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ENVIRONMENTAL ASSESSMENT FOR IMPLEMENTATION OF BIOLOGICAL CONTROL FOR THE LEUCAENA PSYLLID IN ASIA AND AFRICA:

Case Studies from India, Indonesia, Laos, Malaysia, Nepal, the Philippines, and Thailand

Office of Forestry and Natural Resources
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Preface

This Environmental Assessment of a grant by the Agency for International Development to CAB International Institute of Biological Control for the training of Asian scientists in international accepted procedures for the release of biocontrol agents, and for the development of an early-warning system for Africa in preparation for the psyllid's anticipated arrival on that continent ["*Implementation of Biological Control for Leucaena Psyllid, Heteropsylla cubana, in Asia and Africa.*] was conducted in Malaysia, Nepal, the Philippines, and Thailand from July 21 to August 8, 1991; in Indonesia September 30 to October 6: Laos October 10 - 25; and the Philippines October 25 - 31, 1991. Information was gained primarily through AID/S&T/FENR, AID/S&T/AGR, the AID funded F/FRED Project, CAB International Institute for Biological Control, and the governments of Indonesia, Laos, Malaysia, Nepal, the Philippines, and Thailand. In the case of India, information was obtained in writing from Dr. S.P. Singh, Biological Control Coordinator at the Biological Control center in Bangalore, India. This is the first A.I.D Environmental Assessment dealing with biocontrol agents for pest control purposes and as such, it provides background on the topic of biocontrol itself. Therefore, this Environmental Assessment could potentially serve as a model for subsequent and similar efforts requested of A.I.D. in other Leucaena psyllid infested countries, or for countries requiring assistance for the introduction of other biological control agents for forest, tree and food crop, livestock, or human health protection purposes.

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Acronyms and Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AGR	Office of Agriculture (A.I.D.)
A.I.D.	Agency for International Development
ASEAN	Association of South East Asia Nations
BPH	Brown plant hopper
BPI	Bureau for Plant Industry (Philippines)
cc	Cubic centimeters
CIBC	Commonwealth Institute of Biological Control (now IIBC)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DENR	Department of Energy and Natural Resources (Philippines)
DOA	Department of Agriculture
EA	Environmental Assessment
ERDB	Ecosystems Research and Development Bureau (Philippines)
FAO	Food and Agriculture Organization of the United Nations
FNR	Office of Forestry and Natural Resources (A.I.D.)
GOM	Government of Malaysia
GON	Government of Nepal
GOT	Government of Thailand
ICAR	Indian Council for Agricultural Research
IIBC	International Institute of Biological Control
IPIL	Integrated Program for Ipil-ipil Leafmeal (Philippines)
IPM	Integrated pest management
IRRI	International Rice Research Institute
km	kilometers
MARDI	Malaysia Agricultural Research and Development Institute
MBRLC	Mindanao Baptist Rural Life Center in the Philippines
mm	millimeters
MOA	Ministry of Agriculture
MSB	Manila Seedling Bank
MT	metric tons
NBCRC	National Biological Control Research Center (Thailand)
NCCBC	National Coordinating Committee on Biological Control (Malaysia)
NFTA	Nitrogen Fixing Tree Association
NGO	Non Governmental Organization
NTT	Nusa Tenggara Timor (Indonesian province)
NTTIADP	Nusa Tenggara Timor Integrated Agricultural Development Project (in Indonesia)
P	Pesos (Philippines)

PCARRD	Philippine Council for Agriculture, Forestry and Natural Resources Research and Development
PLANTI	Plant Quarantine Center and Training Institute
PVO	Private Voluntary Organization
Rp	Rupiah (Indonesia)
RRDP	Rainfed Resources Development Project (Philippines)
SALT	Sloping Agricultural Land Technology (MBRLC project in the Philippines)
S&T	Bureau for Science and Technology (A.I.D.)
sp.	Species (singular)
spp.	Species (plural)
TISTD	Thailand Institute of Scientific and Technological Development
UGM	Gadjah Mada University (in Yogyakarta, Indonesia)
UNDP	United Nations Development Programme
UPLB	University of the Philippines at Los Banos
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
ViSCA	Visayas State College of Agriculture (Philippines)

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1.0 EXECUTIVE SUMMARY

The leucaena tree, Leucaena leucocephala, is the most widely planted exotic multipurpose legume tree grown in Asia. It can be used as a livestock fodder and as a wood and fertilizer source; a substrate for nitrogen fixing bacteria; a hedgerow tree for windbreaks, animal fencing, and soil conservation; and a shade tree for estate crops that are light sensitive (e.g., coffee, vanilla, cocoa). Since it was introduced to southeast Asia by the Spanish in the 1600s from its native habitat in tropical America, the leucaena tree has spread throughout most of southeast Asia and the Indian subcontinent and has, in many cases, been promoted for one or more of its uses by international development agencies, country governments, private industry, and private voluntary organizations. In a number of Asian countries, reliance on L. leucocephala as a wood and fodder source has become nearly complete.

The leucaena psyllid, Heteropsylla cubana, was first scientifically identified in Asia in 1985. It is a small winged insect which sucks the juices from leucaena shoots and leaves, and it is thought to have been accidentally introduced to Asia from tropical America (by way of Hawaii and Pacific island chains until it reached the Philippines in 1985) and quickly spread throughout the leucaena growing region particularly in the absence of effective natural enemies to check the rapidly increasing populations. Also, the narrow genetic base of the introduced L. leucocephala made the tree more susceptible to intense attack. The results were devastating - leucaena production in all affected countries stopped, and where reliance on leucaena trees was great, economic consequences were significant to agricultural and industrial sectors.

This environmental assessment was designed specifically to discuss the conditions and background to the recent infestation of Asia and the Indian subcontinent by H. cubana and its impacts on L. leucocephala, options for the control of H. cubana, the viability of using biological control tactics, and possible consequences of introducing exotic natural enemies of H. cubana into the environment.

Findings show that the uses of L. leucocephala and its economic importance, the extent to which H. cubana inflicted damage to leucaena, the viability of indigenous biological control agents and exotic natural enemies to control the leucaena psyllid, the ability of each country to safely import and effectively implement classical biological control techniques, the political and economic support for doing so, and the needs to improve the capacity to conduct biological control programs against H. cubana differ markedly from country to country. It is for this reason that sections of this environmental assessment are devoted to each selected country: India, Indonesia, Laos, Malaysia, Nepal, the Philippines, and Thailand. However, it is important to note that those countries that relied most heavily on leucaena, especially when leucaena was planted in

monocultures, suffered the most profound economic losses.

In each country section, the importance of the leucaena tree and the characteristics of leucaena psyllid populations and damage inflicted are described and quantified where possible. A perspective on biological control of agricultural pests and, in specific, H. cubana, is presented followed by a description of quarantine regulations and procedures for the importation of exotic biological control agents. The giant form of L. leucocephala was introduced to Asia mainly from a single seed source, which invited insect and disease infestation by promoting a narrow genetic base. Various options for controlling H. cubana are then assessed, which include pesticide application, use of resistant varieties of L. leucocephala and creating a larger genetic diversity within the species, replacement of L. leucocephala with indigenous legume tree species, the effect of pruning or grazing of leucaena on the psyllid populations, and biological control using indigenous and exotic organisms. Each country's capacity for responsibly and effectively conducting biological control programs is evaluated, and country-specific recommendations are provided in the final section to enhance each country's ability to use biological control tactics in the most effective and environmentally benign manner possible. Use of alternative tree legumes also presents an option where H. cubana is not being controlled by indigenous or exotic natural enemies. Leucaena should not be the sole legume tree source for fuelwood and fodder; some economic stability can be imparted to the agricultural system by diversifying among legume tree species.

For control of H. cubana in Asia, the use of classical biological control has proven to be effective where a sustained and well-managed biological control program was conducted. The potential efficacy of exotic natural enemies of the leucaena psyllid has been demonstrated in certain Asian countries, and should be promoted for use in those countries where leucaena production is still limited by the presence of the psyllid.

Finally, this environmental assessment is the first to examine classical biological control as a tactic for pest management, and can be used as a precedent for future A.I.D. activities involving biological control of agricultural pests.

2.0 SCOPING PROCEDURE

A.I.D. Environmental Procedures [22 CFR 216.3(a)(4)] describe the scoping procedure to be used in identifying the major issues to be addressed in an Environmental Assessment (EA). Critical elements include: (1) determining the breadth and significance of issues to be analyzed as they relate to the proposed action, (2) identifying the issues that are not significant, (3) format, (4) decision-making schedule, and (5) description of how the analysis was conducted and who will participate (representatives of host governments, public and private institutions, and staff and contractors). Due to the critical need for this document the Scoping process was reduced to verbal exchanges in A.I.D./Washington with representatives from S&T/FNR, S&T/AGR, S&T/SCI, the F/FRED Project, and USDA.

2.1 Document Preparation

Analysis and document preparation was performed by:
Dr. Allan Showler, R&D/AGR/AP, IPM Specialist
Dr. Jaye Melcher, R&D/AGR/EP, Ecologist

Drs. Showler and Melcher travelled to Malaysia 23-26 July, to Thailand 26 July - 1 August, and to Nepal 1-8 August, 1991; Allan Showler later traveled to Indonesia 30 September - 6 October, Laos 10 - 25 October, and the Philippines 25 - 31 October 1991. They reviewed, on a country by country basis, documentation on screening for exotic biological control agents, background information on the leucaena psyllid in Southeast Asia and uses of the leucaena tree and alternative crops that could be used for the same purposes, attempts to control the leucaena psyllid by means other than biological control methods, government quarantine and screening procedures in place, and possible environmental impacts that may result from introducing biological control agents for leucaena psyllid control. Information on India was obtained in writing from Dr. S.P. Singh, Coordinator for the Biological Control Center in Bangalore. The environmental assessment team members were unable to personally visit India due to time constraints.

This EA was compiled in Kuala Lumpur (Malaysia), Bangkok (Thailand), Kathmandu (Nepal), Vientiane (Laos), Jakarta (Indonesia), Manila (the Philippines), and A.I.D./Washington, and was presented to the Office of Forestry and Natural Resources in September, 1991. The EA process was managed from Washington, D.C., by Michael Benge (R&D/FENR).

3.0 PURPOSE OF THE ASSESSMENT

The purpose of this EA is to engender full discussion of the significant environmental effects of releasing exotic insects Olla abdominalis, Curinus coerulus (both Coleoptera: Coccinellidae), Psyllaephaeus yaseeni (Hymenoptera: Encyrtidae), and Tamarixia leucaenae (Hymenoptera: Eulophidae) for the biological control of the leucaena psyllid, Heteropsylla cubana (Homoptera: Psyllidae), in parts of Asia and the South Pacific Islands. The discussions and available reports set forth the alternatives which could minimize potential adverse effects after introducing such exotic biological control agents. Expected benefits of development objectives can be weighed against any adverse impact upon the environment and/or human health or any irreversible or irretrievable commitments of resources.

This EA was conducted, in specific, to assess the potential environmental impacts that may result from the introduction of exotic biological control agents such that an informed decision as to whether or not to proceed can be rendered. A.I.D.'s role would be to support training in production and use of P. yaseeni and T. leucaena against the leucaena psyllid in Asia (see Appendix D for details).

Because there is no precedent for the introduction of biological control organisms sponsored in part, completely, directly, or indirectly by A.I.D., this EA was conducted without a prior Initial Environmental Examination (IEE) in the interest of being thorough for such a first time endeavor. This EA was conducted in accordance with A.I.D.'s Environmental Procedures, 22 CFR 216. Participants of this process have addressed the environmental aspects of the proposed action for leucaena psyllid control as set forth in the scoping process requirement of S216.3(a)(4)(i). These participants included USAID, USDA, and the concerned academic, scientific and governmental organizations of India, Indonesia, Laos, Malaysia, Nepal, the Philippines, and Thailand.

Detailed information on the biologies and behaviors of the leucaena psyllid and the four beneficial insects listed above are detailed in the text of this document, and can be researched further in many of the references listed in Appendix A that were used to compile this EA.

3.1 A.I.D.'s Historical Involvement with Leucaena and the Control of the Psyllid

A.I.D. has a long historical involvement in the development of Leucaena and a more recent role in the control of the Leucaena psyllid. In the mid-1960's, an Australian agriculturalist introduced an improved variety of Leucaena to the central highlands in Vietnam. Soon after, an A.I.D. officer recognized Leucaena's potential and began researching its use in agroforestry systems and for reforestation of degraded lands. In the mid-1970s, he was assigned to the A.I.D. Mission in Manila

and wrote a pamphlet on Leucaena's potential for agriculture, energy and reforestation in the Philippines. Afterward, the Mission conducted a highly publicized seminar in the Philippines and funded Dr. James Brewbaker from the University of Hawaii to give a lecture on Leucaena's potential. This resulted in the launching of a nation-wide program using Leucaena for agroforestry, reforestation, and energy production. The A.I.D. officer's pamphlet was also used to convince the National Academy of Sciences (NAS) of Leucaena's potential, which resulted in A.I.D. funding the NAS publication , *Leucaena: Promising Forage and Tree Crop for the tropics*. Later, NAS updated it and published a second edition.

Also, Leucaena has been widely used in a number of A.I.D. projects in the developing countries, perhaps most notably in Haiti where it was used to convince both Haitians and the international donor community that reforestation in Haiti was possible. Additionally, A.I.D. funded a number of Leucaena research activities through its small activities and science research grants programs, such as: nitrogen-fixing tree germplasm collection and evaluation by Dr. Brewbaker and by A.I.D.'s NifTAL project at the University of Hawaii--which evolved into the establishment of the Nitrogen Fixing Tree Association (NFTA); and the development of acid-tolerant strains of Leucaena by a Malaysian research institute. Also, Leucaena seed and improved strains of nitrogen-fixing bacteria, Rhizobium have been distributed around the world for research purposes through A.I.D.'s plant material distribution project with the United States Department of Agriculture, and A.I.D.'s NifTAL project. Leucaena became the most widely used and economically important new plant species introduced in Asia in the last decade.

In the mid-1980s when it became apparent that the Leucaena psyllid was causing millions of dollars in lost revenue to small farmers in Asia, A.I.D., through its Forestry Support Project with USDA Forest Service, paid for a leading entomologist, Dr. Max McFadden, to go to Asia to identify the insect and to evaluate the scope of the problem. This was followed by convening a conference on the Leucaena psyllid problem in Bogor, Indonesia--Jan. 16-21, 1989, funded by A.I.D., through the F/FRED WINROCK Project and through NFTA, and by the International Development Research Centre (IDRC). Also A.I.D. sponsored a number of the conference participants. Papers presented at the conference were published in NFTA's publication, *Leucaena Research Reports* (Vol. II, Nov. 1990), and in a combined publication by the conference sponsors titled *Leucaena Psyllid: problems and management*. As a follow up, A.I.D. provided a research grant to conduct network trials of psyllid resistant varieties of Leucaena developed by Dr. Brewbaker through NFTA. Through the F/FRED WINROCK project, *A Regional Research Plan for Leucaena Psyllid Control* was developed. Simultaneously, CAB International Institute for Biological Control (CBIC) submitted an unsolicited proposal to A.I.D. for the search in the Americas

of host-specific parasites for the biological control of the Leucaena psyllid. This proposal was administratively approved by A.I.D.; however, actual funding was never realized, and CIBC had to absorb the costs. When A.I.D. funding was finally broken loose, CIBC submitted this proposal--*Implementation of Biological Control for Leucaena Psyllid, Heteropsylla Cubana, in Asia and Africa*, which was fully funded.

Even though Leucaena was one of the most important agroforestry species identified for research in the F/FRED WINROCK project, its administrators chose not fund the CBIC proposal for the biological control of the psyllid. However, F/FRED WINROCK funded several small grants to some Asian scientists for work on the psyllid problem but since no progress reports were ever submitted, the grants were canceled at substantial loss to the project. Psyllid damage to Leucaena in Asia is now at an economically tolerable level, and Leucaena is still the tree of choice for planting by small farmers there. CIBC's work has played a major role in the biological control of the Leucaena psyllid in Asia. Unfortunately, the introduction of the control there was too late before the psyllid spread to Africa, and the host-specific parasatoids introduced by CIBC in Asia were evidently not carried to Africa, thus CIBC is now seeking funds to effect control there.

4.0 BIOLOGICAL CONTROL

This EA is designed to serve as a model for future A.I.D. activities in support of using exotic biological control agents, where necessary, for pest management in developing countries. However, prior to discussing the case of the leucaena psyllid in selected Asian countries, the term "biological control" should be defined with some degree of precision, especially in light of the fact that biological control encompasses several shades of meaning depending on the specific method by which such control is imposed.

Populations of plants and animals are limited by a combination of factors that prevent any one species from becoming overwhelmingly abundant. The ultimate factor which governs the upper limit of abundance of any species is competition between individuals of the same species for available food or space. However, this intra-specific competition is rarely invoked as a regulatory mechanism because the population is limited at an earlier stage by other factors, both physical (e.g., climate) and biological - notably by natural enemies that act as control agents. Thus, both plants and animals are attacked by diseases, parasites and predators which can limit host populations.

A term commonly used for certain natural enemy species is "parasitoid," which is different from "parasite." While a true parasite uses a host organism at some point during its life

cycle, it does not kill the host. A parasitoid, on the other hand, uses the host as part of its development, but this results in the eventual death of the host. In the context of biological control, parasitoids are most commonly miniature wasps (often referred to collectively as "microhymenoptera") that oviposit in or on the host (e.g., a caterpillar); upon egg eclosion, the larval stage of the wasp feeds externally or internally upon the host until the larvae pupate. Some parasitoid species lay one egg per host; others lay many eggs per host which does not necessarily result in intense intra-specific competition for the host provided that the host is sufficiently large to accommodate the resulting larval parasitoid population.

A natural enemy may kill a plant or animal outright, or impair its vigor in various ways; for example, by weakening its growth or reproductive ability. The importance of natural enemies in pest management is demonstrated most dramatically by situations in which a pest organism has been accidentally introduced to an area free of natural enemies, and without natural ecological checks and balances, it can become a widespread and serious problem. Similarly, the use of pesticides in the last 40 years has often resulted in the depletion of indigenous natural enemies of indigenous pests (which are normally held to economically tolerable levels by natural enemy populations). Without the constraint of natural beneficial organisms, pest populations can surge to major proportions and cause serious economic injury to crops and livestock, and pose health hazards to humans where organisms of medical importance (e.g., vectors of malaria) are concerned.

For practical purposes, the term "biological control" is defined as the activity of living natural enemies as pest control agents. These include vertebrates, invertebrates, and a wide variety of microbial pathogens including fungi, bacteria, and viruses. Biological control can be, and has been, used against vertebrate, arthropod, weed, and microbial pest organisms.

Other methods of control, sometimes classified erroneously as biological control, such as autocidal methods (e.g., sterile male release), the use of pheromones, kairomones, botanically derived pesticides, and host plant resistance are not considered as such for this EA. Those approaches that can be categorized under the rubric of biological control are discussed briefly in the following sections.

4.1 Biological Pesticides

Currently used formulations of live pathogens, often applied like chemical pesticides, are biological control agents. Although, like chemical pesticides, they have a relatively short term effect and there is little evidence that they have a prolonged impact on any organisms, they possess the potential for propagation and persistence in the environment. The most noted biological pesticide in use is Bacillus thuringiensis, although there are many others in use as well. At this time there are no

microbial biological control agents that are available for use against H. cubana, although research in this regard should be encouraged based upon those entomopathogens that have been found in association with the leucaena psyllid (sections 9.5, 11.3, 13.3, and 15.3).

4.2 Conservation and Enhancement

This involves conscious attempts to both maintain and enhance populations and/or the activity of indigenous natural enemies that control or contribute to the control of pests. Cultivation practices, particularly crop patterning in time and space, and conservation of weeds within or external to the field, are promising methods to conserve biological control agents. For example, in California, vineyards are attacked by the grape leafhopper, Erythroneura elegantula (Homoptera: Cicadellidae), which is, in turn, attacked by a parasitoid wasp, Anagrus epos (Hymenoptera: Mymaridae). During the winter, there are not enough grape leafhoppers to support sufficient A. epos numbers to impose biological control of the grape leafhopper early in the next growing season when grape leafhopper control is critical. A. epos, however, can parasitize an alternate host, another leafhopper, Dikrella cruentata. Dikrella populations exist on blackberry vines year-round such that if blackberry vines are conserved within six kilometers of the vineyard, A. epos can measurably control grape leafhopper damage at the beginning of the grape growing season.

Similarly, in Louisiana sugarcane, conservation of weeds in the furrows has been observed to increase imported fire ant, Solenopsis invicta (Hymenoptera: Formicidae), populations and to enhance foraging by supporting additional prey items. The high numbers of prey items permit greater fire ant colony densities because the foraging territories are smaller than in weed-free sugarcane regimes, while supporting the same number of ants per colony. As a result, fire ant foraging on sugarcane stalks is more intense and control of the sugarcane borer, Diatraea saccharalis (Lepidoptera: Pyralidae), is comparable to that achieved with some insecticides. In addition, use of broad spectrum pesticides, especially when soil incorporated, leads to a significant decline in fire ant populations even in areas where weeds are selectively conserved, and sugarcane borer damage is consequently severe.

