Ashanti and Western Regions of Ghana (Opuni Frimpong and Atuahene, unpublished data) confirmed that the taxonomy of *Hypsipyla* requires further investigation.

While a few natural enemies have been collected, most have not been sufficiently described and their effect on the *H. robusta* population is not known. The occurrence, impact and possible manipulation of natural enemies should be further investigated.

Brunck and Mallet (1993) emphasised the need to bring the experience gained in Latin America and Europe together with work in West Africa, particularly on the selection of resistant or tolerant stock. Recent work in Latin America has identified partial resistance to *H. grandella* within *S. macrophylla* and *C. odorata* (Newton et al. 1993). Although no work has been conducted on resistance in the Meliaceae in Ghana, experience of similar research in other systems support the use of such an approach. Cobbinah (1990) has demonstrated that considerable variability exists in intensity of infestation of seedlings of *Milicia* spp. by the noxious psyllid, *Phytolyma lata* (Walker), thus presenting an opportunity for control of the psyllid.

Conservation of the germplasm of West African Meliaceae is urgently required before the loss of the natural forests further depletes genetic diversity. FORIG, in collaboration with the Ghana Forestry Department Planning Branch, the Institute of Terrestrial Ecology and Edinburgh University in the UK, have proposed the development of an integrated pest management strategy. The proposed strategy is based on the incorporation of pest resistant planting stock in silvicultural systems to reduce *H. robusta* impact (Atuahene et al. 1996). This proposal was submitted to the International Tropical Timber Organisation (ITTO).

Conclusion

Since plant resistance or any other method alone is unlikely to reduce the impact of *Hypsipyla* spp. to less than economic levels, an integrated pest management strategy is recommended (Newton et al. 1993). In order to implement and effective integrated programme of *H. robusta* management in West Africa we need to build the capacity to research the critical issues of its biology. Research efforts should then:

- describe the relationship of *H. robusta* populations with the host plants;
- identify if there is variation in susceptibility of West African Meliaceae;
- determine if there is a genetic and biochemical basis for susceptibility or resistance;
- test silvicultural systems such as the use of tree mixtures as an effective strategy in managing the insect;
- acquire better knowledge of the efficacy of natural enemies and determine their potential use in biological control.

To provide funds for all these is a considerable undertaking. I wish, therefore, to recommend the assistance of international organisations and institutions such as the ITTO, the Department of International Development (DFID) and others in providing the necessary funds for forestry research in West Africa and hope for their continued support.

Acknowledgments

The author would like to thank DFID for funding which has allowed the author to attend this workshop. The author would like to acknowledge the work of Mr Emmanuel Opuni-Frimpong, FORIG, in rearing and collection of *H. robusta*. The author would also like to thank Dr Caroline Hauxwell and D. Martin Speight of the Department of Zoology, University of Oxford for permission to reproduce unpublished results and reports from the DFID Forestry Research Program project R6055.

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A Review of *Hypsipyla grandella* Zeller Research in Pará State, Brazil

M.M. Maués[1]

Abstract

The shoot borer *Hypsipyla grandella* Zeller is the most important pest of the forest trees of the Meliaceae family (*Swietenia macrophylla* King, *Cedrela odorata* L. and *Carapa guianensis* Aubl.) in Pará State, Brazil. Despite the economic importance of these species and interest being shown by the timber industry in establishing plantations of *S. macrophylla*, little attention has been given to attempting to solve this problem. Two approaches to diminish the occurrence of attack have been investigated: firstly, to control the insect by the use of light traps; secondly, to use line planting and planting in species mixtures. The light trap proved ineffective even in small-scale plantations. The silvicultural methods reduced the level of attack but did not completely eliminate damage from *H. grandella.* No large-scale trials have been established. Due to the importance of these timbers in the local economy and in the international market, systematic research on *H. grandella* in the Amazon region is recommended as a priority.

TIMBER products are the fourth most important source of export earnings in Pará State, Brazil. The most commercially important species of Meliaceae of the sub-family Swietenioideae are *Swietenia macrophylla* King (Mogno or 'big leaf' mahogany), *Cedrela odorata* L. (Cedro or Cedar) and *Carapa guianensis* Aubl. (Andiroba or Crabwood). These are exported in significant volumes from the state (Carvalho 1994a, b) (Figure 1) but are produced by selective logging from native forest at a rate that is considered unsustainable.

Native species of Swietenioideae have been planted by enrichment of forests, in mixed species plantations and in agroforestry. Areas planted for each species are given in Table 1, with *S. macrophylla* being the most extensively planted. The greatest limitations to planting of these species are: damage caused by *Hypsipyla grandella* Zeller, competition for light in enrichment plantings, nutrient deficiencies and poor genetic makeup of the planting stock (Lyhr 1992). In addition, *Khaya ivorensis* A. Chev. from west Africa and *Toona cilliata* Roem from Asia have been introduced on an experimental scale**.**

Species of the genus *Hypsipyla* are found throughout the Americas (Berti Filho 1973; Newton et al. 1993). In Pará State, *H. grandella* is the most important pest of Meliaceae, attacking growing shoots of *S. macrophylla*, *C. odorata* and *C. guianensis*. *Hypsipyla ferrealis* only attacks the fruit of *C. guianensis* (Newton et al. 1993). There is no published information about *H. grandella* attack on *T. ciliata* in Pará State, despite an experiment that is being conducted in order to evaluate the 'preference' of *H. grandella* attack in a mixed 1:1 *T. ciliata* and *S. macrophylla* plantation. In an experimental *K. ivorensis* plantation in eastern Amazon, there was no damage caused by *H. grandella*, but there was severe damage by *Trigona* sp. causing either abnormal sprouting or atrophy of the stem (Falesi and Baena 1999).

Control of *H. grandella* investigated in the Brazilian Amazon

In Brazil, despite the economic importance of the Swietenioideae and the interest shown by the timber

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industry in planting *S. macrophylla*, little attention has been directed at the problem of attack by *H. grandella*. Berti Filho (1973) determined methods for the laboratory production of *H. grandella* using artificial and natural diets and studied its life cycle as a first step in the search for biological or chemical control methods. The research that has been conducted on control has followed two approaches (Table 2); firstly control of the insect by the use of light traps, and secondly control through silvicultural systems that reduce insect prevalence.

Light trapping

A light trap experiment was implemented from 1993 to 1995 in a two-year old plantation of *S. macrophylla* in secondary vegetation in the State of Acre (Fazolin and Oliveira 1994). The objectives were to determine the insect population patterns associated with the *S. macrophylla* plantation and to test the effectiveness of the trap in the control of *H. grandella* by capturing adults on an adhesive-coated plastic sheet. Based on three years observations, this method was determined to be ineffective.

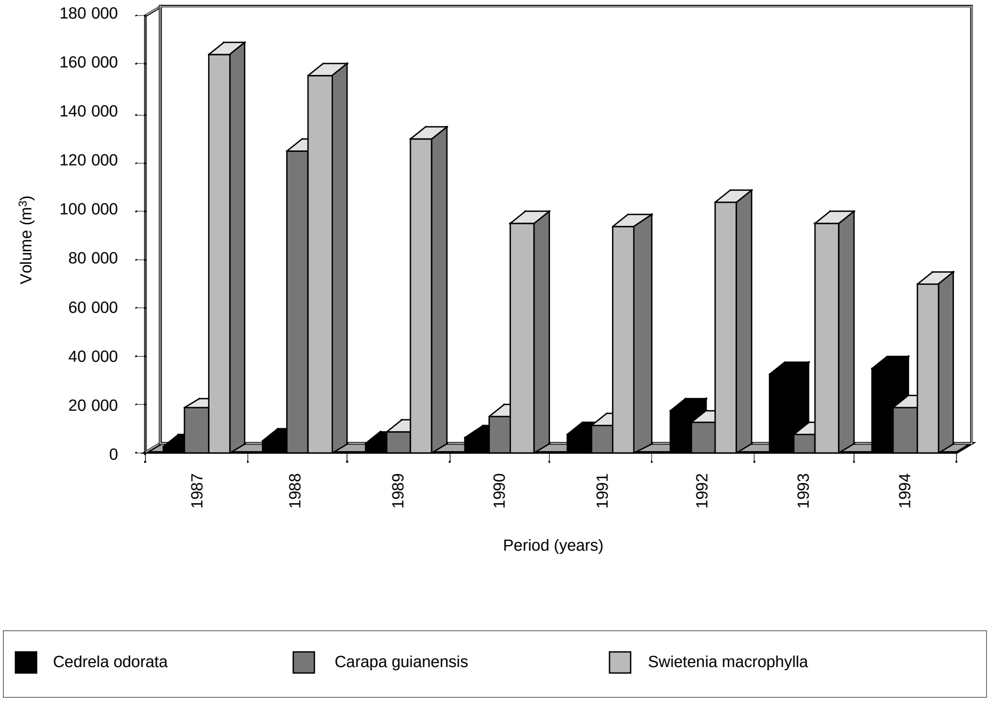

Figure 1. Volume (m^3) of sawn timber exported from Pará State, Brazil in the period of 1987 to 1994. Source: Carvalho (1994a, b).

Table 1. Native and exotic species of Meliaceae subfamily Swietenioideae planted in Pará State, Brazil.

Tree species	Origin	Present area planted (ha)	Program status[1]
Swietenia macrophylla King	Native	603	A
Cedrela odorata L.	Native	100	A
Carapa guianensis Aubl.	Native	100	A
Toona ciliata M. Roem.	Introduced	100	B
Khaya ivorensis A. Chev.	Introduced	100	B

[1] A. Ongoing but having limited or variable success, B. Preliminary or experimental only.

Table 2. Summary of current and past research effort on various aspects of Hypsipyla grandella Zeller biology and control. – none; * minor; ** major.

Area of study	Current research	Historical research
Biology		
Taxonomy	–	–
Life history	–	**
Ecology in natural stands	–	–
Ecology in plantations	–	–
Population dynamics	–	*
Natural enemies	–	–
Other		
Control		
Biological control	–	–
Chemical control	*	–
Silvicultural control	*	**
Provenance trials	–	*
Pheromone studies	–	–
Genetic engineering	–	–
Other		

Silvicultural control

Two alternative strategies of silvicultural control have been attempted; however, the results are inconclusive (Yared and Carpanezzi 1981). The first was to promote rapid establishment and early growth so that the plant quickly passes through the period when it is most susceptible to damage. This can be through site selection and soil preparation (including fertilisation), giving abundant overhead light and lateral shade to promote vertical growth, intensive plantation maintenance (e.g. weeding), and pruning of attacked plants to concentrate vertical growth on one stem. The second strategy was to screen the trees from attack through planting a low density of plants per hectare, creating a dense matrix of other vegetation and maximising forest heterogeneity, thus attempting to reproduce forest conditions.

Ohashi et al. (1993) recommended the first strategy, emphasising rapid growth for the first 4.5 metres and not exceeding 50% shade. Citing Dubois (1978) based on plantations at Curuá-Una Experimental Station, located in the Amazon basin, they recommend that plantations of Meliaceae in the Amazon use wide spacing, partial shading and control of competing vegetation in mixtures with non-susceptible species in groups or lines with less than 100 trees per hectare.

The absence of attack on four year-old *S. macrophylla* and *C. guianensis* in enrichment plantings (the 'recru' method) in 25-year old secondary vegetation was attributed to the screening (Yared and Carpanezzi 1981). Furthermore, Marques et al. (1993) reported the results of fertilised mixed plantations of *S. macrophylla* with other tree species, including *Cordia goeldiana* Cham., *Dipteryx odorata* Aubl., *Vochisia maxima* Ducke, *Bagassa guianensis* (Aubl.) and *Bertholletia excelsa* (Humb. & Bompl.), and fruit species including *Theobroma grandiflorum* (Willd. ex Spreng.) Schum., *Inga* sp. and banana (*Musa* sp.) in Santarém, Pará. In these trials, *H. grandella* attack was only observed in the second year (21% attack) when the *S. macrophylla* had reached 5.7 m, whereas, at three years and height of 6.9 m, there was little attack. The authors considered that even the attacked trees would produce timber if pruned. It is believed that the lateral barrier provided by banana could explain the reduced and delayed attack.

S. macrophylla and *C. guianensis* have been grown in Taungya along with maize, manioc, and *C. goeldiana*, in Santarém. Attack on one-year-old, 0.8 m high *C. guianensis* was 4%. In the same area, 82% attack was reported on 2-year-old, 5 m high *S. macrophylla* that was planted with maize, banana, *C. goeldiana* and *Cordia alliodora* Huber (Brienza Júnior et al. 1983).

Experimental or commercial-scale plantations of native Meliaceae in Amazonia have been shown to suffer severe attack by *H. grandella* when grown in full sun, but that attack may be reduced in shade. Yared et al. (1988) found 56.8% mortality in plantations of *S. macrophylla* at 3.4 m high in full sun in Belterra, Pará, and up to 100% mortality of *C. guianensis* and *C. odorata* by 6.5 years. The high mortality rates were caused by intolerance to full sun and a severe *H. grandella* attack. Brienza Júnior et al. (1990) report *H. grandella* attack in *S. macrophylla* plantations in Capitão-Poço, Pará, being more pronounced in plantations in full sun, although there was also damage to line enrichment plantings in secondary vegetation. The authors recommended that *S. macrophylla* should not be planted in pure plantations but in conditions of partial shade or in mixed plantations with fast-growing species. Similarly, Kanashiro et al. (1983) reported severe attack by *H. grandella* on provenance trials of *C. odorata* planted in full sun in Belterra, Pará: 50% of plants were attacked at six months and subsequently all plants were attacked, while plants in secondary vegetation in partial shade were not attacked at six months. Berti Filho (1973) also observed less attack in *Cedrela* sp. planted in partial shade compared to full sun in southern Brazil.

Results of growing under shade do not provide consistent protection. Ohashi et al. (1993) conducted an experiment on enrichment planting with *C. odorata* and *C. guianensis* in different light regimes at different spacing in primary and logged humid

Amazonian forest in the Curuá-Una Experimental Station. *H. grandella* attack increased with reduced light and spacing. According to the above-mentioned authors, this happened because more than 50% shade inhibiting growth of the tree and consequently increased of *H. grandella* attack. Rate of growth of Meliaceae in enrichment plantings can be slow. At age 4 years in enrichment plantings in secondary forest, *S. macrophylla* and *C. guianensis* have been reported to have a height increment of 1.3 m per year and a diameter at breast height increment of 1.3 cm/year and 1.5 cm/year respectively (Yared and Carpanezzi 1981). Mean height increment *C. odorata* was recorded as 0.7 m/year after 6 years in enrichment planting in native forest (Ohashi et al. 1993).

Based on the studies described above, partial shade (not surpassing 50% shade), mixed planting and intensive maintenance (fertilisation, weeding and pruning) may reduce *H. grandella* attack in Meliaceae plantations.

Conclusion

Research on *H. grandella* attack on Meliaceae in the Amazon region is preliminary. However, promising results have been shown with measures to accelerate growth and plantings in situations similar to natural forest habitat with a low density of plants per hectare and high species diversity.

Silvicultural methods that avoid attack in the first two years and ensure fast growth can produce a worthwhile timber log. However, adequate protection cannot be assured. It will be necessary to initiate studies on the population dynamics of the insect and further investigate the productivity and economics of different plantation systems on different sites. The potential for genetic resistance through chemical composition or strong recovery following attack also warranted further study.

Acknowledgments

Thanks to Dr Jorge G. Yared and Dr Sílvio Brienza Jr. of the Embrapa Eastern Amazon, for reading and offering suggestions on the manuscript and providing bibliographic material, and to Dr Ian Thompson of the DFID (former ODA) /Embrapa Eastern Amazon for help with the revision of the English and comments.

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Current Status of the Taxonomy of *Hypsipyla* Ragonot (Pyralidae: Phycitinae)

M. Horak[1]

Abstract

The current taxonomic knowledge about *Hypsipyla* Ragonot is summarised, the gaps in knowledge are identified and an outline is given about how these questions should be addressed. Eleven species of *Hypsipyla* are currently recognised, four from the New World and seven from the Old World. The taxonomy of the New World fauna is well documented, with biological information available on the main pest species *Hypsipyla grandella* (Zeller) as well as on *Hypsipyla ferrealis* (Hampson) and two species of the related genus *Sematoneura* Ragonot, all feeding on Meliaceae. The taxonomy of the Old World species of *Hypsipyla* is poorly understood, with several species known only from the types, and the status of the different populations of the pest species *Hypsipyla robusta* (Moore) remains unresolved. Two closely related genera (*Catopyla* Bradley, 1968, and *Eugyroptera* Bradley, 1977) with larvae feeding on Meliaceae have been described from Nigeria. In Australia, *H. robusta* or a very closely related species has been reared from fruit of the meliaceous mangrove *Xylocarpus granatum* König. Ideally, Old World *Hypsipyla* should be revised using a combination of morphological and molecular methods, and based on comprehensive, reared material from Africa, Asia and Australia, including information on biology and pheromones.

THE TAXONOMY of *Hypsipyla* Ragonot was last summarised in a world-wide context by Entwistle (1967) in a review on shoot, fruit and collar borers of the Meliaceae for the Ninth British Commonwealth Forestry Conference, and by Bradley (1968) in the introduction to the description of two new African genera closely related to *Hypsipyla*. Both authors concluded that the New World fauna was reasonably well documented but that *Hypsipyla* in the Old World was in urgent need of study. Taxonomic studies on *Hypsipyla* and related phycitines feeding on Meliaceae have since been published for Costa Rica (Becker 1974a, b), but no progress has been made with respect to the Old World fauna of *Hypsipyla*. The current state of knowledge about *Hypsipyla* in the Oriental and Australian regions is reviewed here in the light of the taxonomic studies in Africa and Costa Rica, biological information about the pest species and unpublished observations from Australia.

Ragonot (1888) proposed the genus *Hypsipyla* for an Indian species, *Hypsipyla pagodella* Ragonot, 1888 (Figure 1), in a brief description without any biological information. However, Moore [1886] had already described the same species as *Magiria robusta* (in his 'Lepidoptera of Ceylon') (Figure 2) based on material from Sri Lanka and provided colour figures (Figure 3) of adult, larvae and pupae, and ended the description with the biological information 'larva feeds within the branchlets of mahogany'. Just a few years later, Olliff (1890) described *Epicrocis terebrans* Olliff, 1890, from Australia as 'a species of moth destructive to red cedar (*Toona ciliata* M. Roemer) and other timber trees', giving drawings of adult, wing venation and immature stages (Figure 4). In his world-wide monograph on the Phycitinae, Ragonot (1893) synonymised *pagodella* with *robusta*, included the New World species *Hypsipyla grandella* (Zeller 1848) in the genus and named a new species from Madagascar, *Hypsipyla scabrusculella* Ragonot, 1893, and provided coloured figures of all three species.

During the next 50 years, a number of additional species were described in scattered publications

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(Table 1), either as *Hypsipyla* or later to be referred to that genus, but there was no taxonomic review of the genus during that time. In his still exemplary volume *American Moths of the Subfamily Phycitinae* Heinrich (1956) revised *Hypsipyla* based on the four New World species and *pagodella*, the Indian type species of the genus. He pointed out that the genus *Sematoneura* Ragonot, 1888, is closely related and difficult to distinguish from *Hypsipyla*.

Figure 1. Female syntype of *Hypsipyla pagodella* Ragonot from India in the Paris Museum.

Figure 2. Female holotype of *Magiria robusta* Moore from Sri Lanka in The Natural History Museum, London.

The next round of revisions was prompted by field studies on the pest species of the genus, by life history studies on shoot and fruit borers in Meliaceae in Nigeria (Roberts 1966, 1968) and Costa Rica (Becker 1974b). A survey of Meliaceae, especially their fruit, and comprehensive rearing of material led in both cases to the discovery of new species in genera closely related to *Hypsipyla* that feed on Meliaceae in a manner similar to *Hypsipyla*. From Nigeria, Bradley (1968) described two new genera with one species each, *Catopyla disorphnaea* Bradley, 1968, and *Gyroptera robertsi* Bradley, 1968, the latter renamed *Eugyroptera robertsi* (Bradley 1968) as *Gyroptera* Bradley was found to be a junior homonym. Becker (1974a, b) reported from Costa Rica that *Sematoneura atrovenosella* Ragonot, 1888, the type species of the genus, is a fruit borer *of Cedrela tonduzii* C. de Candolle, and he described a new species, *Sematoneura grijpmai* Becker, 1974, from the fruit of *Cedrela odorata* L.

These field studies confirmed that there is one main pest species in each region, *grandella* in the New World and *robusta* in Africa, both of which attack a wide range of Meliaceae and feed in shoots as well as fruits, with *robusta* also found in flowers, and in bark in Nigeria (Roberts 1966, 1968). Other species of *Hypsipyla* may have a much narrower host range, with *ferrealis* in Costa Rica only found in fruit of *Carapa guianensis* Aublet (Becker 1974b). The status of *albipartalis* in Africa is not clear as despite reports of damage by this species from several east African countries, the single female type from the Congo in the Natural History Museum, London, is the only specimen available (Bradley 1968). Unlike observations from India (Beeson 1919, 1941) and Indonesia (Kalshoven 1926), where larvae are only occasionally recorded feeding on bark (Kalshoven 1926), in Nigeria *robusta* is commonly found boring in bark (Roberts 1966, 1968). Based on this contrast in biology, together with a different position of the signum in the female genitalia of the Nigerian population, Bradley (1968) suggested that *robusta* might comprise several geographic races or subspecies. This has not yet been resolved.

The Oriental/Australian species of *Hypsipyla* have not been revised since Ragonot's monograph in

Table 1. Species described as or later referred to *Hypsipyla*. The country from which the species was originally described and the reference for the original descriptions are included.

Oriental/Australian Regions	Africa	New World
robusta (Moore, [1886]); Sri Lanka	*robusta* (Moore [1886]); Sri Lanka	*grandella* (Zeller, 1848); Brazil
pagodella Ragonot, 1893; India	*pagodella* Ragonot, 1893; India	*cnabella* Dyar, 1914; Mexico
terebrans (Olliff, 1890); Australia	*terebrans* (Olliff, 1890); Australia	*dorsimacula* (Schaus, 1913); Costa Rica
scabrusculella Ragonot, 1893; Madagascar	*scabrusculella* Ragonot, 1893; Madagascar	*fluviatella* (Schaus 1913); Costa Rica
elachistalis Hampson, 1903; Sri Lanka	*albipartalis* (Hampson, 1910); Congo	*ferrealis* (Hampson, 1929); Costa Rica
rotundipex Hampson, 1903; Sikkim	*ereboneura* Meyrick, 1939; Congo	
debilis Caradja, 1933; China		
swezeyi Tams, 1935; Samoa		

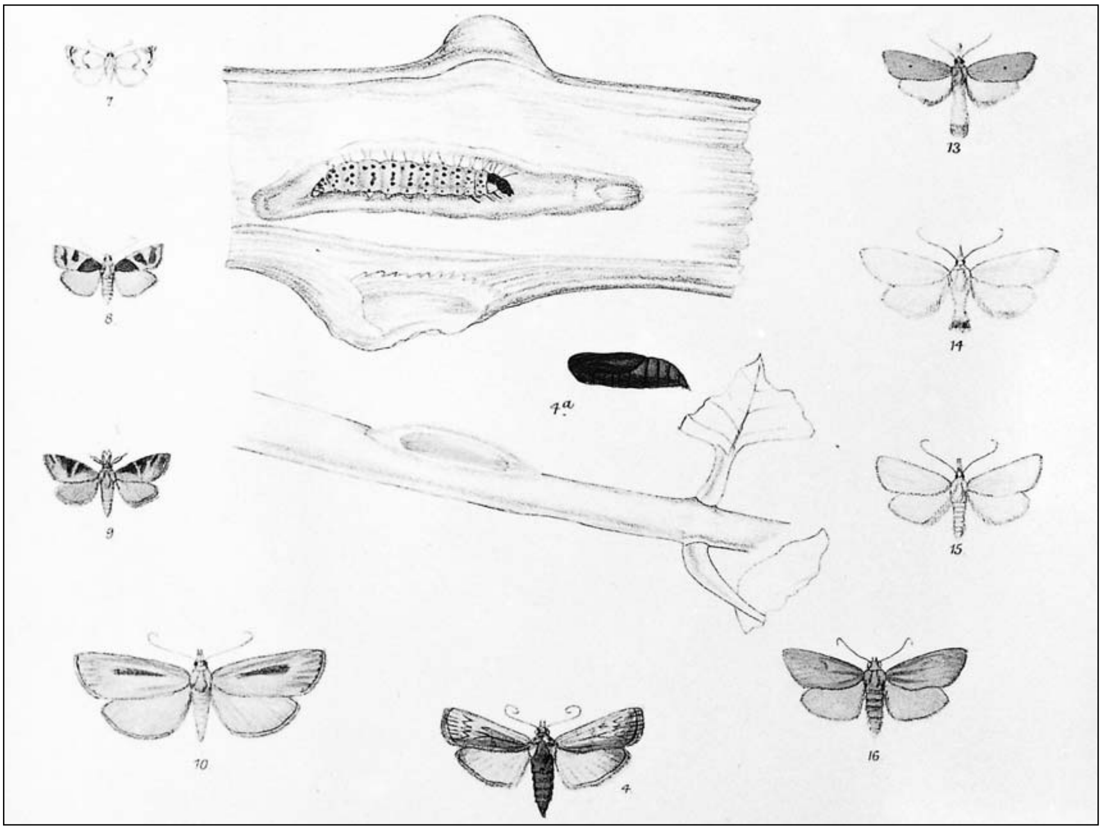

Figure 3. Original illustrations of adults and immature stages of *robusta* (numbered 4 and 4a above) in 'Lepidoptera of Ceylon' by Moore [1886].

1893. No information is available beyond the original description and the type material on the four species described since 1893 from the Oriental region and assigned by Bradley (1968) to *Hypsipyla* (Table 1). It is by no means clear that they are all correctly placed in *Hypsipyla*, or that others should not be included. The task is further complicated since several of the remaining types of *Hypsipyla* species are single females whose genitalia provide only very limited diagnostic characters. In Australia, *robusta* or an extremely similar-looking species has recently been reared by Paul Dixon (Australian Institute of Marine Science, Townsville) from fruit of the meliaceous mangrove *Xylocarpus granatum* König (Figure 5), leading to questions about a possible sister species to *robusta* or an alternative host for *robusta*. Adults of *Hypsipyla* are rarely encountered in the field, a fact already commented on by Beeson (1919) and confirmed by Paul Dixon (pers. comm.), and specimens are generally scarce in collections. The material available at present, even if assembled from numerous museums, is insufficient to allow a satisfactory revision of the genus. Bradley (1968) concluded his remarks on the taxonomy of *robusta* by saying that taxonomic progress will depend on adequate series becoming available, with associated biological information. It is important that collaboration across several continents be established, to provide at last the material necessary to resolve the taxonomy of *Hypsipyla*.

A comprehensive revision of *Hypsipyla* in the Oriental/Australian region will have to address the following three questions. Firstly, the types of all species from the Oriental, Australian and African regions possibly associated with *Hypsipyla* will have to be examined to establish their identity. Several are females and an effort will have to be made to find males from close localities since their genitalia provide the taxonomically most meaningful information. Secondly, extensive collections of reared material from a wide range of Meliaceae will have to be studied, from both fruits and shoots, to establish whether other closely related genera live on Meliaceae in the Oriental and Australian regions. Thirdly, to resolve the identity of the different populations of *robusta*, adequate material will have to be compared throughout the range of the species, from Africa, Madagascar, throughout Asia and Australia. Morphological studies may well have to be complemented with molecular and/or pheromone studies. In Australia in particular, biological observations and possibly a study of molecular markers will be required to establish the status of the population in fruits of *X. granatum*.

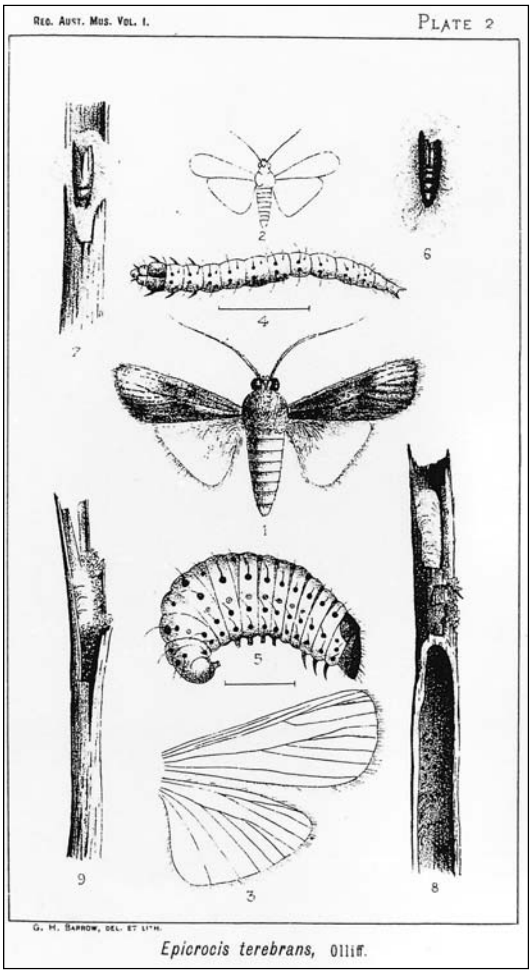

Figure 4. Original illustrations by Olliff (1890) of adults and immatures of *Epicrocis terebrans* Olliff from Australia.

The need to adequately understand the relationships of the various species of *Hypsipyla* and their biology is obvious if we want to consider any sort of biological or integrated control of *robusta*. It is of importance to know whether the population in *X. granatum* fruit in Australia is the same as the one in shoots of *T. ciliata*, and whether the moths move between the two hosts. We have to know how different the populations of *robusta* on the different continents are if we want to use parasitoids or other organisms for biological control. We should also be aware as to whether there are species of other genera related to *Hypsipyla* living in Meliaceae in the Oriental and Australian regions. Phycitines are a notoriously difficult group that have long defied taxonomists, and *Hypsipyla* is no exception. The species, and often genera, look superficially very similar and the differences even in the genitalia may be minimal. However, a concerted approach combining morphological and molecular studies with information on biology and pheromones, based on long series from different populations across an adequate area, has a good chance of resolving the taxonomy of *Hypsipyla*, especially in the Old World where knowledge about the genus is particularly deficient.

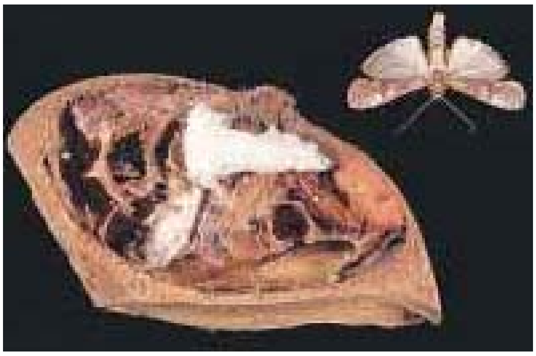

Figure 5. Cross-section of seed of *Xylocarpus granatum* König with cocoons and adult of *Hypsipyla* sp. from Crystal Creek, Daintree River (coll. Paul Dixon).

Acknowledgments

Grateful thanks are due to Mr M. Shaffer of The Natural History Museum, London, and Dr Joel Minet of the Muséum National d’Histoire Naturelle, Paris, for providing access to types of *Hypsipyla* and to Mr Paul Dixon of the Australian Institute of Marine Science, Townsville, for material of *Hypsipyla* sp. on *Xylocarpus* spp. and information on this species. I also thank the following colleagues of CSIRO Entomology for their help: Ms Manon Griffiths for supplying much of the taxonomic literature on *Hypsipyla*, Ms K.L. Smith for photography, and

Mr E.D. Edwards and Dr R.B. Floyd for helpful comments on the manuscript. Initial research on *Hypsipyla* was supported by Australian Biological Resources Studies, and a travel grant by RIRDC allowed my participation at the Workshop.

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The Biology and Ecology of *Hypsipyla* Shoot Borers

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Abstract

The *Hypsipyla* shoot borers are apparently restricted in their feeding to plants belonging to the family Meliaceae, subfamily Swietenioideae, including the high value timber species of *Swietenia*, *Khaya*, *Toona* and *Cedrela*. The two most important *Hypsipyla* species with respect to shoot borer activity are *H. grandella* (Zeller) occurring in the Americas, and *H. robusta* Moore occurring through areas of Africa and the Asia/Pacific region. Larvae of these species tunnel in the developing shoots of young trees, and in some regions also feed upon the flowers, fruit and occasionally bark of their hosts. Feeding on these non-shoot plant parts may have a significant impact on the population dynamics of the species. A generation usually takes 1 to 2 months, extending to 5 months if larvae enter diapause. Females mate only once and lay between 200 and 450 eggs over 5 to 8 nights. Adults are strong fliers, able to locate host trees over considerable distances. Egg and early instar mortality are high, however even low levels of feeding can significantly impact on tree form. Shoot-feeding larvae pupate within the stem tunnel or amongst soil and plant material at the tree base. The behaviour of larvae and the sites of oviposition and pupation while feeding on fruit, flowers and bark are less well known, and vary according to the host species and the plant part being eaten. Damage to fruit results in their premature shedding, which is circumvented in some areas by webbing produced by the feeding larva. Larval diapause has been reported from areas of low temperature or low rainfall, and occurs immediately following cessation of fruit-feeding despite apparently suitable climatic conditions.

DAMAGE from shoot borers of the genus *Hypsipyla* Ragonot (Lepidoptera: Pyralidae) presents the greatest deterrent to the establishment and cultivation of the high value timber species belonging to the family Meliaceae, including species of *Swietenia*, *Khaya*, *Toona* and *Cedrela*. The most serious damage to the tree results from the tunnelling of the larva in the developing shoots. This boring leads to the death of the terminal shoot and subsequent production of laterals, eventually resulting in a stunted, continuously branched and crooked tree of greatly diminished value for timber production. Growth rate is reduced and death can result from heavy and repeated attacks. Damage has been recorded on trees from age three months old and 50 cm height (Beeson 1919, 1941; Kalshoven 1926), up to age 14 years and 15 m height (Froggatt 1923; FAO 1958; Streets 1962; Morgan and Suratmo 1976; Suratmo 1977). The borer is thus a problem to both nursery and planted stock.

The *Hypsipyla* species have attracted considerable attention, with mention in over 300 publications. The great majority of these works focus on the shoot-feeding habit of the insect and are directed towards management and control. Although causing greatest economic damage during shoot boring, *Hypsipyla* larvae also feed upon the flowers, fruit and occasionally bark of their hosts. Few studies have been directed at or even mention the biology and population dynamics of the insect when feeding on these alternative plant parts. This review describes the biology and ecology of the main *Hypsipyla* species and highlights areas warranting further research.

Distribution

Eleven species of *Hypsipyla* are currently recognised (Horak these Proceedings) of which four occur in the Americas and seven in the Africa/Asia region (Heinrich 1956; Bradley 1968). *Hypsipyla robusta*

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(Moore) is the most widely distributed, occurring through West and East Africa, Asia and the Pacific (Fig. 1). *Hypsipyla grandella* (Zeller) is found throughout Central and tropical South America, in the Caribbean and on the southern tip of Florida (Entwistle 1967) (Figure 1).

The remaining species are less well known and are more restricted in distribution. Those occurring in the Americas are *H. dorsimaculata* (Schaus), *H. fluviatella* Schaus, and *H. ferrealis* (Hampson), and those present in the African region are *H. albipar-talis* (Hampson), *H. ereboneura* Meyr., *H. debilis*

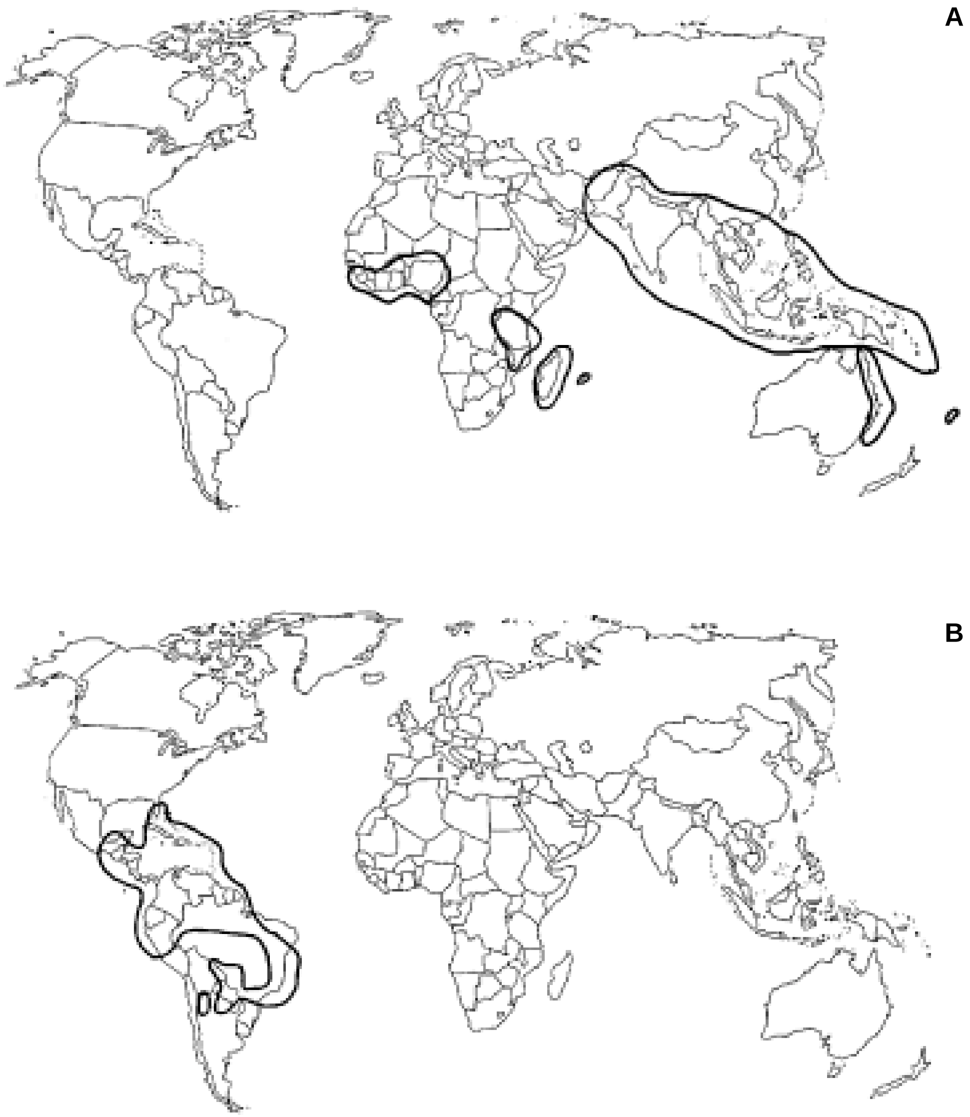

Figure 1. Geographic distribution of *Hypsipyla robusta* (A) and *H. grandella* (B).

Caradja, *H. elachistalis* Hampson, *H. rotundiplex* Hampson, and *H. swezeyi* Tams.

