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

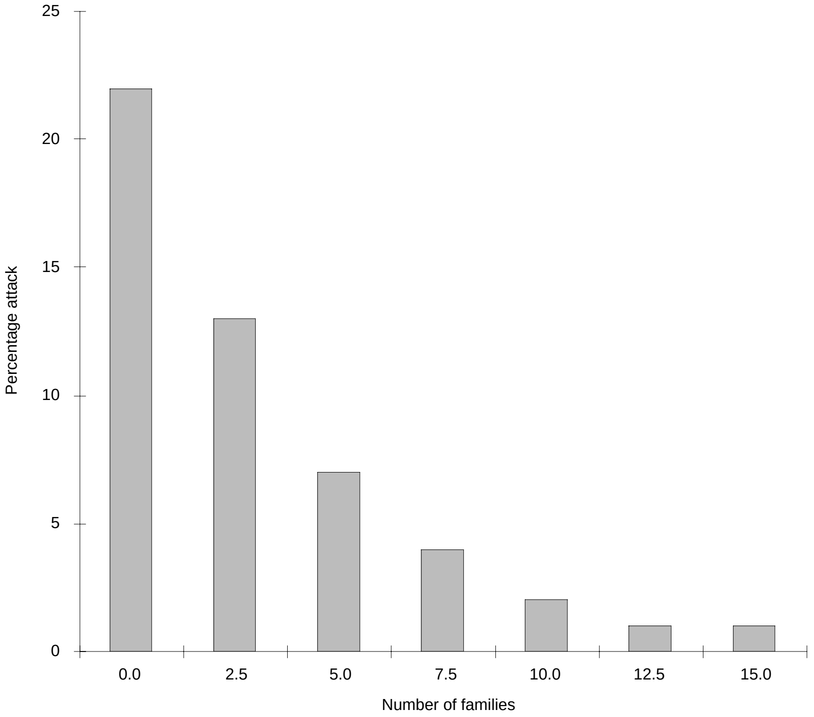

Figure 1. Percentage attack by *Hypsipyla* sp. per family in a *C. odorata* seed orchard at age 6 months, La Soledad, Comayagua Valley, Central Honduras.

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.

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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

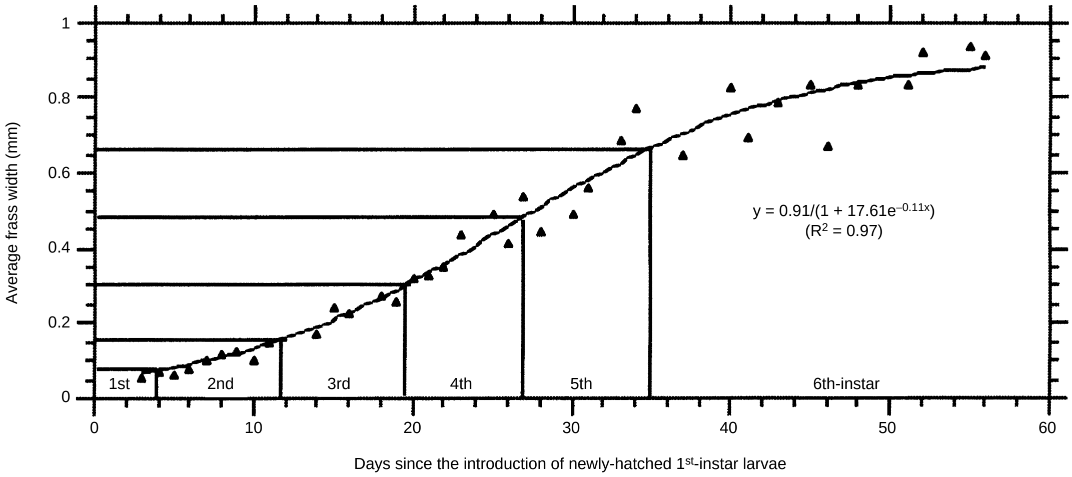

Figure 1. Average width of frass (mm) and the estimated larval instars during the larval development on *T. ciliata*. Divisions between larval instars are taken from Mo and Tanton (1995).