Other conservation techniques would include using upright sticks in rice fields to serve as roosts for insectivorous birds, multiple cropping (both polyculture and crop rotation), and use of windbreak trees that provide food and shelter on a perennial basis for beneficial organisms.

4.3 Augmentative Methods

When natural enemies existing in an agroecosystem are unable to reduce pest damage to a tolerable level, even when

conservation methods have been employed, then native or exotic natural enemies can be reared and released into the agroecosystem periodically, much like repeated pesticide applications. In the simplest terms, this involves the propagation of natural enemies already present in the environment or exotic species unable to survive between seasons, and their release early in the season in order to establish a favorable beneficial organism to pest ratio which will prevent build-up of damaging pest populations throughout the ensuing growing season. When this is not effective, or when natural enemies are used which do not survive in sufficient numbers to maintain control for more than a short time, inundative releases may be made preferably at times when an economic threshold level for the pest is about to be reached.

4.4 Classical Biological Control

This is where an exotic beneficial organism is introduced to a new area and becomes permanently established. Most such introductions have been made after a pest species, controlled by natural enemies and thereby rendered relatively harmless in its indigenous habitat, has been accidentally introduced into a new region without natural enemies. Classical biological control therefore involves the planned introduction of one or more of its natural enemies which, when successful, decrease the pest population to stable and tolerable levels. This form of biological control is the aim of the leucaena psyllid control programs that use exotic predatory beetles and parasitoid wasps. In this case, the host plant to be protected (leucaena), the pest (leucaena psyllid), and the natural enemies of the pest have been or will be all introduced to Asia from the same area of origin (Latin America). The same procedure, however, can be applied to the deliberate introduction of biological control agents for management of indigenous pests. Before releasing biological control agents, certain criteria should be met to justify their use; justification for using natural enemies is discussed in Appendix E. This EA indicates that most of the Asian countries examined herein do not conduct studies on interactions of exotic biocontrol agents with nontarget organisms. It is strongly recommended that quarantine procedures study nontarget interactions and the survivorship and ecology of the introduced biocontrol agent in nontarget systems (e.g., forests and other uncultivated areas).

5.0 A.I.D. ENVIRONMENTAL PROCEDURES

It is A.I.D. policy to ensure that the environmental consequences of A.I.D.-financed activities are identified and considered by A.I.D. and the host country(s) prior to a final decision to proceed and that appropriate environmental safeguards are adopted. This policy is embodied in the legal requirements

set forth in Title 22 of the Code of Federal Regulations, Part 216, "A.I.D. Environmental Procedures" (22 CFR 216). This environmental assessment (EA) for the proposed introduction of exotic biological control agents for control of the leucaena psyllid is based on the requirements set forth in 22 CFR 216. A.I.D. environmental procedures include specific requirements for assessment of pesticide use (22 CFR 216.3[b]) but do not specify procedures for assessing the use of biological control agents. For this EA, the procedures outlined in 22 CFR 216.3(b) were used as guidelines (substituting the words "biological control agents" for "pesticides") as recommended during the scoping session for identifying and evaluating the potential environmental impacts of the introduction of biological control agents, and for recommending measures for mitigating adverse impacts and enhancing beneficial impacts.

6.0 FAO CODE OF CONDUCT FOR INTRODUCTION OF BIOLOGICAL CONTROL AGENTS

A draft code of conduct for the introduction of biological control agents was recommended to the FAO in November 1990. The draft code addresses considerations for importation of and information required on candidate biological control agents, recommended granting import permits, quarantine and screening procedures, procedures for release of biological control agents into the environment, and post-release monitoring, assessment, and evaluation procedures. This EA was conducted using the FAO draft code of conduct (Appendix F) as a minimum standard guideline for assessing the adequacy of current country capacity and training needs related to biological control.

7.0 GENERAL QUARANTINE AND SAFETY ISSUES FOR BIOLOGICAL CONTROL OF THE LEUCAENA PSYLLID IN ASIA

Many introductions of biological control agents for leucaena psyllid management have been made in Asia. However, many more introductions are possible given the wide distribution of the pest and the number of biological control agents that are currently available (and, possibly, others yet to be discovered). Still, some countries have not introduced any biological control agents for the leucaena psyllid, although, particularly in contiguous Southeast Asia and the Indian subcontinent, it is possible that deliberate introductions will not be required because insects, including pest and beneficials alike, do not "respect" international boundaries. Nevertheless, for all countries where introductions are being contemplated, administrators, quarantine officers and scientists have a responsibility for deciding on the ecological soundness of permitting the introduction of exotic biological control agents (while also paying attention to the social, economic and political realities that may run counter to environmental concerns). Recent history has revealed that some biological control attempts against other pests, such as the use of the mongoose in Hawaii for rat control, may indeed prove detrimental to the local ecology, and could cause irreversible damage, including the extinction of nontarget species.

Whatever the value of a natural enemy, importation of any given species must be accomplished carefully to minimize the risk of accidentally introducing undesirable organisms that may accompany the shipment of the biological control agent. Such undesirable organisms include plant pathogens; insect pests; pathogens and hyperparasites of the introduced beneficial organism; and other species that may aggressively compete with nontarget organisms. Hyperparasites of *T. leucaenae* and *P. yaseeni* were found in tropical America but were not common, and an *Entomophthora* fungus has also been recovered from Trinidad. As a result of stringent quarantine and research efforts in Hawaii, none of these organisms have been introduced to Hawaii or those Asian countries where parasitoids have entered quarantine or have been released. The critical concerns are to a) identify an effective biological control agent that b) would not disrupt the existing ecological complex.

In the case of the leucaena psyllid, shipments of tropical American natural enemies to Asia could carry rubber tree diseases or other organisms that would attack crops grown in both regions. For this reason, material from Latin America should be immediately quarantined at a site enroute from Latin America to Asia (e.g., Hawaii) with reliable quarantine facilities and stringent procedures, then the organisms should be quarantined again in the recipient country. Measures should be taken there to ensure that the material does not carry spores, hyphae, bacteria, etc., of pathogens that infect Asian crops, or parasites of the biological control agent to be introduced.

Exploration by IIBC in Central America revealed damaging infection of leucaena by the fungal pathogen, Camptomeris leucaenae, which as yet has not arrived in Asia.

IIBC and others have developed a procedure to safeguard against the risk of introducing undesirable pathogens and parasites. Pupae of shipped beneficial insects, including leucaena psyllid parasitoids, are surface sterilized using a fungicide such as benomyl, which is conducted in the country of origin or at a site enroute to the receiving country (e.g., IIBC's Quarantine Center in Britain). The pupae should be derived from a culture that has been certified free of hyperparasites, parasites, and pathogens, which can be accomplished by raising the beneficial parasitoid or predator through several generations under rigidly controlled conditions. Despite such precautions, it is advisable that the shipment be similarly screened in the recipient country, which should include raising the natural enemies through at least one generation under quarantine conditions.

In addition to considering the possibility of accidentally introducing undesirable organisms, it is also important to assess the likelihood that the beneficial organism will survive and propagate in the recipient country habitat. In Indonesia, for example, the effectiveness of C. coerulus has been notably hampered by the presence of indigenous organisms that can prey upon it, such as various species of ants, lizards, and birds (nevertheless, C. coerulus has been effective in controlling H. cubana in Indonesia). It is also important that the introduced natural enemies demonstrate efficient searching abilities for the pest and rapid population growth. A disadvantage of generalist predators, for example, is that they may not concentrate their feeding activities on the pest, especially when other prey species are abundant. For this reason, parasitoids (which tend to be more host specific) are recommended by some scientists over generalist predators as control agents, provided that they will not disrupt target and nontarget ecosystems.

Insect natural enemies, especially parasitoids, are usually certain not to be pests of plants (although some may be), and tests to assess the interaction of introduced biological control agents with crop and noncrop plant species are usually not conducted. However, in the Philippines, C. coerulus was tested on bean plants because some other coccinellid species are herbivorous (e.g., Mexican bean beetle), but C. coerulus was shown not to inflict damage to beans (an entirely expected result given that C. coerulus is strictly a predator). However, due to unexpected possibilities, such tests are prudent.

Concerns have been raised about the specificity of C. coerulus in the context of other beneficial insects which it might attack. In India, for instance, it was suggested that exotic predatory coccinellids might attack the lac insect (which is in the same taxonomic order as the leucaena psyllid (Homoptera), from which shellac is produced; it was recommended that both the predators and parasites of the leucaena psyllid be

tested on the lac insect. In Papua New Guinea, introduction of C. coerulus was rejected on the basis that it might create problems for existing cocoa pest management tactics. Leucaena is commonly used as a shade tree for cocoa production in Papua New Guinea. A certain mealybug feeds on cocoa pods, but causes little damage and attracts ants to its secreted honeydew. The ants, in turn, act as important predators of more serious pests. In Papua New Guinea, it was thought that if C. coerulus was effective against the leucaena psyllid on leucaena trees used for shade, it would then consume the mealybug and consequently disrupt the natural biological control of other pests provided by the ant. In all cases, it is recommended that the biology, behavior, and ecological interactions of exotic biological control agents be determined to the extent possible prior to their release in new areas.

Sometimes biological control programs encounter conflicts of interest, where some people see the introduction of the potential biological control agent as beneficial while others perceive it as being detrimental. In the case of the leucaena psyllid, a conflict of interest arises because another leguminous tree from tropical America, Mimosa invisa, is a serious weed in some Asian countries. In its native range, M. invisa is attacked by Heteropsylla spp. (but not H. cubana), and one such psyllid was introduced to Australia to control M. invisa. If the imported natural enemies of H. cubana can also attack the Heteropsylla sp. that is used to control M. invisa, then a success in controlling the leucaena would be in conflict with success in controlling the weed.

Where conflicts of interest are identified, a cost-benefit analysis would be the most rational approach to determining the feasibility of introducing the exotic organism intended for control of one or both of the pests. It is recommended, too, that a search for alternative and less disruptive tactics for control of one of the pests be conducted. IIBC tests showed that C. coerulus, T. leucaenae, and P. yaseeni will each attack the psyllid that feeds on M. invisa, so the two hymenopterous parasitoids will not be introduced to Australia, either.

There are no native Asian psyllids which are considered endangered or of special value for conservation (the Latin American Heteropsylla sp. being used to control M. invisa in Australia, however, is important). But in Australia there are rare and endangered birds that feed to a large extent on psyllids, such as the bell bird which feeds on a psyllid of eucalyptus. Were an introduced biological control agent of the leucaena psyllid to also be effective against the eucalyptus psyllid, it might threaten the food supply of the bell bird. The eucalyptus psyllid, however, is sufficiently different from H. cubana to make the possibility of some of H. cubana's enemies (especially those that are host-specific parasitoids) eliminating the eucalyptus psyllid a slim prospect.

In light of the above discussion on conflict of interest, it is recommended that informed decisions be made based upon as much

information on ecological relationships as possible. The economic and/or ecological cost of introducing seemingly beneficial organisms may, upon close examination, be deemed too high in the long term to warrant their use. For this reason, it is strongly urged that exotic biocontrol agents be thoroughly studied to determine their interactions with nontarget insects and the local ecology in general.

7.1 Production of Leucaena Psyllids and Their Parasitoids

After deciding to introduce natural enemies of the leucaena psyllid, both the psyllid and its enemies (particularly host specific parasitoids) must be reared in the laboratory for mass production purposes. Large scale releases into the field may be required in different parts of the recipient country on a repetitive basis for at least a limited period of time. Well selected sites of introduction may then serve as sources for the biological control agents to spread on their own elsewhere. Methods for rearing the leucaena psyllid and the two parasitoids being considered for importation, *T. leucaenae* and *P. yaseeni*, have been developed in Trinidad and Hawaii, and are designed to be carried out in small, well run insectaries. The procedure for rearing the psyllid and the parasitoids are described in Appendix G.

8.0 THE PROBLEM: BACKGROUND

8.1 The Leucaena Tree

The leucaena tree, Leucaena leucocephala is a mimosid leguminous plant native to Mexico, but it spread throughout much of tropical America and the common type was introduced to Asia by Spanish colonists in the 1600s. The giant type of L. leucocephala was first introduced to Asia in the early 1970s from a collection from Mexico by a scientist at the University of Hawaii. Because of its prolific growth, it the giant type leucaena is popular for use in agriculture while the slower growing type, with some value in agriculture, was more often viewed as a weed. Leucaena spp. have been utilized for fuelwood, human and animal food, erosion control, nitrogen fixation, and shade for light sensitive crops such as coffee and cocoa. The priority of importance regarding the use of leucaena trees may vary from country to country, and even among different areas within a single country.

Leucaena is more than a multipurpose tree, as it can be considered to be a noxious weed, especially the common type, because of its prolific seed production, under certain circumstances. When leucaena is categorized as a weed, H. cubana would then be considered to be a potential biological control agent rather than a pest. However, the efficacy of the psyllid as a beneficial insect in this instance is questionable because of the ability of the leucaena tree to recover except where psyllid populations are large and feeding is prolonged.

Records suggest that most Heteropsylla spp. are host genus specific, if not species specific. While L. leucocephala is the only recorded host for H. cubana in Asia, in its native range the psyllid has been recovered from L. diversifolia in Guatemala, Acacia villosa and Mimosa sp. in Jamaica, and from Albizia guachepele in Cuba. These associations may be casual, but the possibility that there exist specialized races of H. cubana on different legume species cannot be excluded from consideration. However, of the 19 other known species of Heteropsylla, only H. cubana has been consistently found on L. leucocephala in tropical America. Other Heteropsylla spp. also attack perennial weedy legumes, including such genera as Prosopis, Acacia, Cassia, Albizia, Mimosa, Samanea, Desmanthus, and Calliandra. Of the 12 Leucaena species, and over 50 recognized interspecific hybrids, each exhibits different degrees of susceptibility, tolerance, and resistance to leucaena psyllid attack. Leucaena collinsii, L. esculenta, L. pallida, and L. retusa showed some resistance to H. cubana in Hawaii and Taiwan, but L. leucocephala lines that are demonstrated to be resistant in some areas are susceptible in other areas. Also, resistant lines were shown to set seed poorly, or have problems with infertility.

8.2 The Leucaena Psyllid

The leucaena psyllid, Heteropsylla cubana, is a small (2 - 3 mm) insect which feeds by sucking juices from the phloem of new leucaena tree shoots and leaves. Eggs are laid in groups on very young shoots between the folds of the developing leaflets (usually on the upper surface of the leaflets). Leaflets may be virtually covered with eggs when psyllid populations are high; each female can produce 300 - 500 eggs. The eggs are oval in shape; 0.3 mm long and 0.1 mm wide. When oviposited, the eggs are whitish, but turn light tan after one day. As the eggs mature, the color deepens to orange or reddish brown. One day prior to eclosion, a pair of red eye spots (of the embryonic nymphs) appear at the pointed end of the egg. The incubation period for eggs seems to differ from area to area, but is generally 2 - 5 days. It takes 11 - 20 days for the leucaena psyllid to develop from egg to adult.

Nymphs are dorso-ventrally flat and oblong from a dorsal view. Although whitish when newly hatched, nymphs eventually turn various shades of colors - yellow, light green, green, tan, or orange, but most are yellowish green. The psyllid nymph undergoes five nymphal instar stages before molting to winged adulthood. The first four instars each develop in 2 - 3 days and the fifth instar develops in 2 - 5 days. The total nymphal period lasts 8 - 17 days, which may differ from area to area, depending mostly on climatic conditions.

Adults are slender and about 1.5 - 2 mm long. They are usually yellowish green in color although some may be varying shades of brown. On average, the female is 2 mm long and the male is 1.8 mm long. The wings of newly emerged adult psyllids are opaque and gray, but become transparent with age.

Immediately after hatching, the first instar nymphs begin feeding near the oviposition site. As the nymphs grow, they colonize and feed on other terminal portions of stems, branches, and petioles of young leaves. Both adults and nymphs feed by sucking from the phloem of developing shoots and young leaves. The piercing of leaf tissue by their stylet mouthparts produces visible punctures, and the insects exude droplets of sticky fluid, called honeydew, which can cause the leaflets to remain appressed together rather than developing naturally. The honeydew can also interfere with the movement of predatory insects. Massive psylla populations can cause necrosis of the shoots, defoliation, and death of the tree. Complete defoliation and death of leucaena stands has occurred in Southeast Asia in some locations.

The leucaena psyllid was first described in 1914 in Cuba. Distribution records for H. cubana have been assembled from recent surveys and material in the U.S. National Museum, the British Museum, and other sources. These indicate a range for H. cubana from Florida and Mexico to Argentina and Peru, and throughout the Caribbean. Surveys for the present attempt to identify biological control agents for H. cubana began in

tropical America at the end of the 1988 dry season (June). Exploration between June and August in the Caribbean and Mexico revealed very low H. cubana populations; infested plants were rare. In July, for example, about 10,000 leucaena shoots were examined in Yucatan without finding psyllids. Populations of psyllids are usually restricted to only one leucaena plant in a population of many healthy, apparently identical trees. Other psyllid species were found on other mimosid legume species, which suggests that seasonal climatic conditions were not responsible for H. cubana's scarcity on L. leucocephala in tropical America.

By contrast, surveys at the start of the dry season in November 1988 revealed that the psyllid was ubiquitous on leucaena throughout the survey area. Subsequent studies in both Mexico and Trinidad suggested the seasonality of H. cubana populations in the Western Hemisphere. Similar trends are apparent in Asia (see sections on specific countries in this EA), but these are apparently less distinct, and in some areas populations oscillate more frequently and not in association with seasons. In fact, even in Trinidad, population upsurges occurred weeks after the new flush of leucaena shoot growth that happens at the start of the wet season.

Heteropsylla cubana was first reported in Asia in India in 1979, and it was again reported in Indonesia in 1981 (both identifications are unconfirmed, and may have been inaccurate - other dubious identifications were made since). The psyllid's identity was uncertain when it was first reported to be causing major damage in Asia in 1985, and it remains unclear as to how such a rapid outbreak and rate of spread occurred in Asia. Air traffic and air currents were likely responsible for the introduction of H. cubana to Asia and its subsequent dissemination. Since 1985, the leucaena psyllid spread throughout Southeast Asia, the Indian subcontinent to Pakistan, parts of China, and the South Pacific Islands (but not Australia). Being specific to the leucaena tree, which was previously "pest free" in Asia, the leucaena psyllid was able to quickly fill an ecological niche unhindered by indigenous predators, parasites, and pathogens. During certain times, however, psyllid populations wane despite continual host availability. These population fluctuations have yet to be explained in full. In some Asian countries north of the Equator, such as Thailand, the Philippines, and Vietnam, H. cubana is absent from leucaena trees from late March to early October, but there still exist pockets of psyllid populations even when the psyllid has disappeared from surrounding areas. It is speculated that population declines are a result of density-independent or physical factors rather than biological or density-dependent factors (e.g., natural enemy populations or host plant availability). H. cubana exhibits multivoltinism during the outbreak season, from October to April, each year to the extent of being cryptovoltine. It is not known if leucaena psyllids aestivate or undergo summer diapause, or in what life stage(s) these events occur.

9.0 LEUCAENA PSYLLID CONTROL TACTICS

Because leucaena is a multipurpose plant species, different control strategies may be required for the leucaena psyllid depending on the primary use of the tree in each area. Due to the improbability of identifying a single psyllid control strategy, an integrated pest management approach made flexible for the specific use(s) of the leucaena tree in each given area is the only way to impose control. Various control tactics, although not yet developed sufficiently to incorporate together into IPM strategies, may become available especially if appropriate and well-directed research is supported in this regard.

9.1 Chemical Control

Chemical control measures, aside from being environmentally hazardous, expensive, and logistically impractical (particularly as leucaena trees are mostly grown by small farmers), are largely ineffective and would likely require multiple applications. Even if a chemical were to be developed for effective psyllid control, such a tactic would be difficult to adopt in light of the probable expense to small farmers and because of the undesirability of having pesticide residues on a crop primarily used for fodder.

9.2 Other "Chemical" Control Tactics

The use of microbial biocontrol agents, pheromones, botanically derived antifeedants, repellents, and pesticides, and plant growth regulators for controlling the leucaena psyllid have not been explored. Therefore, at this time, there is no means by which to control the psyllid by application of chemicals, whether synthetic or biologically derived. Research on this could be an avenue of investment; however, the intrinsic value of the leucaena tree in Asia must first be clearly delineated before such efforts can be justified.

9.3 Host Plant Resistance

Resistance trials have been conducted in several countries, but progress has been slow and the results inconclusive. Some lines showing resistance to the leucaena psyllid can change with regard to the degree of resistance from generation to generation, year to year, and from area to area. Resistant leucaena species, such as *L. diversifolia* K156 cannot compete with *L. leucocephala* for fodder production purposes. In addition, the physical or physiological mechanism that imparts resistance or tolerance has not been identified, which makes breeding efforts all the more difficult to direct. In anticipation of breeding stable resistant varieties, commercial seed production has been considered, but its feasibility is uncertain. Many attempts to

propagate trees from seed have been shown to be of questionable utility because of seed sterility problems or failure to germinate for other, as yet undetermined, reasons (although photoperiod sensitivity is suspected). Propagation by planting cuttings has similarly produced relatively poor results. For more detailed discussions on host plant resistance, see country specific sections in this EA.