Host plants

Hypsipyla spp. are generally restricted in their feeding to plants belonging to the family Meliaceae, subfamily Swietenioideae. The Swietenioideae comprises 13 genera, most of which have been recorded as hosts of *Hypsipyla* spp. The lack of records of *Hypsipyla* feeding on some genera may be a result of limited work on these groups rather than a true reflection of their host status. Despite the strong association between *Hypsipyla* and the subfamily Swietenioideae, there are a number of reports of feeding damage on plants in other groups (Olliff 1890; Beeson 1919; Queensland Forest Service 1921; FAO 1958; Streets 1962; Entwistle 1967; Browne 1968; Rao and Bennett 1969). These reports are generally single records and probably constitute misidentification of the insect and/or misinterpretation of the damage (see Kalshoven 1926; Diakonoff and Bradley 1976; Luego 1989). Some records may represent chance feeding events.

The Swietenioideae is one of two major subfamilies within the Meliaceae. It is biochemically distinct from the other major subfamily, the Melioideae, specifically in the structural form of its limonoid compounds (Das et al. 1984; Agostinho et al. 1994). Limonoids are a group of tetranortriterpenoids with antifeedant or toxic properties against a wide range of invertebrate species (Taylor 1981; Arnason et al. 1987; Jacobson 1989). The apparent restriction of *Hypsipyla* spp. to hosts of a single subfamily containing limonoids of a particular structural type suggest possible coevolution between *Hypsipyla* and the Swietenioideae.

Hypsipyla grandella and *H. robusta* generally feed on growing shoots however feeding on flowers, fruit and bark has been reported for some host species and/or geographical regions. Larvae normally feed on shoots, and on other plant parts only when new shoots are not available (Beeson 1919, 1941). However, feeding on reproductive parts occurs concurrently with feeding on shoots in the high wet forest areas of Nigeria, in Java and in Australia (Kalshoven 1926; Roberts 1966; Campbell 1966; Griffiths 1997). Feeding by larvae of *H. robusta* on *Xylocarpus* mangroves is apparently restricted to the fruits and flowers (Das and Dev Roy 1982; Hutacharern and Tubtim 1995; Horak (these Proceedings)). *Hypsipyla ferrealis* feeds on the fruit only of *Carapa guianensis* Aubl. (Becker 1973; Heinrich 1956; McHargue and Hartshorn 1983). The absence of feeding records for alternative plant parts of many species may reflect the extent of observations undertaken, rather than the extent of feeding damage inflicted. Non-shoot feeding may have a significant influence on the population dynamics of the species, with fruit feeding larvae often occurring at very high densities (Department of Public Lands, Queensland 1917; Beeson 1941; Entwistle 1967; Mathur 1967; Bennett and Yaseen 1972; Brunck and Mallett 1993; Wali-Ur-Rehman 1993).

Reproduction and host plant choice

The reproduction of *H. grandella* has been studied by Grijpma (1971), Samaniego and Sterringa (1973), Sliwa and Becker (1973), Sterringa (1973) and Holsten and Gara (1977b), and of *H. robusta* by Beeson (1919), Atuahene and Souto (1983), Mo and Tanton (1996), Mo (1996) and Griffiths (1997). The two species are similar in many respects. Pheromones are produced by the female moth (Assiri Bosson and Gallois 1982; Borek et al. 1991). Mating occurs within six days of emergence, and females commence egg laying on the following night. Females mate once and proceed to oviposit throughout their life (approximately 5–8 days), laying between 200 and 450 eggs. Sex ratios of adults are variable with reports of even (Atuahene and Souto 1983; Griffiths 1997), male dominated (Beeson 1919; Intari 1978) and female dominated sex ratios (Achan 1968). Adults are generally nocturnal (Grijpma and Gara 1970a; Holsten and Gara 1974; Griffiths 1997).

Hypsipyla adults have a strong flight capacity as evidenced by laboratory flight studies (Fasoranti et al. 1982) and their ability to locate isolated hosts. The period of maximum flight activity differs between the sexes. Females are most active for the first two nights after emergence, during which time they probably disperse and locate hosts (Fasoranti et al. 1982). After this time females become less active and more attractive to males (Holsten and Gara 1977a; Mo 1996). Males have capacity for sustained flight over a longer period (Fasoranti et al. 1982), and will mate on several consecutive nights (Holsten and Gara 1977b) which allows them to locate distant females. Although *Hypsipyla* moths have a great capacity to disperse, they are unlikely to leave an area of active infestation while new shoots are available, thus causing severe local damage.

Successful mating and oviposition of adult *Hypsipyla* spp. in captivity have been difficult to achieve (Beeson 1919; Queensland Forest Service 1921; Roberts 1968; Grijpma 1971; Fasoranti 1985). Mating is generally more successful in outdoor cages than in laboratory conditions, possibly due to greater illumination (Campbell 1966; Griffiths 1997), exposure to wind (Mo and Tanton 1996), or a greater propensity for flight (Fasoranti 1985).

Eggs of both *H. grandella* and *H. robusta* are oval and dorso-ventrally flattened, measuring 0.7–1.0 mm × 0.5–0.7 mm (Ramirez Sanchez 1964; Atuahene and Souto 1983; Griffiths 1997). Eggs are white when first laid and develop distinct red and white banding within 24 hours if fertilised. The head capsule of the developing larva is visible through the chorion during the final 24 to 48 hours of development. Eggs hatch after three to five days, although egg mortality is high for both species (Allan et al. 1970; Griffiths 1997).

Eggs laid on young trees are deposited singly, or occasionally in clusters of three to four, on the shoots, stems and leaves, particularly the upper leaf surface (Beeson 1919, 1941; Kalshoven 1926; Ramirez Sanchez 1964; Roberts 1968; Rao and Bennett 1969; Owadally 1980; Yamazaki et al. 1990; Griffiths 1997). Eggs are concentrated around the growing shoots (Beeson 1919, 1941; Kalshoven 1926; Roberts 1966; Yaseen 1984; Yamazaki et al. 1992) but may occur at all heights, including low on the stem (Ramirez Sanchez 1964; Griffiths 1997). Eggs are often placed in concealed locations such as leaf axils, leaf scars, veins, lenticels and fissures in the bark (Ramirez Sanchez 1964; Lamb 1966; Grijpma 1971; Brunck and Fabre 1974). Adults are apparently attracted to young trees bearing new foliage (Grijpma and Gara 1970a; Gara et al. 1973; Yamazaki et al. 1990, 1992; Howard 1991), and to trees with existing damage and frass (Grijpma and Gara 1970a; Holsten and Gara 1977c; Yamazaki et al. 1990; Griffiths 1997). Eggs laid on fruit are initially deposited singly on the fruit surface (Beeson 1919; Roberts 1966; Rao and Bennett 1969) but are later laid in clumps of up to 12 among the frass and webbing associated with existing damage on fruit of *T. ciliata* in Australia (Griffiths 1997). Sites of oviposition prior to flower and bark feeding are unknown but are probably close to the feeding sites (Beeson 1941; Roberts 1966, 1968).

Immature development and diapause

Larvae of *Hypsipyla* spp. exhibit developmental polymorphism, with the reported number of instars ranging from 4 to 6 for *H. robusta* (Beeson 1919; Achan 1968; Roberts 1968; Atuahene and Souto 1983; Mo and Tanton 1995; Griffiths 1997), 5 to 7 for *H. grandella* (Hidalgo-Salvatierra and Berrios 1973; Ramirez Sanchez 1964; Yamazaki et al. 1990), and 3 to 4 for *H. ferrealis* (Becker 1973). The total development time takes 1 to 2 months, including a 10 day pre-pupal and pupal period. The life cycle can extend to 5 months if larvae enter diapause (Beeson 1941). Feeding behaviour, sites of pupation, and damage inflicted vary greatly according to the part of the tree being eaten.

Shoot feeding

Newly hatched larvae wander over the plant surface before commencing to feed, generally directly into the growing tip or into a nearby leaf or leaflet axil (Kalshoven 1926; Froggatt 1923; Ramirez Sanchez 1964; Roberts 1966; Grijpma and Gara 1970b). Feeding larvae spin a network of webbing across their feeding site onto which plant fragments and frass pellets are attached, eventually producing a dense mat. The webbing and associated material potentially provide protection for the burrowing larva from natural enemies, desiccation and rain water. Older larvae behave similarly when commencing feeding at new sites (Gu and Liu 1984). Shoot boring larvae will also feed on leaves, particularly during early instars (Kalshoven 1926; Ramirez Sanchez 1964; Roovers 1971; Suharti and Santosa 1990).

Larvae usually move and initiate feeding at several locations on a plant, particularly during the early instars (Anon. 1882; Kalshoven 1926; Gu and Liu 1984; Yamazaki et al. 1992; Mo 1996; Griffiths 1997). The reasons for these movements is not known but it is possible that larvae may move to avoid plant defences, predators and/or competitors, or to locate more nutritious feeding sites. Frequent wandering by first instar larvae probably contributes to the high rates of mortality by increasing exposure to natural enemies, weather and accidental loss (Kalshoven 1926; Griffiths 1997). Despite poor survival amongst early instars, the damage they inflict can have a significant impact on tree form since even very low levels of feeding on the growing tip can destroy apical dominance and lead to heavy branching.

Pupation occurs within cocoons spun in the stem tunnels, or amongst the leaf litter and soil around the tree base. Cocoons in a stem are usually located beneath a silken mat within the tunnel, while at the base of a tree they incorporate soil and plant material.

Fruit feeding

The behaviour of larvae feeding on fruit varies considerably according to the host species. *H. robusta* feeding on *T. ciliata* fruit initially feed externally on the epidermis and then feed inside seeds and fruit (Beeson 1919; Griffiths 1997). Neighbouring fruits are often joined by a tunnel of silk and frass through which larvae move, and surrounding fruit are incorporated into a large, loose conglomeration. On fruit of *K. senegalensis* (Desr.), larvae feed singly or in small, mixed age groups, ejecting frass and only moving between fruit as older instars (Roberts 1966).

In fruit of *Carapa procera* DC, larvae have been observed to feed in groups of up to 26, retaining frass around the point of feeding and not moving between fruit (Roberts, 1966). These differences in behaviour may be related to the size of the fruit and the amount of food required to complete larval development. The fruits of *T. ciliata* are relatively small (1.2 cm diameter × 2.5 cm length). Fruits of *K. senegalensis* are larger (4–6 cm diameter, spherical), and those of *C. procera* larger still (9 cm diameter × 15 cm length).

Larvae feeding on host species which have large fruits generally pupate inside the fruit, either within the canopy, or on the forest floor following fruit fall (Prosser et al. 1965; Robert, 1966). Larvae feeding on the smaller fruit of *T. ciliata* generally emerge from the fruit to pupate beneath the bark towards the base of the tree, or amongst surrounding soil and leaf litter (Beeson 1919, 1941; Griffiths 1997).

Hypsipyla spp. feeding on the fruit of some species such as *Khaya* species in Nigeria (Roberts 1966, 1968) and *T. ciliata* in Australia (Griffiths 1997) results in premature fruit fall. In Australia, the larvae circumvent fruit fall by spinning a mat of webbing across the point of abscission so that larvae complete feeding in the tree canopy.

Flower feeding

Larvae hatching from eggs deposited on flowers feed gregariously within the inflorescence of *T. ciliata* (Beeson 1919, 1941) but individually on flowers of *Khaya* spp. (Roberts 1966, 1968). During feeding, larvae spin a network of silken threads, within which there are denser cells or tunnels considered to be either moult cells (Beeson 1919) or a daytime retreat (Roberts, 1966). Larvae lower themselves on silken threads (Beeson 1919) or crawl down the trunk (Roberts 1966) to pupate in crevices or recesses under the bark on the trunk or larger branches.

Bark feeding

Later instar shoot-feeding larvae often resort to feeding on lignified tissue when younger material is no longer available (Kalshoven 1926; Ramirez Sanchez 1964; Gu and Liu 1984; Yamazaki et al. 1992; Griffiths 1997). In addition, some populations of *Hypsipyla* seem to feed exclusively beneath bark. In Nigeria, there have been instances of larvae of *H. robusta* feeding entirely beneath the bark of *K. grandifoliola* C.DC (Roberts 1966), causing damage similar to that described for *H. albipartalis* on mahogany in Malawi (Ballard 1914). Larvae of *H. grandella* have been observed to strip away bands of bark from around the base of *Cedrela odorata* L. in Cuba (Menendez and Berrios 1992), and may even extend their feeding to the roots of some hosts (Yamazaki et al. 1990).

Diapause

The incidence of diapause varies between regions. In some regions, attack is continuous with larvae going through 10–12 generations per year (Kalshoven 1926; Gu and Liu 1984). However, under conditions of low temperature or low rainfall, as experienced in regions such as Northern India, Myanmar, the Nigerian savannah and sub-tropical Australia, larvae may undergo a period of arrested development during the last instar, with the total number of generations reducing to four or five (Beeson 1919; Brunck and Fabre 1974). Also, in southern Queensland, larvae completing development in the fruits of *T. ciliata* enter diapause at a time when larval activity in shoots continues for at least a further five months (Griffiths 1997). The triggers inducing or breaking diapause in different localities have not been identified.

Conclusion

The biologies of *H. robusta* and *H. grandella* are similar in many ways, allowing some research results to be applied across regions. A number of differences and discrepancies exist, both between and within the currently recognised species. Some of these apparent differences may reflect a lack of knowledge rather than true biological differences. Further work is required to clarify many aspects of the biology and ecology of *H. robusta* and *H. grandella* so that integrated pest management strategies can be devised with confidence.

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Biology and Impact of *Hypsipyla robusta* (Moore) on *Toona ciliata* M. Roem. in Himachal Pradesh

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Abstract

Toona ciliata M. Roem. is a versatile timber tree that grows in forest and agroforestry situations under sub-tropical and tropical conditions of India, Southeast Asia and the Pacific. It is attacked by an insect, *Hypsipyla robusta* (Moore) which voraciously feeds on its fruits and shoots. The infested trees become stag-headed with crooked boles. Studies on the biology of *H. robusta* revealed that oval, white eggs with an average size of 0.9 × 0.5 mm were laid on young fruits and shoots. Incubation period was 3–4 days. There were five brownish instars. Full-fed larvae were violet blue and pupated in a cocoon. Pupae were obtect, 14.2 × 4.07 mm in size and lasted for 10–11 days. Male moths were smaller (26 mm in wing expanse) than females (28 mm). Insects completed four generations in a year and over-wintered as prepupae from October to mid-March. Larvae fed voraciously, particularly after the third instar. A single larva was found to feed on 6–10 fruits, or to form a tunnel with an average length of 65 cm in shoots. Tress between 2 and 3 m in height had the highest incidence of damage (93.3%) and the maximum shoot infestation per tree (66.5%). In addition to the effects on form and growth of the affected saplings, insect infestation also adversely affected seed germination. There was 20% seed germination in heavily infested fruits compared with 98% in seeds obtained from healthy fruits. The impact of insect damage on natural regeneration of *T. ciliata* saplings growing in pure stands and in solitary situations was studied.

THE SHOOT BORER, *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae) is an important pest of trees belonging to family Meliaceae in the tropical and subtropical parts of the world. A related species, *H. grandella* (Zeller), causes similar damage to species of Meliaceae in the Americas. These pests are the major constraints to successful planting of multipurpose trees like *Toona ciliata* M. Roem., mahogany and other trees of this family. In India, Beeson (1919) reported that the life history and sequence of generations of *H. robusta* vary with the food plant and climate. During 1994–1995, the biology and impact of this pest on *T. ciliata* was studied at Nauni campus of the Y.S. Parmar University of Horticulture and Forestry, Himachal Pradesh (31°N, 77°E) situated at 1200 m above sea level.

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Materials and Methods

An insect culture was raised from fruits and shoots of *T. ciliata* collected in the field. Insects were reared on their natural food by placing plant parts in rearing cages (60 × 58 × 70 cm) with their cut ends placed in water, or by using potted plants maintained in an outdoor cage. Observations on life stages of the insect were made by splitting open the infested parts. Insect incidence and seasonal history were studied under field conditions by examining relevant plant material at suitable time intervals.

The nature and extent of insect damage were studied on both the fruits and shoots of *T. ciliata.* Ten fruit-bearing trees were selected and 100 fruits from five branches in each crown were collected. Fruit were categorised into heavily infested (>60% damage), moderately infested (30–60% damage), slightly infested (1–30% damage) and uninfested fruits with no damage to seeds. Germination tests were conducted using 100 seeds from each damage category and percent germination was calculated. In addition, the effect of insect infestation levels on natural regeneration of *T. ciliata* was recorded by counting newly germinated seedlings within a 5 m radius of mature trees of known levels of fruit infestation. The nature of damage on fruit was studied and the number of damaged fruits was recorded.

T. ciliata saplings were grouped into 0–1, 1–2, 2–3, 3–4 and 4–5 m height classes. The proportion of trees damaged, length of tunnels made by the larva, and number of lateral shoots infested were determined for trees in each height class. Ten observations were taken in each case.

Results and Discussion

Biology

Egg

White, oval eggs were laid on young green fruits in the first generation and on new unexpanded leaves and growing shoots in the subsequent generations. The average size of the egg was 0.87 × 0.45 mm and hatchability was 82.3%. This stage lasted for 3–4 days. Beeson (1941) reported the egg size as 0.9 × 0.75 mm and duration of egg stage as 4–5 days.

Larva

A larva was observed to shed its skin four times before pupating thus having five instars. Linear measurements of larval stages are given in Table 1. All the instars had numerous black spots on their body and each black spot had two light brown setae. The appearance of each instar varied. In some cases even within an instar there were colour differences including pale straw-brown, pink, green or blue. Beeson (1941) reported four larval stages at Dehra Dun.

Table 1. Linear measurements of larval stages of *H. robusta*.

Instar	Length (mm)		Width (mm)	
	Range	Mean ± S.E. (n=10)	Range	Mean ± S.E. (n=10)
I	3.3–3.5	3.4±0.1	0.5–0.6	0.6±0.05
II	7.0–7.2	7.1±0.1	0.9–1.0	1.0±0.04
III	11.0–11.5	11.2±0.2	2.0–2.1	2.0±0.05
IV	15.4–15.8	15.7±0.2	2.7–3.0	2.9±0.12
V	26.7–27.5	27.1±0.3	3.5–4.0	3.9±0.20

Prepupa and pupa

Fully fed fifth instar turned violet-blue before prepupal formation. Under laboratory conditions, larvae of the first generation came out of the fruit and, after a brief prepupal period, pupated under the flakes of damaged fruits in a silken cocoon. In the field, larvae descended the tree trunk with the help of a silken thread and pupated in crevices of the bark in loosely woven white silken cocoons. Pupae were reddish brown and of obtect type. These observations are in conformity with those of Beeson (1919). The prepupae measured 22.63 × 3.97 mm and the pupa 12.40 × 4.07 mm. The duration of the prepupal stage ranged from 3–4 days and that of pupae from 10–11 days. Beeson (1919) reported prepupal and pupal periods as 4–5 and 8–12 days respectively.

Adult

The adult was grey, fore wings darker with black crossed zigzag lines and patches on hind-wings that were whitish, semi-hyaline with darker margins and costal zones. Adults usually emerged during the evening. Male moths were smaller than females, measuring 13.8 mm in mean body length and 26.0 mm in wing expanse, whereas females measured 14.7 mm and 28.1 mm in mean body length and wing expanse, respectively. Adults survived for 10–12 days without food under laboratory conditions.

Seasonal history

The insect had four generations under sub-tropical/sub-temperate conditions. Field and laboratory observations revealed that adults from the overwintering generation emerged during the first week of March and laid eggs during the second week. Eggs of the second, third and fourth generations were noticed during the second week of May, the first week of July, and the last week of August respectively. The fourth generation prepupae started over-wintering from mid October and pupated toward the beginning of March. Beeson (1941) reported five generations in Dehra Dun which may be attributed to climatic variations.

Nature and extent of damage

Fruit generation

Eggs of the first generation were laid on inflorescences and soft developing fruits. The first instar mainly fed on the epidermis. Older larvae bored into the fruits and fed voraciously leaving only the hard epidermal tissues. During feeding, larvae would bind 5–7 fruits together with silken threads and entangled pieces of fruit and excrement in the web. After consuming edible parts of the fruit, another fruit was fastened by silken threads to the partially eaten fruit and feeding would continue. Thus, a larva could damage 6–10 fruits during its lifetime. Infestation of fruit varied from 12–44%. Trees with lowest fruit infestation (12%) had 12 seedlings under them compared with only 4 seedlings under trees with the highest infestation rate (44%). The degree of insect infestation also affected seed germination. Seeds obtained from healthy fruits had 98% germination compared with 20% for seeds from heavily infested fruit.

Shoot generations

Eggs of subsequent generations were laid on unexpanded leaves and growing shoots. The larvae initially fed on epidermis and produced irregular patches during the process of finding a suitable spot to enter into a shoot. A gummy mass of frass bound with silken threads marked the entrance hole of the larvae. The larva fed inside the shoot and excavated a tunnel downward. The shoot above the entrance hole eventually died and fell off. Even below the site of entry, the buds and lateral shoots dried up. Usually one larva infested a shoot but sometimes it abandoned the infested shoot and entered into an adjacent shoot. The observations on the nature of damage are in conformity with earlier work (Beeson 1919).

The length of tunnel in shoots of saplings of different height classes ranged from 9.3–26.6 cm (Table 2). Most of the tunnelling was formed by larvae in the third to fifth instar (Table 3) with later instars feeding the most. Saplings less than 1 m high were not attacked while saplings between 2 and 4 m height had in excess of 50% of shoots infested (Table 4). Furthermore, more than 90% of saplings in the 2 to 3 m height class were infested while saplings of less than 1 m height or over 4 m height were less frequently infested (Table 5).

Table 2. Length of tunnel formed by *H. robusta* larvae in shoots of saplings of *T. ciliata* of different height.

Height class (m)	Mean tunnel length (cm) (n=10)
0–1	9.3
1–2	35.5
2–3	54.3
3–4	62.4
4–5	68.3

Table 3. Length of tunnel formed by different instars of *H. robusta* in *T. ciliata* shoots.

Instar	Length of tunnel (cm)	
	Range	Mean ± S.E. (n=10)
I	0–1	0.8±0.1
II	3–5	4.4±0.3
III	8–13	10.6±0.8
IV	16–24	19.9±1.8
V	26–32	29.9±0.8

Table 4. Percent infestation of lateral shoots in saplings of different height classes.

Height class (m)	Number of shoots/ sapling	Percent shoot infestation
0–1	1	0.0
1–2	4	50.0
2–3	8	62.5
3–4	13	53.8
4–5	16	37.6

Table 5. Percent of saplings of *T. ciliata* in different height classes that were infested by *H. robusta*.

Height class (m)	Percent of saplings infestated
0–1	10.0
1–2	66.6
2–3	93.3
3–4	63.3
4–5	26.6

In Indonesia, Suratmo (1977) also reported that the degree of infestation decreased with greater age and height. Trees growing in solitary situations were less infested than in pure stands. However, saplings growing under mature *T. ciliata* suffered more shoot borer attack than otherwise. Saplings growing under dense canopy had 15.5% infestation as compared with 63.6% in open situations. Various workers have reported that saplings growing under a dense canopy suffer less attack from *Hypsipyla* species than trees in open situations. This may be due to the release of attractants from the host tissues (Beeson 1941; Dourojeanni 1963; Yamazaki et al. 1990). As a result of insect attack on shoots, apical growth was stopped and lateral shoots developed, resulting in the production of bushy and stag-headed trees with forked and crooked boles that rendered them unsuitable for timber production.

Conclusion

This study on the biology and impact of *H. robusta* on *T. ciliata* described the behaviour of this pest in northern India and indicated that damage from the insect had an adverse effect on growth and germination of the host tree species. It revealed that 2–3 m high saplings were most attacked by insects. Results relating to the location of damaged saplings can be useful in planning plantings of this tree species.

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Discussion Summary
Taxonomy, Biology and Ecology of *Hypsipyla* spp.

M.W. Griffiths

DESPITE the critical role of *Hypsipyla* spp. in limiting the commercial production of species of Meliaceae, many aspects of the taxonomy, biology and ecology remain unknown. A proper understanding of these issues was recognised by the Workshop as fundamental to the development and implementation of many proposed management options.

Foremost, a thorough taxonomic investigation of the group is required in the light of recorded variation in the morphology, biology, behaviour, and pheromone composition within the species currently recognised as *H. robusta*. This review will require collection of specimens throughout the geographical range of the species and from a range of host species and plant parts. In addition to morphological examination, molecular and bio-chemical techniques may be necessary to determine the taxonomy. Protocols for collecting, storing and sending material and for accessing the information obtained should be established. The relationship of the plants on which *Hypsipyla* spp. occur must also be clarified, since there are concerns over the taxonomy of some of the host species within the Swietenioideae.

Most studies on *Hypsipyla* spp. have been directed towards pest management rather than towards biology or ecology. In particular, the biology and population dynamics of *Hypsipyla* in natural stands and when feeding on non-shoot plant parts have been little studied. The behaviour of both adults and larvae is central to life history studies. However, adult movement and flight capacity, which influence mating, dispersal and host location, and larval movement, which has a significant impact on survival and the distribution and impact of damage, are not sufficiently understood. Several sites of pupation have been identified but their relative importance and the mortality rates in each are not known. The incidence of dormancy, its nature and triggers are not known, despite its importance in influencing seasonal fluctuations and population dynamics.

The study of the biology and ecology of *Hypsipyla* spp. is difficult, since the adults are nocturnal, larvae feed in concealed locations, and population densities are generally low. Many researchers have experienced difficulties in rearing shoot borers in captivity. The development of an artificial diet and techniques to maximise mating and oviposition success in captivity are required for successful rearing.

The research priorities identified by the meeting were:

- Taxonomic revision of the genus *Hypsipyla* and closely allied species, particularly from the Old World.
- Investigation of adult mating behaviour, dispersal, host location and oviposition, larval movement, pupation and dormancy.
- Understanding of population regulation and shoot borer behaviour in natural forests, particularly in relation to host tree phenology.
- Establishment of practical and effective rearing techniques, including improved mating in captivity and successful artificial diets.

Resistance in Mahoganies to *Hypsipyla* Species — A Basis for Integrated Pest Management

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Abstract

Considerable research effort into *Hypsipyla* shoot borers has failed to produce effective methods of control. However, the deployment of pest-resistant planting stock as a basis for managing these pests has not been considered until recently. This paper reviews evidence for the existence of different forms of resistance in Meliaceae to shoot borers, with particular emphasis on research carried out in Costa Rica on resistance to *Hypsipyla grandella* Zeller in *Cedrela odorata* L. and *Swietenia macrophylla* Jacq. This research has shown that appreciable genetic variation in resistance to attack by shoot borers occurs in these tree species. The basis for resistance appears mainly to be tolerance, but variation in non-preference and antibiosis may also occur within *C. odorata.* Strategies for future research are discussed and it is concluded that the best option for successful shoot borer management lies in the deployment of resistant planting stock in silvicultural or agroforestry systems that encourage natural biological control or otherwise minimise the abundance and impact of shoot borers.

WITHIN the context of these Proceedings, the *Hypsipyla* problem needs little introduction. Mahogany shoot borer species, *Hypsipyla grandella* Zeller in the neotropics and *Hypsipyla robusta* Moore elsewhere, have severely restricted reforestation programs with *Cedrela odorata* L., *Swietenia macrophylla* Jacq., *Toona ciliata* M. Roem., *Khaya ivorensis* A. Chev. and other Meliaceae species (Entwistle 1967; Newton et al. 1993a; Wagner et al. 1991; papers in these Proceedings). The larvae of these pyralid moths destroy the terminal shoots of the host plant by boring the pith, which results in a highly branched tree of little economic value (Newton et al. 1993a).

Considerable research effort into these pests (Grijpma 1974; Whitmore 1976a, b) has failed to produce effective methods of control (Newton et al. 1993a). However, recent research on resistance to *H. grandella* in *C. odorata* (Spanish cedar) and *S. macrophylla* (American mahogany) has indicated that the deployment of pest resistant planting stock could form an effective basis for managing this shoot borer (Newton et al. 1993b, 1996, 1998, 1999).

The aims of this paper are:

1) to discuss the ways in which plants may show resistance to insect pests and the value of resistance in pest management;
2) to describe research on resistance to shoot borers in Meliaceae species, with particular reference to recent work on resistance to *H. grandella* in *C. odorata* and *S. macrophylla*; and
3) to discuss research priorities in the development and deployment of resistance to mahogany shoot borers.

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Resistance to Insect Pests

Much has been written about resistance in plants to insects and pathogens. Generally, three different forms of resistance in plants to insect attack are recognised (Painter 1951; Tingey 1981; Van Emden 1987):

1) non-preference (or antixenosis), where a plant is not preferred for colonisation, oviposition or feeding by insect pests;
2) antibiosis, where insects on a plant take longer to develop, suffer greater rates of mortality, grow more slowly or produce less offspring;
3) tolerance, where a plant shows a tendency to recover from insect attack.

Several aspects of resistance should be noted:

- All categories of resistance define phenomena that are relative. A tree may be attacked by pests; these pests may survive on that tree and that tree may show signs of damage, but it may be resistant in comparison to other individuals or provenances of that tree species (or in comparison to other tree species). Thus, resistance in a clone, family or provenance may or may not be economically acceptable to a farmer or forester.
- The above definitions are based on the insect-plant relationship, the first two being defined by the response of the insect and the third being defined as the response of the plant. However, all forms of resistance are caused by some plant property — chemical, morphological or physiological. Thus, a plant may demonstrate non-preference because of leaf hairiness or the composition of the volatile chemicals emitted by the plant; a plant may demonstrate antibiosis because of leaf toughness or the chemical composition of the plant; and a plant may be tolerant because it grows vigorously or because of its particular response to damage, e.g. apical dominance.
- A plant may show different forms of resistance. For example, plant factors that cause antibiosis may also cause non-preference (Tingey 1981).
- Apparently, insignificant resistance may bring about acceptable damage suppression in conjunction with other control methods such as biological control (Van Emden and Wearing 1965).
- Insect pests and pathogens can evolve to overcome plant resistance (Gould 1983). The identification of resistance in plants must, therefore, be followed by the formulation of a strategy, or strategies, to fully exploit and conserve that resistance.

This paper concentrates on genetically-based resistance in plants. However, as discussed elsewhere (these Proceedings), plants may show resistance in its widest sense in other ways too, including:

- phenological variation in non-preference, antibiosis and tolerance (Watt 1987);
- shade-induced antibiosis (Dudt and Shure 1994);
- fertiliser-induced antibiosis and tolerance (Kyto et al. 1996);
- stress-induced antibiosis (Watt 1994);
- insect damage-induced antibiosis (Haukioja 1990).

These forms of resistance in plants mean that the environment of a plant may be manipulated to the detriment of insect pests (Hauxwell, Mayhew and Newton, these Proceedings). However, the fact that resistance to insect pests in its widest sense depends upon so many factors means that genetically-based resistance may be masked. Thus, studies on genetically-based resistance must include field trials established with statistically sound designs across as wide a range of growing conditions as possible.

To summarise, resistance in plants is a potentially valuable means of managing insect pests. Several forms of resistance occur and resistance has a variety of underlying causes. Resistance may usefully be combined with other approaches to pest management and, indeed, given the possibility that resistance may be overcome by pests, the deployment of resistance with one or more other methods of pest control in a pest management program is likely to be a much more successful strategy than the use of resistant plants alone. The next sections consider the extent to which resistance may be used to manage shoot borers.

Resistance to *Hypsipyla* Spp.

Newton et al. (1993a) reviewed published research on resistance between and within Meliaceae species. This is summarised below.

Although *Hypsipyla* spp. only attack Meliaceae spp., most susceptible species are in the sub-family Swietenioideae. Most Melioideae, including *Guarea* spp., *Melia* spp. and other desirable timber tree species, are not attacked by these shoot borers. It has frequently been suggested that these, apparently resistant, species are suitable plantation trees (e.g. Grijpma 1976).

Within the Swietenioideae, exotic (non-native) species have often been reported to be resistant to the native species of *Hypsipyla*. There are reports that the neotropical *S. macrophylla* has been successfully established in plantations in Southeast Asia and the south Pacific (Evans 1982) suggesting that *S. macrophylla* is susceptible to *H. grandella* but is resistant to *H. robusta*. However, most reports from countries in Asia, the Pacific and Africa in these Proceedings show that *S. macrophylla* is susceptible to *H. robusta*. Similarly, there are conflicting reports of the susceptibility of the neotopical *C. odorata* to *H. robusta*. This tree species is susceptible to *H. grandella* and although plantations of this species have been successfully grown in West Africa (Atuahene, these Proceedings), there are reports of damage caused by *H. robusta* to *C. odorata* in, for example, Australia (Cameron and Jermyn 1991) and Indonesia (Entwistle 1967). Reports on resistance to

H. grandella in *Khaya* spp. and *Toona ciliata* may be more reliable. *Khaya* spp., which are attacked by *H. robusta* in West Africa, have been successfully grown in Latin America and the Caribbean (Motta Maues, these Proceedings; Duarte et al. these Proceedings). Similarly, *Toona ciliata*, native to Asia and the Pacific and susceptible to *H. robusta*, is apparently resistant to *H. grandella* (Whitmore 1976).

It is still unclear which type, or types, of resistance are operating in the cases where resistance does occur but there is evidence to suggest that both non-preference and antibiosis confer resistance to *H. grandella* in *T. ciliata* (Roberts 1966; Grijpma and Gara 1970; Grijpma and Roberts 1975). Although it has been suggested that the biochemical basis for resistance in *T. ciliata* may be alkaloids (Grijpma 1976), most research on the biochemical basis for resistance to shoot borer attack in Meliaceae has concentrated on limonoids, many of which are powerful insecticides and feeding deterrents (Kubo and Klocke 1986). One limonoid in particular, cedrelone, which is found in *Toona* and *Cedrela,* is a powerful insect growth inhibitor (Kubo and Klocke 1986; Koul and Isman 1992).

Although the evidence for resistance to shoot borers in species planted out with their natural ranges is more convincing for *T. ciliata* than other species, it is notable that attempts to establish plantations of this species have ended in failure (Sanchez et al. 1976), probably as a result of incompatability of the tree species with local growing conditions (Newton et al. 1993a). Clearly, the use of exotic Meliaceae, in plantation monocultures at least, is not the answer to the shoot borer problem

Despite the repeated suggestion that variation in resistance to shoot borers may occur within Meliaceae species (Roberts 1966; Grijpma 1976), there have been few attempts to screen for genetic variation in resistance. Some information on resistance within *C. odorata* has, however, been obtained from international provenance trials (Whitmore 1978; Chaplin 1980; McCarter 1986, 1988). Although survival in these trials has usually been poor and they have been heavily attacked by *Hypsipyla*, a few provenances in these trials have shown apparent resistance to shoot borer attack, in each case tolerance through pronounced vigour and the production of a new single strong leading shoot after attack.

Thus, there is sufficient published information to warrant a closer examination of the presence of resistance to shoot borers within Meliaceae species. It was considered that these earlier experiences justified a closer examination of the presence of resistance to shoot borers within Meliaceae species. Such a study was launched in 1990 as a joint initiative of ITE (Institute of Terrestrial Ecology, Edinburgh) and CATIE (Tropical Agronomic Centre for Research and Higher Education, Costa Rica).

Case study: resistance to *H. grandella* in *C. odorata* and *S. macrophylla*

An investigation designed to assess the occurrence of genetic variation in characteristics conferring pest resistance in *C. odorata* and *S. macrophylla* by the use of seedling screening trials was started in 1990 at CATIE (Newton et al. 1995, 1996, 1998, 1999).

Seed of *C. odorata* was collected from trees in four localities (provenances) in Costa Rica, namely Carmona, Hojancha, Cañas, San Carlos and from one locality in Trinidad. These trees were selected on the basis of stem straightness and lack of forking. Seed of *S. macrophylla* was obtained from bulked collections from five provenances, namely Haiti, Trinidad, Honduras and two from Puerto Rico. Details of seed origins and seedling establishment are given in Newton et al. 1995.

Two field trials, screening *C. odorata* (25 families divided equally between the five provenances) and *S. macrophylla* respectively, were established at CATIE, during February 1991 (Newton et al. 1995). *C. odorata* trees were arranged by family in fully randomised 5-tree row plots, in nine replicate blocks. In the second trial, seedlings of *S. macrophylla* were arranged in fully randomised square plots of 25 trees in five replicate blocks.

Each tree in both experiments was assessed for the incidence of shoot borer attack at 14-day intervals, for 84 weeks from April 1991. Tree height was measured after 26, 56 and 88 weeks. In addition, the two experiments were assessed after 141 and 177 weeks (*C. odorata* and *S. macrophylla* respectively) for height to first branching and for the number of damage loci, indicated by forking.

The results of these trials are fully described by Newton et al. (1996, 1999). In summary, genetic variation in height growth was recorded for both tree species, differences between both provenances and families tending to become more pronounced with time. At the final assessments, *C. odorata* mean height ranged from 183–501 cm in Hojancha and San Carlos respectively (Figure 1) and *S. macrophylla* provenance mean values ranged from 211–267 cm in Dirici and Guajataca respectively. Genetic variation in *C. odorata* phenology was also observed, particularly with respect to leaf abscission during the dry season, trees from San Carlos and Trinidad being more heavily foliated than the other three provenances. The majority of *S. macrophylla* trees possessed foliage throughout the experiment.