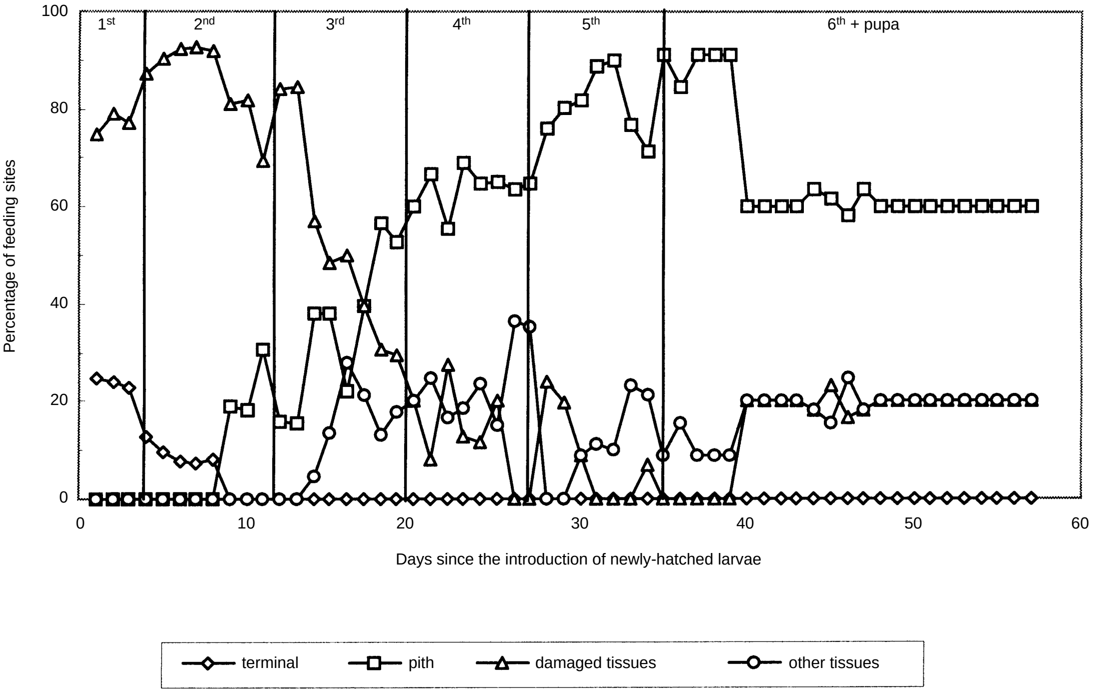

Figure 2. Within-tree distributions of feeding sites with respect to host tissues during the course of larval development on *T. ciliata*.