9.4 Crop Diversification

Research on the effect of crop diversification has not been conducted with regard to ecological interactions that impinge upon H. cubana. The fact that leucaena is used as a shade tree in cocoa and coffee plantations suggests that close association of leucaena with at least those two crops has not reduced psyllid damage to an appreciable extent. However, research in other agroecosystems (not involving leucaena) has shown that crop diversification can have potential for harboring greater numbers and higher diversity of beneficial organisms. Other studies have similarly shown that weed conservation, if the weeds are kept at economically acceptable levels, can sustain beneficial insects which significantly reduce insect pests. If it is determined that L. leucocephala is indispensable for fodder and fuelwood production in parts of Asia, then research should be encouraged to ascertain the appropriate crop/plant associations that would conserve and enhance natural enemies of the leucaena psyllid.

9.5 Biological Control

Because the leucaena psyllid is an introduced species to Asia, there are few indigenous natural enemies for it there. Those that do exist are generalist predators which are incapable of measurably or consistently reducing leucaena psyllid populations even on a site specific basis. However, surveys for indigenous Asian species of predators and parasitoids have been relatively sparse and future efforts may result in the discovery of organisms with greater potential than those already identified. Should indigenous and effective biological control agents be found, it is conceivable that they could be mass reared and released on and around leucaena trees. Such a tactic, if developed, should be combined with studies on the effect of plant diversification for field conservation of such natural enemies.

Despite the fact that an IPM strategy has not been comprehensively implemented for psyllid control on leucaena (F/FRED assisted in developing a regional IPM program in five countries but the plan has apparently not been used or has not been successful), biological control using exotic insect species, either of a classical or augmentative nature, is the most promising tactic. Following the discovery of H. cubana in Hawaii in 1984, a search was conducted for biological control agents by IIBC in early 1987 in Trinidad, Mexico, and the Caribbean; all native habitats of the leucaena psyllid. During exploratory

studies, psyllids on all mimosid legumes were collected, along with natural enemies and information on the plant, habitat, and climate. Attention was also paid to other pests on leucaena. Herbarium specimens were retained for plants from which psyllids were collected and records were maintained on the various plant growth patterns. The IIBC survey revealed a diverse natural enemy complex for H. cubana and related New World psyllids which includes spiders, coccinellids (see Table 1 for predatory Coleoptera), mirids (Hemiptera: Miridae), assassin bugs (Hemiptera: Reduviidae), phymatids (Hemiptera: Phymatidae), wasps, ants, syrphids (Diptera: Syrphidae), and parasitoid wasps in two main genera, Psyllaephaeus (a Psyllaephaeus sp. has successfully controlled H. cubana in Florida, but it was not deliberately introduced or used as a biocontrol agent) attacked) and Tamarixia. The search resulted in the discovery of Psyllaephaeus yaseeni (Hymenoptera: Encyrtidae), a parasitoid of first and second instar leucaena psyllid nymphs; Tamarixia leucaenae (Hymenoptera: Eulophidae), a parasitoid of third and fourth instar nymphs; and Cycloneda conjugata (Coleoptera: Coccinellidae), a general predator of nymphs and adults. While both P. yaseeni and T. leucaenae are both apparently host specific to H. cubana and each female can parasitize more than one psyllid nymph, P. yaseeni is an endoparasitoid that lays one egg inside each psyllid where the larva develops, and T. leucaenae is an ectoparasitoid that lays one egg per nymph just behind the hind coxae. Each wasp can parasitize more than one psyllid nymph (up to 50). The fact that P. yaseeni prefers earlier instar psyllid nymphs makes it a more promising parasitoid because it kills psyllid nymphs at an earlier life stage and thus can potentially reduce damage more than T. leucaenae which parasitizes nymphs at a later life stage. One visual method of determining whether a psyllid has been parasitized by P. yaseeni or T. leucaenae is that T. leucaenae, being an ectoparasitoid, creates a web around the psyllid nymph body that is fastened to the leaf. P. yaseeni, on the other hand, being a endoparasitoid, causes "mummification" of the psyllid nymph, whereby the parasitized nymph appears discolored, hollowed out, is not covered with webbing and is therefore not attached to the leaf.

A third parasitoid wasp, Sectiliclava spp. (Hymenoptera: Encyrtidae), was collected from plants harboring H. cubana in Mexico, and some species of this genus are parasitoids of the adult leucaena psyllid. Sectiliclava spp., however, have not been introduced to Hawaii or Asia for biological control of H. cubana.

Tamarixia leucaenae failed to propagate under quarantine conditions in Hawaii, and C. conjugata was not adequately host specific to H. cubana to ensure effective and selective control. Psyllaephaeus yaseeni, however, was propagated and found to be host specific, and was therefore approved for field releases in June 1987. It has since become widely established in Hawaii. Other biological control agents, Olla abdominalis and Curinus

Table 1. Predatory Coleoptera found in association with *Heteropsylla cubana* on *Leucaena leucocephala* in tropical America.

Coccinellidae	**Countries of Origin**
Curinus coerulus	Colombia, Trinidad
Cycloneda sanguinea	Haiti, Mexico
Olla v-nigrum	Mexico, Trinidad
Olla sp. nr. *v-nigrum*	Trinidad
Hippodamia convergens	Mexico
Coleomegilla maculata	Cuba, Mexico
Brachiacantha laevis	Mexico
Procula dovei	Jamaica
Chilocorus cacti	Jamaica
Exochomus jamaicensis	Jamaica
Hyperaspis sp. *distinguenda*	Trinidad
Hyperaspis sp.	Trinidad
Coccinella emarginata	Trinidad
Chnoodes terminalis	Trinidad
Nephus sp. nr. *flavifrons*	Trinidad
Nephus sp.	Mexico, Trinidad
Diomus sp.	Jamaica, Trinidad
Scymnus sp.	Jamaica
Staphylinidae	
Euwira sp.	Mexico

coerulus (both Coleoptera: Coccinellidae), were introduced to Hawaii in 1908 and 1922, respectively (long before the leucaena psyllid arrived there), for control of scale insects and the coconut mealybug, Nipaecoccus nipae (Homoptera: Pseudococcidae). These two beetles have provided supplementary control although they are not particularly active predators of the leucaena psyllid (they feed on a number of homopteran insect species, so the psyllid is only incidental prey). Also, O. abdominalis and C. coerulus tend to stay on one plant rather than to move from plant to plant in search of psyllids. Curinus coerulus was introduced in 1989 to several Pacific islands, including Guam, Saipan, Indonesia, the Philippines, and Papua New Guinea, and to Thailand in 1987, and to Vietnam, India and Burma in 1988. O. abdominalis was introduced to New Caledonia in 1987 and to Thailand in 1989. Their effects on the leucaena psyllid populations has not as yet been systematically determined (C. coerulus appears to be effective in Indonesia - section 11.2).

In Hawaii hyperparasites were reported on P. yaseeni which include Pachyneuron siphonophorae (Hymenoptera: Pteromalidae), Syrphophagus aphidovorus and another Syrphophagus sp. (Hymenoptera: Encyrtidae). In Thailand, P. yaseeni was found to be hyperparasitzed by a Coccophagus sp. (Hymenoptera: Aphelinidae) and an unidentified encyrtid. The presence of indigenous hyperparasites of an exotic psyllid parasitoid in Thailand may lead to a decrease in the effectiveness of Psyllaephaeus, but it is unlikely to be of serious consequence.

The New World survey for possible biological control agents of H. cubana yielded some entomopathogens, such as Conidiobolus coronatus, Entomophthora sp., Hirsutella thomsonii, and Paecilomycetes farinosus; the possible application of these organisms has not been fully explored.

In any event, whether a biocontrol agent is an arthropod or a microbe, studies should always be conducted prior to its release to determine its interaction with nontarget organisms and its role and impact on target and nontarget ecosystems.

9.6 Grazing and Pruning

One method of control, although it has not been adequately researched, is the pruning or grazing of leucaena trees infested with H. cubana. Researchers at MARDI in Malaysia indicated that grazing could be an effective control strategy (section 13.5.3) given the lack of alternatives and because, in Malaysia, leucaena would primarily be employed as a source for animal fodder anyway. A selective method for cutting or grazing of leucaena shoots and branches at critical H. cubana population levels could be developed to hold leucaena psyllid populations to more economically benign densities. Such a method, however, could preclude the use of leucaena for shade, although the tree is not noted in Southeast Asia as a particularly effective shade tree for light sensitive crops. On the other hand, after leucaena

trees have been pruned or grazed, there is usually a flush of new shoot and leaf growth which is highly favorable to the psyllid. Such new shoot and leaf growth can lead to rapid propagation of H. cubana. This tactic for leucaena psyllid control is too poorly understood to be recommended as being suitable in H. cubana management strategies.

9.7 Alternative Crops

The "no action" option for leucaena control would most likely entail the abandonment of L. leucocephala as viable multipurpose resource in Asia due to the impact of the leucaena psyllid. In each country the team visited there were many indigenous plants which serve some or all of the same purposes as leucaena. While the abandonment of leucaena may be perceived as a "negative" option, it may also be the most rational approach unless a cost-effective control strategy for H. cubana is developed which would be amenable to the small land holder. The currently cautious view of the Malaysians regarding promotion of leucaena as an answer to fodder and fuelwood shortages seems a sage position; continued investment in a tree crop which may well fail as a result of psyllid infestation when there are alternative plant species invulnerable to the pest may not be an appropriate focus.

10.0 INDIA

10.1 Importance of Leucaena

The leucaena tree, or "subabul," as it is known in India, was introduced to India during the 19th Century. However, cultivation of leucaena did not occur until early 1972 mainly to strengthen the social forestry program, soil reclamation, fuel, fodder, green leaf manure, shade for plantation crops, and timber. In 1974, the University of Agricultural Science in Bangalore collaborated with the Karnataka Dairy Development Corporation to expand the area under leucaena cultivation. The Karnataka Forest Plantation Corporation initiated a plan to plant over 10,000 ha of leucaena to meet the fodder requirements of Karnataka. Many of these efforts were designed in the hopes of alleviating the shortage of fodder caused by the continuous drought during the previous four years. In Uttar Pradesh, Madhya Pradesh, Maharashtra, and Andhra Pradesh, leucaena is also grown in alley cropping schemes that involve cotton, sugarcane, and cocoa. Much of the alley cropping using leucaena has been done on marginal and submarginal lands.

Due to the psyllid infestation, plans to use thousands of ha of land for leucaena cultivation were abandoned. In Karnataka alone there are about 10,000 ha planted to leucaena, and more than 200,000 leucaena seedlings and 4,000 ha of leucaena plantation were completely destroyed by H. cubana.

10.2 Leucaena Psyllid Population

The leucaena psyllid is suspected to have entered India from Sri Lanka or the Andaman Islands and the pest was first recorded in southern India in early 1988. Within two years, the psyllid spread throughout the rest of India. Peak months of infestation have been identified as being August, September, October, and November which occur in the dry period in India. Populations of H. cubana in India fluctuate depending on the availability of feeding space on leucaena plants. On completely defoliated plants, a large number of psyllid adults overcrowd on older leaves due to the lack of young, more vulnerable leaves on which to oviposit.

Overall percent infestation of terminal shoots under 10 cm long ranged between 80% and 100%. Even isolated leucaena plants in the middle of evergreen forests in the Western Ghats of Karnataka were attacked by the psyllid. The leucaena psyllid has halted most plans to promote the propagation of L. leucocephala in India.

10.3 Past and Present Biological Control Efforts

Formalized efforts to implement biocontrol in India started in the early 1900s with a biocontrol laboratory set up at the Indian Agricultural Research Institute in New Delhi. In 1930 a

consignment of Aphelimus mali (Hymenoptera: Eulophidae) from the U.S. was sent to India where it was released and was found to be effective in Punjab for controlling Eriosoma lanigerum (Homoptera: Aphidae). In 1940, a large biocontrol unit was set up to mass produce Trichogramma in Karnataka. A Commonwealth Institute of Biological Control (now IIBC) Indian Station was established in 1956 at Bangalore, and from 1958 to 1960, CIBC imported Prospaltella perniciosi (Hymenoptera) from the U.S., China, the Soviet Union, and Switzerland, and Aphytis diaspidis (Hymenoptera) (from the U.S. to control the San Jose scale, Quadraspidiotus perniciosus (Homoptera: Diaspididae). A predator, Platymeris laevicollis (Hemiptera: Reduviidae), was introduced to Androth Island from Africa to control Oryctes rhinoceros (Coleoptera: Scarabaeidae) in coconut.

For control of potato tuber moth, Phthorimaea operculella (Lepidoptera: Gelechiidae), Bracon glechiae (Hymenoptera: Braconidae) was imported from Canada in 1944, and releases were made from 1952-1958 and it became established in Patna, Biharshariff, and Sabour in Bihar state. Between 1964-1965, CIBC introduced seven other parasitoid wasp species for potato tuber moth control but not all of them became established.

In sugarcane, Trichogramma species were introduced by CIBC to Tamil Nadu, Karnataka, and West Bengal in the 1950s with encouraging results. Later, Telenomus alecto (Hymenoptera: Scelionidae) was introduced from Colombia to West Bengal which resulted in 53% parasitism of sugarcane stem boring moths. Released hymenopteran and dipteran larval parasitoids did not become established.

Cottony cushion scale, Icerya purchasi (Homoptera: Margarodidae), an exotic pest to India, was successfully combatted using Rodalia cardinalis (Coleoptera: Coccinellidae) in 1929 and Cryptochaetum iceryae from California in 1947 but the latter natural enemy did not become established.

In 1977, the All India Coordinated Research Project on Biological Control on Crops and Weeds was initiated by the Indian Council of Agricultural Research mainly to identify promising natural enemies of pests. Since 1981, 59 species of exotic natural enemies have been introduced; 38 of these have been reared and released with success. Improved production techniques for 27 natural enemies have been developed, and commercial production of Trichogramma spp., Chrysoperla spp. (Neuroptera: Chrysopidae), Cryptolaemus montrouzeiri (Coleoptera: Coccinellidae), and Leptomastix dactylopii (Coleoptera: Coccinellidae) has started. Presently, this program alone is releasing parasitoids, predators, and nuclear polyhedrosis viruses in 1,500 ha used for experimental purposes.

The first example of biological control against a weed species occurred in 1795 when Dactylopiocus ceylonicus (Homoptera: Dactylopiidae) was introduced from Brazil and it controlled Opuntia. Other attempts to control weeds with biological control agents include introducing Neochetina eichhorniae (Coleoptera: Bruchidae), N. bruchi, and Orthogalumna

terebrantis in 1983 for clearing waterways of water hyacinth. These three organisms have cleared more than 940 ha of water hyacinth.

In 1989, C. coerulus was introduced for control of H. cubana; the predator has since become established around Bangalore, but has only spread within a 25 km in the following two years. Efforts are being made to introduce P. yaseeni, T. leucaenae, and O. abdominalis.

10.4 Regulations on and Quarantine of Biological Control Agents

Since the inception of the All India Coordinated Research Project on Biological Control of Crops and Weeds at Bangalore, the Project Coordinator is authorized to import natural enemies of crop pests and weeds to India. The procedure requires that all information pertaining to natural enemies be sent to the Plant Protection Advisor of the Government of India. A meeting of experts is held to decide about introduction of biological control agents; once cleared by the expert committee, an import permit is issued. The shipment of the exotic biological control agent must be handled by a quarantine laboratory. Natural enemies are reared, in quarantine, for two or three generations to obtain a pure culture (e.g., without hyperparasites or pathogens). Once it is determined that the culture is pure, then the organisms is transferred to a main laboratory for evaluation. In the case of insects that are to be used against weeds, host specificity tests are carried out using most economically important crop species. Based upon the results, the plant protection advisor can give a permit to release the organism into the field.

After releases are made, observations on recovery and percent host parasitism or predation are recorded for three or four seasons. Newly introduced natural enemies are tested in the field at different agroclimatic zones of India. If field tests show that the natural enemy is promising, large scale propagation through government agencies and private insectaries can commence. If any newly introduced natural enemy gives more than 60% control, it is recommended for large scale trials.

10.5 Leucaena Psyllid Control Options

10.5.1 Pesticides

Endosulfan, monocrotophos, quinalphos, and phosalone (all at 0.05% a.i.) have been found effective against adult psyllids for 14 to 30 days after application. Nymph populations, however, were not affected in many treated trees. Use of these pesticides would require that applications occur periodically, which would present logistical, financial, safety, residue, and environmental problems that would not be encountered if appropriate nonchemical control tactics become available.

10.5.2 Resistant Varieties of Leucaena

Strategies for developing psyllid resistant or tolerant species or varieties of leucaena were initiated in 1988. A number of tolerant varieties of L. leucocephala have been identified in India. These tolerant varieties support large populations of H. cubana without affecting tree growth, but leaf production is reduced. Although some degree of resistance to the leucaena psyllid has been noted in some varieties, this does not yet appear to be an answer to the psyllid problem in India.

10.5.3 Grazing and Pruning

Early attempts to control the leucaena psyllid included short-term measures, such as pruning and burning of heavily infested shoots and even exposing the tree to smoke. While these methods were reported to result in some amount of control, it was of a very limited nature, and these methods are unlikely to be useful as a sustainable means of control.

10.5.4 Alternative Crops

In a Nitrogen Fixing Tree Association trial, Leucocephala pallida, L. collinsii, L. diversifolia, Gliricidia sepium, Acacia angustissima, A. villosa, Callandria calothyrus, Sesbania grandiflora, and S. sesban were not susceptible to H. cubana. Use of these species would have to be tested for different areas of India where L. leucocephala has become an important multipurpose tree. As in the other countries discussed in this EA, the use of alternative species would be the most logical choice of strategies if it became impossible to continue growing L. leucocephala. For the present, study of alternative species should be encouraged such that even if H. cubana were to be controlled, promotion of diversity among multipurpose legume tree stands would be possible, which would result in a more stable agroecosystem.

10.5.5 Biological Control

There is a complex of natural enemies that attack H. cubana in India which includes Menochilus sexmaculatus (Coleoptera: Coccinellidae), Scymnus gracilis (Coleoptera: Coccinellidae), Harmonia sp. (Coleoptera: Coccinellidae), Cardiastethus sp. (Hemiptera: Anthocoridae), Paederus fuscipes (Coleoptera: Staphylinidae), Ropalidia montana (Hymenoptera: Vespidae) mantids, reduviids, mirids, syrphid fly larvae, dragonflies, spiders, and chrysopids. Despite the number of different organisms that feed on the psyllid, none of them apparently are able to regulate populations of the pest below economically damaging levels. The white muscardine fungus, Beauveria bassiana, has been reported to give 64-100% control in 7-35 days after application.

Curinus coerulus was brought to India through the Biological Control Center in Bangalore in early 1988, supplied by Dr. Banpot Napompeth (director of Thailand's National Biological Control Research Center - see section 17.0). Olla abdominalis, P. yaseeni, and T. leucaenae are also being explored as potential biological control agents against H. cubana. According to Dr. Singh, these other natural enemies would be obtained from Dr. Banpot Napompeth. Biological control represents a promising tactic for managing H. cubana populations in India and in most other Asian countries infested by H. cubana.

10.6 Country Capacity

10.6.1 Institutional Responsibilities and Coordination

In India, biological control work is conducted through the Indian Council for Agricultural Research (ICAR) system, agricultural universities, and central government agencies. Main research programs are carried out through the All India Coordinated Research Project on Biological Control of Crop Pests and Weeds, headquartered at the Biological Control Center in Bangalore. There are 16 biological control centers in 13 different Indian states. The centers can perform basic studies, and be responsible for mass production, storage, release, and monitoring programs. The centers are reported to be well staffed with technical specialists and laborers.

Dr. S.P. Singh has been appointed to be the Project Coordinator for biological control of H. cubana; he has been responsible for the production of about 30,000 adult C. coerulus which have been supplied to various areas in India.

10.6.2 Equipment and Facilities

India has 16 centers that are used for biological control purposes in 13 states. Each center is staffed by at least three or four scientists, six to ten technicians, and a number of laborers. At the main biological control center in Bangalore, there is a laboratory in a separate building for rearing insects, entomopathogens, and quarantine of biological control agents. Needs regarding equipment and facilities were not reported by the Indian contact (Dr. S.P Singh) for this part of this EA, and it is assumed that there are no urgent requirements.

10.6.3 Data and Information Management

There is a separate computer section through which all types of data can be processed for biological control purposes, and each scientist in the biological control centers has a personal computer. The Indian contact (Dr. S.P. Singh) for this part of this EA did not relate any urgent needs regarding data information and management.

10.6.4 Environmental and Economic Assessment

The destructive potential of the leucaena psyllid is recognized, but its impact in different agroclimatic regions has not been assessed. The impact of the psyllid on the environment, and that of C. coerulus on the environment, have not been determined either.

10.6.5 Training Needs

The only areas where Dr. Singh indicated a need for training was in rearing and releasing the parasitoids P. yaseeni and T. leucaenae. It would seem, based upon the descriptions of India's capacity for conducting biological control in the past, that India has sufficient experience in the realm of biocontrol such that training of technical staff would not be as urgent as in most other countries discussed in this EA.