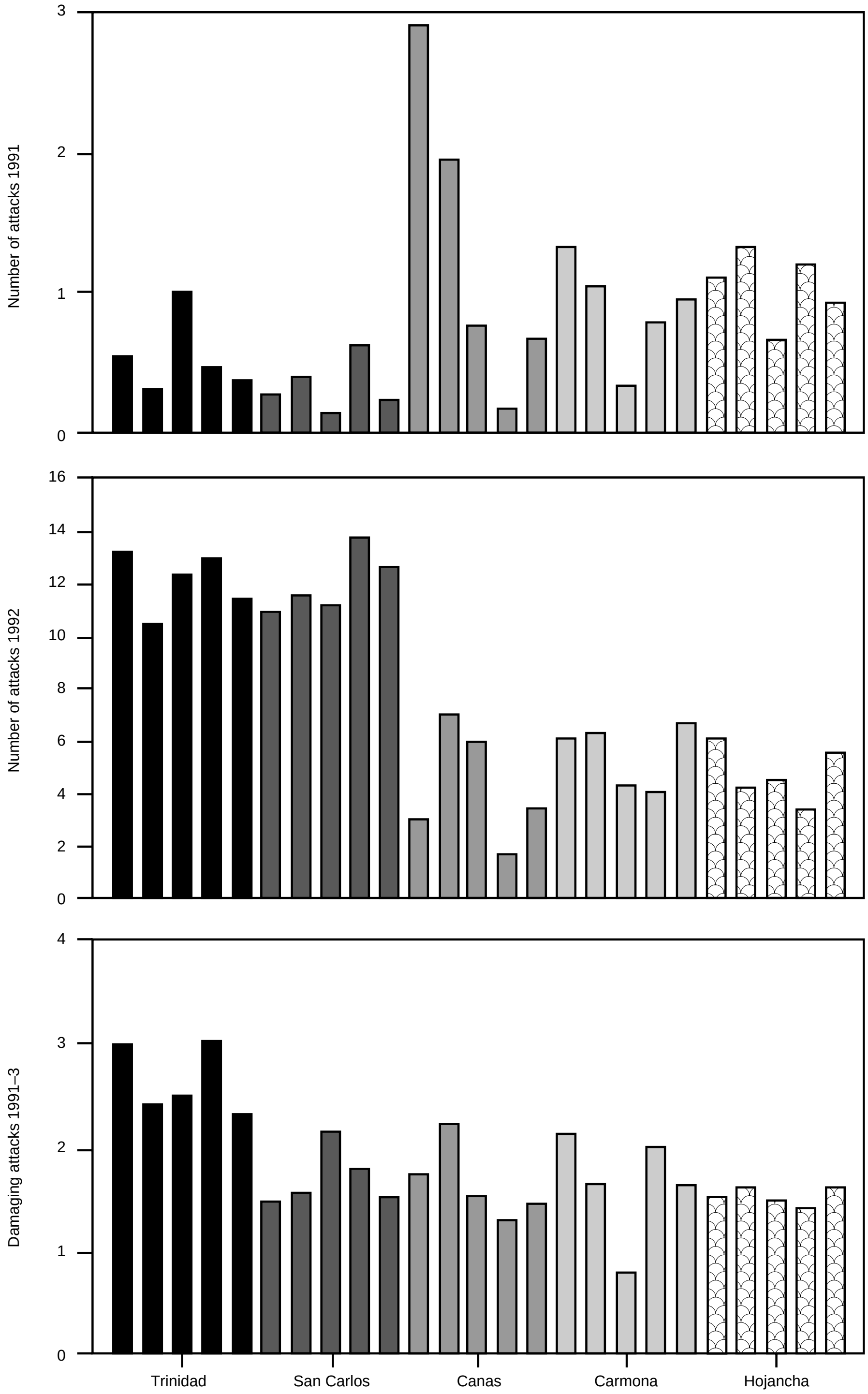

Figure 1. The numbers of shoot borer attacks to different *C. odorata* families in 1991 (top) and 1992 (middle), and the total number of damage loci resulting from attacks 1991–93, as assessed in 1993 (lower).

In *C. odorata*, two pronounced peaks in attack were observed, one each year (Newton et al. 1998) (Figure 2). At the first peak, the San Carlos provenance was least attacked, but these trees and those from the Trinidad provenance experienced the greatest number of attacks during the second peak. A single peak of attack was observed in *S. macrophylla*, in the second year of the trial. The number of damage loci in *C. odorata*, assessed after 141–177 weeks, was significantly affected by provenance. The mean number of damage loci per tree varied between 1.55–2.64 in Hojancha and Trinidad respectively (Figure 2).

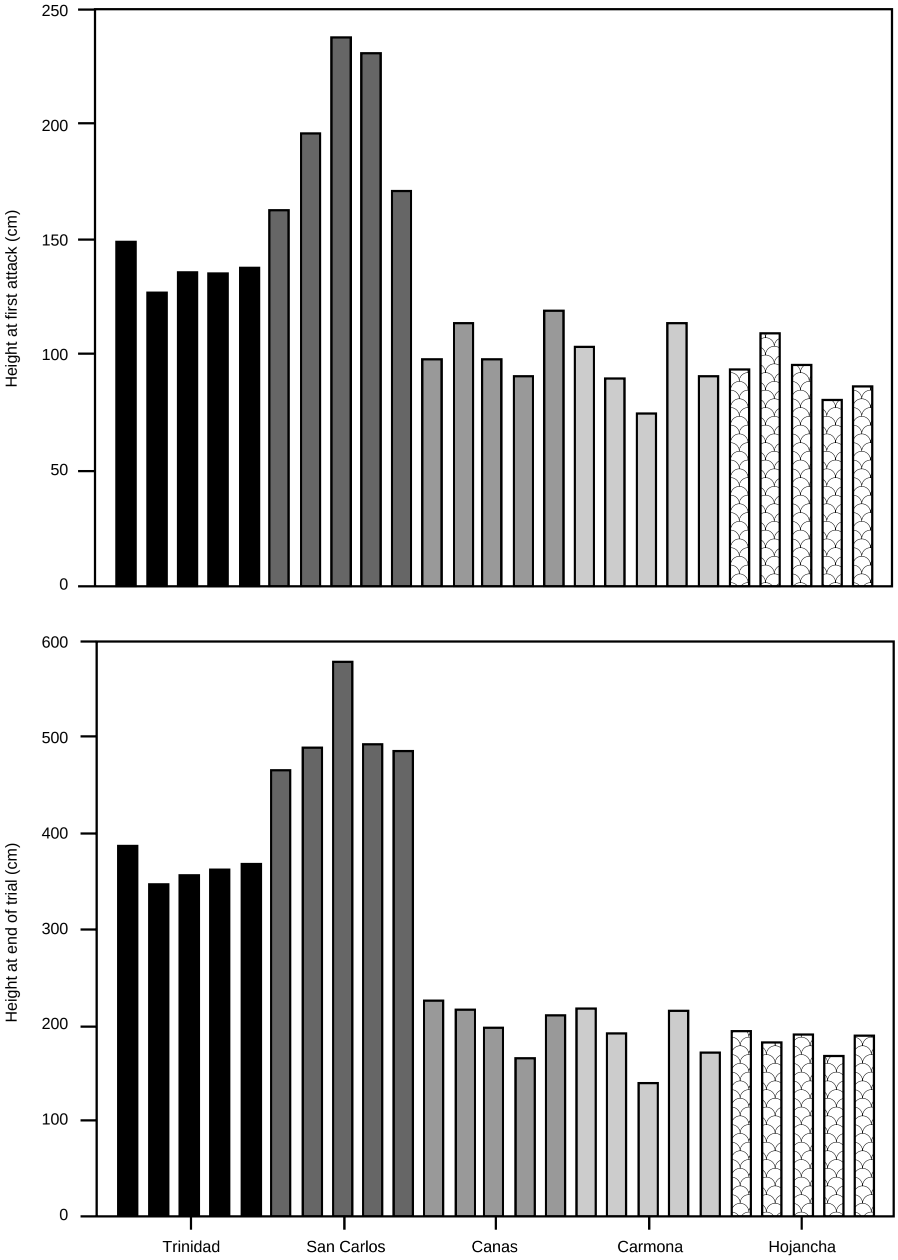

Figure 2. The height at which the first damaging shoot borer attack occurred in different *C. odorata* families (top), and the total height in 1993 (lower).

Thus, the results from the *C. odorata* trial were particularly promising, indicating that the San Carlos provenance, derived from the Atlantic zone of Costa Rica, is highly distinctive in terms of leaf morphology, growth and resistance to *H. grandella*. In terms of resistance, San Carlos provenance trees showed evidence of non-preference through a lower incidence of shoot borer attack in the first year of growth than trees from other provenances.

In addition, although San Carlos trees were heavily attacked after their first year of growth, they showed a greater degree of tolerance than other provenances, having a lower number of damaging attacks than expected for their height, and reaching a greater height than other provenances before experiencing their first damaging attack. Trees from the Trinidad provenance also demonstrated tolerance to *H. grandella* attack but they did so by producing several vigorously growing stems, whereas the San Carlos trees tended to respond to attack by producing a single main stem. The latter provenance therefore demonstrated better apical dominance, an important characteristic in the response of trees to pests such as the mahogany shoot borers and a characteristic which can be selected for in seedling decapitation tests (Newton et al. 1995).

Antibiosis is difficult to demonstrate in field trials such as this one. However, the fact that large numbers of shoot borer attacks led to small numbers of damaging attacks may have been due to antibiosis as well as tolerance. That is, some of the attacks may have been reduced in severity because of greater larval mortality in the San Carlos trees. Support for this possibility comes from the greater concentrations of proanthocyanidins (condensed tannins) in the foliage of San Carlos trees relative to trees from other provenances (Newton et al. 1999).

Discussion

Recent research in Costa Rica (summarised above) has shown that genetic variation in resistance to attack by *H. grandella* occurs in *C. odorata* and *S. macrophylla*, the results on the former tree species being particularly promising. As with previous provenance trials, the basis for resistance appears to be tolerance but this study has also demonstrated that variation in non-preference and antibiosis may occur within *C. odorata.*

These results should serve to encourage studies on resistance to shoot borers in other Meliaceae, such as *Khaya* spp. in West Africa. However, two points should be emphasised. First, the recent research in Costa Rica has been unique in combining regular assessments of attack (similar to that carried out by Yamazaki et al. 1990, 1992) with assessments of growth, form and damage. Future research should also include assessments of both shoot borer attack and the impact of that attack.

Second, as discussed above, resistance to insect pests is a characteristic to be cherished and used to the maximum effect. Thus, research on resistance should go hand in hand with research on other potential control methods so that resistant mahoganies once identified can be deployed in an integrated management strategy. We therefore agree with the conclusion of Newton et al. (1993a) that the greatest potential for successful management of shoot borers lies in incorporating resistant planting stock in appropriate silvicultural or agroforestry systems. These systems include those that encourage natural biological control by predators and parasitoids or otherwise reduce the abundance and impact of shoot borers (Speight, these Proceedings). We do not believe that effective control will be achieved by a single method of controlling shoot borers, be it silvicultural control, resistance or any other method. An integrated approach is strongly recommended.

Acknowledgments

The CATIE/ITE link project was financed by the UK Overseas Development Administration. The advice and encouragement of Dr Roger Leakey and Dr Francisco Mesén are gratefully acknowledged.

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Research into Species of *Cedrela* and *Swietenia* in Honduras including Observations on Damage by *Hypsipyla* sp.

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Abstract

Preliminary results are presented for species of *Cedrela* and *Swietenia*, based on field observations and recent trials of CONSEFORH (Conservation and Silviculture of Honduran Dry Forest Species) in two experimental stations located in the central and southern dry zones of Honduras. These results include the initial effects of *Hypsipyla sp.* on *C. odorata* L. and *S. humilis* Zuccarini. Recent observations suggest the presence of *Hypsipyla* sp. in a breeding seedling orchard of *S. humilis*. Recent attacks in a seed orchard of *C. odorata* and an enrichment planting of *S. humilis* in the central dry zone of Honduras are described. The distribution and conservation status of species of *Cedrela* and *Swietenia* in Honduras are briefly described. Species of these genera are valuable sources of sawn timber and round wood for rural people living in the dry zones of Honduras and have a long history of use of their durable timber. However, forest clearance and dysgenic selective harvesting have reduced and degraded the remaining natural stands. Current research and conservation activities are described. 'Conservation through use' by means of rural forestry programs with non-government organisations is currently perceived to be the most effective strategy for long-term conservation of these species. The paper concludes with an outline of future research opportunities and how the results will be used for *Cedrela* and *Swietenia* genera within Honduras.

SPECIES of *Swietenia* and *Cedrela* are highly valued and sought after due to their desirable wood properties. *S. humilis* Zuccarini and *C. odorata* L. are preferred by the communities of the southern and central zones as both sawn timber and round wood, and are used mainly for local construction but also for sale (Colindres et al. 1995; Colindres and Allison 1995). Both species are also used for furniture and handicrafts (Table 1). However, in spite of their value in the national market, carpenters from the communities receive a very low price that does not vary greatly with species. Although the wood properties relating to density and grain are very similar between provenances, utilisation is affected by considerable differences in growth and stem form.

CONSEFORH (Conservation and Silviculture of Honduran Dry Forest Species) is a bilateral project between the governments of Honduras and the United Kingdom, which was started in 1987 to combat the depletion of the Honduran forests estate including dry forest, cloud forest, conifer forest and humid forest. A third phase of the project started in September 1995 with a focus on the dry forest zones, which are high in biodiversity and are most threatened. The project's principal objective is to facilitate, through genetic conservation and improvement of trees, forestry interventions which will benefit local farmers and their environment. The project aims to assist forest conservation by:

- exploring forest genetic resources, especially of priority species, and producing improved seed of native and exotic species;
- supporting development organisations within Honduras through collaborative links with governmental and non-governmental agencies and provision of services such as training courses, seeds, information, and the establishment of on-farm demonstration trials;
- production and publication of information directed at forestry and agroforestry extension workers.

Despite the fact that species of the genera *Cedrela* and *Swietenia* are native to Honduras and have high utility and economic value, it was not until the last

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Table 1. Natural distribution of species of *Cedrela* and *Swietenia* native to Honduras.

Species	Distribution	Elevation (m.a.s.l.)	Rainfall (mm)	Forest zone	Uses
C. odorata L.	Central, Northern and Southern zones	150–1200	800–2500	Tropical dry and humid forests	Sawn and round wood, poles, furniture, tools
C. salvadorensis Standley	Comayagua valley, Central zone	600–800	800–1000	Tropical dry forest	Construction and poles (secondary product)
S. humilis Zucc.	Central and Southern zone	150–800	800–2500	Tropical dry forest	Construction, poles, furniture, tools
S. macrophylla King	Northern zone	200–600	>2000	Tropical humid forest	Construction, fine furniture

Table 2. CONSEFORH trials and seed orchards including species of *Cedrela* and *Swietenia*.

Title	Location	Year established
Seed orchard with 15 families of *S. humilis*; origin Comayagua Valley, Honduras	La Soledad	1991
Evaluation of 9 native species and 3 exotic species. Includes *C. odorata*	La Soledad	1991
Seed orchard with 19 families of *S. humilis*; origin La Venta, Honduras	Santa Rosa	1991
Silvicultural trial: *C. odorata*, origin Tablones Arriba, Choluteca, Honduras	Santa Rosa	1991
Seed orchard with 51 families of *S. humilis*; origin San Antonio del Norte, Honduras	Santa Rosa	1992
Evaluation of *C. odorata*, unknown origin	La Soledad	1992
Silvicultural demonstrations: Enrichment of the secondary forest with *S. humilis*	La Soledad	1993
Silvicultural evaluation: Permanent sample plot of *S. humilis* with a pruning treatment	La Soledad	1994
Seed orchard with 50 families of *C. odorata*; origin Tablones Arriba, Choluteca, Honduras.	La Soledad	1995
Silvicultural evaluation: Performance and form of timber and firewood species in boundary planting. Includes *C. odorata* and *S. humilis*	La Soledad	1995
Silvicultural evaluation: Performance and form of timber and firewood species in boundary plantings. Includes *C. odorata* and *S. humilis*	Santa Rosa	1995
Seed orchard with 50 families of *C. odorata*, origin Tablones Arriba, Choluteca, Honduras	Santa Rosa	1996
Performance evaluation of 6 timber species. Includes *C. odorata*	Comayagua farm trial	1996
Performance evaluation of 11 native species and 5 exotic species. Includes *C. odorata*	Lempira farm trial	1994
Silvicultural evaluation: Permanent sample plot of three species in a mixed plantation. Includes *C. odorata*	Lempira farm trial	1994
Species evaluation of 9 native species and 4 exotic species in the humid zone. Includes *S. macrophylla*	La Liberación, Yoro farm trial	1993*

Table 3. Environmental conditions at the experimental sites of La Soledad and Santa Rosa, Honduras.

Experimental station	Elevation (m.a.s.l.)	Mean annual precipitation (mm)	Duration of dry season	Mean annual temp (°C)
La Soledad	640	870 mm	5–7 months	25
Santa Rosa	100	2500 mm	6 months	26

eight years that they have attracted attention from national and international development agencies. Trial plantations of *S. macrophylla* King were established in the Lancetilla Botanic Garden in Atlántida at the beginning of this century as informal trials by the Standard Fruit Company. However, establishing plantations of this species was not a priority activity of the company. A number of trials and seed orchards have been established by CONSEFORH (Table 2). There are no other plantations of these species in Honduras.

Species of *Cedrela* and *Swietenia* have suffered substantial genetic degradation, particularly in the dry zone of Honduras. Considerable research effort has therefore been directed by CONSEFORH, in collaboration with the Oxford Forestry Institute (OFI), at conservation of the natural remnants of dry forest. A collaborative pilot study was commenced in 1994 on the genetic diversity and population structure of *S. humilis*, *Leucaena salvadorensis* Standley ex Britton & Rose, and *Bombacopsis quinata* (Jacq.) Dugand in Costa Rica and Honduras. Work by OFI has focused over several years on the distribution and genetic degradation of local species by collecting botanical samples and seeds, and disseminating information on these species. CONSEFORH have focused on collecting seed and establishing trials of *S. humilis* and *C. odorata* to test and conserve the genetic material that could be used in future reforestation activities in the dry zones of Honduras.

Distribution and status of Meliaceae in the dry zone of Honduras

Species of *Swietenia* and *Cedrela* native to Honduras are *S. macrophylla*, *S. humilis*, *C. odorata* and *C. salvadorensis* Standley. Except for *S. macrophylla*, which is mainly found in the Atlantic zone of the country, the other species are characteristic components of the tropical zone of the dry forest in the southern and central Departments of Honduras (Table 1). The dry zone is characterised by mean annual precipitation of 600–2400 mm, with a long and severe dry season of 5–7 months (November–May) during which there is little or no rain. The dry zone extends from the southern coastal plain up into hills of the Pacific watershed, to a maximum elevation of approximately 800 m above sea level. Isolated extensions of the dry zone occur in the deeper valleys of central Honduras where the mountainous relief produces pronounced rain shadows.

C. salvadorensis, was reported as rare in Honduras by Pennington et al. (1981). Recently, 20 additional trees were discovered in Cerro de Manzanillos in the central valley of Comayagua. Cerro de Manzanillas is the only area of dry forest in the interior of the country and represents a vital reserve of *C. salvadorensis* in Honduras (Hughes 1988; Boshier 1995).

The tropical dry forest has been reduced to about 2% of its original distribution by a combination of human activities, principally subsistence agriculture and cattle ranching. As the rural population is almost exclusively dependent on local sources of construction timber and fuelwood, the forest remnants are under severe pressure (Mejía 1994). Exploration work performed by OFI in the dry zone identified the risk of genetic degradation within populations of *S. humilis* and *C. odorata*. Until now, the major conservation effort has been through establishment of ex-situ trials on experimental stations. CONSEFORH has established a series of trials in experimental stations located in Comayagua valley (central zone) and Choluteca valley (southern zone). All provenances represented in the CONSEFORH trials originate from the dry zone of Honduras.

Conservation measures

A participatory study was carried out in 1995 in the Comayagua valley and in the southern zone of Honduras to support the information currently being produced by the experimental stations and at the same time to improve contact with rural communities. Due to the accelerated degradation of the dry forest, effort has been focused on those species most in demand by communities that depend on dry forest products. Among these species are *S. humilis* and *C. odorata*, both in serious danger of genetic degradation due to constant selective exploitation. Various methods of conservation are discussed below.

Natural forests

Natural stands of trees are the most important means of in situ conservation for *Swietenia* and *Cedrela* species. Remnants of natural dry forest such as Manzanillos in Comayagua valley are scarce. There is little knowledge about *C. salvadorensis* and other species found in this remnant forest. Consequently, CONSEFORH is attempting through AFE-COHDEFOR (Administración Forestal del Estado—Corporación Hondureño de Desarrollo Forestal) Department of Protected Areas to declare Manzanilla a forest reserve where further research on dry forests can be carried out. Other important remnant population of natural dry woodland include Guanacaure Hill in the Department of Choluteca (Southern zone). In the southern zone, where *S. humilis* is found, management of natural regeneration is a viable forestry system which benefits rural populations at all socio-economic levels.

Plantations on small farms

Reforestation projects in the dry zones of Honduras have concentrated on the use of fast-growing species for firewood and other uses. Implementation of CONSEFORH's conservation strategy in the central and southern zones of Honduras, through collaborative activities with non-governmental organisations working with communities, aims to reduce the pressure on remnants in the dry zone, and to promote planting of timber species such as *S. humilis* and *C. odorata*.

Genetic improvement and establishment of breeding seed orchards

As a response to the genetic degradation of many of the dry zone tree species, CONSEFORH has established an evaluation and improvement process which essentially involves 3 stages:

1. *Species evaluation/elimination trials.* These compare the performance of various species for certain products.
2. *Provenance evaluation trials.* Promising species identified (in 1.) are subjected to further intra-specific trials to identify the most productive provenances. In species of *Meliaceae*, between and within provenance differences in susceptibility to *Hypsipyla* attack is examined.
3. *Seed orchards.* The majority of native species in greatest demand have been subjected to dysgenic selection. The establishment of seed orchards aims to produce outbred seed from selected trees of known provenance to meet future promotion demands. In Meliaceae, heritable resistance to *Hypsipyla* attack is examined.

Preliminary observations on *Hypsipyla* sp. attack

Damage by *Hypsipyla* sp. has been observed in trials at two experimental stations of La Soledad, in the Comayagua valley (Central zone) and Santa Rosa (Southern zone) (Table 3). The soils at La Soledad are mainly neutral to slightly acidic alluvium derived from relatively young volcanic rocks (ignibrites and tuffs). In Santa Rosa, the soils are also of volcanic origin but are deeper, better drained and slightly less acidic. Parameters routinely recorded from trials being assessed for *Hypsipyla* attack include diameter breast height (dbh), tree height, height to first fork (commercial height), stem form (including number of basal forks and new shoots at the stem apex), presence or absence of apical or lateral attacks, incidence of *Hypsipyla* sp. attack and resin production. Trials at both stations contain provenances of *C. odorata* and *S. humilis* from the central and southern zone of Honduras.

At La Soledad, a seed orchard was established in 1991 containing 6 blocks of 15 families of *S. humilis* in plots of 25 trees spaced at 2 × 2 m and were attacked by *Hypsipyla* sp. during the first two years after establishment. A selective thinning was carried out at 36 months. At 52 months, the plants had a mean height of 4.7 m and mean dbh of 5.6 cm, with an average commercial height (height to first fork) of 2.4 m, and a high form score of 2.6. However, due to the lack of the records on *Hypsipyla* sp. attack, it is impossible to determine the effect of *Hypsipyla* sp. on the commercial height and form.

A permanent sample plot of 576 *S. humilis* trees was established at La Soledad in 1994. At age 11 months, 18% of trees had attack by *Hypsipyla* sp. and 11% of the trees were forked as a result. A small percentage of the trees were also damaged by leaf cutting ants.

Experience with line enrichment planting of *S. macrophylla* in the humid forests of Honduras has shown only limited attack from *Hypsipyla* sp. It was expected that this apparent reduction in attack might also apply to *S. humilis* in the dry forest regions. An enrichment planting trial of *S. humilis* was established at La Soledad in 1993 with spacing treatments of 2 × 10 m and 4 × 10 m. Trees in the secondary forest next to the plots were pruned to allow more light to enter. At six months, survival was 79.2% and 9.7% of the surviving 948 trees had been attacked by *Hypsipyla* sp. At one year of age, survival had decreased to 67.7% with an average height of 0.7 m. There was practically no change in survival at 2.5 years but attack by *Hypsipyla* had increased to 53.5% of trees (mainly apical). There was no evidence of differences in attack between the two spacing treatments. Evaluations of incidence of *Hypsipyla* attack and measurements of growth continue during 1996.

A seed orchard of 50 families of *C. odorata* originating from Choluteca established in July 1995 at La Soledad was first attacked by *Hypsipyla* sp. six weeks after planting with 4.2% of all trees attacked and up to 15.5% of trees within a family attacked (Figure 1). Some trees have incurred damage and recovered while others have suffered permanent damage with poor form due to forking. Data collection will continue so that the relative resistance of families can be accurately determined.

Similar measurements are being taken in a seed orchard of *S. humilis* planted in 1996 at Santa Rosa. Seed orchards of *S. humilis* at Santa Rosa containing

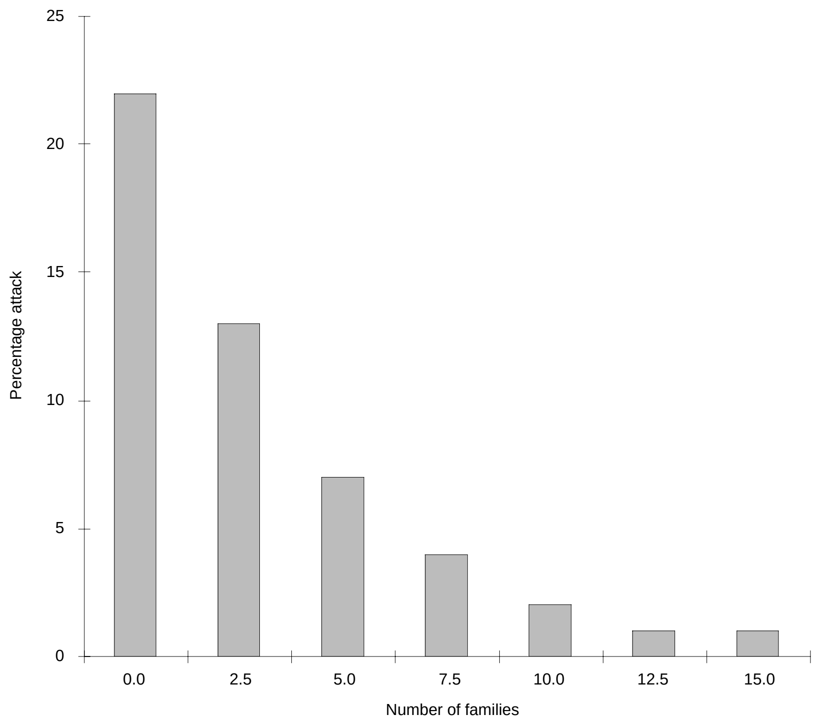

Figure 1. Percentage attack by *Hypsipyla* sp. per family in a *C. odorata* seed orchard at age 6 months, La Soledad, Comayagua Valley, Central Honduras.

provenances from La Venta (Choluteca) and San Antonio del Norte (La Paz) were established in 1991 and 1992. At age two years, the seed orchard of La Venta provenance suffered minor damage with less than 38% of trees attacked. The seed orchard of the San Antonio del Norte provenance has much better stem form than the seed orchard of La Venta provenance.

Species of *Meliaceae* included in on-farm trials have shown little evidence of *Hypsipyla* attack in *C. odorata*, possibly less than 10% of all plants. This may be because the on-farm trials include several other species. These on-farm trials are relatively recent and more results are required to assess their performance. Seed orchards and other trials will continue to be monitored to provide information on silvicultural techniques for these species.

Future opportunities

The future of *Cedrela* and *Swietenia* species are not secure since every day more trees of these species are being harvested without control. AFE-COHDEFOR, who are responsible for controlling timber utilisation in Honduras, recognise the need to encourage reforestation with these and other species through the forestry incentives law. It is hoped that in the near future more non-governmental organisation working in the dry zone will conduct practical works of benefit to communities dependent on forest resources.

Priority activities for CONSEFORH are to study management techniques for *Cedrela* and *Swietenia* species and to promote these techniques to interested users. This will be achieved through product identification and the optimisation of silvicultural methods for these products. Testing and evaluation of these species will be carried out through collaboration with non-governmental organisations as a component of its Rural Forestry Promotion program, especially in the central and southern dry zone of the country. This shall improve in situ conservation of species of *Swietenia* and *Cedrela*. Improved seed from seed orchards will be made available to interested organisations.

Recommendations

1. Species of *Cedrela* and *Swietenia* are readily accepted by rural people due to the quality of the products from these trees and their economic value. Consequently, it is important that rural people are encouraged to establish plantations for various products which include species from these two genera.
2. The majority of natural woodlands which include these species are rapidly disappearing and remnants are often isolated trees which at times have undesirable characteristics. Consequently, further attention must be given to the use of material of good genetic quality and seed should be accompanied with as much information as possible about its source, to ensure confidence about the material to be used in future plantations.
3. Through this workshop, a standard format should be developed for the collection of data which will be more precise and facilitate the understanding of *Hypsipyla* attack control in plantations. This could be possible through the creation of an international network about *Meliaceae* in which information and knowledge could be combined and duplication of effort caused through working in isolation avoided.
4. Sources of funding should be secured to support continued applied research work which is vital for improved knowledge about the management of species of *Meliaceae.*
5. Information and advice should be provided to non-government organisations so that they can promote sustainable management of these species.

Acknowledgments

This paper is based on the results of CONSEFORH obtained from its experimental stations and on-farm trials, and through its collaborative activities with the Oxford Forestry Institute. The funding of the Department for International Development (UK) and AFE-COHDEFOR (Honduras) are acknowledged in this respect. The author would also like to thank all the personnel of CONSEFORH for their support and assistance in the production of this paper. In addition, CSIRO are thanked for funding attendance at the workshop and also Caroline Hauxwell for her support and interest in my attendance.

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Within-tree Distribution of Feeding Sites of Larvae of *Hypsipyla robusta (*Moore) (Lepidoptera: Pyralidae)

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Abstract

The feeding sites of larvae of *Hypsipyla robusta* (Moore) on its host *Toona ciliata* M. Roem. varied as the larva aged. Feeding by larvae of the first two instars was mostly found in terminal foliage (buds and unexpanded foliage) or damaged tissues (leaf scars or other damaged areas on the surface of shoots or stems). Pith-feeding (tunnelling) started at later than second instar. On average, a larva initiated feeding in 5.4 different locations during its life time. Switching of feeding sites was most frequent during much of the third and early fourth instar.

HYPSIPYLA ROBUSTA (Moore) (Lepidoptera: Pyralidae) is a shoot borer of Australian red cedar (*Toona ciliata* M. Roem.) and a number of other Meliaceae species in Asia and Africa. Attack by the insect is considered as a major factor restricting the establishment of plantations of these valuable species (Newton et al. 1993). Although primarily a shoot borer, the insect has been reported to feed on various types of host tissues, including flowers and fruits (Beeson 1919), bark (Roberts 1968), and leaves (Beeson 1919). To better understand the feeding behaviour of the insect, a study was made to quantify the distribution of feeding sites of larvae with respect to host tissue types during the course of larval development. The results are presented and discussed in this paper.

Methods

Test trees were two-year-old pot-grown *T. ciliata* maintained under glasshouse conditions which had been previously artificially infested with *H. robusta* and then cut to a height of approximately 30 cm in the previous year. Regrowth was then pruned so that only one shoot was retained for each tree from the coppices. At the start of the experiment, the new shoots had grown to an average height of 122 ± 35 cm and an average basal diameter of 0.65 ± 0.08 cm. Each shoot was allowed to retain eight mature compound leaves, the rest being removed from the bases. Larvae were from a laboratory stock established from mature larvae collected in a *T. ciliata* plantation near Macksville on the north coast of NSW, and maintained on the artificial diet of Couilloud and Guiol (1980).

Fifty test trees were arranged in a 5 × 10 layout in the glasshouse. Spacing was not strictly controlled but care was taken that foliage of neighbouring trees did not touch. One newly hatched first instar larva was introduced onto the shoot stems of each tree with a fine brush. Plants were examined daily between 10:00–12:00 a.m. from day one onwards. Locations and tissue type of new feeding sites, recognised by the presence of new frass, were recorded and then marked with tiny paper labels kept in position by sticky tape and numbered according to the attack sequence (#1, #2, etc.). The frass was carefully removed from the feeding sites with a fine brush, transferred into a plastic jar and air dried. Twenty air-dried frass pellets were randomly selected from each day's frass collection and measured for width under a stereo microscope to the nearest 0.025 mm. The frass-width data were used to estimate the development stages of test larvae at particular dates following introduction as described by Mo and Tanton (1995).

Feeding tissues were grouped into terminal foliage, pith, damaged tissues, and other tissues. Terminal foliage included terminal buds, unex-

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panded or juvenile leaflets and leaf petioles. Feeding at leaf axils was considered as the start of tunnelling, i.e. pith-feeding. This behaviour had been noted previously (Coventry 1899; Anon. 1958) and was supported by personal observations. New frass at tunnel openings on the day of checking, or the day before, was taken as the continuation of pith-feeding. The latter situation was included to take into account the fact that larvae would stop feeding at some stage before and after moulting. Observations ceased when no more new frass was found on any of the test trees. One week later, all test trees were examined thoroughly and shoots dissected to determine the developmental stage of remaining larvae. Data from individual trees were pooled to estimate the proportions of larvae feeding in the different tissue categories.

Results

The development stages of test larvae estimated from frass measurements at days following introduction are shown in Figure 1. The proportions of feeding sites in terminal foliage, pith, damaged tissues and other tissues varied as larval development progressed (Figure 2). Feeding by first instar larvae was exclusively confined to the terminal and damaged tissues, of which damaged tissues were attacked about four times as much as terminal tissues. Among terminal tissues, buds and leaf petioles were most favoured. On only one occasion was a larva found feeding on the surface of a young leaflet. Feeding on damaged tissues was mainly found on leaf scars. The same confinement of feeding activities continued until late second instar, when terminal feeding dropped to zero and feeding in pith through stem tunnelling commenced. No more terminal feeding was observed thereafter.

The period from late second to late fifth instar revealed a steady decrease of the proportion of larvae feeding on damaged tissues (from about 90% to zero) and an increase of the proportion feeding on pith (from zero to about 90%), reflecting a continuing shift from surface feeding to pith feeding. All pith feeding began at leaf axils.

Feeding in other tissues commenced at early third instar and the proportion of larvae feeding on other tissues fluctuated around 20% during the rest of the larval period. Typical ‘other tissue’ locations were epidermis (or bark) of shoots or stems, shoot bases (junctions of shoots and tree stems), and bases of tree stems at the soil level. Coincident with the sudden rise of feeding in other tissues was a sharp drop of the proportion of larvae feeding in pith which occurred early in the sixth instar. Despite the decrease, pith-feeding still accounted for most of the feeding activities (60%). The proportion of larvae feeding in the various tissues stabilised after 48 days of larval development.

Larvae seldom remained at the same feeding locations throughout their development. Larvae initiated feeding at between 3 and 11 (average 5.4) different locations during its life time. When plotted against larval development time, a peak in the number of new feeding sites per larva was evident during the third and early fourth instar (Figure 3).

The length of time that a larva would stay at a particular feeding site differed with the tissue category of the feeding site. The average length of stay was highest in pith (6.8 ± 7.6 days), followed by damaged tissues (4.3 ± 3.6 days), terminal foliage (3.0 ± 2.1 days) and other tissues (2.6 ± 2.0 days). The difference was significant ($p<0.05$, Wilcoxon rank sum test) when pith was compared with any of the other tissue categories. However, most feeding sites were abandoned within one day of feeding initiation (66%, pooled data), regardless of the tissue where feeding took place.

Discussion

It is striking to note that more early-instar larvae were found feeding in damaged tissues than in terminal foliage, considering that the latter has been described as the favourite site for initial feeding (Beeson 1919). The selection of damaged tissues was also observed in the field where young larvae were found inside old, abandoned tunnels or tunnels occupied by mature larvae (personal observations). Feeding in damaged tissues may offer some advantages, such as physical protection and possibly weaker antibiosis reactions from host plants. Early location of suitable feeding sites is of vital importance to newly-hatched larvae. As they did not seem to move far before starting feeding (personal observations), the initial feeding site of these larvae depends very much on the oviposition sites.

The sudden drop in the proportions of pith-feeding larvae early in the sixth instar indicates that a considerable number of larvae left their original tunnels, probably searching for alternative pupation sites. Abandonment of old feeding sites was common in this study and probably resulted from vigorous sap exudation or shoot size being too small (Beeson 1919). It seems that larvae sample a number of locations in the plant before settling down to feed.

As feeding begins outside the plant, changes in the number of new feeding sites per larva per day can be considered as a measure of the changes in the surface activity of larvae. The pattern of the changes suggests that there was a re-emergence of larvae from previously established feeding sites during

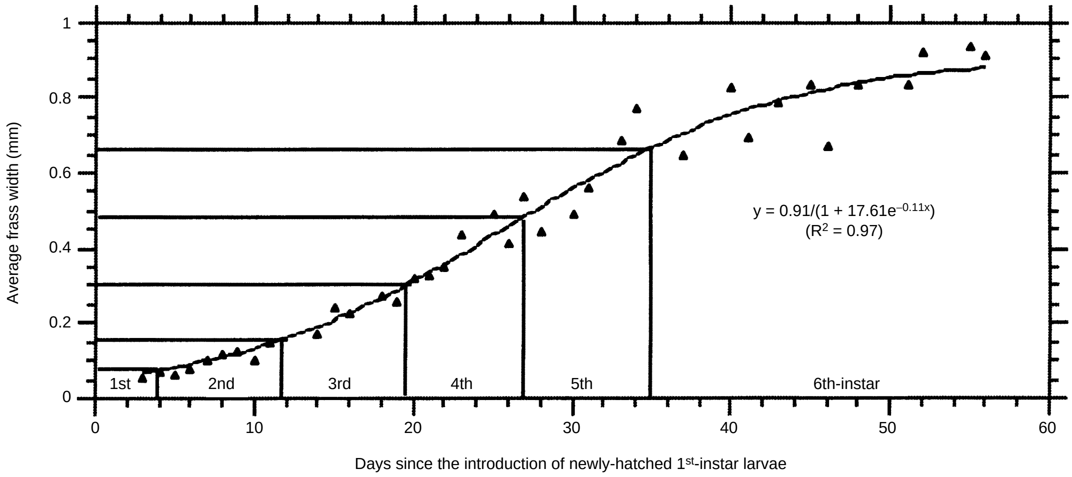

Figure 1. Average width of frass (mm) and the estimated larval instars during the larval development on *T. ciliata*. Divisions between larval instars are taken from Mo and Tanton (1995).

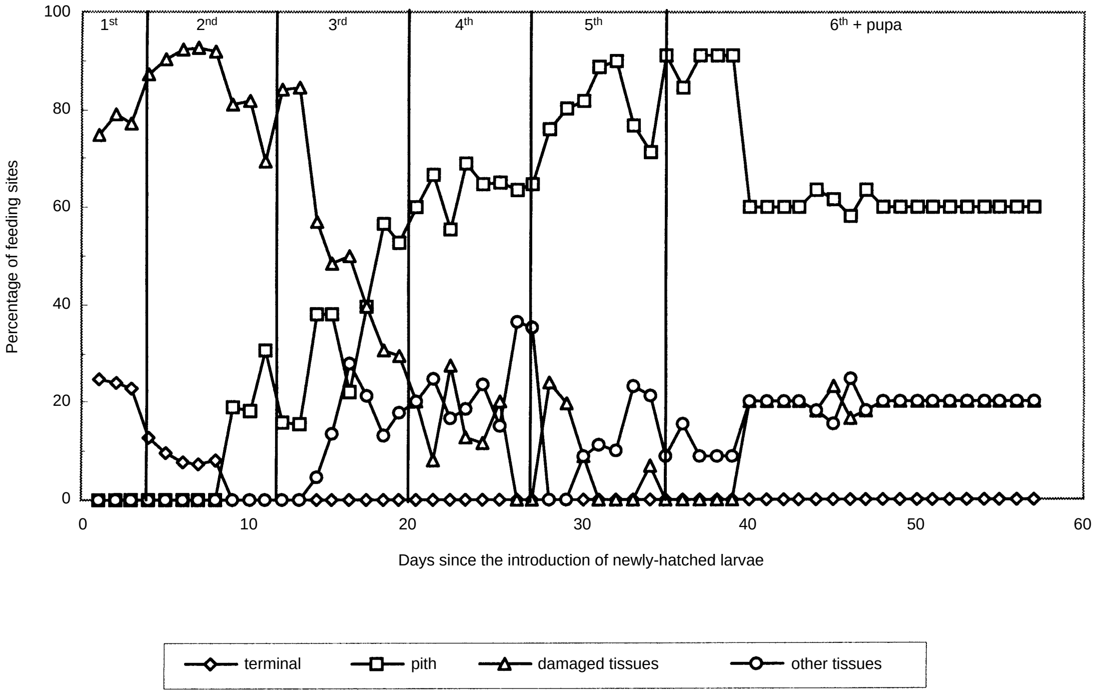

Figure 2. Within-tree distributions of feeding sites with respect to host tissues during the course of larval development on *T. ciliata*.