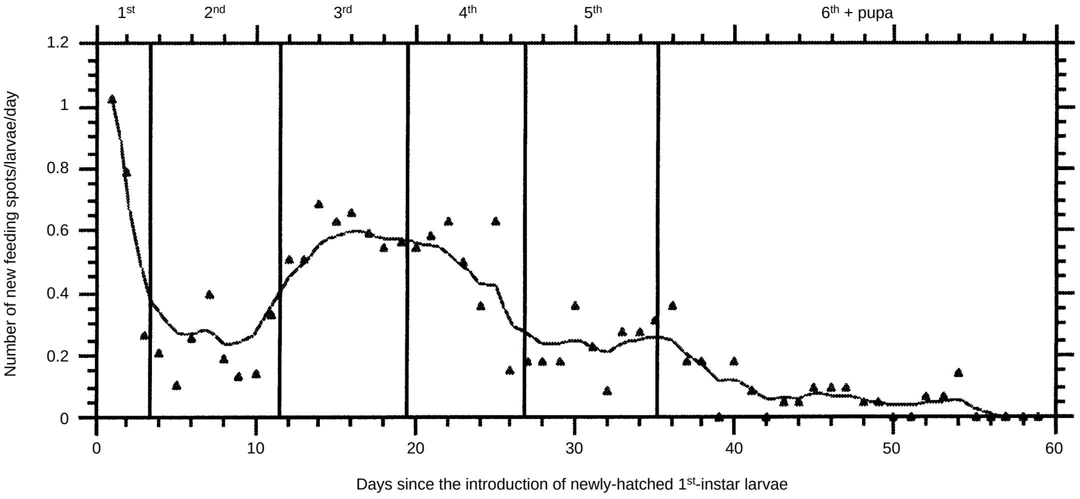

Figure 3. Frequency of occurrence of new feeding sites during the course of larval development on *T. ciliata*.

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.

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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.

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

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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.

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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.

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

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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 ($\chi^2 = 85.11$; 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

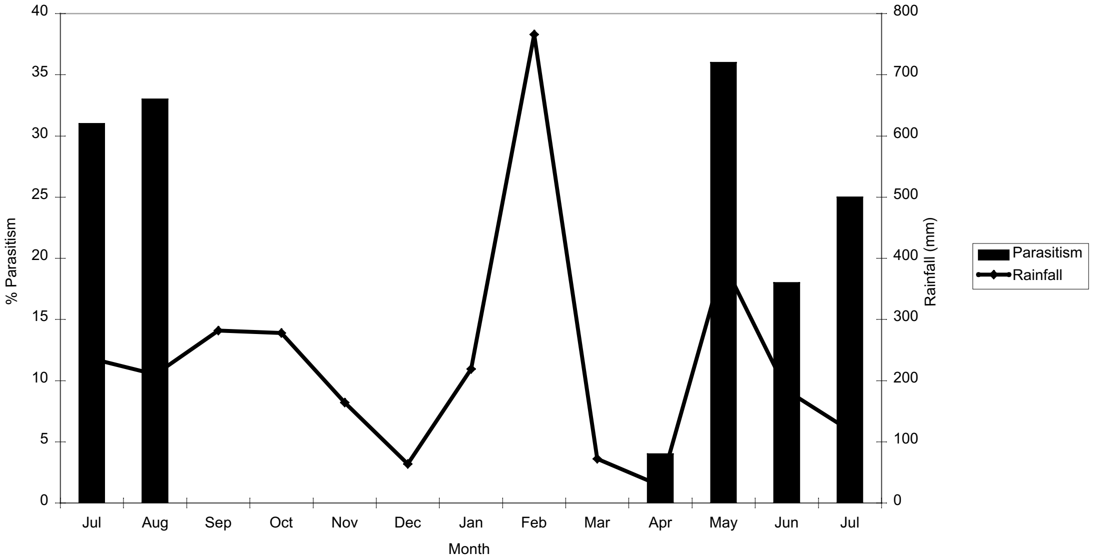

Figure 1. Percentage parasitisation of *Hypsipyla grandella* and rainfall at Turrialba, Costa Rica, 1995–1996.

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.

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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 subfamily Swietenioideae of the family Meliaceae (hereafter 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.

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).

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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 underthinned (400 stems/ha as compared to 150 in other treatments). Keenan et al. (1995) recommend underplanting 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.

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Ecology and Possible Control of the Mahogany Shoot Borer *Hypsipyla robusta in* Kerala, India

K. Mohanadas[1] and R.V. Varma[1]

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.