11.0 INDONESIA

11.1 Importance of Leucaena

Since the 16th Century, leucaena was planted widely in Java and Sumatra for shade, erosion control, and nitrogen fixation in plantation crop systems. In 1930, leucaena was planted in the Sikka and Amarasi areas of Nusa Tenggara Timur (NTT) Province. In Amarasi, leucaena was also used to prevent the spread of the weed Lantana camara in grazing land. An order from the local Raja in 1932 required the people of Amarasi to plant leucaena so that it eventually covered about 2/3 of the province.

Indonesia has planted 1.2 million ha of leucaena trees ("lamtoro") for a wide variety of purposes: shade for cocoa, tea, coffee and vanilla; livestock fodder; reforestation; soil reclamation; charcoal and fuelwood production; green manure; timber; leaf meal; and human food. The uses of leucaena seem to vary according to region. For example, the provincial government of Nusa Tenggara promotes leucaena for shade, land stabilization, and fodder; on Timur leucaena is used primarily for cattle feed. Nearly all plantations of cocoa, tea, coffee, and vanilla run by estates (20% of plantations) or individual farmers (80% of plantations) use leucaena for shade. In addition, the Department of Forestry has used leucaena for reforestation and soil reclamation.

Leucaena was highly regarded and was incorporated into several governmental development programs, and it formed the base of the "paron" system for fattening tethered cattle which increased income of many small farmers. Leucaena planting contributed toward intensification of land use which helped to reduce shifting cultivation.

Leucaena leucocephala is an important component of the taungya system for establishing teak forest plantations in Java. The taungya system, an agroforestry practice, has been used in Java since the 1800s and leucaena was incorporated into this technique in 1907. After 40 years of development, the taungya system has been the most productive and popular method for establishing teak plantations in Java.

Cultivation of leucaena, however, is impeded by the effects of deforestation, soil degradation (which often involves increased acidity, reduced organic matter, and high aluminum content), and the dominance of Imperata and Themeda grass species. Leucaena survives best on alkaline soils, but 66% of Indonesian soils are red/yellow podzolic having very low pH, which is largely unsuitable for leucaena production. The soils in Kalimantan and Sulawesi have particularly acidic soils and, consequently there are few leucaena trees in Sulawesi and none in Kalimantan. On the other hand, leucaena is both common and widespread in Java and Bali.

On Sumatra, leucaena is primarily grown as a shade tree for cocoa, but its use for animal fodder is being promoted. In Sumatra's Lampong Province, a project using 2,000 ha of leucaena

for charcoal production is being supported by Lembaga Ilum Penetahuan Indonesia (LIPI: Institute for Sciences of Indonesia), with a possibility to develop leucaena use for paper pulp. In northwest Sumatra there are about 3,000 coffee smallholders in Aceh Province.

In Bali, leucaena is used to shade about 12,000 ha of vanilla grown by small farmers.

In Java, plantation crops, especially cocoa, are grown and leucaena is used in many areas for shade. Throughout Central Java, small farmers employ leucaena for multiple purposes. In West Java, leucaena has been planted for sheep fodder.

Leucaena is being introduced to Irian Jaya as a shade tree for oil palm and cocoa.

In Timor, the Nusa Tenggara Timur Integrated Agricultural Development Project (NTTIADP) is designed to benefit small farmers in NTT. Leucaena plantings were successful at arresting severe land degradation due to deforestation. The Amarasi region of Timor has benefitted from the use of leucaena by releasing much land previously used for grazing by tethering cattle and feeding them cut leucaena. As a result, all but a small portion of land at the dry eastern end of Amarasi was soon reopened for cultivation. About 1 - 1.3 ha are used in the Amarasi system to provide cut and carry fodder for every three head of tethered cattle. The remaining 0.6 - 1.0 ha owned by a typical family is used to grow maize, cassava, beans, and melons. Real incomes of households in Amarasi have been estimated to be 20 - 30% higher than the average in West Timor; the difference is largely attributed to the stabilization of farming systems developed around leucaena. In 1974, government policy specified that only farmers who planted leucaena would receive credit in the Sikka District of Flores, which stimulated leucaena planting. By 1982, about 20,000 ha of hilly land had been terraced with local leucaena and giant leucaena trees. Leucaena is an important component of the farming systems in Timor Tengah Selatan and Timor Tengah Utara where population pressure and overgrazing threaten the sustainability of agriculture. There is evidence of increasing livestock carrying capacity in these areas as a result of leucaena growth.

Now that *H. cubana* is being effectively controlled by *C. coerulus* and *P. yaseeni* in most of Indonesia's leucaena growing areas (section 11.3), leucaena production levels at least match those of pre-infestation years, and leucaena is considered once again to be a very promising tree for fodder and fuelwood production. Because of the success of biological control, replanting leucaena growing areas with alternative legume tree species is not as much of a priority as it once may have been. In fact, leucaena is being planted widely; in southern Sumatra, for example, about 3,000 ha have been recently planted to leucaena for fuelwood.

11.2 Leucaena Psyllid Population

Prior to 1986 no economically significant pests attacked leucaena. In March 1986 H. cubana arrived and was responsible for defoliating and killing leucaena trees around Bogor, Java (it probably arrived from the Philippines). By August, the pest had spread throughout the entire Indonesian archipelago due to the favorable climate and absence of effective indigenous natural enemies. By the end of August 1986, about 50% of the 4,300 km^2 planted with leucaena was damaged by H. cubana, and by the end of 1987, 343,329 of 1,215,000 ha of leucaena were infested. During 1986 economic losses were estimated at Rp 536 billion ($310 million, Table 2). In Siluwok Sawangan and Assinan/Banaran, the reduction of coffee production in 1987 and 1988 was 50% and 35%, respectively. If no control action was taken, the losses to estate crops, animal production, and forestry during 5 years would have been an estimated Rp 1.4 trillion, Rp 11.2 trillion, and Rp 42 billion, respectively (Rp 2.64 trillion total; $1 = Rp 1,700). Heteropsylla cubana was declared a national disaster and a Ministerial Decree in 1986 established the National Task Force for Control of the Psyllid (section 12.6.1). Psyllid damage to leucaena reduced farmer income by reducing carrying capacity of farms for livestock, hindering the land rehabilitation and conservation program, and reducing farmer confidence in leucaena. In addition, the destruction of leucaena on estate plantations threatened the sustainability of the taungya system in Java.

Livestock carrying capacity on each small farm is estimated to have been reduced by 75%, which represents an annual cash loss of Rp 500,000 or about 50% of total income. The Amarasi area supported 18,800 cattle in 1985; this declined to 15,900 by 1987 which is a 16% reduced. In NTT, about 50% of the 4,300 km^2 of leucaena was injured by the psyllid and losses each year may include Rp 7,500 million in livestock exports, and Rp 1,430 million in coffee, cocoa, and vanilla exports.

In East Java the defoliation of leucaena trees by the psyllid in 1986 stimulated the vegetative growth of cocoa which resulted in weakening of the crop, predisposing it to attack by the fungus Colletotrichum gloeosporiodes. By 1987, cocoa production fell by 40%. The effect of leucaena shade defoliation in coffee plantations was to stimulate large areas of coffee to flower prematurely. As a result, young trees (< 3 years old) flowered and died from overbearing. Older coffee plants survived but berries were scorched and consequently quality was downgraded. The death of young coffee trees due to overbearing resulted in the need to replant. The area of immature coffee planted by smallholders and estates in 1987 was about 195,000 ha. On the assumption that 30% of the area was occupied by leucaena shade trees, the total area of young trees lost is estimated to have been about 59,000 ha. The estimated cost of establishing one ha of coffee over the first three years amounts to $2,000; therefore, the cost of reinstating the area lost would be about $118 million. Also, leucaena serves as an important source of

fuel for coffee drying. State owned and private coffee estates in East and Central Java alone produce an average of 20,000 tons of dry coffee beans per year; each ton requires four cubic meters of fuelwood for drying the beans which is obtained from pruned leucaena trees. This results in a savings of Rp 50,000 per ton.

A population dynamics study on H. cubana was initiated in May 1986 and psyllid population fluctuations were noted during 1986 and 1987. Nymph populations changed over time, apparently in response to physical and biotic factors. Populations were found to be highest during the dry season. It is speculated that population increases during the dry season are due to higher wind velocities which encourage the spread of the psyllid. Leucaena is still infested by H. cubana, especially in the dry areas of eastern Indonesia. In East Java and the Sunda Islands, leucaena trees which are heavily infested with H. cubana during the short rainy season may be defoliated or killed. During the subsequent long dry spell, the surviving trees are unable to produce a new flush of foliage and the psyllid population almost disappears.

With the exception of East Java and the Sunda Islands, the proliferation of C. coerulus appears to have reduced H. cubana levels such that no other control measures seem to be required. Observations by Dr. Showler in Bogor attest to this: leucaena psyllid numbers were quite low on both L. leucocephala and the giant leucaena; C. coerulus was prevalent and H. cubana nymphs and adults parasitized by the more recently introduced P. yaseeni were common.

11.3 Past and Present Biological Control Efforts

The first use of IPM with a biological control component in Indonesia was instituted by the Dutch in the late 1920s whereby an indigenous parasitoid wasp was employed in combination with pesticide applications against Artona catoxantha (Lepidoptera: Pyralidae), a pest of coconuts. Other examples of biological control being used in Indonesia include the importation of Diadegma cerophaga (Hymenoptera: Ichneumonidae) from New Zealand in the mid 1950s to control the diamondback moth, Plutella xylostella (Lepidoptera: Plutellidae); this parasitoid permitted the reduction of pesticide applications on cabbage by 50%. Lysiphlebus rotundiformis (Hymenoptera: Braconidae) was imported from the U.S. for control of aphids on soybeans and mung beans, and a granulosis virus was successfully used against a beetle that attacked coconuts.

In addition, because of the rampant use of pesticides prior to 1980 and their detrimental effects, the government of Indonesia officially adopted a policy of using IPM in 1979. Presidential Decree No. 6 was issued in November 1986 to reduce pesticide use against the brown planthopper, Nilaparvata lugens (Homoptera: Delphacidae), that emphasizes IPM principles (Appendix H). The decree banned the use of 57 registered brands of broad-spectrum insecticides used in rice; only a few selective pesticides are now permitted. In addition, pesticide subsidies

Table 2. Damaged leucaena plantations in the forest areas of Central Java in 1986.

Forest District	ha damaged	Financial loss (million Rp)
Balapulang	1,241	21.1
Blora	505	8.8
West Banyumas	3,528	60.0
East Banyumas	1,103	18.8
Cepu	1,942	46.5
Gundih	1,035	17.6
Kebonharjo	745	12.7
South Kedu	1,987	33.8
Kendal	1,414	24.0
Magelang	10	0.2
Mantingan	1,186	20.2
Pati	2,186	37.2
West Pekalongan	2,716	46.2
East Pekalongan	896	15.2
Pemalang	619	10.5
Purwodadi	2,137	36.3
Randublatung	1,504	25.6
Semarang	2,517	42.8
Surakarta	1,655	33.1
Telawa	1,350	25.4
Total	30,287	535.8 ($310.6 million)

Source: State Forest Corporation Perhutani, Central Java, 1988.

were reduced from 70 - 75% in 1986 to about 40 - 45% in 1987. In January 1989, pesticide subsidies were completely eliminated.

In terms of implementing IPM and biological control, Indonesia has demonstrated a great resolve and probably is one of the most progressive Asian countries in this regard. This atmosphere has undoubtedly been very instrumental in the adoption and success of biological control methods used against H. cubana.

In August 1986, 8,300 living specimens of C. coerulus were shipped by air and hand-carried from Hawaii into Indonesia. The predator's biology, behavior and rearing methods were studied and results were made available to about 150 extension agents from Indonesia's provinces in a 1 - 2 week training program. Each of the extension agents was given 50 - 150 C. coerulus to be reared by simple methods in their respective provinces. These extension agents trained local extension agents and farmer leaders to rear the predator; the program accelerated the propagation and dissemination of C. coerulus throughout Indonesia. By December 1986, about 10,000 C. coerulus had been released.

The first official release of C. coerulus occurred in November 1986 in the Tea Experimental Garden, West Java; soon thereafter releases were made in 50 other locations. Predator releases and evaluations of predator performance were conducted periodically.

There are several illustrative examples in Indonesia on the use of C. coerulus for control of H. cubana. In coffee plantations that use leucaena for shade (about 133,000 ha), 18 months after the release of C. coerulus in 39,000 ha of coffee, the canopy of leucaena shade trees flushed out. About 40 C. coerulus per tree are required for effective control of H. cubana. The National Team of Leucaena Psyllid Control recommended the release of 50 C. coerulus per leucaena plant. Curinus coerulus populations were monitored mainly at the coffee estates in Central Java during the dry season of 1988 (after releases in 1986). Damage to leucaena decreased at the Jollong Coffee Estate to the extent that insecticide applications were terminated, and by 1987 the mass rearing program was stopped because the predator was well-established in the field. Growth of the C. coerulus population fluctuated at the Jollong Coffee Estate during the dry season (Table 3). The lowest growth increment was 4.4% in May 1988 when leucaena leaves were pruned to increase light intensity to the coffee. The level of damage to sprouting leucaena foliage was 43% on average, but this was low enough to maintain adequate shade for the coffee. Overall, on estate plantations in Central Java, the cost of controlling the leucaena psyllid with C. coerulus was considerably less than the cost of using chemical methods (Table 4). As a side benefit, C. coerulus was shown, in laboratory studies, to feed on mealybugs and, in the field, on the green scale, Coccus viridis (Homoptera: Coccidae), both of which attack coffee; further investigation regarding the potential for this incidental control should be encouraged.

As of 1991, C. coerulus appears to have controlled H. cubana in Indonesia, except in areas with long dry spells, such as the Sunda Islands and parts of East Java. Dr. Showler observed large populations of C. coerulus on leucaena in Bogor, and H. cubana populations were correspondingly low. Curinus coerulus has not only been effective at controlling H. cubana, it has also been successful at preying upon mealybugs on coffee where leucaena is used as a shade tree. According to Dr. Ida N. Oka, the biological control specialist at the Bogor Research Institute for Food Crops, the control of mealybugs on coffee is not in any way disruptive of ongoing pest management programs in contrast to concerns raised in Papua New Guinea.

Because the Sunda Islands and parts of East Java have long dry spells (7 - 8 months) during which leucaena trees are dormant (do not produce new shoots), H. cubana populations are too low at that time to support sufficient quantities of C. coerulus for adequate control during the wet season. For this reason, P. yaseeni was imported from Thailand in November 1990 as larvae in mummified psyllids. Entomologists in Indonesia have been successful in rearing P. yaseeni in large enough numbers to disseminate in the field by a simple method (Appendix G; P. yaseeni can even be raised in large numbers outside of greenhouse conditions). Dr. Showler observed large numbers of parasitized H. cubana in Bogor, which, in combination with large C. coerulus populations, has resulted in healthy and vigorous stands of leucaena trees. Psyllaephaeus yaseeni was sent to the Sunda Islands in August 1991 in the hope that it will be adapted to the climatic variation which has been unfavorable to the survival of C. coerulus. However, it is still too early to assess its effect on H. cubana populations there.

So far, no indigenous pathogens or hyperparasites of P. yaseeni have been discovered in Indonesia; therefore, this parasitoid may be able to proliferate unhindered by natural enemies.

Searches for potential indigenous biological control agents of H. cubana have yielded a number of organisms, the utility of which have yet to be determined. Studies on the predatory capacity of Coccinella arcuata and Coccinella repanda (Coleoptera: Coccinellidae) showed that their ability to consume psyllids is low. The two coccinellids preyed upon nymphs and adults, but not eggs, and aphids are the preferred dietary item which may explain why they are not particularly promising solutions for biological control of the leucaena psyllid. Other coccinellids studied with similar results are Coelophora inaequalis, Chilocorus politus, Cryptogenus orbiculus, Menochilus sexmaculatus, and Heteroneda reticulata. In general, these indigenous coccinellids were observed to consume 8 - 26 psyllids (nymphs and/or adults) per day.

Table 3. *Curinus coerulus* population growth on leucaena and coffee in the Jollong Coffee Estate during the dry season of 1988.

Month	Average size of *C. coerulus* pop. (individuals/plant)		Estimated pop. of *C. coerulus* (millions) in the whole estate			Estimated population growth (%)
	Leucaena	Coffee	Leucaena	Coffee	Total	
Feb.	20.5	1.2	4.5	0.8	5.3	-
Mar.	22.9	2.0	5.1	1.2	6.3	15.2
Apr.	40.6	3.8	7.3	1.6	8.9	30.3
May	35.9	2.9	7.7	1.7	9.4	4.4
Jun.	47.3	4.0	9.8	2.4	12.2	23.0
Jul.	49.7	4.7	10.3	2.9	13.2	8.0
Aug.	65.6	8.0	13.5	4.8	18.3	38.4
Mean	40.3	3.8	8.3	2.2	10.5	19.9

Table 4. Costs of using chemical and biological control (*C. coerulus*) against leucaena psyllid in estate crops in Central Java.

Location	Year	Methods: Biological	Methods: Chemical
		(Rp million)	(Rp million)
Assinina/Banaran	1986	-	13.9
	1987	2.4	20.3
	1988	2.1	13.8
subtotal		4.5	48.0
Jollong	1986	-	12.9
	1987	10.3	4.4
	1988	-	-
subtotal		10.3	17.3
Tlogo	1986	-	2.4
	1987	0.1	0.8
	1988	0.4	0.3
subtotal		0.5	3.5
Total		15.3	68.9

Dragonflies (Odonata: Aeshnidae) were more effective indigenous predators which could capture about 105 psyllids per day. Dragonflies feed on flying organisms only and are therefore only effective against adult psyllids. However, mass rearing and release of dragonflies has never been successful in Indonesia or elsewhere.

A red ant, Oecophylla smaragdina (Hymenoptera: Formicidae), was found to prey upon psyllids. One ant colony could capture an average of 1,200 psyllids per day.

The predatory capacity of a Chrysopa sp. (Neuroptera: Chrysopidae) on psyllids is very low.

A web spinning spider was found to be the poorest of the potential indigenous predators (can consume only 9 psyllids per day) and the spider populations appear to fluctuate greatly.

No indigenous parasitoid wasps that attack H. cubana were found, and even if they were, most native parasitoids are heavily hyperparasitized - a condition would likely limit their utility.

An unidentified fungus was observed near Yogyakarta and the Timor Islands that killed from 60 - 80% of the leucaena psyllids during the rainy season. The fungus, however, has been observed to be an effective pathogen in some years, but not in others. In addition, a Fusarium sp. was noted as being one of the dominant fungus pathogens of H. cubana. Systematic studies on entomopathogens of H. cubana have not been performed, but such endeavors should be encouraged. Indonesia is currently without specialists in insect pathology, and the country could benefit from such expertise particularly in light of its policy supporting IPM.

The potential for use of indigenous natural enemies of H. cubana in Indonesia exists, but has not been adequately researched especially in the context of IPM strategies in which use of indigenous predator complexes can be optimized or augmented. Although research on indigenous natural enemies in Indonesia has been more thorough than in many Asian countries afflicted with the leucaena psyllid, further research on improving their potential should be encouraged. However, given the recent success of exotic natural enemies of H. cubana in Indonesia, there may not be a pressing need for use of indigenous natural enemies.

11.4 Regulations on and Quarantine of Biological Control Agents

Indonesia has quarantine facilities and regulations for both plants and introduced insects. Shipments of insects that arrive in Indonesia are held in quarantine facilities, which are under controlled conditions in Bogor, Sumatra, and East Java. Regulations stipulate that shipments must be accompanied by complete documentation on the insect's biology, behavior, and ecology (including host range), and the regulations have provisions regarding the stringency of quarantine procedures and the condition of quarantine facilities. Exotic insects are held

for at least one generation to screen against hyperparasites, entomopathogens, and effects on economically important crops. More often than not, insects are held in quarantine for months to obtain a certificate for release that is issued by the National Committee for Importing Biocontrol Agents (the committee is chaired by Dr. I. N. Oka, biological control specialist at the Bogor Research Institute for Food Crops) and a decision by the Ministry of Agriculture. Periodic post-release assessments are required by the Ministry of Agriculture.

Quarantine procedures do not include tests for possible interactions of exotic biological control agents with nontarget fauna and studies on the potential impacts of pesticides used in crops where the biological control agent will be used. It is suggested that procedures be introduced to quarantine institutions that include those recommended for Malaysia (section 13.4).

11.5 Leucaena Psyllid Control Options

11.5.1 Pesticides

In response to the psyllid infestation, the government of NTT initiated a program (Operosi Flobamora II; Operosi Flobamora I was a 1984 program in NTT to encourage widespread planting of leucaena) in late June 1986 to cut and burn all leucaena trees and to impose chemical control using diazinon and azodrin injections. The large areas of leucaena were, however, impossible to spray regularly due to logistical and financial constraints (the same was true for cutting and burning). Overall, 14 systemic pesticides were found to be effective, albeit expensive, for psyllid control, and residues (if applications were timed appropriately) were found to be safe on leucaena leaves used for cattle feed. The most effective method of application was to treat superficial leucaena tree wounds with the pesticides by brush or pipette. Monthly spraying with azodrin or diazinon was not effective; this practice reduced leucaena psyllid infestations by only 10% and could not be recommended to control such a mobile pest.