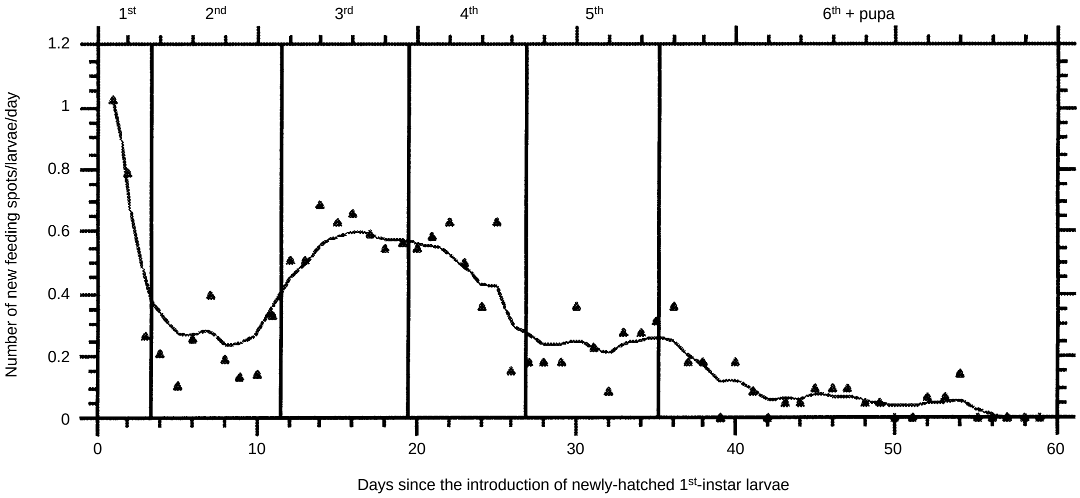

Figure 3. Frequency of occurrence of new feeding sites during the course of larval development on *T. ciliata*.

much of the third and early fourth instar. If the timing of this re-emergence could be predicted, this period may be useful for the application of insecticide.

Acknowledgments

The authors thank Dr Allan Watt of the Institute of Terrestrial Ecology, North Edinburgh Research Station, Scotland, for his comments on the an earlier version of the manuscript.

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Discussion Summary
Host Plant Resistance for Control of *Hypsipyla* spp.

A.D. Watt

ALL SESSION groups felt that the most promising finding was that differences in resistance to shoot borers have been found between different provenances of *Cedrela odorata* and *Swietenia macrophylla.* The other promising findings noted were:

- the possibility that even low levels of resistance could be valuable when integrated with biological control and other methods of control;
- the differences in plant chemistry in different provenances of *C. odorata*, the correlation between proanthocyanidin concentration and resistance, and the consequent potential for selecting resistant plant material on the basis of plant chemistry;
- the apparent relationship between the age of trees and both the susceptibility to attack and its expression in terms of damage;
- the influence of environment (e.g. shade) on resistance;
- the effect of host plant volatiles on adult moth behaviour.

Discussions on priorities for future research centred on the establishment of species and provenance trials of a range of species and in a range of countries and regions to screen for resistance. There was also much discussion on methodology, particularly the need for standardised protocols for damage assessment. Rather than highlight this as a separate priority, it is better to see it as an essential pre-requisite to resistance trials, and, indeed, to other areas of research on *Hypsipyla* spp.

There was also discussion of the use of resistant plant material, particularly the breeding and multiplication of resistant plants and the deployment of resistant trees in different silvicultural systems. Although clearly important areas, they were not seen as immediate priorities because of the present general lack of *Hypsipyla*-resistant plant material. Nevertheless, it is hoped that the multiplication and deployment of resistant *C. odorata* will go ahead in the near future, as resistance in this species currently shows most promise.

Other priority areas for research identified were:

- studies of the biochemical basis of resistance;
- studies of the entomological components of resistance such as the phases of host selection.

One topic not discussed by the workshop groups was the conservation of Meliaceae. This is hardly surprising, given that it is not an entomological matter. However, the development of resistance as a strategy for managing *Hypsipyla* spp. depends upon identifying resistance in natural populations of Meliaceae. Current forestry practices are undoubtedly leading to the genetic erosion of these tree species and, with it, one of the most promising prospects for controlling shoot borers. Thus the development of genetic conservation strategies for Meliaceae must be seen as a priority for research.

Control of *Hypsipyla* spp. Shoot Borers with Chemical Pesticides: a Review

F.R. Wylie[1]

Abstract

Research into the chemical control of *Hypsipyla* spp. shoot borers in Meliaceae now spans about eight decades and has involved more than 23 countries throughout the tropics. Despite this, there is still no chemical or application technology which will provide reliable, cost-effective and environmentally sound protection for any of the high-value meliaceous tree species for the period necessary to produce a marketable stem. Reasons for this relate mainly to the biology of the insects, the nature of their damage, constraints imposed by climate, and the period of protection required. These factors are all interlinked and some of the key aspects are discussed in this paper. A list is provided of 51 chemical pesticides which have been used against *Hypsipyla* spp. in various countries and notes given on their efficacy, drawing both on published and unpublished information. It is concluded that the future role of chemical pesticides in *Hypsipyla* spp. control will continue to be in the protection of nursery stock or as part of a program of integrated pest management.

ATTACK by shoot borers, *Hypsipyla* spp. (Lepidoptera: Pyralidae), has greatly restricted the commercial growing of some high-value timber species belonging to the family Meliaceae (for example, species of *Swietenia, Khaya, Toona, Cedrela*) in many countries. The problem occurs throughout the tropics, particularly where these trees are planted in homogeneous stands (Newton et al. 1993). The two main pest species are *H. grandella* (Zeller) which occurs in Central and South America, the Caribbean and southern Florida, and *H. robusta* (Moore) which is widely distributed throughout West and East Africa, India, Southeast Asia, Australia and parts of the Pacific.

Newton et al. (1993) discuss the prospects for control of *Hypsipyla* spp. and review some of the attempts at chemical control. Generally, these attempts have failed but controlled-release (CR) insecticides showed some promise for use in nurseries or as part of an overall program of integrated pest management. In this paper, the author lists all chemical pesticides, excluding biological insecticides, which have been used against *Hypsipyla* spp. in various countries and provides brief notes on their efficacy, drawing both on published and unpublished information.

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Attempts at Chemical Control of *Hypsipyla* Spp.

Australia

Griffiths *et al.* (these Proceedings) summarised the Australian experience of growing red cedar, *Toona ciliata* Roem., in Queensland and New South Wales. Commercial exploitation of this species has been virtually precluded because of attack by *H. robusta*. The earliest Australian record of an attempt at chemical control of the insect is contained in the Annual Report of the Queensland Forest Service (1921) where it is mentioned that the application of sulfur around the roots of nursery trees was not successful. Major insecticide trials against the pest in Queensland commenced in 1952. Early work was with contact and stomach poisons such as DDT, endrin, lead arsenate and lindane, and was often compromised by logistical problems. In the north, the period of heaviest infestation coincided with the wet season, and the rain often rendered contact sprays ineffective. In southern Queensland, reasonable to good control of *H. robusta* was obtained with DDT and endrin but frequent spraying was required (every one or two weeks). Trials with systemic insecticides commenced in 1967. Monocrotophos and azinphos methyl offered some control but phorate and dimethoate were ineffective. Trials with controlled release carbofuran were also disappointing. A small-scale trial in New South Wales in 1990, which involved stem injection of phosphamidon, was reportedly successful in reducing incidence of attack (P. Hadlington pers. comm.).

Bangladesh

For control of *H. robusta*, Baksha (1990) recommended the use of dicrotophos as a foliar spray, or carbofuran granules applied to the soil around the base of each tree.

Brazil

Maués (these Proceedings) reported that attempts have been made at chemical control but none have been successful.

China

In Hainan Province, laboratory feeding trials were conducted using shoots treated with carbaryl, phoxim, acephate and chlordimeform. The first three chemicals listed caused larval mortality of 90–100% and were then used in field trials along with carbofuran. The insecticides were applied to the shoots with a brush. Carbaryl was the most effective in protecting against attack by *H. robusta* (Gu and Liu 1984).

Costa Rica

Considerable research has been conducted in this country on chemical control of *H. grandella*. In laboratory and greenhouse trials at Turrialba, Allan et al. (1970) screened 28 systemic insecticides (Table 1), comparing their translocation properties in young *Cedrela odorata* L., toxicity to *H. grandella* larvae and phytotoxicity to the plant after soil application. The best combinations of pest control and lack of acute phytotoxicity were exhibited, in decreasing order, by carbofuran, methomyl, Isolan, phosphamidon and monocrotophos (Allan et al. 1973, 1974). Controlled release formulations of these five were then tested in the field, being applied in pelleted form at planting (Wilkins et al. 1976). Carbofuran was found to be the most effective, and at one site gave complete control for 340 days. Treated trees also had lower mortality and higher growth rates than untreated trees. In a separate trial, non-CR formulations of aldicarb and carbofuran applied to soil gave only short-term protection to *Swietenia macrophylla* King against *H. grandella* attack (Allan et al. 1975).

Cuba

Manso (1974) reported that solutions of DDT + trichlorphon, and of trichlorphon + carbaryl gave the best results in controlling *H. grandella* in plantations of *C. odorata* and *S. macrophylla*. The effectiveness of fenitrothion, omethoate and pirimiphos-methyl for the control of *H. grandella* attacking *C. odorata* in nurseries was tested by Berrios et al. (1987). Trichlorphon was included in the trial for comparison. The most effective control was provided by pirimiphos-methyl. Duarte Casanova (these Proceedings) suggested that a system of integrated pest management involving the use of mixed plantations and opportune applications of the entomopathogen *Beauveria bassiana* (Balsamo) Vuillemin with sublethal doses of pirimiphos-methyl and trichlorphon can maintain a reasonably low population of *H. grandella*.

Ghana

According to Wagner et al. (1991), attempts to control *H. robusta* with systemic insecticides have been only partially successful. They recommend brushing dicrotophos onto affected parts.

Honduras

Queensland Forest Service unpublished reports indicate that sodium selenate was trialed against *H. grandella* in Honduras prior to 1955.

India

According to Lamb (1968), the use of sacking impregnated with insecticide was recommended for the control of *H. robusta* in India. Recently, spot applications of selected organophosphate insecticides such as dimethoate and phosphamidon have been trialed in young plantations of *S. macrophylla*. Logistical problems have been experienced with these trials but preliminary results indicate that phosphamidon killed larvae in treated plants within 48 hours and dimethoate within 72 hours (Mohanadas and Varma, these Proceedings).

Indonesia

Trials with several systemic organophosphate insecticides have been conducted and have been more effective in reducing *H. robusta* attack on *S. macrophylla* than have measures such as pruning of infested shoots, mixed plantings and closer spacing of trees (Rachmatsjah and Wylie, these Proceedings).

Table 1. List of the insecticides used in attempts to control *Hypsipyla* spp. in the various countries, together with details of their classification, mode of action and the type of trial in which they were used. Common names are according to Thomson (1989). The names in parenthesis are those used in some of the source documents. The abbreviations used for trial types are: L = laboratory, G = greenhouse, N = nursery, P = plantation.

Common name	Insecticide class	Mode of action	Countries where used	Trial types	Tree species in trials
Acephate (orthene)	Organophosphate	Contact & systemic	China, Surinam, Solomon Islands	L,N,P	*Carapa guianensis* Aubl., *Chukrasia tabularis* A. Juss., *Swietenia macrophylla* King
Aldicarb	Carbamate	Systemic	Costa Rica, Papua New Guinea	G,P	*S. macrophylla*, *Toona ciliata* Roem.
Aldrin	Organochlorine	Contact & stomach	Venezuela	P	*Cedrela odorata* L.
Aminocarb	Carbamate	Contact, stomach & systemic	Costa Rica	G	*C. odorata*
Azadirachtin	Botanical	Antifeedant, insect growth regulator	United States of America	G	*Swietenia mahagoni* Jacq.
Azinphos methyl (Gusathion)	Organophosphate	Stomach & contact	Australia	P	*T. ciliata*
Carbaryl (Sevin)	Carbamate	Contact, stomach & slight systemic	China, Cuba	L,P	*C. odorata*, *C. tabularis*
Carbofuran (Furadan)	Carbamate	Systemic & contact	Australia, Bangladesh, China, Costa Rica, Ivory Coast, Papua New Guinea, Puerto Rico, Trinidad, Virgin Islands	G,L,N,P	*C. odorata*, *C. tabularis*, *Khaya* spp., *S. macrophylla*, *T. ciliata*
Chlordimeform (Fundal)	Organochlorine	Contact	China	L	*C. tabularis*
Cyfluthrin (Laser)	Pyrethroid	Contact & stomach	Pakistan	L	*T. ciliata*
Demeton	Organophosphate	Contact & systemic	Costa Rica	G	*C. odorata*
DDT (rulene)	Organochlorine	Stomach & contact	Australia, Cuba, Malaysia, Peru, Venezuela	N,P	*C. odorata*, *S. macrophylla*, *T. ciliata*
DDVP	Organophosphate	Fumigant, stomach & contact	Pakistan	L	*T. ciliata*
Dicrotophos (Bidrin)	Organophosphate	Contact & systemic	Costa Rica, Ghana	G,P	*C. odorata*, *C. tabularis*, *Khaya* spp., *S. macrophylla*, *T. ciliata*
Dieldrin	Organochlorine	Contact & stomach	Australia, Ivory Coast, Malaysia	N,P	*Khaya* spp., *T. ciliata*, *S. macrophylla*
Dimethoate (Rogor)	Organophosphate	Contact & systemic	Australia, Costa Rica, India, Papua New Guinea	G,P	*C. odorata*, *T. ciliata*, *S. macrophylla*
Dimetalan	Carbamate	Contact & systemic	Costa Rica	G	*C. odorata*
Disulfoton	Organophosphate	Systemic	Costa Rica, Ivory Coast	G,N	*C. odorata*, *Khaya* spp.
Endrin	Organochlorine	Contact & stomach	Australia, Venezuela	P	*C. odorata*, *T. ciliata*
Fenchlorphos	Organophosphate	Systemic	Costa Rica	G	*C. odorata*
Fenitrothion (Sumithion)	Organophosphate	Stomach & contact	Cuba	N	*C. odorata*
Fensulfothion	Organophosphate	Contact & systemic	Costa Rica	G	*C. odorata*
Fenthion	Organophosphate	Contact, stomach & systemic	Costa Rica	G	*C. odorata*
I-12	Organophosphate	Systemic	Costa Rica	G	*C. odorata*

Table 1. Cont. List of the insecticides used in attempts to control *Hypsipyla* spp. in the various countries, together with details of their classification, mode of action and the type of trial in which they were used. Common names are according to Thomson (1989). The names in parenthesis are those used in some of the source documents. The abbreviations used for trial types are: L = laboratory, G = greenhouse, N = nursery, P = plantation.

Common name	Insecticide class	Mode of action	Countries where used	Trial types	Tree species in trials
I-19	Organotin	Systemic	Costa Rica	G	*C. odorata*
Isolan	Carbamate	Systemic	Costa Rica, Papua New Guinea	G,P	*C. odorata*, *T. ciliata*
Lead arsenate	Inorganic arsenical	Stomach	Australia, Peru	N,P	*T. ciliata*
Lindane (BHC)	Organochlorine	Stomach, contact & fumigant	Australia	P	*T. ciliata*
Malathion	Organophosphate	Contact	Pakistan	L	*T. ciliata*
Menazon	Organophosphate	Systemic	Costa Rica	G	*C. odorata*
Mephosfolan (Cytrolane)	Organophosphate	Contact, stomach & systemic	Costa Rica	G	*C. odorata*
Methamidophos (Monitor)	Organophosphate	Systemic	Costa Rica	G	*C. odorata*
Methidathion (Ultracide)	Organophosphate	Contact & stomach	Ivory Coast	N	*Khaya* spp.
Methocrotophos (C 2307)	Organophosphate	Systemic	Costa Rica	G	*C. odorata*
Methomyl	Carbamate	Contact & systemic	Costa Rica, Ivory Coast	G,P	*C. odorata, Khaya* spp.
Monocrotophos (Azodrin)	Organophosphate	Systemic & contact	Australia, Costa Rica, Ivory Coast	G,P	*C. odorata, Khaya* spp., *T. ciliata*
Omethoate (Folimat)	Organophosphate	Systemic	Cuba	N	*C. odorata*
Oxydemeton-methyl (Metasystox)	Organophosphate	Systemic & contact	Costa Rica, Venezuela	G,P	*C. odorata*
Parathion	Organophosphate	Contact & stomach	Ivory Coast, Peru, Venezuela	N,P	*C. odorata, Khaya* spp.
Phenamiphos (Bay 68138)	Organophosphate	Systemic & contact	Costa Rica	G	*C. odorata*
Phorate (Thimet)	Organophosphate	Contact, systemic & fumigant	Australia, Costa Rica, Ivory Coast	G,N,P	*C. odorata, Khaya* spp., *S. macrophylla, T. ciliata*
Phospholan (Cyolane)	Organophosphate	Contact, stomach & systemic	Costa Rica	G	*C. odorata*
Phosphamidon	Organophosphate	Systemic & contact	Australia, Costa Rica, India, Papua New Guinea	G,P	*C. odorata*, *T. ciliata*, *S. macrophylla*
Phoxim (Baythion)	Organophosphate	Contact & stomach	China	L,P	*C. tabularis*
Pirimicarb (Pirimor)	Carbamate	Contact, fumigant & systemic	Costa Rica	G	*C. odorata*
Pirimiphos-methyl (Actellic)	Organophosphate	Contact	Cuba	N	*C. odorata*
Propoxur (aprocarb)	Carbamate	Contact, fumigant & systemic	Costa Rica, Papua New Guinea	G,P	*C. odorata*, *T. ciliata*
Schradan	Organophosphate	Systemic	Costa Rica	G	*C. odorata*
Sodium selenate	Inorganic	Systemic	Honduras		
Sulfur	Inorganic	Fungicide, acaricide	Australia	N	*T. ciliata*
Trichlorphon (Dipterex)	Organophosphate	Contact, stomach & systemic	Costa Rica, Cuba, Papua New Guinea	G,N,P	*C. odorata*, *S. macrophylla*, *T. ciliata*

Ivory Coast

Brunck and Fabre (1974) and Brunck and Mallet (1993) report on a series of insecticide trials conducted between 1963 and 1983 seeking to prevent or reduce attacks by *H. robusta* on *Khaya* spp. in nurseries and in the field. Spray treatments of dieldrin, disulfoton, methidathion, parathion and phorate were tested as well as soil applications (including CR formulations) of carbofuran, methomyl and monocrotophos. Spraying with methidathion gave good results in nurseries but was not sufficiently persistent for plantation treatment. Systemic insecticides mixed with slow-release resins did not give positive results either by bark applications or soil incorporation.

Malaysia

A 1958 report of the Food and Agriculture Organisation mentions that DDT solutions have been used in nurseries in Malaysia for control of shoot borers. Khoo (these Proceedings) stated that attempts in 1958 to control *H. robusta* by dieldrin were unsuccessful.

Nigeria

Roberts (1968) mentioned that control of *H. robusta* using insecticides did not seem possible due to the hidden location of the larva, the number of hosts available for attack, and the widespread distribution of the pest.

Pakistan

In a laboratory trial against *H. robusta* boring in fruits of *T. ciliata*, solutions of DDVP, cyfluthrin and malathion were sprayed onto immature fruits. DDVP gave 100% kill of larvae but malathion showed poor results (Wali-Ur-Rehman 1993).

Papua New Guinea

In 1975, 25 organophosphate and carbamate insecticides were screened for their systemic activity in young *T. ciliata* averaging 45 cm in height. This work was organised by Professor G.G. Allan and paralleled that conducted in Costa Rica. The highly systemic insecticides were aldicarb, dimethoate, Isolan, phosphamidon, propoxur and trichlorphon (Dobunaba and Kosi, these Proceedings). In these trials, good results against *H. robusta* were reported for CR formulations of propoxur, carbofuran and trichlorphon (Griffiths, these Proceedings), and some treatments provided protection for several months (J. Dobunaba pers. comm.).

Peru

Trials were conducted with lead arsenate, DDT and parathion applied at two-weekly intervals. Parathion was more effective than DDT or lead arsenate, but none of these chemicals gave more than partial control. The trials were abandoned as a result of a low success rate and high costs (Dourojeanni 1963; Newton et al. 1993).

Puerto Rico

Weaver and Bauer (1986) stated that chemical control is most easily accomplished in the nursery phase but do not name a specific pesticide. Wilkins et al. (1976) in the conclusion to their paper mentioned that trials with longer lived carbofuran formulations based on a biodegradable matrix were underway in Puerto Rico and other locations.

Solomon Islands

In the nursery, spraying of seedlings of *S. macrophylla* with acephate has been effective in controlling attack by *H. robusta*, but chemical application is regarded as too expensive for use in the field situation (Ngoro, these Proceedings).

Surinam

Treatment of plantations of *Carapa guianensis* Aubl. of age two to five years with acephate reduced damage by *H. grandella* (Gonzalez et al. 1991).

Trinidad

Ramnarine (1992) reports that a polymer preparation of carbofuran was completely ineffective in controlling *H. grandella* attack.

United States of America

Spraying with azadirachtin, an antifeedant or insect growth regulator extracted from the seed of the neem tree *Azadirachta indica* A. Juss., reduced damage by *H. grandella* in *Swietenia mahagoni* Jacq. in Florida (Howard 1995).

Venezuela

Ramirez Sanchez (1966) tested sprays of DDT, metasystox, endrin, aldrin, parathion and combinations of these insecticides against *H. grandella* in young plantations of *C. odorata*. Little difference was observed between the insecticides used, but 2–3 applications were required every six weeks during the oviposition period because frequent and heavy rains as well as the high evapotranspiration shortened the period of effectiveness of the insecticides.

This was impractical on economic and ecological grounds (Newton et al. 1993).

Virgin Islands

Wilkins et al. (1976) in the conclusion to their paper mentioned that trials with longer-lived carbofuran combinations based on a biodegradable matrix were underway in St. Croix and other locations.

Discussion

Research into the chemical control of *Hypsipyla* spp. in Meliaceae now spans about eight decades and has involved more than 23 countries throughout the tropics. Despite this, we still do not have a chemical or an application technology that will provide reliable, cost-effective and environmentally sound protection for any of the high-value meliaceous tree species for the period necessary to produce a marketable stem.

Reasons for this relate mainly to the biology of the insect, the nature of its damage, constraints imposed by climate, and the period of protection required. These are all interlinked, and some of the key aspects are outlined below.

- The life cycle of these insects can be very short (4–6 weeks), they are multivoltine and generations often overlap. While the level of pest activity may fluctuate throughout the year it does not entirely cease, and continuous protection is required to completely prevent attack.
- Once the larva commences tunnelling, it is then physically inaccessible to contact insecticides, but may be susceptible to systemic insecticides.
- In many countries, populations of *Hypsipyla* spp. reach a maximum at the start of the wet season (e.g. Griffiths, these Proceedings; Roberts 1968). Heavy rainfall and high temperatures will quickly diminish the effectiveness of protection provided by contact insecticides.
- Systemic insecticides, such as some of the carbamates and organophosphates, have been more effective and persistent than contact insecticides. However, both classes of these compounds are readily biodegradable in tropical conditions, and conventional formulations have usually lasted only 20–30 days (Allan et al. 1976).
- It sometimes only requires a small amount of damage by a single larva to the leading shoot to badly affect the growth and form of the tree (Allan et al. 1970, 1975). The level of tolerance of attack to the terminal shoot of some species is therefore effectively zero, hence the need for constant protection.
- For most of the meliaceous tree species being grown commercially, protection against *Hypsipyla* spp. is required for about 3–5 years until the tree produces a merchantable bole (for *T. ciliata* in Australia this is considered to be 6 m of straight stem). Multiple applications of conventional insecticides would be required to achieve this. Amounts applied are usually greatly in excess of what is required to control the pest because of the need to compensate for pesticide loss by leaching and evaporation (Allan et al. 1971). Such constant and heavy usage of pesticides is both environmentally and commercially unacceptable.

Because of these various constraints, the development of controlled-release insecticide formulations in the late 1960s offered a promise of a solution to the problem. The concept, as described by Allan et al. (1974), is an insecticide-polymer combination capable of slowly releasing the systemic, non-persistent, biodegradable ingredient into the root zone of the plant for prolonged periods. In the calculation of release rates, a balance must be achieved between ensuring longevity of the product, maintaining an internal pesticide concentration in the plant sufficiently high to kill any intruding larva quickly, and avoiding phytotoxicity. A CR formulation of carbofuran performed well initially in Costa Rica, at one site giving complete control for 340 days (Wilkins et al. 1976). However, trials in some other countries (e.g. Australia, Trinidad) with this product have not been as successful (e.g. Ramnarine 1992, Queensland Department of Primary Industries unpublished data).

Development work by chemical companies has continued and CR carbofuran has been tested against the large pine weevil *Hylobius abietis* L. attacking young Douglas firs, *Pseudotsuga menziesii* Mirb., in the United States of America. High levels of this product in the plant were observed after 24 months (Mrlina et al. 1994). The continued future use of CR carbofuran in the USA is under review by the Environmental Protection Authority because of instances of toxicity to bird associated with application of granules in corn crops.

Another systemic carbamate compound, carbosulfan, is being widely tested in CR formulation, mainly against termites in Africa and Asia (Canty and Harrison 1990) but also against Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) in the USA and is showing good results (Peter May, Crop Care Australasia, pers. comm.). However, the maximum effective life of the product so far achieved is two years.

A shortcoming in the use of systemic toxicants, which may be critical in the case of *Hypsipyla* spp., is that the insect is able to damage physically the plant before the toxicant takes effect. Current work by D. Spolc in Australia on *T. ciliata* suggests that even the slightest damage to the leading shoot causes change in growth patterns which can result in deformation. From this viewpoint, an antifeedant would be preferable to a delayed-action toxicant.

Thus, the role of chemical insecticides in the control of *Hypsipyla* spp. remains, as suggested by Newton et al. (1993), an interim measure for protecting plants in the nursery or as part of an overall programme of integrated pest management in the field.

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Semiochemicals of *Hypsipyla* Shoot Borers

T. Bellas[1]

Abstract

Very little is known of the volatile components of the sex pheromone glands of *Hypsipyla robusta* (Moore) and *H. grandella* Zeller. Three components were identified in secretions from *H. robusta* from a culture in France which was originally collected in West Africa. Since *H. robusta* has such a wide and discontinuous geographical distribution, it is important to determine the pheromone composition from a range of locations. Preliminary studies on Australian populations of *H. robusta* have shown the presence of the same compounds but in different ratios. Some other unknown compounds were also detected in these studies. Three compounds have been identified from the ovipositor tip of *H. grandella* but none of them is the same as recorded from *H. robusta*. The remarkable ability of *Hypsipyla* to locate isolated and distant host trees suggests that chemoreception is probably very well developed and important in the insect's behaviour.

INVESTIGATIONS of the volatile components of the sex pheromone glands of *Hypsipyla robusta* (Moore) and *H. grandella* Zeller have been conducted.

Bosson and Gallois (1982) identified three components of the secretion of *H. robusta*. The insects in this study were from a laboratory culture at Montpellier originating in West Africa (Couilloud and Guiol 1980). This paper foreshadowed a field study in West Africa to determine the composition of the attractive mixture but no further publication has appeared on this topic.

The distribution map of *H. robusta* (Commonwealth Institute of Entomology 1983) shows that the species occurs in West and East Africa, Malagasy, South and Southeast Asia, Papua New Guinea and Australia, in some cases with substantial distances between populations. This discontinuous distribution makes it essential to check on the composition of the pheromone in the various populations since it could be that there are differences at the various localities as has been observed for other species, e.g. *Homona coffearia* (Nietner) (Whittle et al. 1987).

A preliminary study of the Australian insects has shown that the three components identified by Bosson and Gallois (1982) are present. The ratios of these three compounds differ from those found in France but, because only five moths have been studied, it is not known whether this difference is significant. Further analyses need to be done, and behavioural and field tests will have to be conducted to establish the optimum composition and dose for lures. There are other components present in the Australian insects but these have not been identified nor is it known whether they play any role in the sex pheromone.

Three compounds have been identified from the ovipositor tips of *H. grandella* (Borek et al. 1991) none of which is the same as any of the three compounds reported in *H. robusta*. However, one of the compounds in *H. grandella* is the alcohol corresponding to Z9, E12-tetradecadienyl acetate which is the major component in *H. robusta*.

H. robusta is remarkably adept at locating its Australian host, *Toona ciliata* M. Roem., and it is likely that chemoreception will be found to play an important role in this ability. To date there have been no studies published on this. Fieldwork in Puerto Rico has shown that *H. grandella* distinguishes between young and mature foliage of *Cedrela odorata* L. and that an acetone extract of the young leaves contains some active material (Gara et al. 1972). None of the compounds responsible for the activity have been identified.

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Discussion Summary
Chemical Control and Pheromones of *Hypsipyla* spp.

F.R. Wylie

AMONG the most promising findings were the apparent differences in the composition of the pheromones in various populations of *Hypsipyla robusta*, and between *H. robusta* and *H. grandella*. This could have important implications for the taxonomy of *H. robusta* given the disjunct distribution of the species in West and East Africa, South and Southeast Asia, Australia and the Pacific. Pheromones were seen as potentially useful tools for monitoring seasonal occurrence of the pests, although further work will be required to establish the optimum composition and dose for lures.

The remarkable ability of *Hypsipyla* spp. to locate isolated and distant host trees was also a focus of discussion. It is likely that chemoreception is very well developed in these insects, and it may be possible to use volatiles from the tips of host trees to attract and trap moths.

It was generally accepted that the use of chemical pesticides alone was unlikely to solve the shoot borer problem, but that they still had a role in nurseries and in integrated pest management programs. There are several new-generation compounds available commercially which may merit testing against *Hypsipyla,* particularly in combination with controlled-release formulations. Two such compounds suggested were imidocloprid and fipronil, which has contact and systemic action. In addition, further research was recommended on the use of antifeedants and of natural plant compounds.

Apart from the vagaries of climate, insect behaviour and equipment failure, factors which characterised much of the work on chemical control of *Hypsipyla* around the world, there has also been a lack of uniformity in screening procedures. The wide range of formulations and application techniques used, the different methods of assessing attack severity and chemical efficacy, and the lack of controls has made comparisons between trials very difficult. In future chemical trials, standardisation of methods of testing, assessing and reporting is essential. Determining the economic threshold level for *Hypsipyla* attack in stands will also aid in decision-making on the use of chemical pesticides.

The main research priorities relating to chemical control and pheromones, as identified in this Workshop, are:

- determination of economic threshold levels for *Hypsipyla* damage in stands;
- screening of new biologically active compounds/formulations against *Hypsipyla* including antifeedants and natural plant compounds, particularly in controlled-release formulations in nurseries and plantations;
- identification of ovipositional stimuli and investigation of the role of chemoreception in *Hypsipyla* spp.;
- investigation of pheromone differences (component and ratios) between and within *Hypsipyla* spp. as taxonomic tools or for monitoring populations;
- development of standard procedures for screening pesticides against *Hypsipyla* spp.

Prospects for Biological Control of *Hypsipyla* spp. with Insect Agents

D.P.A. Sands[1] and S.T. Murphy[2]

Abstract

Agents for classical biological control of exotic arthropod pests are usually selected from natural enemies developing on a pest species, or on hosts closely-related to the pest species in their native range. When a native pest is not controlled by its complex of natural enemies, other enemies from related exotic species may be effective when introduced and freed of their own natural enemies. The two stem borers, *Hypsipyla robusta* (Moore) and *H. grandella* (Zeller), are pests of Meliaceae in their respective native ranges where damage often exceeds acceptable levels. Among insect natural enemies such as parasitoids, some may be sufficiently host specific to the genus *Hypsipyla* to be acceptable for introduction from one country into another, as biological control agents for related *Hypsipyla* sp. Previous attempts at biological control of *Hypsipyla* spp. have not been successful. The generalist egg parasitoid, *Trichogramma minutum* Riley failed to control *H. robusta* when transferred from the same host and released in Madras, India. Several parasitoids of *H. robusta* from India were released in the Caribbean against *H. grandella* including *Anthocephalus renalis* Wtstn., *Tetrastichus spirabilis* Wtstn., *Phanerotoma* sp., *Trichogrammatoidea nana* (Zehnt.) and *Tr. robusta* Nagaraja but only *Tr. nana* and *Tr. robusta* established in Trinidad. Many natural enemies of *Hypsipyla* spp. are related to biological control agents effective against other lepidopterous pests. For example, species of *Apanteles*, *Cotesia* and *Dolichogenidea* (Hymenoptera: Braconidae) are recorded attacking *Hypsipyla* spp. Several of these and other parasitoid groups are potentialIy valuable agents if freed of their native natural enemies. To be eligible as exotic agents, natural enemies considered for introduction must be sufficiently host specific to avoid any undesirable impact on beneficial or non-target native species. Inundative releases of native parasitoids, though the methods may lead to control, are unlikely to be economically viable for *Hypsipyla* spp. The insects as natural enemies of *Hypsipyla* spp. and constraints for their use as classical or inundative biological control agents are discussed.

THE LARVAE of two species of *Hypsipyla* Ragonot (Pyralidae:Phycitinae), *H. robusta* (Moore) from Australia, parts of the Pacific region, Southeast Asia, India and Africa, and *H. grandella* (Zeller) from southern North America, the Caribbean, Central and South America, are serious forestry pests in plantations of a number of species of Meliaceae. The related moths, *H. albipartalis* (Hampson) and *H. ereboneura* Meyrick from Africa (Bradley 1968; Rao and Bennett 1969) and *H. ferrealis* (Hampson) from the Americas and Trinidad (Bennett and Yaseen 1972) are also recorded as pests. Damage is caused when larvae tunnel into the younger stems, particularly the leading shoot of young trees. Terminal shoots may be weakened, their growth is retarded or even die, which may stimulate lateral stem growth and subsequently limit the length of the bole for production of quality timber. In Nigeria, Roberts (1966) reported that *Hypsipyla* spp. also caused damage when larvae tunnelled into the cambium and bark.

Though *H. robusta* and *H. grandella* (hereafter referred to as *Hypsipyla* spp.) are attacked by a range of arthropod natural enemies (Rao and Bennett 1969), these do not reduce the larval abundance and hence damage to acceptable levels in plantations of Meliaceae. Attempts to control *H. grandella* in the Caribbean by introducing parasitoids of *H. robusta* from India have not been very successful (Yaseen 1984).

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We list the recorded insect natural enemies of *Hypisipyla* spp. and the parasitoids utilised in biological control attempts. Difficulties likely to be encountered when selecting exotic agents for biological control of *Hypsipyla* spp. in their native ranges are also addressed.

The natural enemies of *Hypsipyla* spp. as biological control agents

Many diverse groups of parasitoids have been recorded from the immature stages of *Hypsipyla* spp. (Tables 1 and 2). Families of egg parasitoids are not well represented which may be a reflection of the difficulties in recovering eggs rather than their restricted representation. Moreover, the necessary levels of parasitisation generally required by egg parasitoids to achieve control have not been reported. Egg parasitoids of *Hypsipyla* spp. include two well known genera, *Trichogramma* and *Trichogrammatoidea*, which contain species utilised against other pests in both inundative as well as classical biological control programs. *Trichogramma* spp. are inclined to have a broader host range than other genera of egg parasitoids and are therefore less responsive to changes in density of their hosts when in classical biological control programs where sustained impact on the host is required. Several egg parasitoid taxa including Encyrtidae (e.g. *Ooencyrtus* spp.) and Scelionidae (e.g. *Telenomus* spp.) which are usually important natural enemies of other Lepidoptera, have not been recorded from *Hypsipyla* spp.

Recorded parasitoids of larvae of *Hypsipyla* spp. include Braconidae and Ichneumonidae with effective representatives in genera known as agents for other pests. Similarly, the Tachinidae are well represented but most are likely to have a broad host range and therefore, unsuitable for classical biological control of *Hypsipyla* spp. The families Eulophidae and Eupelmidae include known effective primary parasitoids for other Lepidoptera but both also contain hyperparasitoids, some of which attack beneficial Braconidae and Chalcidae. Most Chalcidae are pupal parasitoids and are not sufficiently restricted in their host range but some species may prove to be relatively specific and effective.

None of the general predators listed are likely to be suitable as classical biological agents for introduction against *Hypsipyla* spp. but the effectiveness of certain indigenous species may be enhanced by manipulation, for example, by encouraging or establishing in plantations, colonies of ant species (e.g. *Oecophylla* spp., *Anoplolepis* spp.) already present in some countries (e.g. Malaysia).

The natural enemies of *Hypsipyla* spp. reveal diverse (taxonomically) and species-rich communities. This is especially so in India although the greater number of species recorded in this region may reflect the sampling effort for locating biological control agents, as suggested by Newton et al. (1993). In addition, early studies on natural enemies have indicated that some species may have a significant impact on their hosts. For example, Rao and Bennett (1969) report a peak percentage parasitism of approximately 20% due to larval hymenopterous parasitoids and 45% due to pupal parasitoids of *H. robusta*.

Previous biological control programs for *Hypsipyla* spp.

Attempts at biological control of *Hypsipyla* spp. commenced in the late 1930s (Beeson 1938). Given that the target of these projects are native pests, the majority of early efforts were directed at enriching natural enemy communities by the introduction of biological control agents. The agents utilised in these attempts were insect parasitoids because of their relatively narrow host specificity. However, more recent biological control projects have focused on the augmentation of either exotic or native microbial agents (Hidalgo-Salvatierra 1976).

Classical biological control projects

The first of these projects was set up in 1968 for the control of *H. grandella* in Trinidad and Tobago by introducing insect parasitoids of *H. robusta* from India. This project was followed by others for other countries in the Caribbean and also in Central and South America. Most of this work was reviewed by Cock (1985). Introductions of parasitoids of *H. robusta* from India continued until the early 1980s. All collections, exports and shipment of natural enemies were undertaken by the International Institute of Biological Control (IIBC) from its former station in Bangalore. Parasitoids were further reared for distribution at IIBC's Caribbean and Latin America station (CLAS) in Trinidad. The parasitoids that were successfully received, distributed and released are shown in Table 3.

Trichogrammatoidea robusta Nagaraja and *Phanerotoma* sp. were both successfully reared in large numbers at the IIBC CLAS using as hosts, eggs of the stored product moth, *Corcyra cephalonica* (Stainton) (Bennett 1973). The pupal parasitoids were reared directly on *H. grandella* pupae in cocoons in relatively large numbers. The numbers released in each country are unknown but in most cases, direct field releases were made from the shipments (M.W. Cock, pers. comm.). The IIBC Indian station also sent to Trinidad at the same time, several other parasitoid species but these either died in transit or could not be

Table 1. Insect natural enemies of *Hypsipyla robusta* (Moore).