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

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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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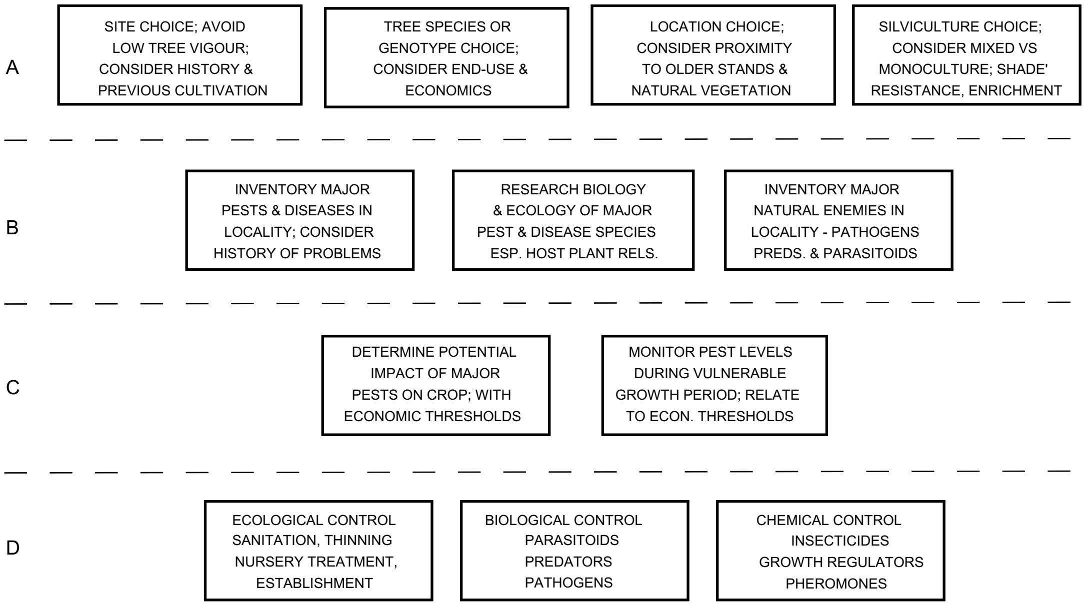

Figure 1. Theoretical components of a generalised IPM system. Stages A & B are entirely preventative, stage C involves monitoring and prediction, while stage D covers control strategies which are available should prevention fail, or monitoring reveal high risk.

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.

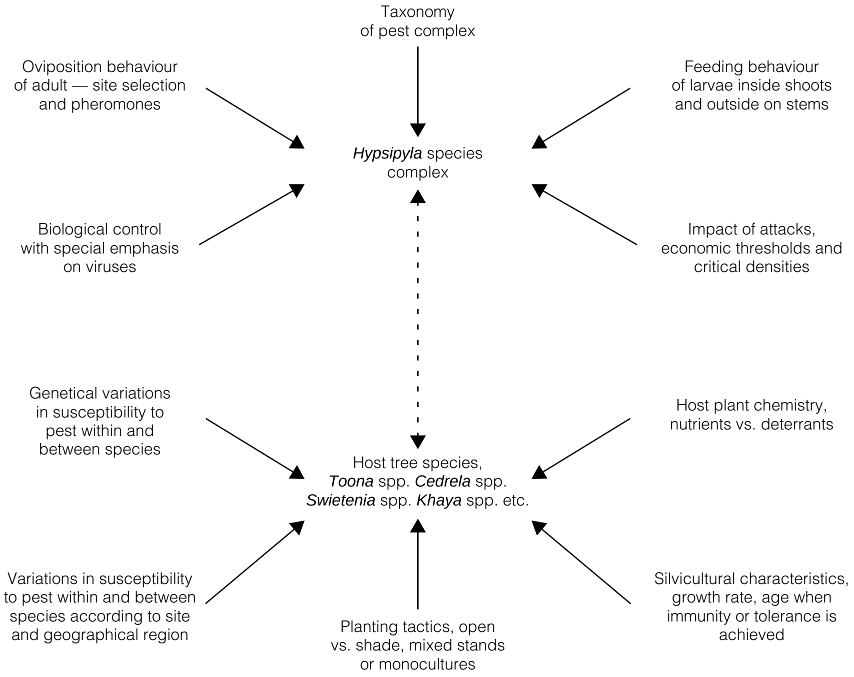

Figure 2. Multidisciplinary approach to the research and development of the management of *Hypsipyla* shoot borers (from Speight 1996).

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.

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

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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.

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