The importance of psyllid damage to the forestry sector, especially teak in the taungya silvicultural system, was estimated to be valued at Rp 63 million in 1988, mainly due to the failure of leucaena seed production. In the absence of detailed economic analyses for the forestry sector, chemical control was implemented by notching leucaena stems in teak stands under the taungya system using a machete and brushing the wound with a systemic insecticide such as monocrotophos, azodrin, and diazinon, or by spraying. The cost of using chemical control compared to that of biological control using C. coerulus in plantation systems in Central Java is shown in Table 4. The cost of chemical control was considered to be prohibitive.

The coffee plantation industry in East and Central Java employed chemicals as the main psyllid control method. This

mostly involved applying 5 ml of systemic insecticide per tree at three-week intervals. The cost of this operation was estimated to be about Rp 340,000 per ha each year which means it cost Rp 8.5 billion for the 25,000 ha of plantations owned by the state and private enterprises.

Because of the comparative economic advantage of biological control (using C. cubana and P. yaseeni) over chemical treatment for control of H. cubana, the possibility of residues on leafmeal for cattle, the need to treat each leucaena tree repetitively, potential nontarget effects of pesticides, and storage, handling and application logistics and hazards, pesticide use against the psyllid is undesirable. The positive results of using biological control and the possibility of developing psyllid resistant leucaena varieties, or the replacement of leucaena with other plant species where necessary, should be pursued in lieu of developing chemical control methods.

11.5.2 Resistant Varieties of Leucaena

The genetic base of the leucaena used in Indonesia is narrow and all local varieties were initially devastated by H. cubana. Research on psyllid resistant leucaena varieties in Indonesia includes the following programs:

1. The establishment of a 100 ha leucaena plot to serve as a collection of species and cultivars, and experimentation located at Pondok Gedeh, near Bogor (studies conducted in collaboration with the University of Hawaii).
2. Periodic collection of domestic and exotic genetic stocks.
3. Active participation in Nitrogen Fixing Tree Association (NFTA) trials to accelerate Indonesia's resistance program.

Three trials for leucaena resistance were conducted in West Timor to measure the adaptation and resistance of L. leucocephala, other leucaena species, and other tree legumes. All varieties of L. leucocephala were severely damaged, while L. pallida K376 and L. diversifolia K784 were well-adapted and psyllid resistant; also, other selections of L. pallida, L. diversifolia, and L. collinsii show promise (Table 5).

Results of research on psyllid resistant leucaena varieties in Pondok Gedeh are encouraging. The Bogor Research Institute of Forestry and the Institute for Animal Production collected about 300 accessions of both foreign (mostly Australia and Hawaii) and domestic origin. Several domestic accessions show resistance to H. cubana, but seed production trials are still underway. The plan is to distribute seeds of resistant varieties (if they become available and are considered viable) to the provinces of Indonesia and in particular to areas where biological control is weak. Nevertheless, it is still too early to declare that resistant varieties of L. leucocephala, even in Pondok Gedeh, represent a panacea to the psyllid problem. At best, currently available results from resistance trials suggest that candidate

cultivars will be useful on a limited scale only where they are best adapted and retain resistant properties. Testing to assess the usefulness of resistant varieties (e.g., productivity, palatability, nutritive value, nitrogen fixing capacity, etc.) and developing seed stock will be necessary for promising cultivars before they are used in large scale programs. However, where leucaena is used as a shade tree in estate crops, seedless varieties are considered most desirable because seed-bearing trees have the potential to become weeds in such situations. As in other countries where L. leucocephala resistance trials are being conducted, the mechanism of resistance should be identified, and its interaction with environmental conditions (e.g., soil type and climate), to facilitate more well directed efforts at breeding for resistance. Some preliminary studies on this topic in NTT have suggested that plant secondary metabolites known as saponins may distinguish resistant and nonresistant leucaenas (Appendix I).

At the present time, C. coerulus has been providing effective control of the leucaena psyllid in most of Indonesia, and P. yaseeni may provide control in the dryer regions that are unfavorable to the survival of C. coerulus (e.g., the Sunda Islands and parts of East Java). Nevertheless, research on resistance should continue mainly because leucaena remains a viable crop in Indonesia, unlike in many other Asian countries.

11.5.3 Grazing and Pruning

Operasi Flobamara II (section 11.5.1) included cutting and burning leucaena trees in NTT with chemical applications. It was not possible to completely eradicate leucaena due to logistical limitations, and the tree regrowth provided abundant new shoot growth for psyllid populations particularly where trees were cut. In fact, it was noted that vegetative plants were attacked more heavily than reproductive plants. These findings are quite different from those in Malaysia (section 13.5.3) which suggest that grazing and pruning may be an effective method of psyllid control.

Leucaena is a particularly good tree for shade in estate crops because it can withstand heavy defoliation regimes to alter the light reaching the crop at critical times. Therefore, in Indonesia it is likely that pruning of leucaena will not be employed as a control technique and will be conducted only when pruning is a required element of a farm management scheme.

11.5.4 Alternative Crops

Replacement of L. leucocephala with other species of legume trees may be a promising method of avoiding the impact of H. cubana in Asia. However, given the efficacy of biological control efforts in Indonesia, the replacement of L. leucocephala with alternative tree legume species is unlikely and unnecessary.

Table 5. Index scores of psyllid damage and adult populations on *Leucaena leucocephala*, other leucaena species, and other tree legumes in West Timor, 1988.

Tree species and variety	Damage*	Adults*
L. leucocephala 85176	8.0	5.0
L. leucocephala 85929	8.0	5.0
L. leucocephala local	8.0	5.0
L. leucocephala K28	7.0	5.0
L. leucocephala 90814	7.5	5.0
L. leucocephala cv. Cunningham	8.0	5.0
L. diversifolia 33820	1.5	5.0
L. diversifolia 46586	1.0	5.0
L. collinsii 46570	3.5	5.0
L. pallida 84581	1.0	5.0
L. pallida 85891	1.5	5.0
Acacia augustissima 40175	1.0	1.0
A. villosa local	1.0	1.0
A. sp. 84998	1.0	1.0
Sesbania grandiflora local	1.0	1.0
S. grandiflora 96461	1.0	1.0
Gliricidia sepium 60796	1.0	1.0
Gliricidia sp. local	1.0	1.0
Calliandra calothrysus local	1.0	1.0

*Higher index numbers represent greater damage and higher *H. cubana* adult populations.

Nevertheless, alternative species are being explored, and some of the results are reported here.

Studies in Timor and Java have addressed the relative susceptibility of tree legumes that might be used as alternatives to L. leucocephala. It has been shown that Acacia augustissima, A. villosa, Sesbania grandiflora, S. sesban, Gliricidia sepium, Calliandra callothrysus, Leucocephala pallida K376, L. collinsii, and L. diversifolia K784 are resistant to attack by H. cubana. Acacia villosa, C. grandiflora, G. sepium, and C. callothrysus are, in fact, already in common use and seed is available so it is possible that planting of these species could be expanded immediately. Despite the use of these species in livestock and crop production systems, there has been no data collected since the 1930s on their comparative productivity. In addition, the low wood density of Sesbania spp. is not conducive for use as fuelwood or building material, and S. grandiflora cannot withstand constant cutting and is therefore not suited to alley cropping systems with heavy defoliation regimes.

In Java, A. villosa, Gliricidia sepium, Tephorosia sp., and Cassia siamea have been found to be resistant to H. cubana, but no data has been collected on their comparative biomass production. Leucaena pulverulenta was shown to be tolerant of high H. cubana infestations and could be used in East Java as a substitute for L. leucocephala in the taungya systems.

It is important to note that more work is needed on the productivity, seed production, palatability, effect on animal production, and use for shade of alternative tree legume species. Research on the potential for these species to be used in Indonesia as substitutes for L. leucocephala, particularly if adapted and resistant L. leucocephala varieties are not developed and in areas where biological control agents are not viable. There is a need to develop more diversified feed regimes for tethered cattle which depend heavily upon L. leucocephala fodder.

Tree legumes which have shown poor adaptability for establishment in Indonesia include Desmodium rensonii, D. discolor, and Codariocalyx gyroides.

11.5.5 **Biological Control**

At present, only C. coerulus appears to be effective against H. cubana in Indonesia. Prolific rearing systems have been devised for laboratory conditions and for farmers (Appendix J and K); at least 150 technicians have been trained in the rearing and release procedures for C. coerulus and 25 rearing facilities have been established in the country. Although C. coerulus is a generalist predator with relatively low mobility, the mass releases of this insect in many parts of Indonesia resulted in measurable control and economic benefits to estate and small farmers who use leucaena for feed and/or shade. Nevertheless, C. coerulus is not particularly effective in areas with dry spells (e.g., the Sunda Islands and parts of East Java). Therefore, P. yaseeni was imported to Indonesia in November 1990, and this

parasitoid was released in the Sunda Islands in August 1991. Assessments on the effects of P. yaseeni on the leucaena psyllid have not yet been conducted, but preliminary observations, at least in the Bogor area, suggest that it is highly efficient. Simple rearing methods for P. yaseeni have been developed in Indonesia and this will greatly influence its dissemination throughout the country.

CAB International has offered T. leucaenae to Indonesia, but the government of Indonesia prefers to wait until more complete assessments on the efficacy of C. coerulus and P. yaseeni are made. Should C. coerulus and P. yaseeni prove to be sufficient, there would be no need to introduce additional exotic insects.

Surveys for indigenous biological control agents have not yielded organisms that offer sufficient advantage to warrant their mass production and release with the possible exception of the unidentified fungus that killed 60 - 80% of leucaena psyllid populations near Yogyakarta. Further studies on this fungus should be encouraged. Indonesia does not possess expertise on insect pathology, and training of personnel in this field should be encouraged to both facilitate the development of microbial agents for use against H. cubana and to study possible pathogens of useful arthropods being employed as biological control agents.

11.6 Country Capacity

11.6.1 Institutional Responsibilities and Coordination

The government of Indonesia set up a National and Regional Committee for Psyllid Control in 1986 by ministerial decree when H. cubana was declared to be a national disaster. The Committee consists of policy makers from the Ministries of Agriculture, Forestry, and Domestic Affairs, and senior researchers from research institutions that include the Bogor Research Institute for Food Crops, Estate Crops, Animal Husbandry, and Spice Crops; the Bogor Agricultural University; and the University of Gadja Mada. Operational functions fall under the purview of personnel from the central governments and extension. The terms of reference of the National Task Force (Committee) are:

- to gather any available information on the psyllid and its control,
- to outline broad policies on psyllid control and to determine priorities for actions,
- to seek financial support,
- to give direction for the nationwide psyllid control program,
- to monitor progress, and
- to prepare monthly reports for submission to the Minister of Agriculture.

The Regional Task Force has been assigned responsibility for:

- o implementing the control measures outlined by the National Task Force,
- o disseminating information to farmers and presenting demonstrations, and
- o evaluating and regularly reporting on progress to the National Task Force.

The research programs priorities are:

a) Pesticides
- o screening of effective pesticides and determining methods for their safe and economic application
- o conducting residue research on treated trees

b) Biological Control
- o searching for indigenous biological control agents
- o searching for exotic biological control agents and exploring possibilities for their importation

c) Plant Resistance
- o collecting domestic leucaena germ plasm
- o importing leucaena germ plasm from abroad
- o developing methods for measuring leucaena resistance to the psyllid

d) Long Term Economic and Social Impacts of Psyllid Damage

Results of studies conducted so far are described in sections 11.5.1, 11.5.2, and 11.5.5.

Many of Indonesia's research efforts, especially those designed to study leucaena resistance, are conducted in collaboration with NFTA's Leucaena Psyllid Trials. Other resistance studies (including studies on possible alternative plant species) are conducted as part of the Shrub Legume Adaptability Trial in conjunction with the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Australian Center for International Agricultural Research (ACIAR).

NTTIADP is targeted to benefit small farmers in NTT, particularly by reducing land degradation, and was responsible for arresting the land degradation in the Amarasi area of West Timor using leucaena. In response to the invasion of H. cubana, NTTIADP attempted to develop the azodrin/diazinon spray regime (section 11.5.1) and conducted research on other tree legumes to use as possible substitutes for L. leucocephala (section 11.5.4).

IRDC support for research on and rearing of biological control agents for H. cubana conducted at the Bogor Research Institute for Food Crops, which is the principle institute for this work, will terminate in December 1991. After December most

research will be conducted by universities, but specific plans for this have not been developed.

11.6.2 Equipment and Facilities

For mass rearing of C. coerulus, techniques have been devised and demonstrated as being effective in Indonesia. A mass rearing program began in 1986 with 196 C. coerulus adults at the Laboratory for Biological Control at Gadjah Mada University (UGM) in Yogyakarta. Some progeny from UGM were sent to the Laboratory of Estate Crops Extension Service in Yogyakarta and the Jollong Coffee Estate for mass rearing under the supervision of UGM entomologists. It is significant to note that mass rearing methods were developed for both the laboratory situation and for farmers. About 25 mass rearing substations were established throughout the country. In Indonesia, rearing and release facilities for C. coerulus appear to be quite adequate, but in the event that parasitoid wasps will be imported, techniques may need to be developed accompanied by the establishment of appropriate facilities.

Research and rearing facilities for biological control agents are good but space is limited. Now the rearing facilities can only handle mass production of one biological control agent at a time. In addition, certain equipment is lacking, such as microscopes (the Bogor Research Institute for Food Crops' biological control labs have only one microscope, and there is also a need for taxonomic keys, particularly for microhymenoptera.

11.6.3 Data and Information Management

Although there are numerous institutions in Indonesia that conduct research and implementation of biological control (e.g., research institutes for estate crops, cotton, and food crops; various universities; and Biotrop) there is a need for more systematic data management and information dissemination. There is a strong connection between research and extension at the national level, but information networking at the international level requires improvement, as is the case for most Asian countries.

11.6.4 Environmental and Economic Assessment

Economic assessments regarding the damage inflicted by H. cubana on leucaena, and effects on other crops, have been conducted to a satisfactory degree with the exception of the forestry sector. Environmental impacts of the insecticide campaign against H. cubana and the incidental effects of C. coerulus on nontarget organisms and IPM strategies in other crops have not been determined. Many economic assessments on the use of leucaena and the impact of H. cubana and control efforts have

been provided by individual estate plantations and estate crop associations.

11.6.5 Training Needs

For rearing and release of C. coerulus, training has already been initiated. About 150 technicians have been trained in rearing and release methods, and a "rough" method for rearing C. coerulus has been developed for use by farmers (Appendix J and K). Each extension agent that received training was sent back to his/her base in Indonesia with 100 - 150 adult C. coerulus for propagation and release. Due to this effective and thorough extension effort, C. coerulus has become well established throughout most of Indonesia. In general, extension services in Indonesia appear to be quite adequate, especially for implementation biological control programs.

With the recent introduction of P. yaseeni, training is needed in the handling of microhymenoptera and their taxonomy. There is also a need to develop techniques for assessing the impact of parasitoid wasps on H. cubana populations in a systematic and reliable fashion. In addition, Indonesia lacks expertise in insect pathology for the possible development of entomopathogens of H. cubana (and other pests) and to survey for pathogens of biological control agents.

With regard to the biological control of H. cubana, Indonesia's method of disseminating information, development of rearing and release techniques, successful results, and favorable policies for IPM can serve to some extent as a model to the rest of Asia. The Indonesian system for controlling H. cubana with biological control agents should be exported to other countries that have thus far been unsuccessful in their attempts. The support of such an international program, using Indonesian expertise, should be considered by donor and international development agencies.

12.0 LAOS

Prefatory Note: The following section on Laos was written based upon information gathered from government agricultural officials and rural farmers. This part of this EA was conducted incidentally while Dr. Showler was participating on an Office of Foreign Disaster Assistance team whose mission was to assess flood and pest related damage to rice production in Laos. Also, although Laos has not received assistance from A.I.D. since 1975, the recent collapse of communist rule may one day permit the realization of democratic government and a free market system. This section on Laos is written on the understanding that A.I.D., including OFDA, may not be able to render assistance in Laos within the realm of pest management until such time as U.S. policy explicitly sanctions A.I.D. assistance to Laos.

12.1 Importance of Leucaena

Unlike the other countries represented in this EA, Laos does not appear to have placed much, if any, importance on the leucaena tree for any of its multiple purposes. Although Dr. Showler was able to interview government agricultural officials in Vientiane, Khamouane, Pakse, Savannakhet, and Champassak, and leucaena is well known throughout most of Asia, the distribution and use of leucaena in Laos remains unclear. It would, however, seem illogical that L. leucocephala would occur in Thailand, China, and Vietnam (three of the countries that border Laos), but not in Laos. Given the increasing deforestation in Laos by the government, newly emerging private industries, and slash and burn highland farmers (even though there is a logging ban in effect), erosion, flooding, and the depletion of biological diversity are occurring at apparently greater and greater rates and levels of intensity. The leucaena tree, and preferably indigenous alternative tree species, will at some point receive attention in an agricultural context as efforts are made to reduce erosion and to reforest land. Also, livestock fodder, especially for cattle and water buffalo, is primarily composed of rice straw; the quality of livestock could be improved and the quantity increased under better management systems that would involve more dietary protein. Cut and carry fodder would permit tethered livestock systems while opening more land to cultivation.

12.2 Leucaena Psyllid Population

Virtually nothing is known with respect to H. cubana, the extent of the infestation, and its effect on leucaena trees in Laos, although infestations are regarded as being serious in Thailand, Vietnam, and China. The lack of information on H. cubana in Laos is not surprising because there are no entomologists in the entire country. Little data exist on other pests in Laos as well.

12.3 Past and Present Biological Control Efforts

The main pest control tactics being used in Laos are limited to insecticide application (without the use of economic threshold levels - instead, insecticides are too expensive to apply on a calendar basis which acts as the limiting factor), resistant varieties of rice (mostly traditional varieties), and mechanical trapping of rodent pests. Biological control and IPM are very new concepts in Laos; most agricultural officials do not understand the meaning of the two terms, and most farmers do not know the difference between beneficial and detrimental insects. In fact, it is doubtful that most farmers are even aware of the range of pests that attack their crops; they concentrate only upon those that are easily observed (e.g., stem borers, armyworms, leafhoppers, and gall midge) and it is doubtful that crop losses incurred by "unseen" pests (e.g., viruses, soil borne pests) are even recognized. This would explain the very low estimates (0 - 10%) of crop losses due to pests in contrast to a much higher global average (35% preharvest).

However, the government of Laos, in conjunction with UNDP and FAO have begun planning for an IPM program in cotton. Biological control of cotton pests has not yet been studied.

Because both the importance of L. leucocephala and H. cubana have not been evaluated in Laos, and because the concept of biological control is relatively unknown there, there has been no attempt to study or utilize indigenous or exotic biological control agents to reduce H. cubana populations.

12.4 Regulations on and Quarantine of Biological Control Agents

Regulations on and quarantine of plants and animals, including biological control agents, do not exist in Laos. Quarantine facilities, trained personnel in pest identification, and affiliation with regional associations that include quarantine activities, such as ASEAN, are also lacking.

12.5 Leucaena Psyllid Control Options

Because there is no data on L. leucocephala and H. cubana in Laos, control options for H. cubana are not discussed herein.

12.6 Country Capacity

12.6.1 Institutional Responsibilities and Coordination

Agricultural institutions in Laos are few. The Ministry of Agriculture and Forestry has departments of Agriculture and Forestry, and there is a Ministry of Livestock, all of which would have an interest in multipurpose legume tree production. However, none of these governmental institutions seem to be working at development of legume trees or on control of their

pests. The National Agricultural Research Center is, in affiliation with the Department of Agriculture, UNDP, and FAO, starting an IPM program for cotton but it is uncertain as to whether or not biological control will have a significant role in the program. There is not institution or agency in Laos that has been designated with a specific responsibility for biological control, nor does an agricultural college or university exist such that academic research on biological control can be initiated.

The agricultural extension service in Laos is understaffed, underfunded, and lacks adequate transportation to be truly effective. Interviews with farmer groups gathered in villages, however, suggested that extension personnel have visited villages and trained one farmer per village in backpack sprayer use and pesticide application. It is doubtful that such training involved pesticide safety; most farmers interviewed were not familiar with safety precautions. Due to the lack of ongoing government sponsored agricultural research in Laos, it appears that extension services are limited to the most basic aspects of crop production and pest control, and do not include advice on farm management, IPM, biological control, livestock nutrition, crop diversification techniques, etc.

Although there are some bilateral donor projects in Laos (e.g., the French are doing varietal studies on coffee in the Boulevans, southern Laos), information generated is both limited and not linked to agricultural extension. Most of this research, in addition, seems to be plantation-oriented and not designed for the benefit of the small farmer.

12.6.2 Equipment and Facilities

Equipment and facilities for quarantine, mass production, release, and research on biological control agents in Laos do not exist. It is likely that laboratory facilities are rudimentary at best, and are the least sophisticated of all the countries described in this EA.

As is the case for Nepal, one of the chief limiting factors for conducting agricultural research and extension in Laos is infrastructure, especially roads. Paved roads in Laos are few and in poor repair. Most roads are unpaved and require the use of heavy-duty 4X4 vehicles to negotiate them. To travel about 100 miles in the dry season can often take as long as 10 hours.