Natural enemy	Host Stage[1]	Country	References
PARASITOIDS			
Hymenoptera			
Bethylidae			
Rhabdepyris zeae Turner	P	India	34
Braconidae			
Bracon sp.	L	India	34
Bracon sp. nr. *welleburgensis* Wlkn.	L	Ivory Coast	13
? *Campyloneurus* sp.	L	India	34
Dolichogenidea hypsipylae (Wlkn.)	L (diapause)	India	6,34,39
Apanteles leptoura (Cam.)	L	India	10,11,34,42
Cotesia ruficrus (Haliday)	L(IV)	India, Australia,Sudan, Taiwan, Sri Lanka	6,34,39
Apanteles taragamae Viereck	L	India	34
Cotesia sp. (nr. *anthelae* Wlkn.)	L	India	34
Apanteles sp. (nr. *puera* Wlkn.)	L	India	10,11,34,42
Apanteles sp.	L	Ivory Coast	13
Apanteles sp. (*ater* group)	L	India	34
Dolichogenidea sp. (*glomeratus* group)	L	India	34
Dolichogenidea sp. (*laevigatus* group)	L	India	34
Dolichogenidea sp. (*ultor* group)	L	India	34
Glyptapanteles sp. (*vitripennis* group)	L	India	10,11,34,42
Macrocentrius sp. (*linearis* group)	L	Nigeria, Ghana	35,36,40
Meteoridea sp. ? *hutsoni* Nixon	L	India	34
Microgaster sp.	L	Ivory Coast	12
Protomicroplitis austrina Wlkn.	L	Ivory Coast	13
Protomicroplitis sp.	L	Ivory Coast, Ghana	12,40
Phanerotoma hendecasisella Cameron*	E/L	India	4,5,10,34
Phanerotoma sp.	E/L	India	10,11,34,42
Dioichogaster sp. (*spretus* group)	L	Nigeria, Ghana	35,36
D. austrina Wilkinson	L	Ivory Coast	13
Undetermined	L	India	3
Undetermined	L	Australia	19
Undetermined	L	Australia	19
Undetermined	L	Australia	19
Undetermined	L	Australia	19
Chalcididae			
Antrocephalus destructor Wtstn.	P	India, Australia	14,34,39
A. renalis Wtstn.	P	India	10,11,34,39,42
Antrocephalus sp.	P	India	34
Antrocephalus sp.	P	Australia	19
Brachymeria euploeae Westwood*	P	India	4,5,34
B. hearseyi xanthoterus Wtstn.	P	India, Australia	14,34,39
B. tachardiae Cameron	P	India, Australia	14,34,39
Dirhinus sp.	P	India	34
Eucepsis sp.	P	India	34
Eucepsis sp.	P	Ghana	40
Stomatoceras imbili Girault		Australia	17,34
Undetermined		India	3
Elasmidae			
Elasmus sp.	P	India	34
Elasmus sp.	L	Australia	19
Eulophidae			
Tetrastichus spirabilis Wtstn.	P	India, Bangladesh Australia	2,10,11,14,34, 39,42
Tetrastichus sp.	P	Ivory Coast	12,13
Eurytomidae			
Eurytoma sp.	P	India	34
Eurytoma sp.	Pre-p.	Australia	19
Eurytoma sp.	L	Nigeria, Ghana	35,36,40
Ichneumonidae			
Apistephialtes sp.	L (diapause)	India	10,25,34,42
Aptesis latiannulata (Cam.)	L	India	11,34,42
Flavopimpla sp. ? *tibialis* Morl.	L	India	34

Table 1. Insect natural enemies of *Hypsipyla robusta* (Moore).

Gotra sp.	P	India	34
Pimpla sp. (*turionellae* group)	P	India	34
Pristomerus fumipennis Wlkn.	L	India	34
P. microdon Cush.	L	India	34
Pristomerus sp.	L	India	34
Rhyssa persuasoria L.	L	Australia	14
Rhyssa sp.	L (diapause)	India	7,24,34,39
Temelucha clausa Kerrich	L	India	34
Temelucha sp.	L	India	34
Trichomma sp.	L	India	34
Undetermined		India	3
Species & Genus nr. *Gotra*	L	India	34
Perilampidae			
Perilampus sp.	P	Australia	19
Myrmaridae			
Undetermined	E	Australia	19
Trichogrammatidae			
Trichogramma chilonis Ishii* (=*T. autralicum* Girault)/*T. minutum* Riley	E	India	4,16 (34 re. identity)
Trichogrammatoidea nana (Zehnt.)	E	India	10,11,34
Trichogrammatoidea sp.	E	Bangladesh	2
T. robusta Nagaraja	E	India	27,30,42
Diptera			
Tachinidae			
Cadurcia auratacauda (Curran)	L	Nigeria, Ivory Coast, Ghana	13,35,36,40
C. nr. *depressa* Villeneuve	L	Ivory Coast	13
Carcelia angulicornis	L	Ghana	40
Compsilura concinnata Meig.	L	India	8,34,39
Drino inconspicuoides Bar.	L	India	5,34
Ethyllina sp.		Ivory Coast	13
Parexorista amicula (Mesnil)	L	Nigeria, Ghana	35,36,40
Sarcophagidae			
Undetermined sp. 1	L	Australia	19
Undetermined sp. 4	L (prepupa)	Australia	19
PREDATORS*			
Hymenoptera			
Vespidae			
Icara sp.	?E,L	Indonesia	23
Eumenidae			
Monorebia splendida F.	L	Australia	14
Formicidae			
Tetraponera rufonigra Jerd.	L	India	38
Undetermined	?L	Indonesia	23
Hemiptera			
Reduviidae			
Acanthaspis rama Distant	L (IV)	India	36,38
Pristhesaneus papuensis Stal		Australia	14,33
Coleoptera			
Cleridae			
Opilo discodirus Corporal	L,P	India	34
Melyridae			
Idgia melanura (Kollar & Redt.)	L,P	India	34
Carabidae			
Odocantha bimaculata Redt.	L (III)	India	38
Catascopus facialis Weid.	L (II,III,IV)	India	38
Undetermined	L	India	3
Halticinae			
Halticella sp.		Australia	33
Mantoidea			
Mantidae			
Amorphoscelis indica Giglio Tos.	L (II,III)	India	39

[1] E=Egg; L=Larvae (I,II,III,IV instar or diapause), P=Pupae, Blank=Not recorded
*likely to be generalist

Table 2. Insect natural enemies of *Hypsipyla grandella* (Zeller).

Natural enemy	Host stage[1]	Country	References
PARASITOIDS			
Hymenoptera			
Braconidae			
Agathis sp.	L	Belize	9,11
Bracon sp.	L	Peru	41
B. chontalensis Cameron	L	Trinidad, Belize	9,11,26,34,42
? *Apanteles* sp.	L	Jamaica	29,34
? *Apanteles* sp.	L	Trinidad	11,42
Dolichogenidea sp. (*laevigatus* group)	L	Belize	9,11
Dolichogenidea sp. (*ater* group)	L	Belize	9,11
Hormius sp.	L	Trinidad	11,34,42
Hypomicrogaster hypsipylae deSantis	L	Costa Rica	10,37
Ipobracon sp.	L	Venezuela	34
? *Iphialtes* sp.	L	Trinidad	11
Microbracon cushmani Mues.	L	USA, Jamaica	16,28,29,34
Stenarella sp.	L	Guyana	39
Stenarella brevicaudis Szep.	L	Guyana, Peru	28,34,39
Undetermined	L	Venezuela	34
Ichneumonidae			
Calliephialtes ferrugineus Cushman	L	Puerto Rico	34
Eiphosoma sp.	L	Belize	9,11
Brachymeria conica (Ashmead)*	P	Costa Rica	21
Philodrymus townesi Graf	P	Brasil	18
Chalcididae			
Undetermined	P	Trinidad	28,34
Undetermined	L	Belize	9
Trichogrammatidae			
Trichogramma sp.	E	Trinidad	11
Trichogramma bennetti Nagarkatti and Nagaraja[2]	E	Trinidad	31,42
Trichogramma sp.	E	Peru	41
Trichogramma sp.	E	Costa Rica	22
T. beckeri Nagarkatti and Nagaraja	E	Costa Rica	31,32
T. semifumatum (Perkins)	é	Costa Rica	20,31,32
T. pretiosum Riley	E	Costa Rica	31,32
T. fasciatum (Perkins)	E	Costa Rica	21,32
Trichogrammatoidea sp.	E	Trinidad	11,42
T. hypsipylae Nagaraja [2]	E	Costa Rica, Trinidad, Venezuela	30
T. nana (Zehnt.) [3]	E	Trinidad	11
T. robusta Nagaraja [3]	E	Trinidad	1
Diptera			
Tachinidae			
Metapiops miribalis Townsend	L	Trinidad, Venezuela, Belize	9,11,34,41
Chrysodoria sp.	L	Trinidad	11,34,42
Hormius sp.	L	Trinidad	11
Sarcophagidae			
Undetermined	L	Trinidad	29,34

[1] E=Egg; L=Larvae (I,II,III,IV instar or diapause), P=Pupae, Blank=Not recorded
[2] Also from *H. ferrealis* in Trinidad (30, 32)
[3] Introduced from India
* likely to be generalist

Table 3. Introduction and release of parasitoids for the control of *Hypsipyla grandella* (Zeller).

Country	Parasitoid species	Years introduced released[1]	No. sent/ No. shipments[2]	Outcome [1,2]	References
Trinidad	*Trichogrammatoidea nana*	1969–71	16 350/32	+	10,11
	T. robusta	1970–77	35 000/118	+	1,15,35
		1972–76	21 570	–	15,35
		1970–77	42 540/142	–	15,42
	Phanerotoma sp.	1972–76	34 000	–	15
		1968	500/1	–	10,11,35,42
	Glyptapanteles sp. (*vitripennis* group)	1968–70	3340/26	–	10,15
	Antrocephalus renalis	1968–70	103 050/155	–	10,15
	Tetrastichus spirabilis	1969–71	47 550/65	–	15
	Apistephialtes sp.				10,11,35,42
	Aptesis laniannula			–	11,35
Grenada	*T. robusta*	1970–72	19 007/28	?	15
	Phanerotoma sp.	1971–72	11 228/27	?	15
	T. spirabilis	1971–72	12 250/26	?	15
St. Vincent	*T. robusta*	1970–72	26 445/43	?	15
	Phanerotoma sp.	1970–72	15 850/33	?	15
	A. renalis	1969	136/1	?	15
	T. spirabilis	1969–72	20 822/45	?	15
St. Lucia	*T. robusta*	1971–72	17 650/29	–	15
	Phanerotoma sp.	1970–72	13 554/40	?	15
	A. renalis	1970	2348/11	?	15
	T. spirabilis	1970–72	25 375/44	?	15
Dominica	*T. robusta*	1971–72	10 650/19	?	15
	Phanerotoma sp.	1971–72	9200/17	?	15
	T. spirabilis	1971–72	7400/18	?	15
St. Kitts	*T. robusta*	1971	700/1	?	15
	Phanerotoma sp.	1971	900/2	?	15
	T. spirabilis	1971	1400/2	?	15
Belize	*T. robusta*	1970–75	7350/9	?	15
	Phanerotoma sp.	1970–75	3730/10	?	15
	Phanerotoma sp.	1969/72	2480/6	?	9
	A. renalis	1972	44/2	?	9,15
	T. spirabilis	1969–72	8340/9	?	15
		1968–72	6350/8	?	9
	Trichogrammatoidea nana	1969–72	3500/5	?	9
Brazil	*T. robusta*	1971–73	?	?	26
	Phanerotoma sp.	1971–73	?	?	26
		1969–72	2480/6		*
	A. renalis	1969–69	?	?	*

[1] Blank=Not recorded. [2]+=established, –=failed

reared. These included: *Apanteles* sp.? *puera* Wlkn., *A. leptoura* Cam. (Braconidae); *Aptesis latiannulata* (Cam.) (Ichneumonidae); and *Brachymeria tachardiae* Cam., *Antrocephalus* sp. and *Antrocephalus destructor* Wtstn. (Chalcididae) (Cock 1985).

Surveys were made in the Caribbean countries and Berlize during the period 1970–1972, to determine whether any of the introduced parasitoids had established. *T. robusta* was recovered in Trinidad where parasitisation ranged from 5–9% (Cock 1985) while *T. nana* was recovered from the eggs of *Hypsipyla* spp. on seed capsules of *Carapa guianensis* (Bennett and Yaseen 1972).

Augmentation projects

Beeson (1938) reported the first attempt for the augmentation of a natural enemy of *H. robusta*. Apparently, the widely distributed egg parasitoid *Trichogramma minutum* Riley was collected from Mysore, India and released in mahogany plantations in Madras, India but the outcome of the release was not reported (Entwistle 1967). Rao and Bennett (1969) pointed out that this parasitoid (referred to as *T. australicum* Girault), usually attacked sugarcane borers in cane fields and was therefore unlikely to afford any benefit against *H. robusta*. Though native species can be utilised, it is unlikely that inundative, repetitive releases of parasitoids in forestry plantations will be economically viable.

Discussion

The list of taxa occurring in each country probably reflects the intensity of sampling rather than species-richness in that country. For example, in India where extensive studies have been carried out on *H. robusta*, the diversity of natural enemies appears to be more extensive than in other countries. The documented natural enemies of *Hypsipyla* spp. contain a range of parasitoids with closely-related representatives effective against a range of other pests. However, it is not possible to select agents for *Hypsipyla* spp. on the basis of their relationships with other successful agents. Percent parasitisation is not a particularly useful way to assess effectiveness (van Driesche 1983) unless accompanied by life table studies.

Frequently, agents very closely-related to one another have different capabilities for controlling a target organism, for example, the different performance of the two parasitoids *Encarsia berlesei* (Howard) and *E. diaspidicola* (Silvestri) as agents for controlling the scale insect *Pseudaulacaspis pentagona* (Targioni-Tozzetti) in the Pacific (Sands et al. 1990). Though it is possible that a natural enemy from one species of *Hypsipyla* will be effective when imported for biological control of another *Hypsipyla* species, insufficient data are available for predicting the potential adaptation of one agent to another target species. Anomalies are frequently encountered when testing the host range of an agent, with natural enemies breeding effectively in the laboratory on an adopted host but failing to recognise the exotic target when released in the field. While the abundance of a natural enemy is a useful indicator for adaptation to a particular host, it is not necessarily an indicator for effectiveness in a new environment or when freed from hyperparasitoid interaction (Newton et al. 1993).

While the abundance of a natural enemy is a useful indicator for its ability as a biological control agent, it is not necessarily an indicator for effectiveness when released in a new environment. Detailed studies on population dynamics and life tables of *Hypsipyla* spp. in their native ranges may identify agents otherwise overlooked. Studies on life tables for the moths may reveal that their indigenous populations, though stabilised by natural enemies, still cause an unacceptable level of damage to plantations. However, manipulation of exotic natural enemies may reduce the level of damage, especially if accompanied by other integrated control methods.

The number of failures in establishment of parasitoids from *H. robusta* released against *H. grandella* (Rao and Bennett 1969) may suggest that some species are narrowly host-specific and adapted to develop only on their natural host species. Unfortunately this type of parasitoid/host interaction is difficult to test. Many parasitoids are limited in their effectiveness or ability to establish by certain climate and habitat requirements. Some parasitoids are likely to attack hosts only when occupying specific parts of the host plant, for example, some may only develop on *Hypsipyla* spp. in seed capsules, shoots, flowers or under bark. Furthermore, others may develop only on diapausing larvae.

The reasons for heavy mortality in shipments of parasitoids (particularly Braconidae) need to be investigated before future consignments are attempted. While there may be easily identified mechanical or environmental causes, it is possible that silvicultural practices (e.g. insecticide use) may have affected the survival of living insects in the consignments.

When agents are being evaluated to control a pest in a country outside of their native range, it is necessary to assess their host specificity prior to release, to ensure that they will not have any detrimental impact on non-target species. With insect agents for arthropod targets, it is impractical and not necessary to test an extensive range of non-target potential hosts, a procedure widely accepted for biological control of weeds (Waterhouse 1991). However, introductions should not place at risk, beneficial organisms or native species which are likely to support the exotic agents. This is especially so when the target *Hypsipyla* spp. are native pests and when non-target species closely-related to the pest are likely to be exposed to an exotic agent after released.

In the past, many biological control projects for arthropod pests have not addressed the risks of impact on other species. For biological control of *Hypsipyla* spp., it will be necessary to conduct host specificity studies on the agents and with selected exotic beneficial (e.g. biological control agents) or native, non-target species of moths which might support their development. Several species of pyralid moths are biological control agents, important for reducing the abundance of weeds. The phycitine moth *Cactoblastis cactorum* (Berg.), for example, is one of the best-known biological control agents, having controlled prickly pear cactus over vast areas following its introduction into Australia. *C. cac-*

torum is also an important agent for controlling other cacti (*Opuntia* spp.) in South Africa and several in other countries (Julien 1987). This beneficial moth belongs to the same sub-family Phycitinae, in which *Hypsipyla* spp. are classified. *C. cactorum* might even be recognised as belonging to the same tribe as the genus *Hypsipyla* on morphological (Figures 1, 2) grounds (M. Horak, pers. comm.). Host specificity studies would therefore be required, should exotic biological control agents be introduced to control a *Hypsipyla* sp., in areas where cacti are under biological control from *Cactoblastis* spp. These tests would ensure that the parasitoids are not capable of reducing the abundance of a beneficial *Cactoblastis* that might pose a risk to the effective biological control of cacti known to be weeds.

Figure 1. Adult *Hypsipyla robusta* (Moore).

Figure 2. Adult *Cactoblastis cactorum* (Berg.).

The lists of natural enemies (Tables 1 and 2) recorded for *Hypsipyla* spp. are likely to include hyperparasitoids which must be carefully identified and screened before releases are attempted. No further direct releases of imported parasitoids should be attempted without these precautions. Otherwise, not only are they likely to reduce the effectiveness of native parasitoids but also pose a threat to beneficial organisms. Some hyperparasitoids, particularly those that develop on egg parasitoids, resemble their hosts and frequently contaminate cultures where they are easily overlooked. A single generation of an agent should be reared under secure quarantine or other suitable conditions before the offspring are considered for release. Direct releases of all stages of field-collected parasitoids should be avoided to prevent risks of introducing hyperparasitoids.

Prospects for biological control of the indigenous *Hypsipyla* spp. may not hold as much promise as for exotic pests, since it is difficult to find exotic natural enemies which are better host-adapted than native natural enemies. However, some exotic parasitoids may become very effective when relocated without their hyperparasitoids. Such parasitoids need to be oligophagous; capable of developing on other species in the same genus as their natural host. Before introduction, these parasitoids must be shown to be narrowly host-specific and unable to cause any detrimental impact on species in related genera, particularly with beneficial species including other biological control agents.

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Entomopathogens for Control of *Hypsipyla* spp.

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Abstract

Published information on the incidence of pathogens in the field and laboratory infections of *Hypsipyla* spp. with entomopathogens is reviewed. In addition, some preliminary results of field collections from Ghana and Costa Rica are presented. Fungal pathogens from the Deuteromycetes have been isolated from both *H. robusta* Moore and *H. grandella* Zeller. Mermithid nematodes, *Hexamermis* spp., have been frequently isolated from larvae in the field and incidence of infection with these pathogens can reach significant levels. Microsporidia have been found in cadavers of larvae collected in the field but none have been identified so far. A number of pathogens of other Lepidoptera have been shown to be infectious to *H. grandella*, including *Bacillus thuringiensis*, Deuteromycete fungi and a nucleopolyhedrovirus (NPV) from *Autographa californica*. *Hypsipyla* spp. are difficult targets for microbial control, since the larvae are cryptic, occur at low density and occur sporadically. In addition, there is a low damage threshold, the plant is susceptible for a number of years and the susceptible part of the plant will rapidly outgrow any surface application. Key features of the biology of entomopathogens with relevance to the control of low density and cryptic pests are discussed. In the light of this experience, we discuss strategies to improve the possibilities of microbial control of this pest and suggest areas for research.

ENTOMOPATHOGENS have been used in control of forest pests as alternatives to chemical insecticides (Cunningham 1988; Ahmed and Leather 1994). They are considered to be safer than chemical insecticides, having little effect on man or other vertebrates and non-target invertebrates, as a result of which natural control by parasitoids and predators is maintained (Burges 1981b; Huber 1986). They do not build up in the food chain and, in most cases, insect populations do not develop resistance. A few have been marketed as microbial insecticides. However, pathogens differ from chemical insecticides in that, in most cases, they replicate in the insect and can spread through the insect population. This spread of infection is an important aspect of the successful use of entomopathogens as insecticides (Entwistle and Evans 1983; Cunningham 1988; Ahmed and Leather 1994).

Hypsipyla robusta (Moore) and *H. grandella* (Zeller) are difficult targets for microbial control. The larvae are cryptic, feeding inside the shoot and avoiding control agents applied to the surface, and they occur at very low density (in field collections, we only occasionally encountered more than one larva per shoot even during the peak of infestation) and attack is sporadic. These characteristics reduce the possibility of the infection spreading between larvae. As the larval stage lasts only a few weeks, a rapid response is required once damage is noticed. The shoot grows rapidly, so applications must be repeated frequently to the new growth. Trees are susceptible for up to five years and the level of damage which can be tolerated is low, which demands prolonged, high levels of control.

Entomopathogens are a highly varied group of natural enemies from a number of kingdoms, and include bacteria, viruses, fungi, protozoa and nematodes. Some have spores or resting stages that can persist in the environment and can be applied with conventional spray equipment while others cannot persist outside of the insect. Some enter the host by penetrating the cuticle, others must be ingested, while others are motile and can seek out the host,

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and others are passed from adult to offspring. Some are obligate pathogens, while others can be produced in bulk on selected media. Most kill by replicating in the host, but others contain insecticidal toxins. Within the main groups, several hundred species and strains have been identified.

Knowledge of entomopathogens, in general and in *Hypsipyla* spp. specifically, is biased towards those which cause acute, fatal infections, since most known entomopathogens were collected after natural epizootics and most research has focused on fast-killing pathogens as alternatives to chemical insecticides (Burges 1981a). Other pathogens cause chronic debilitating diseases that are not as easily detected but may have important longer-term effects on insect populations. The life histories of the different pathogens will significantly affect their efficacy and economic feasibility as control agents.

Epizootics and Transmission of Infection

Many pathogens are transmitted in the environment by spores or occlusion bodies which may be spread by wind (especially fungal spores) or rain, or in faeces of predators such as birds and beetles which eat infected hosts (Hostetter and Bell 1985). They are rapidly inactivated by ultra violet light, heat and desiccation but may persist for years when in a protected environment such as soil (Anderson and May 1980; Entwistle and Evans 1983). They can be applied using conventional spray equipment.

Pathogens such as *Bacillus thuringiensis*, baculoviruses, microsporidia, and Mermithid nematodes infect insect larvae through ingestion of spores, occlusion bodies or eggs. Ingested pathogens are restricted to control of larvae since they are not likely to be eaten by adults or pupae. Thus the probability of *Hypsipyla* spp. larvae ingesting pathogens applied to the surface of the plant will be limited once larvae have entered the shoot. Juvenile (Dauer) stage Steinernematid and Heterorhabditid nematodes penetrate the cuticle of the host. Furthermore, the motile juvenile can locate the host and swim to it in a film of water, and in suitably moist environments they may seek out even cryptic hosts. Juvenile nematodes are very sensitive to desiccation and have been successfully applied against pests in soils (Klein 1990), thus might be useful against *Hypsipyla* spp. pupae in soil. Fungal spores germinate on the outside of a host when there is high humidity (95%) and penetrate the cuticle (McCoy et al. 1988) and could therefore infect adults or pupae.

Bacillus thuringiensis is pathogenic to insects by the action of a toxic protein in spores which disrupts the insect midgut cells, causing cessation of feeding in larvae within as little as 20 minutes (Li et al. 1991). A symbiotic bacterium associated with Dauer stage Steinernematid and Heterorhabditid nematodes kills the host within 24 to 48 hours. Other pathogens kill the host much more slowly by infection after replication in the insect. NPVs typically kill within 7–10 days, early instar larvae usually being more susceptible. Cytoplasmic polyhedrosis viruses (CPVs) and entomopox viruses produce more chronic infections, up to several weeks or months (Katagiri 1981; Arif 1984; Bellancik 1989). Microsporidia differ in their speed of kill. *Vairimorpha necatrix* may kill its host in 3 to 10 days (Maddox et al. 1981). In *Nosema* spp. time to death is slow although feeding, development and fecundity of those insects which survive to adults may be reduced or retarded and progeny may rapidly die from infection (Wilson 1983; Han and Watanabe 1988).

The action of *B. thuringiensis* is primarily that of a toxin. The toxin is often purified in commercial formulation (Bernhard and Utz 1993). However, there have been some reports of the development of resistance to *B. thuringiensis* toxin in other Lepidoptera (Marrone and Mackintosh 1993). Successful control by *B. thuringiensis* does not rely on secondary infections or the development of an epizootic. However, the development of an epizootic initiated by the application of pathogens such as baculoviruses, fungi and some microsporidia is key to their success for control of pests (Entwistle and Evans 1983; Cunningham 1988; Ahmed and Leather 1994). These pathogens are typically highly pathogenic but are predominantly transmitted horizontally, in the environment, and most success in their use for control of forest pests has been against gregarious or high density defoliating larvae where environmental horizontal transmission is greatest (Anderson and May 1981; Cunningham 1988; Ewald 1994; Rothman and Myers 1996). Because *Hypsipyla* spp. larvae are cryptic and occur at such low density, and there appears to be no overlap of generations of larvae in the field between attack outbreaks, environmental spread will be limited, reducing the development of an epizootic and the efficacy of these pathogens. Other viruses such as ascoviruses and some baculoviruses may be transmitted by parasitoids (Hochberg 1991a; Levin et al. 1983; Miller 1996).

Sexual or vertical transmission of pathogens, such as iridescent virus, small RNA viruses, CPVs and some microsporidia, are not dependent on population density and, since vertically transmitted pathogens are transmitted from adult to offspring either within or on the surface of the egg, their transmission is not reduced by cryptic feeding and the pathogen is more likely to persist in the insect population between one pest outbreak and the next (Anderson and May 1981). However, their transmission depends upon survival of the host, and consequently they are typically slow to kill or do not kill the host at all, but may reduce fecundity and build up in a population over several generations (Katagiri 1981; Kellen and Hoffman 1983; Ewald 1994; Sait et al. 1994; Rothman and Myers 1996). They are less useful for short term control as insecticides and typically do not persist for long in the environment, but may be important in long term regulation of populations (Anderson and May 1981). An example of successful 'classical' introduction of a sexually transmitted pathogen is the control of the rhinoceros beetle, a pest of palms, by a non-occluded baculovirus (Jacob 1996).

Some pathogens may be transmitted both vertically and in the environment, and may be more pathogenic than those that are only transmitted vertically, since they are not dependent on the survival of the host for transmission (Ewald 1994). In the microsporidia, *Nosema* spp. are primarily vertically transmitted inside the egg in addition to horizontal transmission while other microsporidia are mainly horizontally transmitted (Maddox et al. 1981; Han and Watanabe 1988; Jeffords et al. 1988). The persistence of *Nosema* sp. introduced from Europe into North American gypsy moth populations has been attributed to transovarial transmission (Jeffords et al. 1989). Vertical transmission may occur in CPVs and some baculoviruses although transmission is primarily horizontal (Rothman and Myers 1996). Sub lethal doses of baculoviruses can reduce fitness and fecundity of adults (Young 1990; Rothman and Myers 1994, 1996; Sait et al. 1994). However, results are inconsistent (Shapiro and Robertson 1987; Murray and Elkinton 1989; Young 1990; Fuxa et al. 1992).

Pathogens for use in inundative release need to be available in sufficient quantities, and either stable in storage or readily available from local production. *Bacillus thuringiensis* can be produced by large-scale fermentation and is available in stable formulations (Bernhard and Utz 1993). Fungi are attractive in that they can often be produced by fermentation on locally available plant material (e.g. Ibrahim and Low 1993). Viruses and microsporidia are obligate pathogens but have been produced on a medium scale by rearing and infecting large numbers of the host insect (Shieh 1989). Steinernematid and Heterorhabditid nematodes can be produced in bulk, but at considerable cost, on semi-artificial media (Bedding 1981). Mermithid nematodes are especially difficult to produce in bulk. However, any pathogen that is host specific or an obligate pathogen is likely to be available only on a small scale from local production (Carlton 1990).

Pathogens of *Hypsipyla* spp.

Pathogens naturally occur in field populations of *Hypsipyla* spp. larvae. Rao (1969) recorded disease levels of between 4% and 16% of *H. robusta* larvae in India. We have observed between 26% and 44% mortality (not including that from parasitoids) of field collected larvae from Sri Lanka, Ghana and Costa Rica. Numerous pathogens have been isolated from *Hypsipyla* spp., and pathogens from other species have been shown to kill larvae of *Hypsipyla* spp. (Table 1).

The most successful of all microbial insecticides is *B. thuringiensis,* constituting over 90% of microbial insecticide sales (Powell 1993). Hidalgo-Salvatierra and Palm (1973) obtained up to 96% mortality of first-instar larvae of *H. grandella* fed on an artificial diet incorporating a variety of *B. thuringiensis*. However, calculation of LD50 or speed of kill, selection of more pathogenic strains, and field tests have not been conducted.

The most successful fungal insecticides are the Deuteromycetes, in particular, species of *Metarhizium* and *Beauveria*. Yamazaki et al. (1990) reported a *Beauveria* sp. infecting *H. grandella* in Peru but produced limited mortality. Kandasamy (1969) isolated *Beauveria tenella* (Delacroix) Siemaszko (*B. brongniartii*) and Misra (1993) isolated *B. bassiana* (Balsamo) Vuillemin from cadavers of *H. robusta* in India. Myers (1935) reported a *Cordyceps* sp. infecting *H. grandella* in Trinidad. By incubating larvae with soil samples for 24 hours and subsequently rearing larvae on an artificial diet, we have collected fungi, possibly *Metarhizium* spp., from *H. grandella* larvae in Costa Rica and *H. robusta* in Ghana. The Costa Rican isolates have been cultured on nutrient agar and await further identification and assessment of pathogenicity.

Berrios and Hidalgo-Salvatierra (1973a, b) and Hidalgo-Salvatierra and Berrios (1973) tested spores of *B. bassiana*, *B. brongniartii* (*B. tenella*) and *M. anisopliae* (Metchnikoff) Sorokin from other, unidentified, species of Lepidoptera against larvae of *H. grandella*. Larvae immersed in a suspension of spores showed 13.9% mortality with *B. bassiana* at a concentration of 1.4×10^6 viable spores/mL, 12.7% mortality with *B. brongniartii* at 2.9×10^6 viable spores/mL, and 50% mortality at 1.2×10^7 spores/mL with *M. anisopliae* in 5th instar larvae. Most larvae died 8 days post infection (pi) with *B. bassiana*, 10 days pi with *B. brongniartii* and 6 days pi with *M. anisopliae*.

Steinernematid and Heterorhabditid nematodes have not been reported to infect *Hypsipyla* spp., but Mermithid nematodes, particularly *Hexamermis albicans* (Siebold) have been reported in *H. grandella* throughout Latin America (Bennett 1968; Rao and Bennet 1969; Nickle and Grijpma 1974; Yamazaki et al. 1990), and from *H. robusta* in Nigeria (Roberts 1965) and India (Chatterjee and Singh 1965; Rao 1969). Nickle and Grijpma (1974) present a detailed description of *H. albicans* and observations of its incidence in Costa Rica and elsewhere. Incidence was highest during the wet season and lowest at the end of the dry season, and varied between 5% and 25% of larvae collected live from shoots. They also reported the collection of some adult nematodes from the sandy clay loam soil at the base of the trees. Yamazaki et al. (1990) reported *Hexamermis* sp. to have the highest incidence of all natural enemies, sometimes exceeding 10% of larvae. Chatterjee and Singh (1965) reported infestation of between 5% and 9% of *H. robusta* larvae at two different sites in India. Roberts (1965) reported up to 40% infection of *H. robusta* by *Hexamermis* sp. in Nigeria, although we have found only low levels in Ghana.

No viruses have previously been reported from *Hypsipyla* spp. However, we have successfully infected and killed fourth instar *H. grandella* larvae in the laboratory with a wide host range NPV from *Autographa californica*. Further calculations of LD50 and tests on plants are needed. Similarly, infections by microsporidia have not been reported in the literature. We have observed spores of microsporidia of different groups in numerous cadavers of larvae of *H. robusta* from Ghana and Sri Lanka, and *H. grandella* collected from shoots in the field reared through to death in the laboratory. These microsporidia require identification and investigation of their pathogenicity.

There are few examples in the literature of field trials of entomopathogens against *Hypsipyla* spp. (but see Duarte et al., these Proceedings). Misra (1993) reported 80% kill of *H. robusta* larvae 'inoculated' with a spore culture of *B. bassiana* in water in experiments on *Toona ciliata* M. Roem in outdoor cages.

Secondary infections and the development of an epizootic of other known pathogens of *Hypsipyla* (*B. thuringiensis*, baculoviruses and fungi), which are all

Table 1. Pathogens known to kill larvae of *Hypsipyla grandella* (Zeller) and *H. robusta* (Moore). Pathogens originally identified in or isolated from *Hypsipyla* spp. are indicated by *.

Pathogen	Source	Host	References
Fungi			
Beauveria bassiana	not known	*H. grandella*	Berrios and Hidalgo-Salvatierra 1973b
Beauveria sp*	Peru	*H. grandella*	Yamazaki et al. 1990
*B. brongniartii (tenella)**	India	*H. robusta*	Kandasamy 1969
B. brongniartii (*tenella)*	not known	*H. grandella*	Berrios and Hidalgo-Salvatierra 1973b
B. brongniartii (*tenella*)*	India	*H. robusta*	Misra 1993
Metarhizium anisopliae	not known	*H. grandella*	Berrios and Hidalgo-Salvatierra 1973a; Hidalgo-Salvatierra and Berrios 1973.
Metarhizium sp.*	Costa Rica	*H. grandella*	Hauxwell et al. unpublished
Metarhizium sp.?*	Ghana	*H. robusta*	Hauxwell et al. unpublished
Cordyceps sp. *	Trinidad	*H. grandella*	Myers 1935
Bacteria			
Bacillus thuringiensis	not known	*H. grandella*	Hidalgo-Salvatierra and Palm 1973
Nematodes			
Hexamermis sp.*	India	*H. robusta*	Chatterjee and Singh 1965
Hexamermis sp.*	India	*H. robusta*	Rao 1969
Hexamermis sp.*	Peru	*H. grandella*	Yamazaki et al. 1990
Hexamermis sp.*	Nigeria	*H. robusta*	Roberts 1965
Hexamermis albicans*	Costa Rica	*H. grandella*	Nickle and Grijpma 1974
Hexamermis albicans*	Belize	*H. grandella*	Bennett 1968
Hexamermis albicans*	Venezuela	*H. grandella*	Rao and Bennet 1969
Protozoae			
Microsporidia*	Costa Rica, Sri Lanka, Ghana	*H. grandella/H. robusta*	Hauxwell et al. unpublished
Viruses			
Autographa californica NPV	A. californica	*H. grandella*	Hauxwell et al. unpublished

environmentally transmitted, will be restricted by the low density, seasonal occurrence and cryptic feeding of *Hypsipyla* spp. larvae. Mermithid nematodes, while relatively common in larvae of *Hypsipyla* spp. are difficult to mass produce and formulate as insecticides, must be ingested and are already ubiquitous, and are unlikely to be used either as microbial insecticides or introductions. However, experience of the biology of entomopathogens in other insect species could be used to identify possible strategies to improve the possibilities of microbial control.

Strategies for Microbial Control of *Hypsipyla* spp.

Of the three described strategies for use of entomopathogens (inundative release, punctuated release and introduction) (Fuxa 1987), inundative release for immediate control (as a microbial insecticide) and introduction for long term control might be successful. Punctuated releases benefit from the spread of secondary infections by horizontally transmitted pathogens, which would appear to be less likely to succeed in *Hypsipyla* spp.

If larvae have been observed on shoots, a rapid response to the entomopathogen is required before damage occurs. *B. thuringiensis* is readily available in commercial formulations and is fast acting but *Hypsipyla* spp. larvae will be difficult to infect once they have entered the shoot. The efficacy of *B. thuringiensis* against other forest pests has been improved by ultra low volume applications which increase the concentration of toxin ingested (Frankenhuyzen 1990). Steinernematid and Heterorhabditid nematodes may be more effective for short term control as in addition to a relatively fast time to kill they are able to enter the shoot.

Environmentally transmitted pathogens such as fungi and baculoviruses, although slower to kill, may also be useful when applied for short term control if they can be targeted at susceptible life stages of the pest. The probability of larvae acquiring a lethal dose of pathogens in the environment will increase in proportion to exposure and to potency of the pathogens it encounters (Burges 1981a; Dwyer 1991). Early instars of many species are more susceptible to entomopathogens, and early instars of *Hypsipyla* spp. could be infected outside the shoot and killed before causing damage. Research on the behaviour of *Hypsipyla* spp. larvae in early instars and at periods of emergence from the tunnel might improve targeting.

An example which might be comparable with control of *Hypsipyla* spp. is the use of the granulosis virus (GV) of *Cydia pomonella* L. (Lepidoptera: Pyralidae), a pest of apples. The virus is highly pathogenic, requiring only a few virus particles to kill early instar larvae, and control is improved by targeting applications at early instars, which are more susceptible, before they tunnel into the fruit and by using frequent applications (Dickler and Huber 1988; Brain and Glen 1989; Guillon and Biache 1995). After two years of application the pest population may be depressed without the need for frequent applications due to the maintenance of natural enemy populations and a build up of pathogen in the environment (Guillon and Biache 1995).

Most pathogens are rapidly inactivated by ultra violet light or desiccation and thus adequate persistence will be a challenge. Although improved formulations and mixed species plantations may increase persistence (Shapiro and Robertson 1990; McClatchie et al. 1994; Inglis et al. 1995; Roland and Kaup 1995; Ignoffo and Garcia 1996), applications of microbial insecticides against *Hypsipyla* spp. larvae would have to be repeated frequently to a rapidly growing shoot and over the several years during which a tree is susceptible to attack. Frequent applications may not be economically feasible in plantations and may only be useable in nurseries. However, identification of peak periods of plant susceptibility and pest monitoring could be used to time and thus reduce the frequency of applications. Application of preparations of fungal mycelia may provide longer protection by releasing spores which are borne by wind (Periera and Roberts 1990) which may also increase transmission in low density larval populations (Brown and Hasibuan 1995).

An alternative strategy might be to target life stages other than larvae. Fungal spores and Dauer stage nematodes penetrate the cuticle and may infect adults and pupae. As their persistence is increased in soil, they might be used against *Hypsipyla* spp. pupae. If suitable baits could be found it may be possible to use traps to contaminate adults which subsequently disseminate the pathogens at oviposition and, in the case of fungal spores, may themselves become infected (Tatchell 1981; Furlong et al. 1995; Vega et al. 1995).

Burges (1981a) observed that burrowing pests were only likely to be controlled by vertically transmitted pathogens. Such pathogens although typically slower to kill, would be more likely to persist in the *Hypsipyla* spp. population and have an effect on the population over several generations. They may therefore be appropriate for use in introductions, which may be more economic in plantations by reducing the need for repeated applications. Care must be taken to recognise these pathogens. They may not cause highly pathogenic infections or epizootics and may be easily overlooked (Burges 1981a; Rothman and Myers 1996). Occlusion bodies are relatively easy to identify by light microscopy (Payne and

Kelly 1981), but non-occluded viruses are more difficult to recognise. In order to increase persistence and pathogenic effects, pathogens which combine vertical and horizontal transmission could be selected. Of known pathogens, CPVs and microsporidia may be suitable for this type of introduction (Rothman and Myers 1996).

Pathogens possess great diversity, and it is possible to select strains with favourable traits such as increased vertical transmission, greater pathogenicity or environmental persistence, or, in the case of nematodes, improved host searching behaviour (Fuxa and Richter 1991; Ibrahim and Low 1993; Gaugler et al. 1993; Matewele et al. 1994; Clarkson and Charnley 1996). However, entomopathogens are unlikely to eliminate *Hypsipyla* spp. altogether and success will depend on tolerance of some damage or inclusion of microbial control in a programme of integrated management.

Conclusions

There is still little information on pathogens of *Hypsipyla* spp. More pathogens need to be identified, but research efforts should be guided by knowledge of entomopathogens in other insects. Replication and transmission of pathogens causing secondary infection has been repeatedly cited as a key advantage of most pathogens over chemical insecticides or *B. thuringiensis* (e.g. Ibrahim and Low 1993; Ahmed and Leather 1994; Lacey and Goettel 1995). The limitations of pathogens in targeting a seasonal, low density and cryptic insect, over several years in a crop with a low damage threshold and a susceptible part of the plant which will rapidly outgrow surface applications should not be ignored. However, a low density species like *Hypsipyla* spp. might be expected to be more susceptible to pathogens than high density species if it can be brought into contact with the pathogen (Hochberg 1991b; Rothman and Myers 1996), and the work of Duarte et al. (these Proceedings) suggests that inundative releases of fungi for short term control is worth further investigation, at least in nurseries. Overall, we might begin by identifying and evaluating pathogens and strains of those pathogens with emphasis on those which are to some degree vertically transmitted, acquire better information on the susceptibility and behaviour of different life stages of the pest (adults and pupae, and early instars), and develop means to co-ordinate applications with *Hypsipyla* spp. attack.

Acknowledgments

Preparation of this paper and results presented in it were supported in part by the British Department for International Development, Forestry Research Programme project no. R6055 on baculoviruses of *Hypsipyla* spp. We wish to thank others involved in these investigations for their support: Martin Speight (Oxford University Dept. Zoology), Jenny Cory (NERC Institute of Virology and Environmental Microbiology, Oxford), S.K. Atuahene and J. Cobbinah (Forestry Research Institute of Ghana), Philip Shannon and Jon Cornelius (Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica), Jim Sandom and John Mayhew (formerly at DFID FORMP, Forestry Department, Sri Lanka) and Keith Jones, (Natural Resources Institute UK/CARE Sri Lanka).

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Indigenous Parasitoids and Exotic Introductions for the Control of *Hypsipyla grandella* (Zeller) (Lepidoptera: Pyralidae) in Latin America

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Abstract

Hypsipyla grandella (Zeller) is the most important insect pest of the Meliaceae in the Neotropics. This paper reviews the information on *H. grandella* parasitoids in Latin America and the Caribbean. Preliminary data on the parasitoid complex in Turrialba, Costa Rica, are presented, where apparent parasitisation of *H. grandella* during 1995–1996 reached 36%. The lowest level of parasitisation occurred during the dry season. The parasitoid *Apanteles* sp. (= *Hypomicrogaster hypsipylae* de Santis?) (Hymenoptera: Braconidae) was the most abundant larval parasitoid with a mean of 22 parasitoids per parasitised larva and a sex ratio of 3:1 females to males. *Brachymeria conica* Ashmead (Hymenoptera: Chalcididae) was found parasitising pupae, but at low frequency.

THE MAHOGANY shoot borer *Hypsipyla grandella* (Zeller) (Lepidoptera: Pyralidae) is the overriding detrimental factor affecting the establishment of plantations of Spanish cedar (*Cedrela* spp.) mahogany (*Swietenia* spp.) and 'cedro macho' or crabwood (*Carapa guianensis* Aubl.) in the Neotropics. Larvae feed inside the young shoot, frequently killing it, resulting in forking and retarded growth of the trees and thus reduced economic yields of timber. Previous attempts at biological control of *H. grandella* have not been successful in reducing damage (Newton et al. 1993).

The present paper reviews available information on parasitoids of *H. grandella* in Costa Rica and other countries of Latin America and Trinidad. It also includes preliminary results on the fluctuation of indigenous parasitoid populations in Turrialba, Costa Rica.

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Occurrence of *Hypsipyla* Parasitoids in Latin America

For any biological control program to be implemented, a thorough search for and accurate identification of existing natural enemies and potential biological control agents must be made. In Latin America, there have been few formal studies of parasitoids of *H. grandella* that can provide information of their identity, distribution and abundance. The existing information is mainly from the Centro Agronomico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica. A survey of natural enemies affecting *H. grandella* in Costa Rica was initiated in 1970. Five *Trichogramma* species (Hymenoptera: Trichogrammatoidea) were found to parasitise the eggs of *H. grandella*, while three species of Braconidae and one species of Chalcididae were found to parasitise the larvae and/or pupae (Grijpma 1973). Hidalgo Salvatieri and Madrigal Sanches (1970) recorded 10% to 40% of eggs of *H. grandella* parasitised by an unidentified *Trichogramma* sp. Bennett (1976a) reported similar species parasitising *H. grandella* in Belize. Table 1 lists indigenous parasitoids of *H. grandella* reported in the literature.

Percentage parasitisation of eggs in the field can be as high as 40% (Hidalgo Salvatieri and Madrigal Sanches 1970). Grijpma (1972) reported a high

Table 1. Parasitoid species reared from *Hypsipyla grandella* (except where indicated otherwise) in Latin America.

Parasitoid	Country	References
Egg parasitoids		
Trichogrammatidae		
Trichogramma spp.	Costa Rica, Peru	Hidalgo-Salvatierri and Madrigal Sánchez 1970, Yamazaki et al. 1990
T. beckeri (Nagarkatti)	Costa Rica	Nagarkatti 1973
T. bennetti (Nagarkatti) (on *H. ferrealis* Hampson)	Trinidad	Nagaraja and Nagarkatti 1973
T. fasciatum (Perkins)	Costa Rica	Grijpma 1973; Nagarkatti and Nagaraja 1977
Trichogrammatoidea hypsipylae (Nagaraja)	Costa Rica, Trinidad	Nagaraja, 1978
T. pretiosum (Riley)	Costa Rica, Mexico	Grijpma 1972, 1973; Nagarkatti 1973
T. near *pretiosum*	Costa Rica	Grijpma 1972; Nagarkatti 1973
T. semifumatum (Perkins)	Costa Rica	Grijpma 1972; Nagarkatti 1973
Larval parasitoids		
Braconidae		
Agathis sp.	Belize	Bennett 1976a
Apanteles spp.	Trinidad	Bennett and Yaseen 1972; Yaseen 1984
Apanteles sp. (= *Hypomicrogaster hypsipylae* De Santis?)	Costa Rica	This paper
Apanteles sp. (ater group)	Belize	Bennett 1976a
Apanteles sp. (laevigatus group)	Belize	Bennett 1976a
Bassus sp.	Costa Rica	This paper
Bracon sp.	Peru	Yamazaki et al. 1990
Bracon chontalensis Cameron	Belize, Costa Rica, Trinidad	Bennett 1976a; Bennett and Yaseen 1972
Hormius sp.	Trinidad	Bennett and Yaseen 1972; Yaseen 1984.
Hypomicrogaster hypsipylae De Santis	Brazil, Costa Rica	De Santis 1972 Bennett 1976a; Nagarkatti and Nagaraja 1977
Iphialtes sp.	Trinidad	Bennett and Yaseen 1972
Myosoma sp. (= *B. chontalensis*?)	Costa Rica	This paper
Unknown (Microgastrinae)	Costa Rica	This paper
Ichneumonidae		
Eiphosoma sp.	Belize	Bennett 1976a
Chalcidoidae		
Indet sp.	Belize	Bennett 1976a
Tachinidae		
Chrysodoria sp.	Trinidad	Bennett and Yaseen 1972; Yaseen 1984.
Larval-pupal parasitoids		
Tachinidae		
Metapiops mirabilis Townsend	Trinidad, Belize	Bennett and Yaseen 1972; Bennett 1976a
Pupal parasitoids		
Chalcididae		
Brachymeria conica (Ashmead)	Costa Rica, Trinidad.	Bennett 1976b; Grijpma 1973.

incidence of *Trichogramma* species parasitising eggs in the field and 10% parasitisation of eggs by *Trichogramma* sp. was reported in the Peruvian Amazon (Yamazaki et al. 1990). Bennet (1976a) gives approximate levels of parasitism of larvae in Belize of 13.8% and 24.5% in 1968 and 1969 respectively. Limited mortality due to parasitisation of larvae by *Bracon* sp. (Hymenoptera: Braconidae) was reported in Peru. Parasites of pupae of *H. grandella* are, however, rare (Bennett 1976a, b).

Population Fluctuation of Parasitoids of *H. grandella* in Turrialba, Costa Rica

The aim of this study was to determine the presence of *H. grandella* larvae and pupae of *H. grandella* and to record fluctuations in parasitoid abundance. Although egg parasitism has been reported (Table 1), the study focused on larval parasitoids due to the difficulties in finding un-hatched eggs in the field. Preliminary results are presented.

Materials and Methods

Field work was carried out at CATIE, at elevations ranging from 600 to 650 m. The mean annual rainfall in the area is 2600 mm, mean temperature is 21 °C, and mean relative humidity is approximately 80%. From July 1995 to February 1996, samples of larvae were collected from *Swietenia macrophylla* King saplings at three different sites within CATIE. From March 1996, samples were collected from 20 trees aged 18 months in the nursery at CATIE.

Damaged shoots were harvested from trees each month. Shoots were examined in the laboratory and the number of larvae and their instar recorded. The larvae were incubated individually on fresh leaves and stems changed every four days in petri-dishes or on artificial diet (Hauxwell 1997) until emergence of either the adult moth or a parasitoid. Percentage parasitism was estimated as the number of larvae parasitised as a proportion of the total number of larvae collected.

Results and Discussion

Five species of hymenopteran parasitoids were recovered from larvae and pupae (Table 2). Four species of Braconidae and one species of Chalcididae emerged from larvae and pupae between 1995 and 1996. There is some confusion regarding the identity of two of the parasitoids. *Apanteles* sp. and *Myosoma* sp. were identified by Alejandro Valerio and Paul Hanson, University of Costa Rica, but are normally referred to as *Hypomicrogaster hypsipylae* De Santis and *Bracon chontalensis* Cameron respectively. The larval parasitoid complex was dominated by *Myosoma* sp. (= *B. chontalensis*?) during 1995 and by *Apanteles* sp. (= *H. hypsipylae*?) during 1996. *Apanteles* sp. (= *H. hypsipylae*?), *Myosoma* sp. (= *B. chontalensis*?) and the pupal parasitoid *Brachymeria conica* (Chalcididae) occurred in both years, while *Bassus* sp. and an unknown braconid occurred only during the first year.

Table 2. Parasitisation of *Hypsipyla grandella* at CATIE, Turrialba, Costa Rica, during 1995 and 1996.

	No. of parasitised larvae reported	
	1995	1996
Larval parasitoids		
Braconidae		
Apanteles sp. (Microgastrinae) = *H. hypsipylae*?	4	17
Unknown (Microgastrinae)	2	0
Myosoma sp. (Braconinae) = *B. chontalensis*?	13	4
Bassus sp. (Agathidinae)	1	0
Pupal parasitoids		
Chalcididae		
Brachymeria conica	3	2

Apanteles sp. (= *H. hypsipylae*?) was the most abundant of the parasitoid species, both in terms of the number of shoot borer larvae parasitised and the number of parasitoids that emerged. *H. hypsipylae* is a gregarious endoparasitoid; i.e. the female lays all eggs at one time (Shaw 1995). Twenty seven larvae parasitised by *Apanteles* sp. were examined in the laboratory, from which 598 parasitoids emerged, with a range between 1 and 75 and a mean of 22 ± 16 (S.D.) wasps per larva.

De Santis (1972) reported that all the adult *H. hypsipylae* which emerged from *H. grandella* were females. In this study, 12 *H. grandella* larvae parasitised by *Apanteles* sp. were taken at random and the sex of their parasitoids determined. Not all were female, although significantly more female than male parasitoids adults were reared (χ^2 = 85.11; df = 1; P <0.001), with a sex ratio of 3:1.

The percentage parasitisation during each year of sampling is presented in Figure 1. The highest degrees of parasitism were found in August 1995 and May 1996, two to three months after the onset of rains and production of shoots. Shoots were plentiful

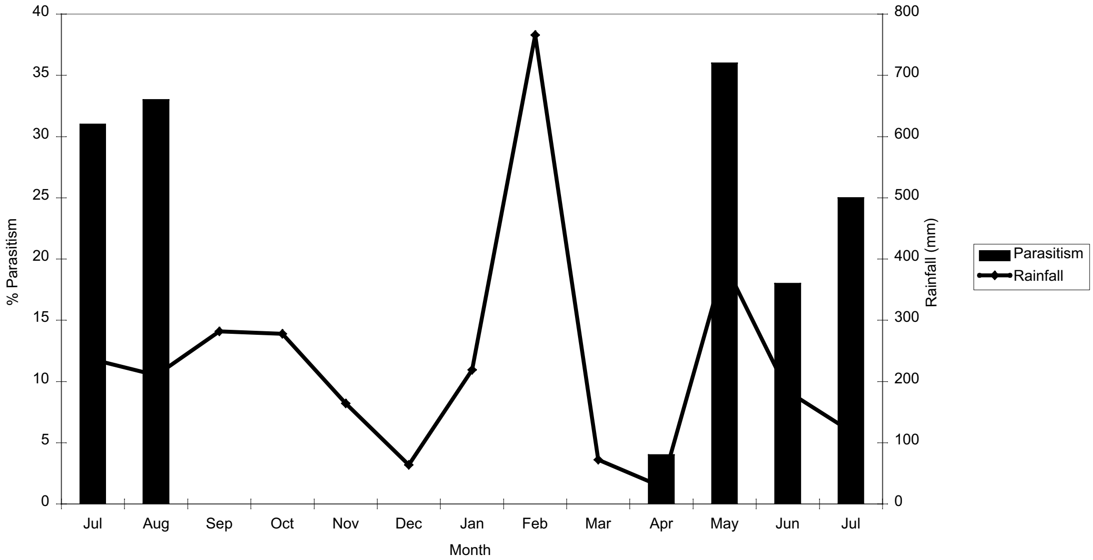

Figure 1. Percentage parasitisation of *Hypsipyla grandella* and rainfall at Turrialba, Costa Rica, 1995–1996.

early in 1996 following exceptionally heavy rain in February in the wake of hurricane Bertha and larvae were recovered, but none were parasitised. Thus, it appears that percentage parasitisation in 1996 lagged behind an increase in the *H. grandella* population. Temperature did not seem to have any influence on the percentage of parasitisation.

Discussion

This is the first survey of the incidence of parasitisation conducted at frequent intervals through a full year in Central America. The results suggest a relationship between percentage parasitism and rainfall, with percentage parasitisation rising following the start of rains. Similarly, Bennett (1976a) reports seasonal variation in shoots and a decrease in attack in Trinidad, the Lesser Antilles and Belize. Results from previous studies suggest that *H. grandella* infestation in Turrialba also peaked during the period when new shoots were available (Newton et al. 1993). Shoot borer activity is reported to increase after the dry season when the first rains begin, and incidence of damage corresponds closely to precipitation (Grijpma and Gara 1970; Howard 1991; Tillmans 1964; Yamazaki et al. 1990). Grijpma and Gara (1970) reported an increase in *Hypsipyla* flight activity 3–4 days after rain, when the moths are attracted to the new foliage produced following the onset of rain (Gara et al. 1973)

The increase in available host insects following the increase in shoots may in turn support an increase in the parasitoid population. These results suggest that there may be a lag between onset of *H. grandella* attack and the onset of parasitisation. Repeat studies relating parasitism to incidence and severity of insect attack and shoot availability are required to confirm this observation.

Parasitisation can cause high levels of mortality in *H. grandella* in Latin America. Egg parasitisation in the region is usually reported to be of the order of 10%, although it may reach up to 40% (Hidalgo Salvatieri and Madrigal Sanches 1970; Yamazaki et al. 1990). These data suggest that more than one third of larvae can be parasitised in the field. Similarly, Bennett (1976a) reported approximately 13.8% and 24.5% parasitisation of *H. grandella* larvae in Belize during 1968 and 1969.

In this survey, four different species of parasitoid, mostly Braconids, were associated with *H. grandella* larvae and were relatively common. The parasitoids which were most abundant in the *H. grandella* population were *Apanteles* sp. (= *H. hypsipylae*?) and *Myosoma* sp. (= *B. chontalensis*?). *B. conica* (Chalcididae), which is a parasitoid of several species and has a broad geographical range from Texas to Brazil and Trinidad (Grijpma 1973), was found to parasitise pupae.

Pupal parasitism was rare and no egg-larval parasitoids were found. Similarly, low levels of parasitisation of pupae and the absence of egg-larval parasitoids in Belize were reported by Bennett (1976a, b). This is in contrast to results of surveys of parasitisation of *H. robusta* Moore in India, where pupal parasitisation can reach 66% and parasitisation of egg-larvae can reach 27% (Bennett 1976b).

Bennett (1976a) suggested that parasitoids keep the *H. grandella* population in partial check, and that even a small increase in mortality levels might reduce populations to an acceptable level. In contrast to many other agents of control, parasitoids can locate a cryptic host by olfactory cues, and have been observed drumming on the shoot to locate larvae in the tunnel (Yamazaki et al. 1990). Yet introductions of parasitoids of *H. robusta* have been conspicuously unsuccessful (Newton et al. 1993). During 1969 to 1982, a program which aimed to introduce *H. robusta* parasitoids from India into Belize and the Lesser Antilles was established by the International Institute of Biological Control (IIBC), and is reviewed in these Proceedings by Sands and Murphy. Recovery surveys showed, however, that only *Trichogrammatoidea robusta* Nagaraja appeared to have established, and that only in Trinidad (Bennett and Yaseen 1972; Cock 1985). In Belize and the other islands of the Lesser Antilles, no introduced species were recovered following release.

In these releases, consignments of insects for release were delayed and many were dead before arrival in Belize. Furthermore, the releases were conducted in November, a time when there were few *H. grandella* in the field. It seems probable that most of the released parasitoids perished before they could find a suitable host (Bennett 1976a). Bennett (1976b) suggested that introductions might fail for several reasons:

- failure of parasitoids specific to *H. robusta* to survive in *H. grandella*;
- failure of an introduced parasitoid to survive under the different climatic conditions of the release area;
- failure of an introduced parasitoid to survive during the dry season when host larvae are scarce;
- release of too few individuals, and/or
- release of inbred or otherwise genetically inferior stock.

Furthermore, the parasitoids released in Belize were reared in Trinidad on *Corcyra cephalonica* (Stainton) (Bennett 1976c; Yaseen and Bennett 1972). Newton et al. (1993) suggested that rearing the parasitoids in this alternative host might have impaired the detection of olfactory cues required to locate *H. grandella* in the field. Thus, rearing these parasitoids on *H. grandella* might improve location, particularly when the *H. grandella* are reared on plant material from Neotropical Meliaceae (Bennett 1976c). Large-scale rearing of *H. grandella* has been successful in Costa Rica (Sterringa 1976; Hauxwell 1997). Grijpma (1972) successfully reared *Trichogrammatoidea semifumatum* (Perkins) in the laboratory over several months and generations in eggs of *H. grandella*. He noted that if the egg was 39 hours old or less when parasitised, then all eggs failed to hatch, but that if parasitised between 50 and 62 hours, 30% of eggs would hatch. Each egg contained on average 2 to 3 parasitoids. Rearing of parasitoids for release against *Hypsipyla* species is discussed in Bennett (1976c) and Yaseen and Bennett (1972).

Some control might be achieved by augmentative releases of indigenous parasitoids. These results suggest that there may be a lag between onset of *H. grandella* attack and the rise in parasitisation. Thus, plants may suffer economic levels of damage before the parasitoid populations can build up sufficiently to reduce the pest. Thus an early release of a parasitoid might be effective: e.g. immediately following the first rains. Bennett (1976b) recommended inundative release of *Trichogramma* sp., a technique that has successfully reduced levels of damages in other cryptic-feeding pest systems. For example, mass release of *T. dendrolini* Matsuma for the control of the codling moth (*Cydia pomonella* L.*)* and the summer fruit tortrix moth, (*Adoxophyes orana* F. R.) in apple orchards was reported to reduce damage by *C. pomonella* by 61% and by *A. orana* by 73% (Hassan et al. 1988).

Augmentation of abundance of one or several of the five native *Trichogramma* species would seem worthy of further investigation. The only reported attempt at such a release, however, was not successful: Orozco Ramos (1989) evaluated the parasitism of *H. grandella* eggs following liberation of the indigenous *Trichogramma pretiosum* Riley in a 50 ha plantation of *Cedrela* sp. and *Swietenia* sp. in Tabasco, Mexico. Five batches each of 1.6 million wasps were released at fortnight intervals. Sampling was undertaken four days after the third and fifth liberation, but only a single parasitised egg was recovered.

Meliaceae need to be protected from shoot borer attack for several years until the tree reaches a commercial height. Thus repeated augmentative release may not be feasible on economic grounds. Furthermore, it may be that the level of attack that can be tolerated commercially may be very low, perhaps as low as one attack per tree. In this case, the numbers of *H. grandella* larvae that can be tolerated may be so low that host-specific parasitoids could not persist. An economic threshold for *H. grandella* attack has not yet been determined but would be useful in assessment of the potential of biological control.

Acknowledgments

The authors thank Paul Hanson and Alejandro Valerio for identification of the parasitoids and Guillermo Chaverri and Luis Fernando Jirón for providing access to specimens collected in Puriscal, Costa Rica. Thanks also to Allan Watt for reviewing the manuscript. This work was supported by the University of Costa Rica and the British Overseas Development Administration Forestry Research Programme project number R6055.

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Discussion Summary
Biological Control of *Hypsipyla* spp.

D.P.A Sands and C. Hauxwell

Parasitoids and Predators

The Workshop highlighted the importance of further taxonomic studies on the major groups of parasitoids, since many of those collected could not be identified precisely. However, parasitoids species related to known effective biological control agents have been identified from both *Hypsipyla* spp.

Extensive studies on the natural enemies of *H. robusta* in India and *H. grandella* in Latin America have provided a basis for selecting the most promising agents for biological control programs. However, attempts to control *H. grandella* in Central America, the Caribbean and Brazil by introducing parasitoids from *H. robusta* have not been successful. It is likely that some of the introduced parasitoid species were specific to *H. robusta* and were unable to adapt to *H. grandella* as a host.

Further surveys for natural enemies of both *Hypsipyla* spp. should be carried out, with emphasis on countries where *Hypsipyla* spp. are less serious pests (e.g. Solomon Islands), where natural enemies may be reducing the pest's abundance. Immature stages of the hosts should be collected and preserved with the parasitoids so that an accurate association of parasitoid and stage of host attacked is recorded. This work can be carried out at the same time as the collection of moths for taxonomic studies, with the advantage that parasitoids and species of moths can be correlated.

Very little is known about the egg parasitoids, a priority area for research. Since eggs are difficult to locate in the field, exposures of laboratory-cultured eggs might serve as a means to capture parasitoids for identification and evaluation.

Detailed studies are needed to quantify the impact of each parasitoid species on *Hypsipyla* spp. populations at selected sites. However, although the importance of life-table studies was recognised, the logistics and time required to gather data were considered to be serious constraints.

The host range of biological control agents for introduction should be evaluated before they are released to ensure that they have no undesirable effects on non-target taxa, since parasitoids may not be host-specific. Furthermore, some parasitoids reared from *Hypsipyla* spp. are likely to be hyperparasitoids and should be carefully identified before their release is considered.

None of the predators recorded for *Hypsipyla* spp. are likely to be sufficiently host-specific to be suitable for use as exotic introductions; however, native predators might be encouraged or introduced locally. Further work is needed to identify predatory ants, such as *Oecophylla* spp. (weaver ants), *Anoplolepis* spp., and some *Iridomyrmex* spp., which have been used for control of other pests and might be established in forest plantations.

Any insecticides used to control *Hypsipyla* spp. should be integrated with the natural enemies in order to minimise impacts on beneficial insects. Climatic factors such as rainfall may influence the effectiveness of parasitoids, as observed in Costa Rica, and collection of climatic data should accompany field studies.

Research priorities identified were:

- Taxonomic studies on the major groups of parasitoids of *Hypsipyla* spp.
- Further collections of parasitoids (including egg parasitoids) should be undertaken especially in countries not previously surveyed and where the abundance of *Hypsipyla* spp. is low.
- The manipulation of native predators, particularly ants, should be evaluated.
- The impact of arthropod natural enemies of *Hypsipyla* spp. should be quantified at selected sites.

Pathogens

There has been little practical work on pathogens of *Hypsipyla* spp. Some pathogens originating from other species, notably *Autographa califomica* nucleopolyhedrovirus and some fungi, have been shown to infect *Hypsipyla* spp. However few pathogens have been isolated from *Hypsipyla* spp. It is therefore important to collect and identify more pathogens of *Hypsipyla* spp.

Hypsipyla spp. are a difficult target for those pathogens which are commonly used as bioinsecticides as the insects are cryptic, occur at low density, and are temporally patchy. This both restricts delivery of the pathogen to the insect and reduces the spread of infection in the pest population. However, pathogens are a diverse group of organisms and several areas for research were identified.

Effective biological control depends on an understanding of the biology of the insect. Studies of shoot borer biology might allow application of pathogens to be targeted at susceptible stages such as leaf-feeding early-instar larvae, larvae that emerge from the tunnel, and those that pupate in the soil. Persistent, vertically or sexually transmitted pathogens that reduce the overall population of the pest might be introduced as in classical biological control. Alternatively, silvicultural treatments might be manipulated to enhance pathogen activity. In particular, mixed species stands may create a microclimate favourable to pathogens by increasing humidity and reducing ultra violet light.

Research priorities identified were:

- Establish a collection of pathogens of *Hypsipyla* spp. with augmentation from a further collection.
- Evaluate pathogens especially in relation to the host’s biology, to determine how they infect and may be used to control *Hypsipyla* spp.
- Identify vertically transmitted, population-persistent pathogens.

Silvicultural Management of *Hypsipyla* Species

C. Hauxwell[1,2], J. Mayhew[2] and A. Newton[2]

Abstract

Existing evidence for successful silvicultural control of *Hypsipyla* spp. is conflicting and to a large extent anecdotal. Levels of attack have been correlated with factors such as shade, planting density, species mixtures, site characteristics, etc. These factors have often been poorly defined and are usually interdependent. The actual mechanisms that determine whether or not *Hypsipyla* spp. adversely affects plants we define as host-finding, host suitability, host recovery and natural enemies. These mechanisms can be influenced by the silvicultural techniques applied to a stand. Success of silvicultural techniques can usually be attributed to more than one mechanism and it is difficult to assess which is most the important for minimising the impact of *Hypsipyla* as these analytical data are lacking. This highlights the need for further research on silvicultural methods for controlling *Hypsipyla* spp. However, several silvicultural techniques that are briefly described show promise for improving the performance of future plantations. Examples of silvicultural control are reviewed with reference to these mechanisms.

A NUMBER of silvicultural treatments have been used to reduce the damage caused by *Hypsipyla grandella* (Zeller) or *H. robusta* (Moore) (hereafter referred to as *Hypsipyla*) on plantings of species of the sub-family Swietenioideae of the family Meliaceae (here-after referred to as Swietenioideae). However, much of the information available is anecdotal, from trials that are often un-replicated, and results have been inconsistent. Consequently, guidelines that give effective, consistent results are not available.

An experimental analysis of the different silvicultural treatments is needed. In order to provide a framework for such an analysis of silvicultural treatments, we describe four fundamental mechanisms that may reduce the impact of *Hypsipyla*. We then review the different treatments practised and discuss the relative importance of mechanisms by which they may achieve control.

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Mechanisms of Silvicultural Management of *Hypsipyla*

Hypsipyla attack causes loss of form and increment, which may be severe, but rarely causes death of the host tree (Newton et al. 1993; Whitmore 1976). Management of *Hypsipyla* therefore attempts to reduce the incidence, severity or frequency of attack, or to promote the recovery of form and height increment. We suggest four essential mechanisms by which silvicultural treatments may effect this:

- interference with locating the host plant;
- reduction in host suitability;
- encouragement of natural enemies;
- recovery of form and height increment of the plant.

Host-finding

A host plant may in theory be screened from the moth by confusing or obscuring the signals by which the moth locates it (Grijpma 1976; Grijpma and Gara 1970a; Kareiva 1983; Morgan and Suratmo 1976).

Other silvicultural treatments may conceivably alter plant growth or chemistry, thereby changing the signals that attract adults to the plant (Gara et al. 1973; Grijpma 1976). Moth dispersal and location mechanisms are clearly important and worthy of further study (Grijpma 1976; Newton et al. 1993).

Host suitability

Silvicultural treatments may modify the plant so as to make it unsuitable for the development of the insect, e.g. by decreasing temperature, by increasing the proportion of woody tissue, or altering the nitrogen content of the plant (Ramos and Grace 1990). Some treatments may enhance plant defences, e.g. by increasing resin flow, which may prevent tunnelling (Lamb 1968; Whitmore 1978; Wilkins 1972), or by enhancing complex secondary plant compounds such as proanthocyanidins or limonoids which may be insecticidal or antifeedants (Adesida and Adesogan 1971; Adesogan and Taylor 1970; Koul and Isman 1992; Kubo and Klocke 1986; Vanucci et al. 1992).

Trees have been reported to recover from attack (Hall 1919; Perera 1955) and to become physiologically resistant to attack at between 3.5 and 7 metres height (Dourojeanni 1963; Suratmo 1976; Vega 1974). Promoting growth in order to reach this 'resistant' height has been suggested (Ramirez Sanches 1964 cited in Grey 1990). The evidence for this 'resistance' is, however, equivocal. Roberts (1966) reported attack on the new shoots of mature *Khaya* spp., and suggested that attack is continual throughout the life of the tree, although the impact on form is not important in older trees.

We have observed *Hypsipyla* attack on *Swietenia macrophylla* King in Solomon Islands at 10 metres, on *S. mahagoni* (L.) Jacq. at over 13 metres in Puerto Rico (USDA Botanical Garden), and M. Annandale (pers. comm.) has observed feeding on *Toona ciliata* M. Roem at over 25 metres in Australia. Thus it appears that attack continues later in the plant's development but may be more critical (or more obvious) in smaller trees, and it is possible that by promoting growth of the leading shoot, trees may reach an acceptable economic bole-length more rapidly.

Recovery

Silvicultural treatments that promote growth of the leading shoot and recovery of form enable trees to recover from damage caused by *Hypsipyla*. Promoting vigorous growth of *C. odorata* L. in order to avoid attack was recommended by Ohashi et al. (1993).

In *C. odorata*, however, taller saplings are reported to be more frequently attacked and to be more attractive to ovipositing moths (Grijpma and Gara 1970a; Holsten and Gara 1975; Ramnarine 1992; Whitmore 1978). Similarly, factors that promote vigorous apical growth in *Khaya* species have been reported as increasing incidence of attack (Akanbi 1973; Brunck and Mallet 1993). Increased attack on vigorous or taller trees may be as a consequence either of the increased number of potential sites suitable for attack on longer lead shoots, or of a greater attraction to the moth of lush foliage produced by vigorous growth. Luxuriant foliage of *C. odorata* is reported to be more attractive to females of *H. grandella* (Gara et al. 1973).

However, even if plants suffer increased attack, vigorously growing plants are subsequently better able to recover (Grijpma 1976; Vega 1976). Vega (1976) reported that attack on *Cedrela angustifolia* Moc. and Sesse ex DC. in Surinam was most critical in the second year after establishment, when rapid growth of the plant provided suitable sites for attack, but that in subsequent years the plants were vigorous enough to gain height satisfactorily even though they continued to be attacked. In *C. odorata*, carbohydrate reserves in roots are mobilised to recover from *Hypsipyla* damage (Rodgers et al. 1995). Thus treatments that reduce root: shoot ratio may reduce the capacity of the plant to recover. Furthermore, treatments which reduce vigour may reduce attack but do not achieve the main objective of any plantation establishment, which is to achieve tree growth.

Natural enemies

Silvicultural treatments such as mixed plantings may maintain the population of predators, parasitoids and pathogens by providing suitable habitat, food-sources and alternative insect hosts, e.g. maintenance of predatory ants by cover crops (e.g. DeBach and Hagen 1964). Shade from nurse crops may change the microclimate and thereby affect natural enemies, e.g. by increasing humidity, which improves germination of some entomopathogenic fungi (Ferron 1981), or reducing solar UV, which improves persistence of entomopathogenic viruses (Entwistle and Evans 1983).

Mechanisms in complex management systems

Silvicultural techniques may affect one or several of the above mechanisms. Even relatively simple treatments such as application of fertilisers may affect not only the suitability of the plant for insect development but also the ability of the plant to recover from attack. Silvicultural treatments such as establishment of species mixtures are even more complex and will be discussed in detail later. Briefly, interplanting with other species may have direct effects such as screening the host plant, thus interfering with locating of the plant by the moth, or by supporting natural enemies such as ants. In addition, the species mixtures may indirectly affect the mechanisms by which the impact of *Hypsipyla* spp. is reduced by modifying other factors e.g. drainage, soil nutrients or insolation.

Management of species mixtures is complex. The quantity of, for example, screening and shade provided can differ significantly with age, height, species selection, planting patterns and degree of pruning of plants in the mixture. For example, shade reduces plant growth, thus canopy opening or pruning are often necessary in order to provide sufficient light for plant growth but pruning can radically alter the amount of light entering the mixture or reduce screening, and might render the Swietenioideae susceptible to attack.

Not surprisingly therefore, different trials of complex silvicultural treatments such as the use of species mixtures have produced conflicting results (Newton et al. 1993), leading to what Whitmore (1976) described as 'myths'. These apparently conflicting conclusions result from the complexity of these systems, variations in management between the different trials (such as choice of species in the mixture, degree of over-storey pruning etc.), and lack of analysis of the mechanisms by which they may reduce shoot borer impact. It is important to understand which of the mechanisms is operating in any silvicultural treatment in order to optimise the management system so as to reduce the impact of *Hypsipyla* spp. in a stand below an action threshold while maximising timber yield.

Silvicultural Treatments

Site effects

Site effects will alter the vigour of the plant thereby affecting recovery and possibly suitability of the plant for larval development. Site effects in combination with genetic variation have also been suggested as responsible for forking which is not due to *Hypsipyla* attack (Bauer 1987). We have observed low forking possibly due to damage on windy sites occurs in *S. macrophylla* in Fiji, where *Hypsipyla* spp. are absent. However, the range of site tolerances for any of the species is not fully understood and interactions of site with provenance have not been investigated in any detail.

Site and topography

Sloping ground providing adequate drainage is important for vigorous growth of *C. odorata* (Anon. 1946; Cater 1944; Guevara Marroquin 1988; Marshall 1939) *C. fissilis* Vell. (Andrade 1957), and *Khaya* species (Ardikoesoema and Dilmy 1956; Hawthorne 1995). *H. grandella* was reported only to be a problem on *C. odorata* in Cuba on poorly drained sites (Anon. 1946). As well as selecting well-drained sites, Cater (1944) recommended planting *C. odorata* on artificial hummocks to increase drainage. Plantings of *S. macrophylla* on ridge tops suffered significantly less *H. grandella* attack in Puerto Rico, although this was attributed to high winds removing adults rather than to increased drainage (Weaver and Bauer 1986).

Soil nutrients

Fertile soil will promote vigorous growth and thereby recovery and suitability, although incidence of attack may also increase. In addition, soil nutrients may directly alter the chemical composition of the plant, and consequently alter plant suitability or location of the plant by the moth (Newton et al. 1998).

Appropriate soils for Swietenioideae are typically high in nutrients: *Cedrela* species grow most quickly when planted on fertile sites with plenty of organic matter in Brazil (Andrade 1957), Colombia (Guevara Marroquin 1988), Surinam (Vega 1976) and Cuba (Fors 1944). *S. macrophylla* grows rapidly on deep volcanic soils in Solomon Islands, and *K. senegalensis* (Desr.) Juss grows rapidly on deep volcanic soils in la Reunion (Roederer 1991). *T. ciliata* once flourished on the volcanic tablelands of Queensland, Australia.

Holdridge and Marrero (1940), Marie (1949), and Huguet and Marie (1951) reported that *Swietenia* spp. are more susceptible to *Hypsipyla* on infertile sites. Vega (1976) reported increased duration of attacks on *C. angustifolia* on low nutrient soils, whereas established trees on fertile sites continued to grow and to apparently tolerate attack. Akanbi (1973) reported increased attack on *Khaya* on fertile soils but did not consider possible improved recovery from increased vigour.

In some species, a moderate pH and high calcium content are favoured (Newton et al. 1998). *Swietenia* species grow relatively vigorously on limestone in Puerto Rico (Anon. 1955b) but suffer serious *H. grandella* attack and poor growth on poor, non-calcareous soils in Belize (Cree 1953). *Cedrela* species grow vigorously in Cuba on brown or white clays with high calcium content and pH above 7 (Anon. 1946), in Surinam on calcareous soils (Vega 1976) and in Brazil on sites with a 0.52% calcium content and pH of 6.9 to 7 (Andrade 1957).

Reports of fertiliser applications to Swietenioideae and their effect on *Hypsipyla* attack are rare. In *Khaya* spp. in Ivory Coast, fertilisers in general increased plant growth but also increased attack, except following the application of potassium sulphate which improved growth and slightly delayed the onset of attack (Brunck and Mallet 1993).

Planting

Delayed planting

As noted above, taller trees have been reported to be less susceptible or resistant to attack by shoot borer. Planting of *S. macrophylla* stock 1 m tall has been advocated by Weaver and Bauer (1986) and between 1.5 to 5 m height by Dillenbeck (1986) on the basis that it is more feasible to use pesticides in the nursery than in the plantation, and that trees would reach the 'resistant' height sooner. This possibly misunderstands the nature of apparent 'resistance' of taller trees, which may be due to failure to observe attack in trees above a certain height, and furthermore creates problems for plantation establishment. Large planting stock has a lower root:shoot ratio, and is probably more susceptible to drought (Evans 1992). Oversized planting stock survives poorly in the field except when pruned to a stump before planting (Anon. 1961; Lamb 1966; Marrero 1942). Furthermore, Bauer (1987) reported higher incidence of *Hypsipyla* attack on *Swietenia* planted out at 1.5 m than on shorter stock. An example of good nursery practice is found in the successful *S. macrophylla* plantations on Kolombangara in the Solomon Islands, which use vigorous planting stock transplanted after only 4 months in the nursery.