12.6.3 Data and Information Management

Prior to 1975 (before the communist regime), it was reported that at least some agricultural information was on record in Laos. However, this information, having been generated by noncommunist donor entities and by Lao personnel who were either placed in re-education camps or fled the country, was not available at the time of this assessment. Because there is no ongoing research on biological control and there is no access to

research results (e.g., through journals or technical assistance), the need for data and information management is clear, but must be conceived from a "ground zero" level.

12.6.4 Environmental and Economic Assessment

Environmental assessments are not performed in Laos. The Lao government has total authority over any projects that occur, and there is no environmental constituency in the country.

Economic assessments have been conducted (but not on leucaena). However, these assessments are of very dubious quality given the incomplete nature and statistically invalid methods of data collection. This was clearly reflected in the economic assessment of pest damage inflicted on rice production in 1991 where losses due to pests in most provinces were recorded as being nil.

Both environmental and economic assessment protocols need to be developed and implemented in Laos not only for legume tree production, but for the entire agricultural sector.

12.6.5 Training Needs

Training needs for agricultural production in Laos are overwhelming, therefore this EA will only deal with those that relate directly to biological control. Because biological control is a very new concept in Laos, and has not even reached most agricultural officers, let alone farmers, training needs are diverse and required at all levels of crop production and pest management. Some needs are listed below.

o Laos does not have any entomologists, plant pathologists, weed scientists, or biological control specialists. Graduate level training in these fields is needed at least in Vientiane to begin work on biological control.

o There should be at least one pest management specialist at the bachelor's degree level of training in each province.

o Training of crop protection personnel is needed for identification and diagnosis of pest problems and this training should cover as many agricultural production systems as possible at this early stage of development.

o As private enterprise grows in Laos, high level government administrators with agricultural responsibilities and concerns should be made aware of the IPM approach such that pesticide use does not become standard operating procedure for pest control as it has in many other countries.

o Extension personnel should be trained in extension methods that can be readily understood and accepted by rural farmers, with an emphasis on nonchemical pest control tactics.

o Extension personnel should be trained in IPM on a continuing basis.

o Researchers in all agricultural disciplines should be trained in statistical procedures and data management and presentation.

o When quarantine regulations and facilities are developed, quarantine officers must be trained in pest identification and proper quarantine procedures.

o Although Laos is not a member of ASEAN, it is suggested that ASEAN PLANTI be requested to provide assistance to the development of quarantine regulations, facilities, procedures, and staff training.

o For the near future, conscious attempts to implement biological control should focus on the use of indigenous biological control agents.

13.0 MALAYSIA

13.1 Importance of Leucaena

Malaysia's National Agricultural Policy identifies development of the livestock industry as an important objective. Increased livestock production is sought to help reduce Malaysia's heavy dependence on food imports and to produce a surplus of mutton, poultry, and pork for export. Production currently is constrained by limited availability of nutritious feed; 80% of the livestock in rural areas are estimated to suffer from malnutrition; mortality rates are as high as 30 - 40% in some areas. Leucaena is recognized as a potentially valuable source of nutritious fodder, and researchers at the Malaysia Agricultural Research and Development Institute (MARDI) have been assessing the performance of different varieties since the first leucaena accessions were received from the Philippines in 1974. Production plans included distributing leucaena seedlings to small landholders (the major food producers in Malaysia) for cut and carry fodder production, and to farmers with larger holdings for planting in 10 ha plots which would be grazed in rotation with other pastures. Leucaena was also slated for use as a source of leafmeal for feed production, again to reduce dependency on imports. The psyllid arrived in Malaysia and caused extensive damage to trees in research plots before large-scale distribution had begun. Distribution was therefore halted while researchers began screening for resistant varieties.

Leucaena in Malaysia could also be useful for fuelwood and as a shade tree for light sensitive crops such as coffee and cocoa. These two functions, however, are not considered to be as important as leucaena's role as a fodder source.

13.2 Leucaena Psyllid Population

The leucaena psyllid was first discovered in Malaysia in 1984. Leucaena psyllid populations in Malaysia decrease during dry periods and increase during the wet periods, although the first heavy attack of the psyllid on leucaena coincided with a dry spell. While leucaena psyllid populations increase with the onset of wet periods, there is generally a lag of several weeks between the beginning of the rains and before the psyllid populations noticeably increase. This may result from a combination of the interval between ovipositioning and egg eclosion and the action of natural enemies, which are ineffective against higher populations of the pest. The exact cause of this time lag, however, is not known. Overall, it is important to note that the leucaena psyllid infestation in Malaysia has been severe enough, despite the recovery of many trees from attack, to cause the GOM to exercise restraint with regard to the promotion of leucaena trees in Malaysia.

Because leucaena had not been widely adopted prior to the arrival of the psyllid, the economic impact of psyllid damage was

quite limited. The main effect has been to halt distribution of leucaena trees to farmers while researchers screen for resistant varieties and investigate other potential control strategies.

13.3 Past and Present Biological Control Efforts

Malaysia has had some experience with classical biological control, mostly for management of aquatic weeds that choke canals and other waterways. One attempt was the relatively unsuccessful introduction of Nicotina bruchei (Coleoptera: Bruchidae) for control of water hyacinth. A more successful effort was made against Salvinia molesta by introducing another bruchid beetle species. A terrestrial weed, the giant sensitive plant, Mimosa pigra, was successfully controlled using yet another exotic bruchid.

The only case in which a biological control agent was introduced against an insect pest was for control of the diamondback moth, Plutella xylostella (Lepidoptera: Plutellidae). Four parasitoids were introduced into Malaysia between 21 October 1975 and 22 January 1978. These parasitoids were Diadegma eucerophaga (Hymenoptera: Ichneumonidae) introduced from New Zealand and Indonesia; Thyraella collaris (Hymenoptera: Ichneumonidae) introduced from India, New Zealand and Australia; and Macromalon orientale (Hymenoptera: Ichneumonidae) and Tetrastichus sokolowskii (Hymenoptera: Eulophidae) introduced from India. The first two parasitoids were established in the Cameron Highlands, the third failed to survive laboratory breeding and was not released, while the eulophid was recovered only for a short period and has not been detected since. Parasitism by the released parasitoids was low and was attributed to excessive use of insecticides on cabbage crops. Since then, another parasitoid (of diamondback moth eggs), Trichogramma sp. (Hymenoptera: Trichogrammidae), was introduced with some success.

In the case of the leucaena psyllid, Malaysia is adopting a cautious approach to biological control. Since 1984, when the psyllid first appeared in Malaysia, the GOM has not been in favor of promoting leucaena cultivation given the prevailing H. cubana infestation. Malaysian scientists prefer to wait until classical biological control can be imposed first, or resistant/tolerant varieties of the leucaena tree are identified. At present, no biological control agents, even the generalist predatory coccinellids C. coerulus and O. abdominalis have been introduced to Malaysia. The GOM prefers not to introduce exotic generalist predators because of the possibility that they will interfere with natural enemy complexes for other pests, best exemplified by concerns raised in Papua New Guinea (section 7.0).

In the probable event that parasitoids are used, T. leucaenae will be the species of choice because the sole effects of T. leucaenae on the leucaena psyllid have never been evaluated (the other natural enemies have been evaluated under such conditions). Therefore, the rationale is primarily academic in nature - the goal being to conduct an experiment on the efficacy

of T. leucaenae without results being confounded by interaction with other exotic predators and parasitoids. The GOM feels that Malaysia can afford to wait until Tamarixia is eventually introduced because the leucaena psyllid populations appear to have reached a point of equilibrium, which is likely a result of the low number and scattered distribution of the leucaena trees and the activity of indigenous predators. Although there are many arthropod species associated with cultivated leucaena in Malaysia (Table 6), there are but only a few that have been shown to prey upon or parasitize H. cubana.

Heteropsylla cubana, being an introduced pest, should prove well suited to classical biological control. However, very little is known about its relationship to local Malaysian fauna, some of which may be predators and parasitoids. Surveys for possible biological control agents of H. cubana have yielded four hymenopterous parasitoids: one trichogrammid, one mymarid, and two scelionids, but these usually attack other homopterous insects. In November 1988, a study was initiated on the MARDI farm to determine whether any parasitoids attack leucaena psyllid eggs, but none were identified. It is recommended that a survey for parasitoids be conducted on a wide scale in Malaysia. A similar survey was carried out for entomopathogens of H. cubana at Malaysia's agricultural university and MARDI in Serdang and Ijok. Diseased psyllids were plated on PDA (potato dextrose agar) and SDA (Sabraud dextrose agar). Preliminary results showed that several entomopathogenic fungi in Malaysia infect H. cubana: Fusarium, Paecilomyces, and Hirsutella, as well as some unidentified and less common fungal species (sent to CMI - CAB International Mycological Institute - for identification). Winrock International has agreed to study the biology and ecology of indigenous natural enemies of the leucaena psyllid in the future as part of the F/FRED Project.

13.4 Regulations on and Quarantine of Biological Control Agents

In Malaysia, there is a National Committee for Science which formed a subcommittee on biological control (section 13.6.1). The subcommittee decided that there is a need to initiate biological control against the leucaena psyllid, particularly as pesticides are not acceptable for use on a fodder crop and because host plant resistance studies have yielded only inconclusive results. The National Committee has accepted the FAO's Guidelines for the Safe Introduction of Biological Control Agents and Procedures for Construction of Quarantine Facilities (Malaysian quarantine posts have been evaluated previously by USDA/APHIS personnel). To import biological control agents, a permit for this purpose must be requested and issued from the Ministry of Agriculture's Department of Quarantine, which, to date, has not yet responded to the request from the Ministry of Agriculture, MARDI, and CABI to import Tamarixia (a positive response, however, is expected).

Tamarixia will most likely be imported in its pupal stage and quarantined according to procedures outlined by IIBC. Many of the quarantine procedures will likely be carried out in Hawaii, and repeated at the Malaysian Department of Quarantine's facilities. However, the GOM prefers to take a cautious approach because of the low numbers of leucaena trees, and to avoid potential problems associated with hasty introductions of biological control agents. The Department of Quarantine's insectary was completed in late July 1991, and the Department of Quarantine will collaborate on quarantine procedures with MARDI and the Malaysian agricultural university, with advice from ASEAN PLANTI. The quarantine process will involve, in addition to screening against undesirable organisms, testing the parasitoid's ability to damage various major crops (e.g., plantain, orchids, rice, cocoa, oil palm) and some economically important insects - most notably bees and other pollinators. The testing, according to ASEAN PLANTI, need not include other indigenous insect fauna. Once Tamarixia is deemed to be both ecologically safe and useful against the leucaena psyllid under laboratory conditions and after testing in field cages on the university grounds, additional research will be conducted such that the parasitoid will likely not be released until two to three years after its importation. During this interval, technical assistance will be requested from the native region of T. leucaenae to help train Malaysian personnel in the use of the parasitoid. First releases into the environment will be limited to selected sites, and then expanded to full scale releases.

Research considered extraneous to normal Department of Quarantine screening procedures can be conducted during the quarantine process (under quarantine conditions) and after T. leucaenae is decidedly safe for release. While there are government regulations for post-release assessments (to be under the supervision of the Department of Quarantine and CABI in the case of T. leucaenae), research aims will be based upon the selection of proposals submitted by university and MARDI researchers. At the time this EA was being prepared, no specific research plans were apparent, although use of T. leucaenae in IPM strategies, effects of commonly used agricultural pesticides, and ecological interactions of indigenous fauna would seem appropriate avenues of exploration. The research capacity of MARDI and the agricultural university is adequate to study the interactions of T. leucaenae with the local environment and currently used pest management strategies. Some additional training in these areas would nevertheless prove to be beneficial (section 18.0). MARDI has two officers devoted to leucaena psyllid control who will likely be searching for indigenous natural enemies to supplement Winrock International's efforts in this regard.

Table 6. Arthropod fauna (identified to taxonomic orders only) associated with cultivated leucaena in Malaysia.

Homoptera
Hemiptera
Hymenoptera
Diptera
Coleoptera
Orthoptera
Lepidoptera
Collembola
Thysanoptera
Neuroptera
Psocoptera
Acarina
Arachnidae

13.5 Leucaena Psyllid Control Options

13.5.1 Pesticides

Pesticide use presents all of the problems associated with their application, including pest resistance, secondary pest outbreaks, contamination of water, disruption of the local ecology, and health hazards to the applicator. Pesticides are not being considered for leucaena psyllid control because leucaena foliage is used primarily as fodder. Residues therefore represent a potential health hazard to livestock and humans. In addition, pesticide use would be a recurrent cost to farmers and could reduce beneficial arthropod complexes in nearby agroecosystems. The pesticide option, given the relatively low importance of leucaena, would be expensive, unsustainable, and pose unnecessary risks to humans and the environment.

13.5.2 Resistant Varieties of Leucaena

Since resistant leucaena varieties are available and can be important in an IPM system for psylla control, many varieties are being screened for psyllid resistance. Breeding trials for psyllid resistant and acid soil tolerant leucaena varieties are being conducted by MARDI's Division of Agriculture and Division of Livestock. Most of those lines that have shown resistant qualities, however, may lose resistance depending upon the location in which they are grown, and the generation of the tree; such a resistance is not spatially or temporally stable. Also, the resistant varieties are apparently photoperiod sensitive which has resulted in inadequate seed set and infertility (propagation by planting cuttings has not been fruitful enough to promote its use at this time). In Malaysia, scientists have expressed a desire to continue breeding trials beyond the F-3 stage, the current generation of those varieties being tested, to the F-6 or F-8 generations which will not be available until 1995 or 1996. This may prove to be fortuitous timing, as *T. leucaenae* may be released by then such that a more integrated approach to psyllid control would be possible.

The potential for imparting resistance through application of biotechnology (e.g., introducing *Bacillus thuringiensis* genetic material to plants; the plant would then produce the *B. thuringiensis* toxin) is an interesting option, but at this time is not feasible because leucaena is not valuable enough in Malaysia to warrant the intensive research. It is, however, possible that such an effort could be attempted elsewhere in countries that can afford such an undertaking.

13.5.3 Grazing and Pruning

Psyllid population monitoring showed that numbers may suddenly and drastically drop after cattle grazing or pruning of new shoots for fodder. In one study, mean psyllid counts of 152

per shoot on 7 October 1988 declined to 10.3 per shoot after cattle grazing. The numbers rose to 72.2 per shoot by 10 December soon after the cattle were removed from the site, and similar observations were made for pruned leucaena trees. These findings indicate that cultural methods, such as grazing and pruning, could be important to psyllid management and should be investigated further. In addition, grazing and pruning could be timed in accordance with economic threshold levels for H. cubana populations. The development of psyllid economic threshold levels on leucaena should therefore be encouraged. However, the implementation of grazing and pruning of leucaena as tactics for control of H. cubana is not recommended until such time as this option is proven effective.

13.5.4 **Alternative Crops**

In Malaysia, the primary interest in leucaena is its function as a multipurpose tree, and especially as a fodder source. There are other crops that can substitute for one or more of the uses of leucaena, such as grasses for forage, other legumes for nitrogen fixation, and straight growing woody trees for fuelwood. While it would be desirable to culture a multipurpose tree such as leucaena on a wide scale, at the moment it is not considered imperative. Continued use of alternative crops is apparently acceptable until an appropriate and ecologically safe control strategy for H. cubana is developed. Given the similarity between the topography and climate of Malaysia and Thailand, possible alternative crops in Thailand (section 16.5.4) would likely be suitable for Malaysia.

The cattle industry in Malaysia is not of major importance; the primary use of cattle is for Islamic holidays when cattle are slaughtered for traditional celebratory feasts. Most cattle are imported for this purpose from Australia, and while it may appear that psyllid control would allow the spread of leucaena which would in turn increase the number of cattle raised, this is considered to be an unlikely scenario by MARDI and agricultural university scientists. Leucaena fodder could, however, improve the quality of the cattle grown, but this has not been demonstrated.

13.5.5 **Biological Control**

There are currently no effective biological control agents, indigenous or exotic, in Malaysia for leucaena psyllid control. Given the dubious imperative for promoting leucaena in Malaysia with or without effective psyllid control, the rationale for importing exotic biological control agents is largely academic in nature rather than based on pressing economic need. However, the search for effective biological control agents indigenous to Malaysia should be encouraged, and the introduction of T. leucaenae, if it will not disrupt the natural ecology and if it is shown to be effective against the leucaena psyllid in

Malaysian conditions, could provide a safe and permanent means of imposing control on leucaena psyllid populations. Such a tactic would be most effective particularly if stable resistant varieties of leucaena are identified and used in conjunction with T. leucaenae. It should also be noted here that the introduction of T. leucaenae could provide an excellent opportunity to build upon scientific protocols in Malaysia for the importation, screening, and release of biological control agents.

13.6 Country Capacity

13.6.1 Institutional Responsibilities and Coordination

The principal institutions and organizations with responsibilities or activities relevant to the development of a biological control program for the leucaena psyllid are the Malaysia Department of Agriculture (DOA), MARDI, the Universiti Pertanian Malaysia, the Association of South East Asia Nations Plant Quarantine Centre and Training Institute (ASEAN PLANTI), and IIBC. The DOA is responsible for issuing permits for importation of exotic biological control agents and for insuring that the introduction of biological control agents meets requirements set forth in the Plant Quarantine Act of 1976, including quarantine and post-entry screening (Appendix L). MARDI has conducted much of the basic research on the population biology and ecology of the leucaena psyllid in Malaysia, and is also investigating a number of control options including resistant varieties of leucaena and cultural practices that could complement biological control in an IPM program. ASEAN PLANTI, a regional center for research and training in plant quarantine, also publishes a variety of technical reports and newsletters, and provides advisory and consultancy services. ASEAN PLANTI sponsored an international training course on quarantine procedures for biological control agents during November 1990, and will host a second course in the fall of 1991. Like ASEAN PLANTI, IIBC publishes a variety of technical reports and offers advisory and consultancy services in biological control. IIBC also supplies biological control agents, and would supply the two exotic parasitoids proposed for psyllid control.

The activities of these different groups are well coordinated, in part because agricultural research in Malaysia tends to be problem oriented rather than discipline driven, and frequently involves collaboration between individuals from different disciplines and institutions. Coordination of biological control activities is specifically promoted by the DOA's National Coordinating Committee on Biological Control (NCCBC), chaired by the director general of MARDI. Members of the committee include staff from MARDI, ASEAN PLANTI, and the Universiti Pertanian Malaysia, as well as representatives from a number of other institutions with activities, expertise, or vested interest in biological control (IIBC often serves in an advisory capacity). Introduction of biological control agents

requires a permit from the NCCBC, which reviews available information on the proposed control agent and conducts a risk assessment before reaching a decision.

13.6.2 Equipment and Facilities

MARDI has conducted the majority of the research in Malaysia on leucaena and potential psyllid control strategies. Equipment and facilities appear quite adequate for these activities, and will soon be complemented by the completion of new facilities for post quarantine screening and research at ASEAN PLANTI. The DOA will be able to use ASEAN PLANTI's facilities and services to conduct post-quarantine activities in-house. Facilities for mass rearing and propagation of biological control agents have not been designated, and investment in both physical facilities and staff training appears necessary to carry out an effective biological control program.

13.6.3 Data and Information Management

Two of the principal institutions with responsibilities or activities related to the development of a biological control program for the leucaena psyllid, ASEAN PLANTI and IIBC, are regional organizations which serve as information clearing houses, among other functions. Both ASEAN PLANTI and IIBC produce a variety of technical reports and can provide consultancy and advisory services in the areas of quarantine (ASEAN PLANTI) and biological control (IIBC). Both have strong capacities in the area of information management, although that of ASEAN PLANTI could be augmented by increasing staff size. The Universiti Pertanian Malaysia and MARDI, the two primary institutions conduction research on leucaena and leucaena psyllid control, appear to have adequate capacity for data and information management related to current activities. Monitoring and evaluation required for full implementation of a biological control program could require additional resources, however. Needs for increased capacity in data and information management are greatest at the DOA. IIBC technical staff believe DOA staff need additional training to improve their capacity to understand and apply information in technical reports on biological control. The DOA currently lacks both the hardware and experience needed to develop a computer-based data and information management system that could improve data analysis and speed information dissemination.

13.6.4 Environmental and Economic Assessment

Although there is a Techno-Economic and Social Studies division at MARDI, it has not been involved in assessment of the economic value of leucaena or the economic impact of the leucaena psyllid. Malaysia was one of the countries included in CAB International's economic review of psyllid damage on leucaena in

Southeast Asia and Australia; the study found limited economic impact in Malaysia because of limited adoption of leucaena for fodder production. MARDI staff, with input from IIBC, have carried out studies necessary to assess the potential environmental impact of introducing the two parasitoid wasps. Researchers have surveyed the natural enemies of the leucaena psyllid and investigated basic psyllid population biology and ecology. The results, together with information drawn from published reports on the biology and ecology of the two parasitoids, have led researchers to conclude that the likelihood of establishment of parasitoid populations and their potential contribution to psyllid control appears favorable, but as is the case with any introduction of a biological control agent, cannot be entirely predicted in advance.

13.6.5 **Training Needs**

Malaysia's short-term training needs for development and implementation of a biological control program are relatively minor. The two areas where additional training would be most beneficial are post-quarantine screening and mass rearing procedures. Current screening requirements are adequate with respect to screening for disease, hyperparasites, or other foreign contaminants, but could be strengthened in areas such as investigating interactions with existing natural enemies, susceptibility of proposed control agents to commonly used pesticides, etc. Short-term training needs could be met through in-service training for DOA personnel. Longer-term capacity building would involve development of curriculum in areas such as biological control, IPM, and ecology within the agriculturally-related programs at the Universiti Pertanian Malaysia, and ongoing in-service training for DOA personnel.

14.0 NEPAL

14.1 Importance of Leucaena

The rural economy of Nepal is almost exclusively agricultural. Smallholder agriculture in the hill regions typically involves an integrated system of crop production, animal husbandry, and forestry. Leaf litter and browse from forests are the principle sources of food for livestock; manure from livestock is used in turn to fertilize cropland. Continuing population growth and declining agricultural productivity have led to increased poverty, deforestation, soil erosion, and overgrazing. Livestock production is limited by a shortage of fodder; estimates indicate that on average, animals are fed at levels about 50% below optimal. Planting of multipurpose tree species, such as leucaena, has been encouraged to improve the supply of fodder and fuelwood, to contribute toward meeting the subsistence and income needs of rural populations while protecting and restoring the resource base. The actual importance of lecuaena in Nepal is unclear, in part because nongovernmental organizations (NGOs) have carried out most of the planting and information consequently is scattered among different groups. While individual NGOs such as World Neighbors have estimated the economic significance of leucaena to their trial leucaena growing communities, there is no estimate of the overall importance of leucaena to Nepal. At present, it appears that benefits from leucaena are limited to a relatively small number of communities where NGOs have taken an active role in promoting its distribution. A number of other multipurpose tree species are being promoted in Nepal (section 14.5.4) including indigenous species that are better adapted to areas with harsh climates and poor soils.

14.2 Leucaena Psyllid Population in Nepal

The leucaena tree is a new introduction to Nepal, having been deliberately introduced from the Philippines only about 12 years ago. A World Neighbors project, however, has promoted cultivation of leucaena mainly as a fodder source for goats and for fuelwood. While adoption of leucaena has not been widespread, the more recent arrival of H. cubana and its rapid establishment throughout the southern two-thirds of the country has retarded proliferation of the tree. In Nepal, the lack of information to assess the value of propagating and disseminating leucaena trees precludes knowledge on the potential or actual economic injury being inflicted by H. cubana on existing leucaena trees. Nevertheless, the environmental assessment team observed heavy psyllid colonization of leucaena trees in Kirtipur (5 km southwest of Kathmandu), Rowa Pati (about 40 km northeast of Kathmandu) which is the World Neighbors nursery site for leucaena propagation, and the Indrawati River Valley near Bahunepati (about 45 km northeast of Kathmandu). At the latter site,

scattered leucaena plantings from the World Neighbors nursery stock in Rowa Pati, between five and ten years old, were being grown by hilltop farmers. By the accounts of two Nepali entomologists, the psyllid population of Nepal is large and is worsening. As in Malaysia and Thailand, leucaena psyllid populations seemed to fluctuate, being highest in the wet season.

14.3 Past and Present Biological Control Efforts

There are two examples of classical biological control in Nepal. In 1970, the parasitoid Aphelinus mali (Hymenoptera: Aphelinidae), was introduced from France to control the wooly apple aphid, Eriosoma lanigerum (Homoptera: Aphidae) with very high success. The parasitoid reproduced so well in the field that mass rearing it in an insectary was unnecessary.

Biological control of the noxious weed, Eupatorium adenophorum, was initiated in 1974 using Cecidochares utilis (Diptera: Cecidomyiidae) which was successful in Hawaii, New Zealand, and Australia. But in western Nepal, where the fly is not found naturally, attempts at biological control of E. adenophorum were met with failure (reason for this is not known).

Although use of indigenous organisms for biological control purposes is of interest to Nepali entomologists, the identification of possible natural enemies by the British Museum has become too expensive for continued efforts in this regard. This poses a problem as well to systematically searching for possible biological control agents of the leucaena psyllid indigenous to Nepal. Two indigenous predatory coccinellids, Coccinella semidecimpunctata and Brumus esuturaralis, have not been compared with C. coerulus for their abilities to control H. cubana.

Nepali entomologists are presently attempting to control H. cubana with exotic natural enemies. In October 1990, Nepal obtained C. coerulus from Thailand's Biological Control Research Center. Official transport of biological control agents to Nepal usually involves a long and bureaucratic process, so attempts to introduce C. coerulus were aborted. Shortly thereafter, Nepal received 30 C. coerulus and 30 O. abdominalis from Thailand by "unofficial means." The O. abdominalis did not culture will in the laboratory in Kathmandu, but enough C. coerulus reproduced to facilitate limited field releases in December 1990 in the districts of Kabre, Ramechap, Tanahun, Pokhara, Niwakat, and Kabre Manchok. No follow-up studies have been conducted to determine the survivorship of the released C. coerulus or their impact against H. cubana. The EA team, however, visited the release site at Kabre and observed that larval and adult C. coerulus were thriving on the leucaena trees at the World Neighbors leucaena nursery, which demonstrates that C. coerulus has become established there.

While Nepali entomologists would like to obtain hymenopterous parasitoids such as P. yaseeni and T. leucaenae, they require appropriate screening technology and assistance in how to rear, release, and monitor these insects (as well as the already released C. coerulus). In the case of Nepal, particularly where leucaena trees are being grown at higher elevations, it is possible that tropical American parasitoid wasps and generalist predators may not survive well. Therefore, it is advisable that preliminary experiments be performed to assess their feasibility prior to mass rearing and release. Nepali entomologists are currently in contact with IIBC for procurement of the parasitoids and technical assistance for their use.

14.4 Regulations on and Quarantine of Biological Control Agents

The GON established its Plant Quarantine Act in 1979, which is designed to protect Nepal from the accidental introduction of pests. However, there are no enforcement procedures to ensure that Nepal's Plant Quarantine Act regulations are followed. The Department of Plant Quarantine does not screen against entomopathogens or parasites of insects that may accompany imports of produce. The Act does not set forth regulations for quarantine of imported biological control agents, nor do such regulations exist under other GON law. However, it is required that a permit be obtained from the Ministry of Agriculture's Department of Quarantine.

Unofficially, plant quarantine studies are the responsibility of Dr. Samudra Joshi, an entomologist in the GON's Division of Entomology, who has also been assigned responsibility for biological control, and oil palm and potato production for Nepal. Therefore, Dr. Joshi must screen imports of biological control agents on major crops and indigenous insect fauna, check for parasitoids and entomopathogens, and mass rear the organisms in his only laboratory without adequate funds, release the biological control agents in the field, and conduct follow-up studies, along with his many other responsibilities. In Nepal, it is the lack of trained personnel, facilities, equipment, and financial support, not a lack of will or motivation, that has hindered attempts to initiate systematic biological control programs and thorough quarantine procedures.

Dr. Joshi has acquired C. coerulus and has been rearing it in his laboratory without modern equipment or methods. Follow-up monitoring to determine the effects of the released coccinellids has been limited to rare opportunities to make rapid and unquantified observations. In Nepal, more than in Malaysia or Thailand, training and support should be provided on quarantine, insect rearing, and biological control.

14.5 Leucaena Psyllid Control Options

14.5.1 Pesticides

Pesticides have not been used to control the leucaena psyllid in Nepal for the same reasons presented in sections 9.1 and 13.5.1. An additional disadvantage of repeated pesticide applications for leucaena psyllid control peculiar to Nepal is the remoteness and ruggedness of the terrain in combination with the scattered distribution of leucaena trees. These two factors will make it difficult to distribute pesticides to farmers, train them adequately, and surmount other logistical challenges. As it has been noted for Thailand, most leucaena trees have been planted by small farmers who likely cannot afford to invest in pesticides on a regular basis for a tree of apparent marginal value.

14.5.2 Resistant Varieties of Leucaena

Resistance trials have not been conducted in Nepal. Once stable resistance to H. cubana has been derived, resistant varieties developed in Nepal, or more likely, in other Asian countries that have ongoing resistance trials, would have the same potential applications as discussed in sections 9.3 and 13.5.2. It is important to note, however, that in Nepal there is an added dimension of extreme variation in elevation and associated climate which could affect the viability of new leucaena varieties for widespread adoption.

14.5.3 Grazing and Pruning

Research on the effect of grazing and pruning infested leucaena trees has not been conducted in Nepal. Nevertheless, it would appear that timely grazing and pruning, synchronized with psyllid population trends, may offer promise as a cultural control tactic. On the other hand, grazing and pruning of leucaena may only exacerbate psyllid infestations and this technique is therefore not recommended as a solution to the H. cubana problem.

14.5.4 Alternative Crops

Fodder trees are preferred for private planting, but contribute only about 6% of the total feed requirement for livestock (which represents 15 - 20% of farmer income). It is estimated that Nepal has 16 million head of livestock and a net fodder deficit of about 20%. This deficit is expected to increase as the forests, from which farmers collect 60% of their fodder, continue to deteriorate. In light of this prospect, there is a need to concentrate on fodder research and extension.

Leucaena leucocephala is only one of many fodder and fuelwood tree species being used in Nepal. A 1983 study

(Campbell and Bhattarai 1983) on fodder tree production found that farmers in hill districts planted Melia azederach, Artocarpus lakoocha, Choerospondias axillaries, and Bassia butyracea as fodder trees, and Pinus roxburghii, P. patula, and Juniperus wallichiana for fuelwood. A more recent field report (Manandhar and Suwal 1991), based on interviews with farmers in the Parbat, Baglung, Myagdi, and Gulmi Districts, indicated that A. lakoocha, Ficus cunia, Litsea polyantha, and Bauhinia purpurea, were preferred as fodder sources. An A.I.D. sponsored PSTC grant study (Karki and Tuladhar 1989) determined that selection of fodder trees varies with topography in Nepal. The best species for tropical flatlands (e.g., the Terai) are Ficus semicordata and Bauhinia spp.; for warm tropical valleys (e.g., Kathmandu), F. semicordata, L. leucocephala, Morus alba, and Bauhinia spp.; and for hilly regions, Morus spp., B. variegata, and Erythrina arborescence. While none of these studies provide conclusive evidence for making the most appropriate selection of fodder tree species, they strongly indicate that leucaena is not essential. Research on fodder production should continue, and should concentrate on all promising tree species, especially those that are indigenous to Nepal and unafflicted by H. cubana.

14.5.5 Biological Control

Biological control, as in Malaysia and Thailand, remains a viable option for controlling H. cubana particularly if the leucaena tree is determined to be significant enough in as a fodder and fuelwood source, and biological control tactics can be integrated with other, preferably cultural, control tactics (e.g., resistant varieties and/or pruning and grazing techniques). For C. coerulus to be effective against large leucaena psyllid populations in Nepal, many more will be required to exert measurable control. In order to produce sufficient numbers of C. coerulus or any other exotic natural enemy of H. cubana, quarantine and insectary facilities, training, and research support will be essential for a systematic and efficient biological control program.

The leucaena tree does not appear to be indispensable in view of alternative fodder and fuelwood species in current use. It is a worthy objective to promote safe and effective biological control capabilities, but such an effort should be attempted in a stepwise and carefully planned manner; then further introductions of exotic biological control agents can be accomplished with greater assurance of avoiding ecological disruption and unexpected failure.

14.6 Country Capacity

14.6.1 Institutional Responsibilities and Coordination

Nepal's Office of Plant Quarantine (under the DOA) is responsible for granting permission to import exotic biological

control agents, but has no official policy or guidelines for post-quarantine screening, and lacks both the manpower and facilities needed to conduct post-quarantine screening. Activities related to development of a biological control program for the psyllid are currently the responsibility of Mr. Samudra Joshi of the National Agricultural Research Center's Central Entomology Division. Joshi imported C. coerulus and O. abdominalis after receiving them from Dr. Napompeth of NBCRC in Bangkok, Thailand, in October 1990 (section 17.3). After screening both for hyperparasites and pathogens, he successfully reared and released C. coerulus but was unable to rear O. abdominalis. There is very little information on psyllid population dynamics and on the impact of C. coerulus on psyllid populations because of a lack of manpower to conduct the necessary monitoring. Research on other elements of an IPM strategy, such as testing resistant leucaena varieties, is being carried out on a limited basis by the Institute of Forestry, but no group is responsible for coordinating these efforts with biological control and other approaches in an IPM framework.

14.6.2 Equipment and Facilities

Equipment and facilities for conducting a biological control program currently are inadequate. Plant Quarantine does not have facilities for post-quarantine screening; Joshi carried our post-quarantine screening for C. coerulus and O. abdominalis in his own laboratory, but given financial limitations has not been able to equip his laboratory either to prevent unintentional releases (escapes) or to provide the environmental conditions needed to rear biological control agents (the laboratory is unheated and Joshi managed to rear C. coerulus during the winter only by using an incubator). Currently there are no facilities for mass rearing of biological control agents in Nepal.

14.6.3 Data and Information Management

Capacities for data collection, analysis, and management would all have to be strengthened for Nepal to conduct a successful biological control program against H. cubana. Few data have been collected, either on psyllid population dynamics and damage levels or on the impact of C. coerulus on psyllid populations primarily because of a lack of manpower. The Institute of Forestry's studies on resistant varieties are similarly limited. Research on resistant varieties began in 1989, but many of the trees planted have not been revisited; data needed to analyze results is therefore often lacking. Improved capacity would require in-service training of existing staff, additional staffing, and improved coordination between groups researching different elements of an IPM strategy. Because NGOs have been responsible for much of the planting of leucaena, improved data management should include the establishment of a central registry for data and information from different NGOs,

PVOs and other groups.

14.6.4 Environmental and Economic Assessment

As noted above, data of any sort is extremely limited and fragmented among different organizations in Nepal. There has been no overall assessment of either the economic value of leucaena or the economic impact of psyllid damage. Potential environmental impacts of release of exotic biological control agents have not been adequately assessed; because of limited manpower, there have been no attempts to survey for indigenous natural enemies of H. cubana or to investigate potential ecological interactions with the proposed exotic biological control agents. Curinus coerulus was released without any advance study of potential adverse ecological consequences.

14.6.5 Training Needs

All activities related to development of a biological control program for H. cubana need strengthening. Immediate needs include the formulation of regulations governing the introduction, quarantine, and post-quarantine screening of exotic biological control agents. Short term training is needed in such fundamental areas as techniques for rearing biological control agents and post-release assessment. Mr. Joshi feels that he would require additional training to successfully rear the two predatory coccinellid beetles in his possession. Additional skilled staff would be needed in all areas: post-quarantine screening, mass rearing, supervised releases, monitoring psyllid and biological control agent populations, assessing damage to leucaena, estimating economic impacts of both psyllid inflicted injury to leucaena and control imposed through the release of biological control agents, and further analyzing and synthesizing information. Training aimed at longer term capacity building will be needed to fully develop the necessary human resource base and to promote the integration of biological control as an element of IPM efforts. Because psyllid damage in Nepal is limited, investment in training should be directed toward transferable skills, i.e., building general capabilities in biological control that are applicable to other pest problems. Because NGOs play an important role in promoting the distribution of leucaena, NGOs should be included in the groups targeted for training; they frequently act as extension agents in many areas.

15.0 THE PHILIPPINES

15.1 Importance of Leucaena

In the Philippines, leucaena is known as "ipil-ipil." It was introduced from Latin America in the 16th or 17th Century and is now grown throughout the Philippines. The adaptability of leucaena to a variety of soil conditions (except acidic soils), and its high seed production, fast growth, coppicing ability, and high leaf protein content have made leucaena popular. Leucaena was promoted in the 1970s as a "miracle" tree for its multiple functions; the dissemination of new varieties was mostly handled primarily by the government under special national programs (e.g., Human Settlement Program, the Leafmeal Program, the Hillside Farming Program, and the Alternative Energy Program).

Of 125 leucaena accessions (70 of them from foreign sources), a number of breeding and agronomic trials were conducted to identify the ideal varieties and management practices. The two principle varieties recommended in the Philippines are the Hawaiian Giant (K8, K28, and K67), and the Peru type. While the Hawaiian Giant is used mainly for timber, wood products, and industrial fuel, the Peru type is more commonly used as a source for fodder and forage. A more detailed characterization of the uses of leucaena in the Philippines, listed according to sector, is provided in Table 7.

The Philippines has a total land mass off about 30 million ha of which 11.3 million ha is used for crop production, 1.1 million ha for pasture, and 17.6 million ha for forest and other uses. Leucaena is grown on about 300,000 ha (1986 figure) among the three sectors listed above. Earnings from leucaena production were estimated at from P 18,000 - 40,000 per ha for a total annual income of between P 5.4 billion and 12.4 billion of which P 4.5 billion were generated at the farm level.

From 1982 to 1989, the Philippine population increased by 22% (from 48.1 million to 58.7 million) while cattle and swine populations declined and other major livestock species (e.g., buffalo, goats, poultry) increased by less than 4%; this led to higher dependence on imported livestock and dairy products. Growth of the livestock industry requires greater efficiency of small farmer production and higher stocking rates on pasture lands. Some studies suggest that the ruminant population could be doubled by introducing useful forage legume trees and shrubs on marginal and pasture land combined with maximum use of crop residues. Until the arrival of H. cubana, leucaena was the sole forage legume used on a large scale.

Since 1973, the Bureau of Animal Industry was responsible for distributing seeds and seedlings, mostly to small farmers throughout the Philippines as a source of fuelwood, cut and carry fodder, and leafmeal. Leucaena leafmeal production started as a cottage industry in central and western Visayas, northern Luzon, and Cebu. Leaves are sold, after drying, to feed mills, and in some areas the sale of leucaena leafmeal to mills has become a

significant source of supplemental income to small farmers. The demand for leucaena can be exemplified using estimates from the Integrated Program on Ipil-ipil Leafmeal (IPIL), developed in 1984 under the administration of the Ministry of Agriculture and Food's National Agricultural Productivity Programs which also include increasing the production of corn, rice, soybean, and other crops to eliminate dependence on imported livestock feed. In general, the objective of IPIL was to develop an export leucaena leafmeal industry within five years. The total demand for leucaena leafmeal by Japan, Taiwan, and Singapore was estimated to be at least 194,000 metric tons (MT) in 1984 (at $109 per MT) and was expected to increase as livestock industries expanded.

The most economic methods for feeding livestock in the Philippines are by cut and carry of leucaena fodder and by using the trees as browse. Leucaena has become the most important legume tree used to supplement crop residues in small farm systems and "backyard" livestock production in particular. There are no accurate estimates regarding the area planted to leucaena in backyard systems; however, the demand for leucaena feed by backyard livestock systems in 1984 was estimated to be 57 MT per year.

Leucaena has been a significant tree for reforestation which is the responsibility of the Department of Environment and Natural Resources. The giant leucaena alone represent 90% of the tree plantings since 1975 for forestry purposes. From 70,000 - 100,000 ha were planted in monocultures or mixed species tree stands.

Leucaena is one of the fastest growing hardwood tree species in the Philippines and is therefore an important source of fuelwood for use in the home and small businesses (e.g., bakeries). Also, the dendro-thermal energy industry was important in the Philippines in the 1970s and 1980s after the rise in world oil prices in 1973. A number of large leucaena plantations were established by the Department of Energy and Natural Resources (DER) and the National Electrification Administration to provide fuelwood. In Bolinao alone, 1,250 ha were planted to leucaena for this purpose. However, the dendro-thermal plants have switched to geo-thermal after the recent declines in world oil prices and the discovery of offshore oil reserves in the Philippines at Palawan. The failure of the dendro-thermal program largely occurred prior to the leucaena psyllid infestation, but this may have been a minor factor which contributed to the demise of the dendro-thermal industry.

The Mindanao Baptist Rural Life Centre has developed an agroforestry scheme called Sloping Agricultural Land Technology (SALT) for reduction of erosion using a variety of techniques including terracing, mulching, contour strip cropping, multiple cropping, cover cropping, reforestation, and agroforestry. The SALT system uses thickly seeded rows of legume trees planted on contour hedgerows which also function as nitrogen fixing plants, sources of green manure, and moisture reservoirs interplanted

with perennial crops (e.g., coffee, cocoa, and citrus) and other crops (e.g., corn, upland rice, sorghum, wheat, melons, pineapples, and legumes). Using SALT, the small upland farmer can conserve soil, reduce fertilizer purchases, increase yield, and progress toward self-sufficiency. Until the arrival of H. cubana, leucaena was the primary legume tree being used in SALT.

Finally, leucaena trees are used as greenbreaks to prevent brush fire spread, and as windbreaks in typhoon-prone areas (e.g., Batones, the Birol region, and Quezon).

15.2 Leucaena Psyllid Population

The arrival of H. cubana in the Philippines is something of a mystery. Unconfirmed reports date as far back as 1969 at Mount Makiling, Laguna, and in 1979 from collections made on cargo ships. Initial confirmed reports were made on infestations on leucaena in Cebu and Leyte in early 1985. The population rose for about eight months, after which the psyllid proliferated more rapidly and began to exact serious damage to leucaena trees throughout the country. By early 1986 the situation had become serious enough to merit public concern which instigated an investigation on pesticide and biological control methods. Pest damage to leucaena trees was estimated at 80% (many surviving trees were stunted) but the severity of attack varied from region to region.