Stocking density

Dense stocking promotes recovery of form, encouraging apical growth and self-pruning at canopy closure (Chaplin 1993; Stevenson 1939). Densely planted *S. macrophylla* and *C. odorata* are reported to be less susceptible to attack in Peru (Dourojeanni 1963), and close spacing (1×2 m or closer) is recommended to avoid attack by *H. robusta* on *S. macrophylla* in Indonesia (Suratmo 1976). We have observed dense planting used to establish *S. macrophylla* in the West Indies. However, Chable (1967) reported that close planting did not reduce attack, and competition in dense stands can cause growth to stagnate. In Cuba, when *C. odorata* is planted in pure, dense stands, no fast growing dominants or co-dominants develop, but instead increment of the whole stand declines (Fors 1944).

The moth may not locate isolated trees. In Cuba, isolated individual *Cedrela* trees show high growth rate and good form (Fors 1944). In Belize, we have observed that small isolated plantations of *S. macrophylla* sometimes escape attack. Isolation can be achieved by planting at low stocking density in mixtures, which enhances screening, and will be discussed later.

Weeding

There are few reports on the effect of weeding on plant growth or *Hypsipyla* attack. Weeding could promote vigorous plant growth by reducing competition for water and nutrients, thereby potentially promoting recovery and altering suitability, although there are no reported studies on this.

Weeding improves growth of *K. senegalensis* (Anon. 1956; Cardoso 1951). Mown pasture increased the biomass and root:shoot ratio of direct-sown or planted *S. macrophylla* seedlings over unmown pasture in Costa Rica (Gerhardt and Fredriksson 1995). However, herbicide treatment of *Imperata cylindrica* did not improve growth of *S. macrophylla* in Indonesia (Otsamo et al. 1995).

Weeds may also act as a screen, interrupting locating of the plant by moths (Vega 1976), or providing shade, which may have numerous effects. *S. macrophylla* plantations established under the Taungya system (interplanting of trees with agricultural crops) in Belize were attacked following weeding, which was attributed to removal of shade cast by weeds (Cree 1954; Kinloch 1933). Weeded plots of *C. odorata* were reported to be more susceptible to *Hypsipyla* in Peru (Dourojeanni 1963) and Costa Rica (Grijpma 1974). Our preliminary observations suggest that weeding of plots of *C. odorata*, *S. macrophylla* and *K. ivorensis* A. Chev. may induce a flush of plant growth which is subsequently attacked. If increased attack is a result of induced flushing, timing of weeding with seasonal variations in *Hypsipyla* attack is worth further investigation in order to optimise growth without increasing the risk of attack.

Pruning

Pruning improves form after attack. Swietenioideae are typically monopodal in growth with delayed canopy development. *Swietenia* self-prunes satisfactorily (Chaplin 1993) and is not pruned in Fiji, where *Hypsipyla* does not occur.

Pruning has been successfully used in open-site plantations, and could be combined with fertile, well-drained sites, weeding and fertiliser treatments to promote growth. Some pruning is conducted in Solomon Islands up to 7 m where *S. macrophylla* is open planted or canopy removed by poisoning. Annual pruning up to age 7 was used by Chable (1967) to combat severe *Hypsipyla* attack in *S. macrophylla*. In the early dry season, trees were pruned with a saw (not a machete) close to the bole and cut surfaces painted. Large branches were lopped to 50 cm before sawing to prevent splitting. Pruning was repeated annually for the first seven years after planting. Although costs were high and stocking density was kept low, well-formed stands were produced in 8 to 10 years.

Species mixtures

Growing Swietenioideae with other species, either planted as a nurse crop or in natural forest, has been used for planting and regeneration of Swietenioideae specifically to reduce the effect of *Hypsipyla*. Mixtures may provide functions other than *Hypsipyla* control, e.g. watershed management, reduction of soil erosion, in providing seed for regeneration (in shelterwood systems), for amenity and for the multiple non-timber products of natural forests. Planted mixtures may improve soil fertility, reduce fire risk, produce agricultural crops or provide fuelwood or a second timber crop. Mixtures can also have negative effects on the Swietenioideae, such as reducing growth increment by increased competition for light, water and nutrients, and reducing stocking density of the valuable timber species.

Mixtures maintain some of the ecological conditions of the original forest (such as floristic diversity and microclimate) (Catinot 1965; Dubois 1971). As described earlier, these complex systems may have several effects on plant susceptibility to and recovery from *Hypsipyla* spp., and there is considerable disagreement as to which mechanisms are responsible for the apparent success of species mixtures.

Screening and the effects of shade have both been suggested as the key components of species mixtures by which *Hypsipyla* damage is reduced (Entwistle 1967; Roberts 1966) but the actual mechanisms have not been determined by experimental analysis. In particular, there is little information on the mechanisms by which shade may reduce shoot borer impact.

Host-finding may be interrupted by the screening effect of a species mixture. Planting at low density in natural forests has been recommended in order to isolate Swietenioideae, and low density planting of *Cedrela* and *Khaya* spp. with mixed species has been advocated (Beard 1942; Cater 1944; Holdridge 1943; Roberts 1966; Weaver and Bauer 1986). Screening by dense undergrowth was suggested as the mechanism by which attack was reduced on *Khaya* spp. in Nigeria (Roberts 1966) and the maintenance of dense undergrowth to act as a screen was recommended in *S. macrophylla* plantations in Solomon Islands (Bigger 1988).

Planting Swietenioideae singly or in groups rather than in lines in a mixture has been advocated on the grounds that it may screen plants more effectively from location by the moth (Roberts 1966; Vega 1976). However, such low density planting will considerably reduce the stocking density of these species.

Shade has multiple effects on the insect-plant interaction. It may reduce *Hypsipyla* attack by altering the host suitability:

- Alteration of shoot morphology by reduction in red: far-red ratio. Stems grown under overhead shade tend to be thinner and woodier: adults may prefer to oviposit on thick succulent shoots of open-grown plants (Grijpma 1976; Vega 1976) or the larvae may not survive on the woodier shoots.
- Change in total insolation alters the nutritional value of the shoot (nitrogen, sugar and water content) (Ramos and Grace 1990) so as to be rejected by ovipositing adults or to be unsuitable for larval survival.
- Modification of plant defences, physical and chemical, such as sap flow, tannin or limonoid content etc. (Lamb 1966). For example, direct sunlight induces changes in leaf morphology that may reduce defences against pest attack in *Toona ciliata* (Westrup 1995).

Shade may also alter the microclimate, thereby perhaps enhancing some natural enemies, or reducing temperature, which might adversely affect the moth (Grijpma and Gara 1970a). Vertical growth and self-pruning may be promoted by lateral shade (Aubreville 1953; Stevenson 1939; Yared and Carpenezzi 1981), encouraging recovery of form and increment and also reducing the number of sites available for attack (Entwistle 1967; Grijpma 1976).

Partial shade has been repeatedly cited as reducing *Hypsipyla* attack (Campbell 1966; Entwistle 1967; Holdridge and Marrero 1940; Kalshoven 1926; Lamb 1966). Vega (1976) reported that attack on open planted *C. angustifolia* occurred sooner after planting than on those planted under semi-shade. Artificial shade eliminates *Hypsipyla* damage in nurseries of *K. grandifoliola* C. DC. and *K. anthotheca* (Welw.) C. DC. in Uganda (Anon. 1951a). Conversely, Chable (1967) and Tillmans (1964) both reported that shade or cover did not reduce attack by *Hypsipyla*, while Combe and Gewald (1979) described a high incidence of *Hypsipyla* attack in trial plots of *Swietenia* planted under *Gmelina arborea* Roxb. and *Cassia siamea* Lam. in Costa Rica.

Shade from species in mixtures reduces growth of Swieteniodeae and may reduce recovery of increment following attack. The light tolerances of most Swietenioideae have not been critically evaluated, although some differences have been observed between species. It appears that most Swieteniodeae will tolerate some degree of shading but not heavy shade, and are probably adapted to colonising medium to wide gaps in the forest (Hawthorne 1995;

Herwitz 1993; Lamb 1966; Marshall 1939; Pennington and Styles 1975; Ramos and Grace 1990; Styles 1981; Thompson et al. 1988).

Competition for light, rather than root competition, decreased biomass of *S. macrophylla* in forests and decreases root:shoot ratio (Gerhardt and Fredriksson 1995). Heavy shade will eventually result in death of the tree (Fors 1941; Lamb 1960, 1966, 1968; Noltée 1926). Shade can provoke other problems such as phytopathogenic fungi in *S. macrophylla* (Garcia Alvarez 1939).

Pruning or removal of overstorey canopies is often necessary in order to provide sufficient light for plant growth. Relative growth rate of *K. senegalensis* increases in response to an increase in red:far red ratio, such as that caused by canopy opening (Kwesiga and Grace 1986; Kwesiga et al. 1986). Canopy opening may have other beneficial effects. The frequency of regenerating *Swietenia* increased as residual basal area decreased following canopy opening to create multiple gaps in Mexico (Negreros Castillo and Mize 1993). Similarly, in Nigeria survival of *K. grandifoliola* C. DC. seedlings was reported to increase with canopy opening and weeding, especially when this was repeated annually (Anon. 1962).

If, however, too much light is allowed to enter, this may result in increased attack (Aubreville 1947; Davies 1958; Dupuy and M'Bla Koua 1993; Oliphant 1926; Roberts 1966). In Belize, Oliphant (1926) recommended canopy opening to provide an irregularly broken canopy, as heavy shade caused growth of seedlings of regenerating *S. macrophylla* to stagnate but too drastic removal of overhead canopy resulted in severe insect attack. We have observed similar effects in *S. macrophylla* in Sri Lanka, and these have also been recorded for *Khaya* and *Entandrophragma* spp. in Uganda (Eggeling 1940). Canopy opening may also provoke problems with weeds, particularly climbing vines (Chaplin 1993; Dupuy and M'Bla Koua 1993). The optimum amount of light required in order to produce maximum growth while maintaining sufficient shade to possibly reduce attack has not been quantified.

Management of species mixtures is complex. Spacing, thinning, canopy pruning and choice of nurse species will be important factors in the manipulation of total insolation and red: far-red ratio, and have effects on screening, natural enemies, the availability of soil nutrients and water, microclimate, and weeds. Furthermore, species mixtures of the same height produce lateral shade or screening but not overhead shade, whereas a shelterwood or nurse crop will provide both overhead shade and screening. The distinction between lateral and overhead shade, their effects on total insolation and light quality (red: far-red ratio), and the subsequent effects on the mechanisms affecting shoot borer impact have not been investigated.

More research on interactions between gap size, plant growth and survival, and *Hypsipyla* attack is needed particularly where shelterwood or nurse crop systems are proposed, as in Sri Lanka (Sandom and Thayaparan 1995). Existing reports of the use of species mixtures, although largely anecdotal, provide a starting point on which to develop silvicultural regimes. Trials that consider how control is achieved and how treatments such as pruning of a nurse crop may result in damage are then needed in order to optimise management for maximum timber yield with minimum pest damage, and to develop reliable silvicultural prescriptions.

Establishment with other timber species

Line and enrichment planting

A light overhead shade was recommended to prevent *Hypsipyla* attack in line planted Swietenioideae (Entwistle 1967). However, excess shade causes growth to stagnate in line planted *Swietenia* spp. and *Cedrela* spp. (Anon. 1955 a; del Amo and Ramos 1993; Ramos and del Amo 1992), *T. ciliata* gains more height when planted in wider strips with more light in Argentina (Riera 1974), and heavy shade kills *C. odorata* in Papua New Guinea (Saigura and Taurereko 1988).

Light shade limited *H. grandella* attack on *S. macrophylla* enrichment planting in Brazil (Yared and Carpenezzi 1981). In Puerto Rico, although *Hypsipyla* attacks were not eliminated completely, damage was reduced to acceptable levels in *S. macrophylla* when planted under thinned canopy while *S. mahagoni* gave improved form when planted under light shade compared to open planting (Anon. 1955 b; Weaver and Bauer 1986). In Solomon Islands, line planted *S. macrophylla* is most successfully cultivated under light shade (Anon. 1979). In India top-canopy shading was recommended for *S. macrophylla* (Anon. 1941a).

Shaded plots of *S. macrophylla* and *C. odorata* were less susceptible to *H. grandella* in Peru (Dourojeanni 1963). In Cuba a 'not too dense' lateral shade was recommended for *C. odorata* (Anon. 1946; Roig 1945). In detailed studies in Surinam, line planted *Cedrela* spp. trees were less attacked than open planted trees (Vega 1976). *Carapa guianensis* Aubl. survived and grew well when planted under undisturbed high forest shade compared to the open in Brazil (Alencar and Araujo 1980).

In Australia, 50% shade reduced *H. robusta* infestations and produced acceptable growth of *T. ciliata* (Campbell 1966). In India, slightly more than top-canopy shading was recommended for *Cedrela toona* (Anon. 1941).

Line planted *Khaya* and *Entandrophragma* spp. in Africa are rarely attacked (Aubreville 1957; Brunck and Mallet 1993; Gouget 1952; Roberts 1966); however, girth and height increment are reduced in line planted Meliaceae (Hauxwell and Opuni Frimpong, unpublished; Roberts 1966). Canopy opening to increase growth results in *Hypsipyla* attack (Aubreville 1947; Dupuy and M'Bla Koua 1993; Roberts 1966) and, in West Africa at least, provokes severe problems with weed lianas (Davies 1958; Dupuy and M'Bla Koua 1993; Osafo 1970).

Nurse trees

Nurse trees have been tested in order to improve establishment of all of the key Swietenioideae. Differences in age, species, height, planting pattern, proportion of each species and pruning of the nurse crop will radically alter the properties of the mixture. Results have been inconsistent and standardised recommendations are not available.

In Puerto Rico, nurse crops of *Casuarina equisetifolia* L. (Anon. 1951b) prevented attack on *Swietenia* spp. by *H. grandella*. *H. robusta* attack on *S. macrophylla* was reduced by shade from an unnamed nurse crop in the early stages of establishment in India (Anon. 1942a) and by shade from a nurse crop of *Artocarpus heterophyllus* Lamk. in Sri Lanka (Beeson 1941; Perera 1955). *Albizia falcataria* (L.) Fosberg was recommended as a nurse crop in Indonesia (Morgan and Suratmo 1976) and *Securinega flexuosa* Comm. ex A.L. Juss. in Solomon Islands (Chaplin 1993; S. Iputu pers. comm. 1996). However, a high incidence of attack occurred under heavily shaded conditions in trial plots of *Swietenia* planted under *G. arborea* and *C. siamea* in Costa Rica (Combe and Gewald 1979), possibly after pruning of the nurse crop.

For *Cedrela* spp., nurse crops of banana (*Platanus*) spp. have been used to provide shade and prevent attack in Jamaica and Cuba (Anon. 1942b; Anon. 1946). Other nurse crops used to provide shade include *Syzygium jambolanum* DC. and *Pinus elliottii* Engelm. in Brazil (Andrade 1957; Toledo Filho and Parente 1982), and *Cordia alliodora* (Ruiz and Pav.) in Surinam (Vega 1978). However, planting of C. *odorata* with *C. alliodora* and *Tabebuia rosea* (Bertol.) DC. in Colombia did not prevent attack or improve form (Anon. 1985).

H. robusta attack on *Khaya* spp. was prevented by nurse crops of *Tectona grandis* L. in Togo (McLeod 1915), *Eucalyptus saligna* Sm. in Uganda (Osmaston 1958) and *Aucoumea klaineana* Pierre and *Nauclea diderrichii* (de Wild and Th Dur.) Merill in Nigeria (Anon. 1943; Henry 1960). Similarly, *H. robusta* attack on *Khaya* spp. was prevented by planting in a mix of 30–50% *Khaya* with mixtures of *N. diderrichii*, *Terminalia superba* Engl. and Diels, *T. ivorensis* A. Chev., *Tarretia utilis*, *Tieghemella heckelli* (*africana*) Pierre *ex* Chev. and *A. klaineana* in Ivory Coast (Dupuy 1995; Dupuy and M'Bla Koua 1993; de la Mensbruge 1962) and in a 20% mixture with *N. diderrichii* and other species in Nigeria (Roberts 1966).

In Ivory Coast, mixed plantings of *Khaya* spp. produced between 2 and 4 m^3/ha/annum by age 30, and up to 7 m^3/ha/annum when mixed with *T. utilis* in evergreen forest zones. In addition, the nurse crop produced between 5 and 9 m^3/ha/annum at age 30 years (Dupuy and M'Bla Koua 1993). While some attack was noted in these mixes, it was, in most cases, moderate (Brunck and Mallet 1993). A mix of *Khaya* with *C. odorata* (which is not susceptible to *H. robusta* in West Africa) also gave satisfactory control (Brunck and Mallet 1993). In mixes with *T. superba*, however, attack was more serious and in some multi-species plantings (*Khaya* with *Triplochiton scleroxylon* K. Schum. and *T. heckelli*, with *T. scleroxylon* and *T. superba*, and with *T. ivorensis*, *A. klaineana* and *C. odorata*) borer attack was numerous and serious (Brunck and Mallet 1993).

Screening, shade and other effects may be altered by differences in planting pattern and age of the mixture. Roberts (1968) noted that when *K. ivorensis* was planted in pure lines under a nurse crop (usually *N. diderichii* or *G. arborea*) there was little evidence of control, but when shade trees and Swietenioideae were planted alternately in the same line some degree of control was obtained. In Ghana, we observed that 4 year old *K. ivorensis* planted in rows in an even-aged mixture with *Entandrophragma utile* (Dawe and Sprague) Sprague and *T. scleroxylon* was severely attacked, although the *Entandrophragma* was little attacked.

T. ciliata was established at different times after establishment of a nurse crop of *Grevillea robusta* A. cunn. ex R.Br. in Australia (Keenan et al. 1995). Although trials were not sufficiently replicated to allow proper statistical comparison, *Hypsipyla* attack was severe in trees planted in the open or under 1 or 2-year-old *Grevillea* but not when established under older nurse crop. After 10 years, 65% of *Toona* over 6 m planted in the open and 34% planted in the first year after the *Grevillea* had multiple leaders, which fell to fewer than 5% of stems planted between 2 and 5 years after the nurse crop. The reason for the control is not clear as the nurse crop is leafless in the spring when most *Hypsipyla* attack occurs. Growth increment was deleteriously affected in the mixture, where both diameter at breast height and merchantable timber were greater in open and earlier-planted plots, probably because later plantings were under-thinned (400 stems/ha as compared to 150 in other treatments). Keenan et al. (1995) recommend under-planting at 2 years, removal of the nurse crop at 10 years, thinning of to 150 stems/ha in two stages and clear fell at 50 years.

Mixtures with 'bioactive' trees

In addition to providing screening and shade, other effects can be enhanced by the use of nurse crops which are nitrogen fixing or have insecticidal properties.

Mixtures with Leucaena leucocephala (Lam.) de Wit

Leucaena leucocephala is a nitrogen-fixing tree and may improve soil nutrition, possibly enhancing recovery, or increasing growth and nutrient composition of the Meliaceae. In Ivory Coast, *L. leucocephala* has been used as a nurse crop in trial plots of *Khaya* spp to provide shade, control of weeds, increase soil fertility, reduce erosion, reduce fire damage and provide fuel wood (Dupuy 1995; Dupuy and M'Bla Koua 1993). *Khaya* are planted two years after the *L. leucocephala* in alleys 5 to 6 m wide. *L. leucocephala* was pruned regularly and plots weeded once or twice annually. *Khaya* under the nurse crop showed better growth and form and *Hypsipyla* attack was reduced, but when pruning of *L. leucocephala* increased exposure to light, *Hypsipyla* attack was severe (Brunck and Mallet 1993). Conversely, *S. macrophylla* in the Philippines grew only as well as that without *L. leucocephala* (Granert and Cadampog 1980).

Mixtures with insect repellent species

An untried method might be to use a nurse crop with insecticidal properties, e.g. *Azadirachta indica* A. Juss., which might enhance screening effects (azadirachtin is active when applied against *H. grandella* in *S. mahagoni* in Florida (Howard 1995)). Anecdotal reports suggest that *Datura* spp. may reduce attacks by olfactory screening.

Establishment with agricultural crops and fruit trees

Crops and fruit to some extent fulfil roles described above, providing either shade or screening, harbouring natural enemies such as predatory ants or increasing soil fertility. Cultivation of the land and fertiliser inputs may improve drainage and soil nutrients.

Cedrela is frequently found as part of agroforestry system in Latin America with coffee, cocoa, maize and citrus trees, (Beer and Heuveldop 1987; Brack Egg et al. 1985, Escalante et al. 1987, Espinoza 1986, Fuentes 1979). Similarly, *S. mahagoni* has been grown in Brazil and the Philippines with agricultural crops (Brienza et al. 1983; Penafiel and Botengan 1985).

Swietenioideae have been established by the Taungya system of mixed crops and trees. *S. macrophylla* and *C. odorata* were established in Taungya in Mexico (Mas Poras and Borja Luyano 1974). *H. grandella* was successfully controlled in Taungya in Belize where *S. macrophylla* was direct-sown with maize at a spacing of 3×3 m in which trees were positioned with half or full shade, and resulted in a reduction in percentage of trees attacked over open-planting (Stevenson 1936). How the reduction in attack was achieved isn't clear, and has been attributed both to reduction in growth rate caused by shading (Cree 1954) and, later, to good species-site matching and early maintenance, including weed control (Palmer 1988).

Entwistle (1967) also recommended the Taungya systems used in Nigeria to prevent *H. robusta* attack, which involved planting with a cover crop in a ratio of 1:5, giving a mixture of species in each row. Again, growth may be reduced in mixtures. For example, Ghana Forestry Department unpublished plantation trial records show a mean annual diameter increment of 0.49 ± 0.2 cm in Taungya trials of *K. ivorensis*, often in a mix with other timber species including *Entandrophragma*, and 1.6 ± 0.2 cm for open-planted trials. However, *H. robusta* attack was severe in open plots and not recorded in Taungya plots. *Entandrophragma* gave similar growth but shoot borer attack was not recorded.

Recommendations

Past trials have demonstrated the use of silvicultural management of *Hypsipyla*. Control can be achieved by planting in a species mixture, and mixed plantings may offer other advantages such as fuelwood, crops, and watershed management. However, choice of species, their proportions, age, height, planting patterns, and degrees of canopy opening can affect several different mechanisms, and results have not been consistent. Alternatively, high growth rate and acceptable form appear possible on open sites by selecting appropriate sites (and plant provenances) in combination with spacing and thinning to manage canopy closure and pruning for form.

All options appear to require considerable inputs. Pruning and weeding are costly, obtaining appropriate sites may be difficult, while mixed plantings reduce stocking density, can require skilled management for pruning and thinning, and may increase rotation length by reducing growth. Analysis of silvicultural regimes should also include the economic costs and returns.

All treatments, but particularly those with complex effects on plant and insect such as shade, must be critically evaluated and the mechanisms by which control is achieved analysed in order that reduction in attack and adequate plant growth can be optimised. For example, planting Swietenioideae individually will increase screening effects but reduce stocking density, whereas if it is shade which leads to reduced pest impact they may be planted at higher density as long as suitable shade levels are maintained. Similarly, the optimum light to achieve maximum plant growth with minimum pest damage needs to be reliably calculated. The lack of analysis of the mechanisms by which silvicultural treatments may alter susceptibility means that few reliable recommendations can be made.

While the workshop will no doubt identify priority areas for research, key questions are:

- What are the effects of silvicultural treatments on location of the plant by the moth, suitability of the host for growth and survival of the larvae, and natural enemies?
- How can recovery of growth increment and form be encouraged?

Above all, experimental analysis of the mechanisms is required so that reliable, practical and cost effective recommendations can be produced.

Acknowledgments

This paper is an output from research projects funded by the United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. Forestry Research Programme R6055 and R6351.

We wish to thank the following for their informative assistance, critical review and hospitality: Mr John Palmer and Mr Chris Turnbull, Natural Resources International, Chatham, UK, the Forestry Dept. Planning Branch, Ghana, the Forestry Research Institute of Ghana and the Swiss Lumber Co., Ghana, the Forestry Department, Sri Lanka, Kolombangara Forest Products Ltd., Solomon Islands, the Centro Agronomo Technical de Investigación y Enseñanza, Costa Rica, and the Forestry Department Silvicultural Research Division, Fiji.

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Ecology and Possible Control of the Mahogany Shoot Borer *Hypsipyla robusta in* Kerala, India

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Abstract

An area of 169 ha has been planted with *Swietenia macrophylla* King in Kerala. The shoot borer *Hypsipyla robusta* (Moore) (Lepidoptera: Pyralidae: Phycitinae) is an important pest of this tree crop. Studies carried out in *S. macrophylla* plantations in Kerala showed that up to 70% of the plants were affected by *H. robusta* in some plantations. A parasitic nematode (*Hexamermis* sp.) was found to cause mortality of the larvae in the field. Preliminary results of a trial of two organophosphate insecticides against larvae of *H. robusta* gave promising results.

ABOUT 169 ha of *Swietenia macrophylla* King plantations have been established in Kerala according to an Administrative Report published by the Kerala Forest Department in 1991. Although a number of insect species have been reported to attack *S. macrophylla* in the Indian subcontinent (Beeson 1919, 1941), the shoot borer *Hypsipyla robusta* (Moore) is the most important. Infestation by *H. robusta* often leads to total failure of plantations. Various attempts have been made to evade infestation by adopting mixed species planting. In Kerala, *S. macrophylla* is planted mainly in mixed plantations, along with other indigenous forest tree species such as *Hopea parviflora* Bedd., *Terminalia crenulata* (Roxb.) Wt. Arn., *T. arjuna* (Roab. ExDC), *T. bellerica* (Gaertn.) Roxb., *Lagerstromia microcarpa* Wt. and *Tectona grandis* Linn. f. Attempts are also being made to establish plantations of *S. macrophylla* under the social forestry program.

Information on the ecology of *H. robusta* is being gathered with a view to developing appropriate management strategies. It has been observed that seedlings up to the age of five years are more susceptible to infestation by *H. robusta* (Table 1). Shoots on trees older than five years are generally slightly woody and less tender and larvae appear not to survive on them.

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Table 1. Incidence of *Hypsipyla robusta* (Moore) infestation in plantations of *Swietenia macrophylla* King in 1994 and 1995.

Year of planting	Age of plants (yrs)	Location	Percentage of plants infested
1995	1	Chaklukuzhi	15
1994	2	Kottakkayam	35
1994	2	Mukkalampad	35
1993	3	Puthenpalam	70
1993	3	Chelakkottuk	70
1993	3	Thodiyilkandam	70
1992	4	Channkkamore	70
1992	4	Maikamain	70
1991	5	Palakulam	15

Materials and Methods

This study was conducted in selected young plantations at two different locations in Kerala (Punalur and Nilambur) in 1994 and 1995. A plot of 100 two-year-old plants was selected in each of these areas. The plots were sampled monthly for the incidence of *H. robusta*. The number of epicormic shoots and the number and stage of insects present on each shoot were recorded. Selected insecticides were tested in the field against *H. robusta*.

Result and Discussion

Throughout the study period, on each sampling day, 2 to 4 larvae of different stages were present on the attacked plants. Between 15% and 70% of trees were attacked by *H. robusta* in 1994 and 1995 (Table 1). The incidence of *H. robusta* was higher in open areas within the plantation compared to areas planted under shade of other forest crops. In the experimental plots, generations of *H. robusta* were present continuously throughout the year. This may be due to the continuous availability of flushing shoots due to epicormic shoot formation. However, the population of *H. robusta* was low in summer months when the number of new, flushing shoots was comparatively low. Usually, various life-stages of *H. robusta* were observed in the field, indicating the occurrence of overlapping generations.

A nematode parasite (*Hexamermis* sp.) was found in *H. robusta* larvae. Examination of the infected larvae showed that each larva contained usually one or occasionally two nematodes. The length of the nematodes varied from 19 to 29 mm. *Hexamermis* sp. were collected mostly during the months of May and July. The rate of parasitism was very low at 5%. Nematode parasitism has also been reported earlier (Ramaseshiah and Sankaran 1994; Rao and Bennet 1969)

In a young infested plantation, spot applications of organophosphate insecticides such as Dimethoate (Rogor) and Phosphamedon (Dimecron) were carried out. Due to the inaccessibility of the infested plantations and the presence of wild elephants, the insecticide spray trial had to be abandoned. However, the preliminary results indicate that in plants treated with Dimecron 85 EC at concentrations of 0.01% and 0.25%, the larvae died within 48 hours of application. In the case of Rogor 30 EC at 0.01% and 0.25% concentration, 90% of larvae died within 72 hours.

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Discussion Summary
Silvicultural Management of *Hypsipyla* spp.

C. Hauxwell

SILVICULTURAL options were recognised by the Workshop participants as showing considerable potential for reducing the intensity of *Hypsipyla* damage. The Workshop groups highlighted two areas as particularly promising:

1. The combination of pruning with selection of high quality sites (fertile soil and adequate drainage) and production of vigorous nursery stock to promote recovery following attack in open plantings.
2. The use of tree nurse crops and of shade to reduce the intensity of attack in mixed species plantings.

The Workshop recognised that for all the silvicultural options, there is a lack of understanding of the mechanisms by which these may affect both the plant and the insect are unknown, and a lack of sound experimental data on which reliable recommendations could be based. The need for analysis of the economic costs and benefits of silvicultural treatments (for both smallholders and industry) was recognised together with the need to identify silvicultural systems appropriate to the different regions.

Overall, the evaluation of mixed plantations and the effects of shade were considered the highest research priorities. Priorites for future research on the silviculture management of *Hypsipyla* included:

- Experimental evaluation of the effects of silvicultural practices in various regions on *Hypsipyla* control;
- Experimental evaluation of mixed species plantations (including nurse crops and agroforestry), to quantify the effects of shade, the physical and chemical plant responses and the impact on insect behaviour and survival;
- Quantification of site effects, such as nutrients (especially calcium) and drainage, on plant susceptibility to and recovery from *Hypsipyla* attack;
- Examination of the impact of silvicultural treatments on natural enemies;
- Economic analysis of silvicultural control options.

In conclusion, silvicultural control options have demonstrated promise for management of shoot borer and were considered an important avenue for future work by the Workshop. In particular, the mechanisms by which silvicultural treatments may reduce the impact of *Hypsipyla* require experimental analysis in order to formulate reliable, appropriate and economically feasible management practices.

Integrated Pest Management of *Hypsipyla* Shoot Borers

M.R. Speight[1] and J.S. Cory[2]

Abstract

Integrated pest management (IPM) is the complementary use of several pest control tactics, which enables a crop to be grown economically. No single tactic is likely to be successful in controlling *Hypsipyla* spp.; a great deal of research has been carried out on many types of pest management, and still mahogany cannot be grown successfully. *Hypsipyla* is a classic low-density pest, where even one or two attacks on young trees may render their future timber production uneconomic. We are now at a position where knowledge and experience of individual strategies should be looked at in combination, utilising the best points of each. We consider examples of IPM in tropical forestry to illustrate how this philosophy may be put into practice, and refer the lessons learnt to the particular problems of *Hypsipyla*. For successful IPM to be developed, fundamental problems will have to be overcome. These include better knowledge of the pest's taxonomy, ecology and host-plant relationships, better understanding of mahogany silviculture in relation to pest impact, limitations of chemical and biological control, and above all, much enhanced systems for international collaboration with central co-ordination of a multidisciplinary approach. The fundamental key is the acquisition of very substantial funding for research and development on an international scale.

A GENERALISED integrated pest management (IPM) system may include the encouragement of natural enemies, an increase in plant species or genetic diversity, and appropriate soil preparation, water management, and sanitation (Sen-Sarma 1992). Even before these tactics are brought to bear, planning and consultation before planting is important to reduce the probability of pest attack as much as possible (Ivory and Speight 1993). Figure 1 presents a general plan of a conceptual IPM system, illustrating various stages in the implementation of a program.

Essentially, phase A is concerned with planning and decision-making, prior to any field operation, and it is designed to provide optimal matches of tree species, environmental conditions and the purposes of growing the trees.

The next two phases (B and C) involve surveillance and monitoring for pests, with particular emphasis on quantitative impact data. If the actual economic losses caused by insect attack are unknown, then it is clearly impossible to make pest management decisions with any confidence.

Finally, phase D covers manipulations that may be carried out only if and when the earlier phases fail to keep pest problems at bay. IPM should always be considered to be a preventative system first and foremost, since if outbreaks beyond economically tolerable levels can be avoided by various forms of planning and management, then no further action will be required. However, complacency must also be avoided, since even the best IPM system cannot be considered to be foolproof, so that strategies to control a pest problem if prevention fails must also be developed, even if they are seldom implemented.

Why Do Pest Outbreaks Occur?

It is extremely useful during the development of an IPM system to consider the major causes of pest outbreaks, and to relate these to the particular scenario under discussion. Table 1 suggests some of the major reasons for insect pest outbreaks (Speight 1996), many of which are particularly relevant to the *Hypsipyla* problem. Some of these reasons concern natural events, such as wind-throw and forest fire, which silviculturists and entomologists can do

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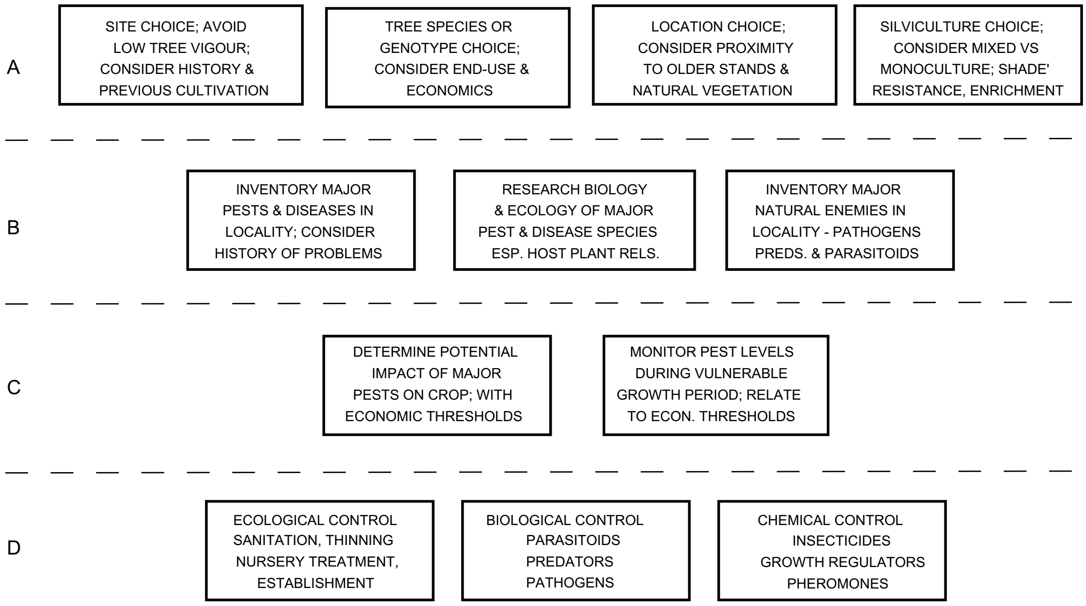

Figure 1. Theoretical components of a generalised IPM system. Stages A & B are entirely preventative, stage C involves monitoring and prediction, while stage D covers control strategies which are available should prevention fail, or monitoring reveal high risk.

relatively little about in many circumstances, while others are certainly within the abilities of managers to influence. The topics of tree susceptibility and environmentally derived stress are two examples of this.

Table 1. Some major reasons for insect pest outbreaks in tropical forestry, topics in italics have special relevance to *Hypsipyla* spp. (from Speight 1997).

Natural disasters
Fire, wind-throw, drought etc. providing food and/or breeding sites
Forest management-avoidance of stress and susceptibility
Site choice and tree species matching in the planning stage
Genetics and variable tree susceptibility
Nursery management and the production of healthy transplants
Choices at planting — monocultures
Stand management — thinning to relieve competition
Post-harvest manipulation
Pest invasions
International — accidental imports from foreign countries
National/regional — invasions from infested stands
Misuse of control systems
Removal of natural enemies
Stress caused by phytotoxicity

Fundamentally, most of these problems hinge on the details of the association between the pest insect and its host-tree. Essentially, insect pests, like all herbivores, are usually restricted by a so-called limiting resource in their diet, that of organic plant nitrogen (White 1993). Plant material, even rapidly growing leaves and shoots, are extremely deficient in organic nitrogen, relative to the needs of an animal, and hence any increase in this commodity, for whatever reason, will benefit herbivorous insects, allowing them to grow and reproduce more efficiently and rapidly.

Host Plant Relationships

Increased organic nitrogen levels in plant tissues very often result from the reduction of vigour in the tree, via some form of stressing agent, often related to the tree's environment (Speight 1996). In brief, these environmental parameters in tropical forestry include: nutrient poor, arid or water logged soils, unsuitable micro- and macro-climatic conditions, competing vegetation, and other pests and diseases. In fact, any factor in the tree's environment which markedly departs from its preferred habitat has a relatively high probability of inducing low-vigour and hence enhanced susceptibility to insects (Speight and Wainhouse 1989). Table 2 suggests various of these factors, with particular reference to *Hypsipyla*. All of the factors in the table occur time and time again as predisposing factors to insect attack in tropical and temperate forestry, and it is of major significance that we still have little or no idea how these factors influence most if not all of the species of Meliaceae that *Hypsipyla* attacks. Table 2, however, provides some suggestions.

Table 2. Environmental factors which may induce low vigour in trees.

Factor	Suggested relevance to *Hypsipyla* spp.
Poor soil nutrients	Possible
Too dry or too wet soils	Possible
Inter- or intra-specific competition	Possible
Bad tree species/site match	High
Lack of shade	High
Lack of humidity	High

It must be pointed out that not all pest outbreaks can be blamed on poor sites or unsuitable planting environments, and some authors are less convinced about pest outbreak/tree vigour associations (Watt 1994). However, any silvicultural project in either the tropics or temperate regions which does not strive to grow trees in as healthy a way as possible is undoubtedly risking pest problems.

Not only do trees provide problems for herbivorous insects in terms of nutrients, but most hosts also try to defend themselves in a multitude of physical and especially chemical ways, to avoid being eaten. In fact, less vigorous trees may also have reduced chemical defences too, though in evolutionary terms it might be expected that a tree which is more susceptible to herbivory might have heightened defences (Speight and Wainhouse 1989). With many insect pest problems, including *Hypsipyla*, the first stage is to provide healthy crops, and the next is to choose those species or genotypes which are least palatable and/or most toxic to the pest. Plant chemistry and insect herbivore interactions are highly complex, and often poorly understood, though work proceeds apace in the mahoganies, where basic phytochemistry (e.g. Wright 1995) is applied to real-world planting situations (e.g. Newton et al. In press).

A final point concerning insect/tree relationships with particular applicability to *Hypsipyla* involves the geographical origin of the tree species or genotype, i.e. is it indigenous to the country or area where the pest is a problem, or is it exotic? Generally, conventional wisdom tends to suggest that exotic species of tropical trees are more likely to be severely attacked by indigenous insect pests than tree species which are also indigenous. There are several possible explanations for this.

Native species probably co-evolved with their herbivores, producing some sort of stable relationship between the two, and are also more likely to be well suited to the environmental conditions than exotics, and thus more vigorous. Exotic plantations only seem to remain pest free for a considerable time when they are truly different and unrelated to any indigenous species which could provide a reservoir of insects to invade the new exotic plantations.

A good example of this would be the early days of growing pines and eucalyptus in parts of Africa, where no native pests were able to succeed on the exotic species. Only when pest species from the trees native homes finally invaded the region did problems really arise. In addition, trees are only likely to evolve complex effective defences against insect attack when their survival and reproductive ability is in jeopardy and hence selection pressure to deter herbivores is high. It can be argued that in nature, the impact of shoot borers such as *Hypsipyla* on Meliaceae is of little consequence to the trees, and hence little or no defences have evolved. This may have significant consequences for the manipulation of host-plant resistance, since naturally-occurring resistance may be hard to find.

Invasion from natural habitats or already infested stands into a plantation of young trees is a very common phenomenon in tropical forestry; the likelihood of problems from this source depends a lot on the proximity of these pest reservoirs and dispersal ability of the insect. A case in point involves pine shoot borers, *Petrova* spp., in the Philippines, which were at their most severe when young stands of trees were established within metres of much older, non-commercial, trees already heavily infested with the pest (Speight and Speechly 1982). In the case of *Hypsipyla* spp., it has been observed that *Swietenia* sp. planted as an urban ornamental in Brasilia seem to remain completely devoid of *H. grandella* attack (H. Wright pers. comm.), even though urban environments are very well known to provoke stress in trees (Speight 1996). In this case, the nearest source of *H. grandella* is probably many kilometres away. Conversely, the establishment of new mahogany plantations close to older ones, or in the vicinity of natural vegetation that may contain alternative hosts for the pests, is almost guaranteed to be attacked.

Lack of Knowledge

In order for an IPM system to be developed with the maximum chance of success, we need to know as much about the biology of the target pest as possible.

It is clear that we still have large gaps in our knowledge of the ecology and biology of *Hypsipyla* spp. (Griffiths these Proceedings), without which we will never get a really successful management system.

Primarily, despite decades of work on the pest, fundamental questions remain unanswered. For example, the genus contains rather a lot of species with different reported lifestyles, some are familiar as shoot borers, but others attack main stems as bark-borers, while others seem to prefer seed pods. Within the genus *Hypsipyla*, there is a very broad host tree range, all certainly within the subfamily Swietenioideae of the family Meliaceae, but with very different timber qualities and growth characteristics. Quite how generalist or specialist each insect genotype is within the genus or even within a region, we have no idea. For instance, does the group of genotypes which we commonly refer to as shoot or tip moth do anything else to trees? Are we looking at an evolutionary process brought about by niche partitioning within a related set of host trees, or is our pest so complex genetically that it is impossible to predict what one genotype, if we are able to recognise it, is going to do next?

Another basic question must concern the moth's natural ecology and biology. What has the insect evolved to do in its natural habitats? How wide is the host range in the forest, how does the insect find its hosts and mates, and how does it disperse? What type of abiotic and biotic conditions does the insect prefer? If we had the answers to some of these questions, we may be able to predict the consequences of a particular silvicultural system for Meliaceae in a given location.

Other IPM Programs from Tropical Forestry

Clearly, each pest problem in tropical forestry has its own characteristics, limitations and possible solutions, but it is of great benefit to analyse as many examples as possible of both successes and failures of IPM, to refer these to the present problem, and to use the experience of others to avoid duplication and to fine tune strategies. Two IPM examples are presented here for comparison, both of which have been selected because of their particular relevance to the *Hypsipyla* spp. problem.

Pine caterpillar in Vietnam (Billings 1991)

Dendrolimus punctatus (Lepidoptera: Lasiocampidae) is a severe defoliator of *Pinus* spp. in North Vietnam, young trees being particularly badly damaged. Current methods to control the pest rely mainly on hand collection and destruction of larvae and pupae, a hazardous and very labour-intensive system, and light trapping for the adults. Biological control has high potential however; the pest is known to have efficient egg parasitoids, and both fungal and bacterial pathogens are also available. The IPM system which is being developed has both short and long-term strategies (Table 3). As indicated in the Table, most of these tactics may also be relevant to the IPM of *Hypsipyla* spp.

Table 3. Strategies for the integrated pest management of pine caterpillar in Vietnam (from Billings 1991).

Tactic	Useful for *Hypsipyla* spp. control?
Short term	
Reduce damage and hence stress to trees (by manual collections)	Unlikely
Record locations, site characteristics and scale of outbreaks	Yes
Study outbreaks, site, history etc. to produce hazard ratings for areas	Yes
Survey high-hazard areas for build up of larval populations	Unlikely
Limited chemical control in high-potential areas	Unlikely
Mass production and release of parasitic and pathogenic enemies	Yes
Provide local entomologists and silviculturalists with IPM training	Yes
Long term	
Research natural biology and ecology of the pest	Yes
Concentrate on silvicultural practices; avoid monocultures, dense plantations, susceptible genotypes and species	Yes

Eucalyptus pests in Brazil (Laranjeiro 1994)

Eucalyptus species in Brazil are attacked by a variety of insect pests, including lepidopteran defoliators and leaf cutting ants. Separate IPM systems have been developed, according to the particular characteristics of each problem, but some general points are considered in Table 4. Again, the tactics employed for these pests are in the main the same ones that a future IPM system for *Hypsipyla* should contain. In fact, most IPM systems so far developed or under development for tropical forest pests contain the same basic recipes.

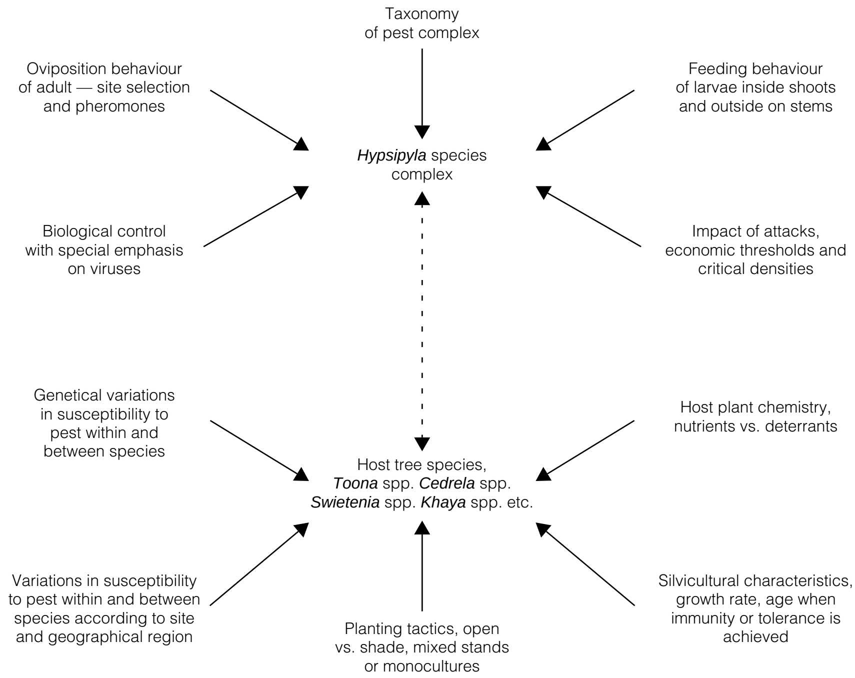

Figure 2. Multidisciplinary approach to the research and development of the management of *Hypsipyla* shoot borers (from Speight 1996).

Table 4. Insect pest management in *Eucalyptus* spp. in Brazil (from Laranjeiro 1994).

Tactic	Useful for *Hypsipyla* spp. control?
Consider the detailed characteristics of pest problems for each scenario	Yes
Promote environmental stability, using natural systems of outbreak prevention	Yes
Maintain forest diversity, including understorey vegetation	Possibly
Try to avoid clonal or mono-specific planting if commercially viable	Yes
Screen for resistant tree species and genotypes	Yes
Chemical control for very young trees soon after planting	Possibly
Use environmentally benign pathogens (b.p.) on older trees	Possibly

IPM of *Hypsipyla* spp.

It is of some concern that there are no good examples of IPM from tropical forest pests which bore into their host trees; so far, it is mainly defoliators or sap feeders that have been considered in this context. However, it is now possible to recognise a variety of potentially complementary tactics which might be brought to bear against *Hypsipyla* spp.; Newton et al. (1993) have suggested that IPM for *Hypsipyla* spp. should revolve around the incorporation of pest resistant trees in mahogany silviculture, which itself is managed to encourage natural biological control as much as possible. Figure 2 presents a flow chart with some of these tactics displayed (Speight 1997), illustrating how important it is to integrate the research into these subject areas, in order to integrate the management later. In other words, we must strive to set up multidisciplinary research and development programs which tackle each topic in depth, but which ideally slot into a bigger scheme of things looking to the IPM of *Hypsipyla* as a whole.

It is sobering to look at the subject areas covered in the first symposium on the integrated control of *H. grandella* in 1973 (Grijpma et al. 1973). Table 5 summarises the titles of the papers and abstracts presented. Nearly a quarter of a century later, many if not all of the topics are similar to those discussed at this workshop. What happened to all this research, and why has it seemingly been forgotten without being developed further? Perhaps the incentive for taking individual pieces of research and moulding them into a single IPM package has been lacking, or no one institution has been established with the responsibility and support to follow research through. To be fair, it is not easy to translate research results into an IPM package; as Nair (1991) points out, there are major stumbling blocks; while most people involved understand and appreciate the concept of IPM, but it is difficult to recommend an appropriate set of actions for a given pest situation, and usually, there is no evidence of the effectiveness of the suggested course of action. Providing such action plans, and demonstrating their effectiveness, is a complex and long drawn-out process, requiring careful and imaginative administration of problem-solving 'task forces'.

Table 5. Some of the topics covered in the first symposium on the integrated control of *Hypsipyla grandella* in 1973 (from Grijpma et al. 1973).

Host plant relationships	Host tree resistance
Plant chemistry	Sensory physiology of *Hypsipyla*
Flight behaviour	Sex attractants
Insect taxonomy	Artificial rearing
Insect population dynamics	Insecticidal control
Natural enemies — parasitoids	Natural enemies — microbes
Effects of gamma radiation	Wood properties and silviculture

Conclusions

For successful IPM to be developed, fundamental problems will have to be overcome. These include better knowledge of the pest's taxonomy, ecology and host-plant relationships and particularly how the latter topic relates to conditions pertaining in managed forests. The limitations of chemical and biological control must also be considered. There can be no doubt that IPM can be complex and sometimes difficult. In order for successful IPM programs to be developed which are appropriate for different regions or circumstances, international collaboration with coordination of multidisciplinary approaches must take place. The fundamental key is the acquisition of very substantial funding for research and development on an international scale.

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Integrated Management of *Hypsipyla grandella* in Nurseries and Plantations of Meliaceae in Cuba

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Abstract

The integrated management of *Hypsipyla grandella* Zeller in nurseries and plantations of Meliaceae was studied in Cuba. Several alternative potential management strategies were demonstrated, including integrated management using mixed species plantations, applications of the entomopathogenic fungus *Beauveria bassiana*, chemical insecticides, and the use of resistant tree species or provenances.

SYSTEMATIC activity in forest protection in Cuba began with the creation of the Institute of Forest Research (IIF) in 1969. Among the forest pests, *Hypsipyla grandella* Zeller is a serious pest of Meliaceae in plantations and of nurseries (Berrios et al. 1987). Methods for control based on an understanding of the biology of this pest have been investigated (Hochmut and Manso Milan 1975).

The host range of *H. grandella* is restricted to species of Meliaceae in the subfamily Swietenioideae. Eleven species of this subfamily, excluding specimens in botanical gardens and arboreta, can be found in the Republic of Cuba (Table 1). One species, *Cedrela cubensis* Bisse is endemic to Cuba, three are non-endemic native species and seven are introduced species. These include *C. odorata* L. and *Swietenia mahagoni* L. (native), and *S. macrophylla* King (Syn. *S. candollei* Pittier) (introduced), which are sources of high quality, high value timbers and are attacked by *H. grandella*, the most severe attack occurring in *C. odorata*. Damage by *H. grandella* restricts the tree species utilised in the development of commercial plantations and the development of reforestation programs as well as conservation of the genetic resource of these species. Research into its control is therefore of particular importance.

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Table 1. Species of Meliaceae, subfamily Swietenioideae, in the Republic of Cuba (excluding species in botanical gardens and arboreta).

Species	Status
Cedrela cubensis Bisse (Cedro caoba)	Endemic
Cedrela odorata L. (Cedro)	Non-endemic, native
Swietenia mahagoni (L.) Jacq. (Caoba antillana)	Non-endemic, native
Carapa guianensis Aubl. (Najesí)	Non-endemic, native
Toona ciliata M. Roemer. (Cedro del Himalaya) and *T. ciliata* var. *australis*	Introduced
Khaya ivorensis A. Chev. (Caoba africana)	Introduced
Khaya senegalensis (Desdr.) Adr. Juss. (Caoba africana)	Introduced
Khaya anthotheca (Welw.) C. DC. (Caoba africana) (Syn. *Khaya nyasica* Stapf. ex Baker f. (Caoba africana))	Introduced
Swietenia macrophylla King. (Caoba de Honduras) (Syn. *Swietenia candollei* Pittier)	Introduced
Swietenia humilis Zuccarini	Introduced
Swietenia cirrhata Blake	Introduced

Control of *H. grandella*

Chemical insecticides

The use of chemical insecticides was one of the first methods attempted to control *H. grandella*. Hochmut and Manso (1975) and Hochmut and Garcia (1979) recommended the use of Dipterex 80% PH (Trichlophon) at a concentration of 0.5% active ingredient in combination with either 1% DDT or 0.5% carbaryl, with repeated applications every 20 days.

Assays were conducted in nurseries of *C. odorata* by Berrios et al. (1987) to determine the most effective doses of Actellic CE 50%, Folimat CS 50% and Sumithion CE 50% (Table 2) in comparison with Dipterex 80% PH, which is widely used commercially against *H. grandella*. Insecticides were applied with knapsack sprayers and conical nozzles. Damaged and healthy shoots were counted at 3, 7, 14, 21 and 30 days post application. Analysis of the percentage of shoots damaged (arc sine transformed) showed significant differences between the different products ($p = 0.05$ analysis of variance and Duncan's test). Of the three products, Actellic 50% CE gave the most effective control, reducing damage by 50%, a result similar to that previously obtained for Diptrex 80% PH.

Table 2. Experimental insecticides for control of *H. grandella*.

Product	Active ingredient	Producer
Dipterex 80%	Trichlorfon	Bayer Ag., Germany
Actellic CE 50%	Pirimiphos Methyl	Zeneca, UK.
Folimat CS 50%	Omithoate	Bayer Ag., Germany
Sumithion CE 50%	Fenitrothion	Sunitomo Chemical Co. Ltd., Japan.

Biological control

Biological control is considered a valuable component of integrated pest management. Legal restrictions on toxic residues, problems with environmental contamination and the high cost of chemical insecticides have led to studies on the control of insect pests by entomopathogenic fungi. The first studies of entomopathogenic fungi for the control of *H. grandella* in *C. odorata* in Cuba used *Metarrhizium anisopliae* and *Beauveria bassiana*. Initial laboratory studies by Duarte *et al*. (1988) examined the infectivity of 8 isolates of *M. anisopliae* supplied by the Department of Biological Control of the Institute of Plant Protection (Table 3). For each preparation 50 larvae in groups of five were put in a petri dish with filter paper treated with 0.1 g of fungus preparation, and fed on leaves of *C. odorata*. Infection was determined at 4, 6 and 11 days, and each assay was replicated 4 times.

The infection rate was determined at each time interval using Abbot's formula (Table 4). With the exception of isolate 44, which resulted in mortality below all the other isolates, all isolates gave high infection rates as early as 4 days after the start of the assay. This demonstrates the high susceptibility of *H. grandella* to *M. anisopliae*. Isolate '79', while having a low percentage infection at 4 days, rapidly increased infection to 100% at 11 days. Using Duncan's multiple range test, the most effective isolates were identified as the isolate from the Philippines and isolates '79' and 'PIC' from Cuba, which all resulted in 100% mortality by 11 days (Duarte et al. 1988). These isolates have been employed in nurseries where they are applied by knapsack sprayer at a rate of 4 kg/ha with a spore concentration of 10^8 spores/mL. Similarly, *B. bassiana* and *M. anisopliae* have been applied by knapsack sprayer in plantations of *C. odorata*, where the *B. bassiana* strain resulted in 40.7% infection, while infection with the *M. anisopliae* strain reached 39.6% (Menéndez et al. 1995).

Table 3. Origin and conidia per gram or isolates of *Metarrhizium anisopliae*.

Isolate	Origin	Conidia /gram
Belice	Belize	6.4 × 109
Filipina	Philippines	4.5 × 109
4	Cuba	4.2 × 109
Niña Bonita	Cuba	4.4 × 109
C. C. 7	Colombia	1.08 × 109
PIC	Cuba	1.12 × 109
79	Cuba	1.21 × 109
44 (var. Mayor)	France	Unknown

Table 4. Percentage mortality of *H. grandella* larvae treated with each isolate of *M. anisopliae* at various intervals after innoculation.

Isolate	Mortality Day 4	Mortality Day 6	Mortality Day 11
Belice	82.6	93.7	97.6
Filipina	87.5	95.0	100
4	47.4	65.0	82.4
Niña Bonita	63.7	85.3	97.7
C. C. 7	56.4	83.5	85.0
PIC	83.2	94.3	100
79	49.3	95.0	100
44	8.6	17.7	35.6

Silvicultural control

Trials of silvicultural measures against *H. grandella* have produced promising results in Cuba. A significant advantage of these treatments is the elimination or reduction in pest damage without recourse to the use of chemical insecticides, as well as allowing treatment to be incorporated at establishment of the plantation.

Replicated plantation trials of *C. odorata* and *S. macrophylla* were established in mixtures with three species that are not susceptible to *H. grandella*: *Cordia gerascantus*, *Gmelina arborea* and *Terminalia catappa*. Three planting designs were tested: alternating lines and columns of *S. macrophylla* and *C. odorata*, alternating lines with the non-susceptible species, and an alternating triangular pattern of the non-susceptible species surrounding individual *S. macrophylla* or *C. odorata*. The trial was established in a randomised block design using three replicates of each treatment (planting design) at a spacing of 2.5 m. The number of plants damaged by *H. grandella* was recorded monthly, length of non-lignified shoots was measured tri-monthly and the height of all species was measured annually. Data were analysed using analysis of variance and means compared by Duncan's multiple range test with a 5% level of significance.

For both species of Meliaceae, the triangular planting pattern provided the best control in the first two years after establishment. The proportion of plants damaged was between 5 and 7% lower in the first year after planting and between 10 and 11% lower in the second year than that observed in the other designs. However, the proportion of plants damaged rose with age, from between 7 and 8% in the first year to between 21 and 22% in the second year. For both species of Meliaceae the peak period of attack was between June and September.

The influence of orientation of lines on *H. grandella* attack during establishment of *C. odorata* was investigated. Lines 10 m apart by 100 m long in each of 4 orientations were planted with *C. odorata* in the triangular pattern with a spacing between plants of 4 m, and each trials was replicated 4 times. In each block, 25 plants were monitored, the number of damaged shoots recorded monthly and the diameter and height of the plants recorded in 1988 and 1989. Significant differences in the proportion of plants attacked in different orientations were observed at the 5% level using the Student-Nueman-Keul's multiple range test. On the basis of these results, planting Meliaceae in lines in a northwest to southeast, or northeast to southwest orientation using the triangular planting design in a mixture with species which are not hosts to the pest. *G. arborea*, which has rapid growth, has been recommended as a suitable species for inter-planting (Berrios et al. 1989).

Genetic Improvement of Meliaceae

Genetic improvement of Meliaceae in Cuba was stared in the first half of the 1970s with three principal programs of research:

1. introduction of African mahoganies (*Khaya* spp.) and *T. ciliata*;
2. inter-specific hybridisation between the American mahoganies *S. macrophylla* and *S. mahagoni*;
3. improvement of *C. odorata* by individual selection.

Of the three introduced *Khaya* species (Table 1) *K. anthotheca* (syn. *K. nyasica*) showed a very low degree of susceptibility to *H. grandella* in Cuba. *T. ciliata* was resistant to *H. grandella* under Cuban conditions (Rodriguez 1988; Marquetti 1990a). The inter-specific hybrid between the American mahoganies showed low susceptibility to *H. grandella* (Marquetti 1990b). However, in this case it is impossible to reproduce material by controlled crossing and traditional methods of vegetative propagation (grafting, cuttings and aerial rooting) of the hybrids is ineffective. These factors limit the production of material for large-scale plantations, although they may possibly be resolved by new techniques in biotechnology (Marquetti and Alvarez 1990). In addition, tolerance of *H. grandella* has been detected in a natural hybrid between the two native species of *Cedrela* in Cuba (*C. odorata* × *C. cubensis*), which could again have considerable importance in the genetic improvement of *C. odorata* (Marquetti 1990c).

As part of the program of improvement of *C. odorata* selected trees were propagated by means of grafts onto a stock of *T. ciliata*. Not only was resistance transmitted to the graft from *T. ciliata*, but a precocious flowering of the grafts was induced at three years of age. This could considerably facilitate the establishment of seed orchards and the early production of improved seed (Marquetti 1990a).

Conclusions

The results of trials conducted in Cuba on control of *H. grandella* in plantations of Meliaceae suggest two possible management strategies:

1. The use of a combination of silvicultural treatments and biological and chemical insecticides by the establishment of mixed plantations with *G. arborea* in a triangular planting formation and line orientation NE-SW or NW-SE, combined with treatment of *B. bassiana* at a rate of 4 kg/ha and a concentration of 10^8 spores, or with 50% E. C. Acetellic or 80% P. H. Diptrex during the months of June to September in the first years of establishment. This option is readily applicable.

2. The use of resistant species or selected material such as *K. anthotheca* (*K. nyasica*) or interspecific hybrids (*S. macrophylla* × *S. mahagoni*, or *C. odorata* × *C. cubensis*) or grafts of *C. odorata* onto a stock of *T. ciliata*. This option is restricted by the difficulties in obtaining controlled cross hybrids with vegetative propagation of hybrids of the American mahoganies while maintaining the commercial value of the wood. The use of biotechnology that is directed at developing clonal hybrids or micro-grafts might solve the practical difficulties of this option.

Finally, the production of transgenic plants incorporating genes that confer resistance to Lepidoptera might offer a third avenue of investigation. This approach has been successfully demonstrated in tobacco (Coego et al. 1995), sugar cane (Arencibia et al. 1995), and other annual crops (Adang 1995). Although forestry presents a greater degree of complexity and requires a longer period of control than annual crops, work on production of transgenic *C. odorata* has begun.

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Discussion Summary
Integrated Pest Management of *Hypsipyla* spp.

M.R. Speight

THE DELEGATES were split into three regional groups: Oceania (Australia, PNG, Solomon Islands), Asia (Bangladesh, India, Sri Lanka, Thailand, Philippines, Malaysia, Indonesia, Vietnam, Laos), and Latin America and Africa (Costa Rica, Brazil, Honduras, Cuba, Ghana, UK). Each group was asked to consider what would be the most appropriate IPM systems for their region. Similar topics were identified as important by all groups, almost all of which centred on the prevention of pest damage rather than its cure.

Any pest management tactics that begin with inferior genetic stock cannot be expected to be fully successful, although it was considered that some countries might have difficulties in locating sources of good seed, and/or paying for it. Appropriate methods for producing the most vigorous planting stock would vary from region to region, but shading, watering, choice of planting soil and the judicious use of insecticides and fungicides in nurseries would be incorporated.

Only those sites likely to be conducive to tree vigour and fast growth should be planted with mahoganies. Poor sites with shallow, impoverished soils, steep slopes, or inadequate or excessive drainage should be avoided. On the assumption, in need of experimental validation, that fast growing vigorous trees were either less attacked by *Hypsipyla*, or more tolerant of it, tactics including soil fertilisation, weeding, use of growth tubes, and pruning should be employed.

Genus, species and provenance selection tests should be used to detect resistant plants. These should then be established in mixtures with other tree species or crops (as required for plantations or agroforestry purposes), under shade, and in isolation from reservoirs of infestation. Monocultures were to be avoided.

Even with the preventative systems described above, pest attack might still occur. Localised chemical control, or the inundative release of natural enemies, if available, might then be necessary. Monitoring of the crops to detect the sudden appearance of insect damage would also be required.

IPM would have to be supported through advisory or extension services to growers. These services would have to be established on local or regional bases.

In summary, the Workshop identified the following priority areas:

- Good genetic stock to be procured and employed.
- Optimal nursery methods established to rear healthy planting stock.
- Sites should be selected to promote vigorous growth
- Early vigorous growth should be promoted by use of fertilisers, weeding, growth tubes and pruning.
- Incorporation of resistant planting stock in appropriate silvicultural regimes, in particular the use of species mixtures, should be promoted.
- Development of emergency control measures including localised chemical control, inundative use of natural enemies and monitoring techniques to detect insect outbreaks.
- Development of extension information and services for growers.

International Workshop on *Hypsipyla* Shoot Borers in Meliaceae: General Conclusions and Research Priorities

R.B. Floyd[1]

Abstract

An international workshop was held to review the ecology and control of *Hypsipyla* shoot borers of Meliaceae, identify promising control methods and prioritise areas for future research. The economic importance of native and exotic species of Swietenioideae (subfamily of Meliaceae), the geographic distribution of *H. robusta* Moore and the severity of *Hypsipyla* damage was summarised from the reports in these proceedings from various countries in the Asian and Pacific Regions. The research priorities identified and ranked by the workshop participants are presented and analysed. The most important research areas were identified as screening host plants for resistance, mixed-species plantations/agroforestry, *Hypsipyla* taxonomy, *Hypsipyla* biology in natural forests, and control using biologically active compounds such as kairomones and novel insecticides.

IT HAS BEEN exceedingly difficult to economically grow plantations of tree species belonging to the subfamily Swietenioideae of the family Meliaceae in areas inhabited by the shoot borers, *Hypsipyla robusta* (Moore) or *H. grandella* (Zeller), hereafter referred to as '*Hypsipyla* spp.' Concerted research effort in the 1970s resulted in the publication of two major reviews (Grijpma 1973; Whitmore 1976a, b) focussing on work principally on *H. grandella* in Central and South America. Recently Newton et al. (1993) have reviewed the prospects for control of *Hypsipyla* spp. with a particular emphasis on the Americas.

Due to the high priority of various countries to grow high grade timber of species of the subfamily Swietenioideae, some recent promising research results, and general advances in techniques and approaches to insect pest management, a meeting to review the ecology and control of *Hypsipyla* shoot borers in Meliaceae was held in Kandy, Sri Lanka on 20–23 August 1996. The meeting took the form of a workshop and was attended by 40 delegates from 18 countries including Sri Lanka, India, Bangladesh, Vietnam, Laos, Thailand, Philippines, Malaysia, Indonesia, Papua New Guinea, Solomon Islands, Australia, Costa Rica, Cuba, Honduras, Brazil, Ghana and the UK.

The aims of the meeting were to:

- review the biology and management of *Hypsipyla* spp.;
- identify successful and promising control methods;
- prioritise areas for future research; and
- facilitate discussion and international collaboration on research into *Hypsipyla* spp.

Participants from various countries presented reports on the economic significance of Swietenioideae species in their country, evidence of the degree of damage from *Hypsipyla* spp. and an overview of research that has been conducted on the biology and control of *Hypsipyla* spp. In addition, scientific papers were presented at the workshop arranged in the following themes:

- taxonomy and biology;
- host plant resistance;
- chemical control and pheromones;
- biological control (predators, parasitoids and pathogens);
- silvicultural control; and
- integrated pest management.

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Each theme consisted of an invited review and several papers reporting on specific work that was being conducted on that topic. At the conclusion of the presentations in each theme, except for integrated pest management (IPM), all delegates participated in workshop groups that identified research priorities for that theme. For the theme on IPM, all delegates agreed with the necessity of an IPM approach and discussed options for combining control technologies in an IPM framework.

At the conclusion of the meeting, participants attempted to set overall research priorities spanning all of the themes of the workshop. Each 'reviewer' was asked to prepare a list of up to 5 priorities and each delegate was given 6 votes to identify the areas which they considered to be the most important.

This paper provides some general observations arising from the country reports and presents the research priorities determined by workshop participants for each theme as well as the overall research priorities.

General Observations from Country Reports

The majority of participants at the workshop were from the Asian and Pacific regions because of the geographic focus of support from ACIAR, the major sponsor. Consequently, country reports from the African and American regions are minimally represented and the following general conclusions will be restricted mainly to the Asian and Pacific regions.

Native species of the subfamily Swietenioideae (*Toona* spp., *Xylocarpus* spp. and *Chukrasia tabularis* A. Juss.) were harvested at a low level or not at all in most countries. The major exception was Papua New Guinea which harvested sustainably *Toona sureni* (Blume) Merr. and *T. ciliata* Roem. Vietnam, Thailand and Lao PDR all harvested *C. tabularis* to a limited extent. The species of Swietenioideae planted most commonly throughout the Asian and Pacific region was *Swietenia macrophylla* King. Significant plantings of this species exist in Philippines, Solomon Islands, Bangladesh, India and Sri Lanka. Other exotic species often planted in the regions are *Cedrela odorata* L., *Khaya* spp. and *S. mahagoni* Jacq.

The known geographic distribution of *H. robusta,* as recorded by Entwistle (1967), has now been extended (See Figure 1 in Griffiths, these Proceedings). The major changes in range since Entwistle (1967) are confirmed records from Bangladesh (Baksha, these Proceedings), China (Gu and Liu 1984), Vietnam (Do, these Proceedings), Laos (Samontry, these Proceedings), Thailand (Eungwijarnpanya, these Proceedings) and Philippines (Lapis, these Proceedings). The report that *H. robusta* is widespread in Tonga (Waterhouse 1997) has not been verified either through experts in Tonga, specimens in collections or from personal observation. It appears that the most southeasterly limit of its distribution is Vanuatu (pers. obs.).

Virtually every country reported that *H. robusta* was a major limitation to commercial growing of species of Swietenioideae. Fifteen species of native or exotic Swietenioideae were recorded as planted in the Asian and Pacific regions and only in three instances were species recorded as unaffected by *H. robusta* (Table 1). These instances were *C. odorata* in Solomon Islands, *Khaya senegalensis* (Desr.) A. Juss. in Malaysia and *Toona calantas* Merr. and Rolfe in Philippines and it is possible that, since these conclusions were based on incidental observations, more extensive searching may have produced evidence of *H. robusta* damage. Table 1 also indicates the relative severity of damage due to *H. robusta* on various host species in different countries. Exotic species such as *S. macrophylla* and *S. mahagoni* and various native species of *Toona* were almost invariably heavily attacked. Species of *Khaya* and *Cedrela* (both exotics) were generally less damaged. The generalisation that *Hypsipyla* spp. attack native species of Swietenioideae to a greater extent than exotic species (Grijpma 1974) is not supported by these observations.

In a number of countries, open plantings were damaged more severely than enrichment plantings or companion plantings (e.g. Sri Lanka, Malaysia and Indonesia). In one case, when *K. ivorensis* was planted within a rubber plantation, trees were not attacked (Gee, these Proceedings). However, enrichment planting did not always provide adequate protection from *H. robusta* damage (Griffiths et al., these Proceedings).

Even though virtually every country reported significant *H. robusta* damage, very little or no research on the ecology or control of the species has been conducted in many countries in the Asian and Pacific region (e.g. Bangladesh, Philippines, Vietnam, Lao PDR). Historically, research on the biology and control of the species has been conducted in India (Beeson 1941) and Indonesia (Kalshoven 1926). In 1996, research was being conducted in Sri Lanka (nurse crops and resistance in *S. macrophylla*), India (biology and biological control), Thailand (species trials), Malaysia (biological and silvicultural control), Indonesia (silvicultural and chemical control), Solomon Islands (chemical and silvicultural control) and Australia (biology, pheromones and silvicultural control). The country reports consistently identified major gaps in knowledge and several countries have recognised research into the ecology and control of *H. robusta* as a national priority (Philippines and Bangladesh).

Table 1. *Hypsipyla robusta* (Moore) damage on species of Meliaceae (subfamily Swietenioideae) grown in various Asian and Pacific countries. Empty cells in the table indicate that there are no records of a tree species in a country. The number of ticks indicates the severity of damage and a cross indicates no damage observed. Countries with a single tick against all species recorded for that country indicates damage has been observed but no indication of relative severity of damage.

Tree species	Bang	Sri L	India	Phil	Viet	Laos	Thai	Mala	Indon	PNG	Sol I	Aust
Cedrela ordorata L.		✓					✓	✓			✗	✓
Cedrela lilloi C. DC.							✓					✓
Chukrasia tabularis A. Juss.	✓				✓	✓	✓✓	✓				✓✓
Khaya anthotheca (Welw.) C. DC.									✓			
Khaya grandifoliola C. DC.									✓			
Khaya ivorensis A. Chev.								✓				
Khaya nyasica Stapf. Ex Baker												✓
Khaya senegalensis (Desr.) A. Juss.		✓			✓			✗	✓			✓
Swietenia macrophylla King	✓	✓	✓	✓	✓	✓	✓✓	✓✓	✓✓	✓	✓✓	✓✓
Swietenia mahagoni Jacq.	✓	✓	✓				✓✓	✓✓	✓			
Toona ciliata Roem.	✓	✓	✓			✓	✓✓		✓	✓		✓✓✓
Toona calantas Merr. & Rolfe				✗								
Toona sinensis (A. Juss.) M. Roem.								✓				
Toona sureni (Blume) Merr.					✓	✓	✓	✓✓	✓	✓		
Xylocarpus moluccensis (Lam.) M. Roem.							✓✓					

Country abbreviations: Bang = Bangladesh; Sri L = Sri Lanka; Phil = Philippines; Viet = Vietnam; Laos = Lao PDR; Thai = Thailand; Mala = Malaysia; Indon = Indonesia; PNG = Papua New Guinea; Sol I = Solomon Islands; Aust = Australia

Research Priorities

The complete list of priority areas is presented in Table 2 with the priority score given by the Workshop delegates. The first five areas, in order of importance, are described in more detail below. Note that these priority areas are research areas on specific control methods (in bold in Table 2), or of a more general nature or research areas which underpin specific control methods (not in bold in Table 2). Thus, for example, the value of developing new insecticides is immediately apparent. In contrast, areas like taxonomic research will not lead directly to better management of *Hypsipyla* spp. but they are likely to contribute to all aspects of *Hypsipyla* spp. management. For example, better taxonomic knowledge might speed the development of pheromones.

1. To establish species, provenance and clonal resistance trials in different countries and regions within these countries.
2. To evaluate the use and efficacy of mixed species plantations (nurse crops/agroforestry) and quantify the effects of shade.
3. To investigate the taxonomy of *Hypsipyla* spp. by collecting from throughout the geographical range, from all host species on which the insects occur, and from all the plant parts on which it feeds and using morphological, molecular and biochemical techniques for species determination.
4. To investigate the biology and ecology of the *Hypsipyla* spp. in native forests, including studies of behaviour (dispersal and host location), mating, oviposition, larval movement, pupation and dormancy.
5. To screen new biologically active compounds/formulations against *Hypsipyla* spp. including antifeedants and natural plant compounds, particularly in control release formulations in nurseries and plantations.

Considering control methods alone, the perceived priorities were (in order):

1. resistance;
2. mixed-species plantations and agroforestry;
3. biologically active compounds (novel insecticides and kairomones);
4. site manipulation (particularly soil nutrients and drainage);
5. development of other silvicultural methods;
6. manipulating the action of predators;
7. insect pathogen introductions;
8. parasitoid introductions;
9. development of pheromones; and

10 traditional insecticides.

The workshop participants strongly supported the use of the above and other control methods as parts of an IPM strategy and not as methods to be used in isolation. The Workshop strongly endorsed a control strategy using plant resistance as showing the greatest potential. For the most part, the Workshop delegates also clearly saw the development of silvicultural and agroforestry 'methods of control' as being more promising than approaches such as traditional insecticides, and biological control through predators, pathogens and parasitoids. However, the prospect of novel methods of control, using kairomones and novel insecticides was seen as a high priority area, perhaps surprisingly, given the lack of research in this area.

Table 2. A complete list of research priorities with their rating by Workshop delegates. Each delegate was allowed to identify six priority research areas. Priority areas have been classified according to whether they lead directly (bold)or indirectly (non-bold) to better control of *Hypsipyla* spp.

Priority area	Rating
Resistance trials	29
Mixed-species plantations/agroforestry	22
Hypsipyla taxonomy	18
Research in natural forests	16
Biologically active compounds (kairomones and novel insecticides)	13
Determination of economic thresholds	11
Control by site manipulation (particularly soil nutrients and drainage)	10
Development of other silvicultural methods of control	10
Research on impact of natural enemies in mixed-species plantations	8
Control by manipulating the action of predators	8
Quantification of the economic benefits of silvicultural methods of control	7
Control by insect pathogens	7
Development of genetic conservation strategies of Meliaceae	7
Basic research on predators and parasitoids in various regions	6
Control by introductions of parasitoids	5
Taxonomy of parasitoids	5
Development of pheromones	5
Basic research on shoot borer physiology (e.g. ovipositional stimuli)	4
Development of deployment strategies for resistant plant material	4
Research on the biochemical basis for resistance	4
Research on shoot borer rearing techniques	4
Basic research on pathogens	3
Control by traditional insecticides	2

The goal of effective control of *Hypsipyla* spp. has not been achieved in any region of the world, in spite of research efforts over many decades. An important omission from the research effort to date is the almost complete absence of studies on the biology of *Hypsipyla* spp. in natural forest. A better understanding of the biology and ecology of the species in natural systems may provide profitably leads for developing effective control strategies. Furthermore, the workshop participants were optimistic regarding the possibility of controlling *Hypsipyla* spp. in the future because of the emergence of new technologies and better understanding of some aspects of biology including mechanisms of host-plant resistance and surveys of pathogens of *Hypsipyla* spp. Studies of the control of *Hypsipyla* spp. are likely to be of greater value if conducted at a regional or global scale and to this end, it is important to develop a network of researchers of *Hypsipyla* spp. for information exchange and collaboration.

Acknowledgements

I wish to thank the Sri Lankan Forestry Department for hosting the workshop and providing invaluable assistance in making arrangements for the smooth running of the workshop. Special thanks to Manon Griffiths and Carrie Hauxwell for their assistance in organising the workshop and to Ross Wylie and Don Sands for their unfailing support and guidance. Carrie Hauxwell also assisted in gathering additional financial support for the meeting and shared the editorial task for these Proceedings. I am grateful for the major financial contribution from the Australian Centre for International Agricultural Research (ACIAR) as well as the Overseas Development Administration (ODA), AusAID, British Council and the Australian Rural Industries Research and Development Corporation. John Fryer and Peter Lynch from ACIAR are thanked for their persistence and patience in bringing these Proceedings into being.

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