Leucaena psyllid populations appear to vary; populations tend to decline during the dry season which may, in part, be a result of reduced food supply. Other sources state the opposite - H. cubana populations are highest in the dry season (begins in December/January) and decline dramatically in April and May because of psyllid overcrowding, entomopathogens, climatological factors, and natural enemies in addition to low food supply. This discrepancy is probably due to the lack of careful psyllid population assessments. Still other sources state that psyllid populations decline in both extreme wet and dry conditions. Water stress can affect psyllid populations in two ways. Plants under stress often become more susceptible to external pressures, such as psyllid feeding which removes moisture from already drought-stressed plants. Observations in 1986 suggested that leucaena trees near water sources, such as rice paddies, were not defoliated while trees farther from constant water supplies were severely damaged (although even trees not stressed by lack of water can still be defoliated during heavy infestations). Secondly, water induces flushes of foliage which is conducive to psyllid propagation, but this, in turn, is also favorable for the proliferation of entomopathogens which may be ultimately responsible for psyllid population declines in April and May.

In late 1987, psyllid populations began to decline, most likely due to the scarcity of leucaena leaves (a result of heavy psyllid infestations and drought), the introduction of C. coerulus, and indigenous natural enemies. By 1988, leucaena trees began to recover; the effects of the infestation,

Table 7. Uses of leucaena in the Philippines.

Sector	Uses
Small farmer	Animal fodder Fuel wood and charcoal Treeline fences Windbreaks and shade Green manure
Commercial	Fuelwood for dendro-thermal electricity Charcoal Leafmeal - pelleted for poultry and swine for local use and export Mine post wood Props for banana plantations Decorating materials Tile wood Furniture Guitars Mosquito coils
Environmental	Reforestation Erosion control

especially on the rural economy, are still considerable despite estimates of 50% leucaena recovery in 1989. Because leucaena psyllid populations are not systematically monitored, much of the data on infestations and resulting damage is anecdotal.

The leucaena psyllid infestation has had a profound effect on the local economy; effects on the incomes of leafmeal growers, fuelwood gatherers, tree farmers, and charcoal producers were particularly severe. Prices of leucaena products doubled (e.g., fuelwood prices rose from P 60 to P 100 per kg, and leafmeal from P 1 to P 2 per kg). Overall leucaena psyllid damage in 1985 was estimated to be valued at about P 60 million. The level of damage to leucaena in the Philippines ranged between 50 - 80% per year from 1986 - 1989 in the 200,000 ha planted to leucaena. During this period, about P 5,200 million was lost (both % damage and losses tended to decline during each successive year).

With specific regard to the psyllid's effect on forage and leafmeal production, leucaena has not been planted since 1985 for these purposes, while alternative forage crops are being sought. Due to the shortage of leucaena fodder, farmers were forced to sell their animals at later than optimal times and at low prices. General Milling Corporation in Cebu was a major buyer of leucaena leaves; the leaf supply vanished in mid 1985, but resumed by November. Since the psyllid infestation, General Milling Corporation ceased planting leucaena and switched to alfalfa. In some of their leucaena plantations the trees are now being harvested for fuelwood. Losses in domestic production of leucaena fodder were compounded by losses of income from exports and resulted in the reversal of potential exports to Japan.

The Manila Seedling Bank (MSB) had a monoculture plantation of leucaena in 1,200 ha; in the Bataan Peninsula alone 400 ha (90,000 - 120,000 trees/ha) for leafmeal production were completely devastated by the psyllid, and the plantation was abandoned. The MSB estimated losses to be valued at about $1.7 million.

The MBRLC's soil conservation project estimated that net income generated through its leucaena plantings dropped from P 1,046 per month in 1984 to P 489 per month in 1987 when leucaena trees were completely destroyed and chemical fertilizers had to be used.

Department of Environment and Natural Resources leucaena plantings (as fuelwood sources) suffered severe damage. There are no precise records on losses, but in Mindanao it was estimated that 70 - 80% of the trees used for this purpose were killed or severely damaged (this is representative of the rest of DENR's leucaena plantation losses). DENR is not planting any more leucaena trees, but is instead replanting with alternative species (section 15.5.4).

The Barili Plantation in Cebu, where leucaena was cultured for mine post production, reported that harvest of leucaena for mine posts ceased in 1986 due to the psyllid infestation. Production losses were estimated at 65%.

With the recent and accidental arrival of P. yaseeni to the Philippines (section 16.3) and its subsequent spread throughout the country, H. cubana populations have been apparently reduced to levels that have permitted the normalization of leucaena wood production (including mine posts) and the projected likelihood of complete leucaena leafmeal industry recovery within two or three years.

15.3 Past and Present Biological Control Efforts

Biological control in the Philippines has received some attention in the past, but is not actively promoted by the government. A Philippino delegate at the Asia-Pacific IPM Conference in Kuala Lumpur (September 1991) returned to Manila and indicated in a letter to the government of the Philippines and the university system that unless biological control efforts were supported more strenuously, the Philippines would lag well behind the rest of Asia with regard to progress in establishing IPM. While there have been previous attempts at importing biological control agents to the Philippines, biological control of agricultural pests has been largely incidental and not emphasized by the government as a tactic for pest management.

In 1986, C. coerulus was brought to the Philippines from Hawaii for control of H. cubana, and in March, 600 adults were released. About 80% of the released C. coerulus failed to survive the first week probably because of sudden changes in temperature. The Department of Plant Industry and Crop Protection then reared a sufficient number of the predators for inoculative release studies despite the labor intensiveness of the mass rearing procedures (psyllids were used as the food supply). Laboratory reared C. coerulus were then released in small quantities at various locations from May 1986 to May 1987 by the Bureau of Plant Industry. A total of about 2,000 of the predators (in all life stages, including eggs) were given to crop protection institutions and plantations for rearing purposes. Most of the releases through the Bureau for Plant Industry were carried out in Luzon, Visayas, and Mindanao. The Regional Crop Protection Center in Cebu began rearing C. coerulus from the original shipment from Hawaii, but more than 90% died. Of the 16 sites monitored after limited releases of surviving C. coerulus, the predator was found at only nine locations after a year had elapsed. Curinus coerulus populations tended to fluctuate with those of H. cubana. In areas with persistent C. coerulus populations, leucaena trees were observed to recover more rapidly than at sites where C. coerulus did not survive or was not introduced.

Overall, C. coerulus did not provide adequate control of H. cubana in the Philippines, which has been attributed to the distinct changes in seasons from wet to dry, and because of the unsuccessful attempts to rear the predator for mass releases. CAB International (1990) reported that when the International Rice Research Institute (IRRI, located in Los Banos) offered the

loan of their biological control laboratory facilities for mass rearing of C. coerulus, but the DOA declined the assistance.

In 1990, P. yaseeni was discovered in the Philippines, presumably accidentally introduced as pupae in psyllid mummies attached to leucaena leaflets carried by wind currents from elsewhere. The parasitoid has since spread throughout the Philippines and has exerted notable (but unquantified) control of the leucaena psyllid. It is estimated that in 2 - 3 years P. yaseeni will completely normalize leucaena wood and leafmeal production and permit its extensive use in reforestation programs.

Surveys for indigenous natural enemies of H. cubana yielded a number of predators (Table 8), most of which have general feeding habits. Besides predatory ants, the potential of these insects for imposing effective control was initially considered to be low. Although the ants are good predators, their ability to sting renders them undesirable to farmers who harvest leucaena leaves. In some areas such as Villoba, the orb spider, Cyclosa mulmeinensis, is thought to be somewhat effective against H. cubana populations especially when this predator occurs in large numbers. By 1990 spiders and indigenous coccinellid beetles appeared to have imposed sufficient control of H. cubana to bring leucaena wood production, especially for mine posts, to pre-1985 levels.

Indigenous entomopathogens, mostly Entomophthora sp., Paecilomyces farinosus, Hirsutella citriformis, and Fusarium sp., may exert more pressure against H. cubana than other natural enemies. Epizootics in H. cubana populations are largely dependent upon the occurrence of humid weather conditions (like in Babatngon and Bontoc [both on Leyte], and the island of Visayas). Low levels of H. cubana in areas such as Bontoc were attributed to epizootics of entomopathogens. However, systematic studies on the effects of these entomopathogens have not been conducted, so the incidence of such microorganisms has not been correlated with fluctuations in leucaena psyllid populations.

There may be potential uses for natural enemies, both arthropods and entomopathogens, in the Philippines. Although preliminary observations suggest that their effectiveness would be low, further studies on their respective abilities to control the leucaena psyllid are urged. While some entomopathogen levels have been negatively correlated with temperature (e.g., P. farinosus and H. citriformis) and others depend heavily on high moisture (e.g., Entomophthora sp.), these fungi could be used selectively during seasons and in areas favorable to their rapid proliferation to epizootic status.

15.4 Regulations on and Quarantine of Biological Control Agents

There are regulations for the quarantine of organisms, both plant and animal, entering the Philippines. Quarantine of biological control agents is the responsibility of the Department

of Quarantine, and IIBC quarantine procedures for biological control agents entering the country are conducted by the National Crop Protection Center in Los Banos. Quarantine procedures are similar to those described in section 13.4 on Malaysia in this EA. Studies on exotic biological control agents do not include ecological interactions with nontarget organisms, pesticide effects on the biological control agent, or possible relationships with ongoing pest management strategies.

15.5 Leucaena Psyllid Control Options

15.5.1 Pesticides

Tests were conducted to ascertain the efficacy of chemical control against H. cubana. Initial work was carried out by the Department of Plant Industry and Crop Protection. Azodrin 202R (concentration 1 - 5 cc for tree trunks of diameter 5 - 10 inches) was found to be effective when injected; no defoliation was observed for up to five months after treatment. Nuvacron (5 cc per tree) was similarly effective. Trunk injection was determined to be more effective than spraying, although spray applications were effective on seedlings and sucker growth. Pesticides were effective against the psyllid but their widespread use was uneconomical and impractical because of high cost, the small target area of shoots to be sprayed (hence a lot of spray is wasted), the need to bore holes in each tree for injections, possible residues in fodder, and the large quantity of water needed for spray applications.

The Department of Plant Industry and Crop Protection advised farmers to minimize psyllid effects and reduce the need for chemical applications by cutting down severely infested mature trees, pruning other trees, and injecting older trees with azodrin and spraying younger trees.

The Philippines Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD)-supported research did not include studies on pesticides because of the likelihood of animal fodder contamination and the high cost of pesticide application.

15.5.2 Resistant Varieties of Leucaena

Field trials for L. leucocephala resistance to H. cubana have yielded only two resistant varieties: K784 and K785. Based upon preliminary results for tests in Carranglan (about 185 km north of Manila) K784 did not set seed well, and was surpassed in rate of growth by K785. Most of the varieties tested were susceptible to mealybugs which infested the blossoms as well as other parts of the tree; this may have had an effect on K784's ability to set seed. Both K784 and K785 do show promise in the Philippines and their respective performances should be evaluated under a wide range of growing conditions to assess their uses for fodder, fuelwood, and green manure production. Resistance trials

Table 8. Predatory arthropods[1] and their relative abundances[2] collected from psyllid infested leucaena stands in Leyte, the Philippines.

Class Order[3] Species	Location Babatnqon	Biliran	Bontoc	Villaba	Visayas
Insecta					
Coleoptera					
Coelophora inaequalis	+	-	-	-	-
Formicamus sp.	+	-	++	++	++
Menochilus sexmaculatus	+++	++	+++	+++	+++
Micraspis sp.	-	-	++	++	++
Hemiptera					
Campylomma livida	+++	+	+++	+++	+++
Deraecoris sp.	+++	++	+++	+++	+++
Geocoris flaviceps	-	-	++	+	++
Philophorus sp.	-	-	-	++	++
Scipinia horrida	+++	+++	+++	+++	+++
Hymenoptera					
Ropalidia flavopicta flavobrunnea	++	++	+++	++	+++
Arachnida					
Araneus sp.	++	++	+++	++	+
Clubiona sp.	-	-	-	+	-
Coleosoma blandum	-	-	-	+	-
Cycloa mulmeinensis	+	+++	+	+++	+
Dexippus sp.	-	-	+	+	+
Diaea xanthoqaster	+	-	+	+	+
Hasarius sp.	-	++	+++	+	++
Leucauqe decorata	-	-	-	+	-
Liocranum sp.	+++	+++	+++	+++	+++
Marpissa calcutaensis	-	++	++	+	-
Misumena sp.	+++	+++	+++	+++	+++
Misumenops sp.	-	-	-	-	+

Table 8 (cont'd).

Class Order[3] Species	Location Babatngon	Biliran	Bontoc	Villaba	Visayas
Oxyopes javanus	++	+++	+++	+++	+++
Tetragnatha sp.	-	-	-	+	-
Thomisus sp.	++	-	++	+	++
Xysticus sp.	++	-	+	+	+
Unidentified spp.	+++	++	+	++	++

[1]*Synharmonia octomaculata* (Coleoptera: Coccinellidae), *Scymnus roepkei* (Coleoptera: Coccinellidae), and mantids (Orthoptera: Mantidae) found elsewhere.
[2]+ = rare, ++ = common, +++ = very common, - = no record.
[3]Orders for arachnids not included.

are still at an early stage in the Philippines so resistance is an unlikely solution to the leucaena psyllid problem for the near future.

15.5.3 Grazing and Pruning

Because H. cubana prefer to feed on young shoots, the practice of periodically cutting leucaena hedgerows resulted in flushes of new shoot growth accompanied by increases in leucaena psyllid populations (especially when the cutting is done at the onset of the rainy season). For this reason, grazing/pruning of leucaena is not considered to be a viable option for control of H. cubana.

15.5.4 Alternative Crops

Over-reliance on L. leucocephala as a fuelwood and fodder source in the Philippines has resulted in the tremendous damage exerted by the leucaena psyllid. To create more sustainable agricultural systems, some degree of crop diversification is a general rule of thumb. The arrival of H. cubana has instigated a great interest by many concerned parties in the possible use of alternative legume trees. In addition, many farmers are now very reluctant to consider growing leucaena, and this reluctance will likely continue even if an effective control method for H. cubana is developed.

Other species of leucaena such as L. pallida and L. diversifolia are tolerant or resistant to H. cubana, but were highly susceptible to mealybugs and other defoliating insects. Although some L. diversifolia is being planted for fuelwood, no leucaena species are being recommended in the Philippines. Hybrids such as L. leucocephala X L. pallida, and L. leucocephala X L. diversifolia were generally very susceptible to H. cubana and mealybugs, although L. leucocephala X L. pallida KX2 showed some promise. Continued work on hybrids may produce a resistant plant, but this is unlikely to be a solution for the near future.

The Bureau of Animal Industry and some farmers are experimenting with Gliricidia, Sesbania, Erythrina, and Acacia for use as fodder sources. Some of these trees are already planted on small farms; in areas of Bicol and Batangas Gliricidia leaves are being used in the dry season when the more palatable yellow leaves are available. Cassia, Cajanus, and Albizia are also being considered for fodder production.

With regard to fuelwood production, DENR leucaena plantations are being replanted with Gmelina arborea, Acacia mangium, Acacia auriculiformis, Albizia eucalypts (Albizia saman has been observed to host H. cubana in the Philippines), South American mahogany, and local dipterocarps. A new National Reforestation Program has a target of 114 million ha of forests to be planted (not in monocultures) by the year 2000 (financed mostly by the Asian Development Bank. The government of the Philippines is contracting much of this work to companies and

agencies such as MSB). Another possible fuelwood tree being considered is Gliricidia.

In 1985, MBRLC began studying the potential of alternative tree species for soil conservation. The most promising appear to be Flemingia congesta, Acacia villosa, L. diversifolia (but not recommended), Gliricidia sepium, and Desmodium gyroides. Other possibilities include Erythrina and Sesbania.

Given the apparent success of indigenous natural enemies of H. cubana and the preliminary but promising observation that P. yaseeni is providing effective control, it is speculated that there may be a tendency to de-emphasize the search for alternative legume trees and to once again promote leucaena. If such a trend were to occur, it may prove to be effective, yet it runs counter to the notion of attaining production stability through diversification of multipurpose trees. Sustainability would most likely be approached by promoting diversification in combination with ecologically sound biocontrol of the leucaena psyllid (see section 7.0).

15.5.5 Biological Control

So far indigenous biocontrol agents and deliberate attempts to implement classical biological control against the leucaena psyllid in the Philippines have not been effective. Although surveys have identified numerous predators of H. cubana in the Philippines (section 15.3), the capacity of these to effectively control the psyllid appears to be low (further studies should be encouraged on this topic). There seem to be no parasitoid wasps native to the Philippines that attack H. cubana (the discovery of indigenous parasitoid wasps would be a favorable development, but the probability of this seems very low).

A number of indigenous entomopathogens have been found to infect the leucaena psyllid (section 15.3), and even to cause epizootics among populations in moist conditions. At this time, the use of such entomopathogens may to be the most promising option with regard to native natural enemies. Concentrated study on the effects and application of these fungi should be a focus for the government of the Philippines, research institutions, and concerned development agencies in the Philippines.

The failure of C. coerulus to control H. cubana in the Philippines is ostensibly due to the inability of the Department of Plant Industry and Regional Crop Protection Centers to rear the predator in sufficient quantities for mass release. Preliminary observations also show that C. coerulus did not survive in many locations where it was released, presumably a function of changes in climatic conditions unfavorable to the predator. In addition, C. coerulus, as noted in the other country-specific sections of this EA, does not disperse well and at least 40 beetles are needed per tree to exert measurable control (another disadvantage of C. coerulus is that it is a generalist predator, and as such, it is less effective against specific pests than more host-specific natural enemies). Even if

crop protection personnel were to be able to produce C. coerulus in the laboratory, the large number of leucaena trees planted in the Philippines would require that tremendous populations be reared, and releases on each tree would be a logistical and economic hurdle to be overcome. Also, such an effort would only be viable in those areas conducive to C. coerulus, leaving many leucaena growing areas of the Philippines without the predator. It would therefore be more advantageous to import host specific and highly mobile natural enemies (e.g., P. yaseeni and/or T. leucaenae) that are demonstrably adapted to the various environmental and climatic conditions in leucaena growing areas.

The need to import parasitoids of H. cubana, however, was circumvented when P. yaseeni was accidentally introduced to the Philippines, presumably as pupae attached to leucaena leaflets blown to the islands on the wind. Since its arrival, P. yaseeni has spread in just a few years throughout the country. This development, in combination with the control imposed by indigenous natural enemies, has resulted in leucaena wood production being normalized and leafmeal production is rapidly recovering.

Because of the preliminary success of P. yaseeni in controlling H. cubana in the Philippines, renewed attempts to release C. coerulus and the possibility of importing T. leucaenae are not being considered.

15.6 Country Capacity

15.6.1 Institutional Responsibilities and Coordination

Control of H. cubana in the Philippines is of concern to numerous businesses, institutions, and agencies (e.g., DENR, General Milling Corporation, MSB, MBRLC, National Electrification Administration, and DOA), but initial responsibility for the effort was assigned to the Bureau for Plant Industry (BPI) which performed pesticide tests and attempted to rear, release, and monitor C. coerulus. In 1987 the responsibility for psyllid control was assumed by PCARRD even though BPI maintains that the DOA's network of Regional Crop Protection Centers is the only organized system through which biological control can be conducted. BPI also claims that the DOA and the Department of Forestry should collaborate more on the psyllid problem.

PCARRD approved research projects in the areas of biosystematics, ecology, population dynamics, biological control, silvicultural management, and socio-economics. Funding for these projects lasted two or three years and offshoots of some projects are currently receiving continued support from Winrock International and the International Development Research Center (IDRC, Canadian). PCARRD support for projects on H. cubana control ended in early 1990.

Intensive research on the leucaena psyllid and methods for its control began in earnest in 1987, after the responsibility was transferred from BPI to PCARRD and the Rainfed Resources

Development Project (RRDP). A PCARRD/RRDP supported program called "Biology and Control of Heteropsylla cubana Infesting Leucaena Species" is being carried out by several institutions in the form of various projects and project studies. The PCARRD/RRDP program consists of:

Project 1 - Biosystematics of ipil-ipil pests by the University of the Philippines at Los Banos (UPLB-IBS)
  Study 1 - Biology of psyllid infesting ipil-ipil

Project 2 - Population dynamics of ipil-ipil psyllid (UPLB-CF)
  Study 1 - Life table analysis of the ipil-ipil psyllid

Project 3 - Biological control of ipil-ipil psyllid
  Study 1 - Evaluation of promising natural enemies of ipil-ipil psyllid (UPLB-IBS)
  Study 2 - Entomopathogenic control of jumping plant lice of ipil-ipil (UPLB-CF)
  Study 3 - Biological control of ipil-ipil psyllid in Leyte (ViSCA)

Project 4 - Silvicultural management for control of psyllid infesting leucaena

  Study 1 - The economics of losses form psyllid-infested leucaena plantations (ERDB)
  Study 2 - Screening of leucaena cultures for their relative resistance against psyllid insect pest (ERDB)

The F/FRED project is supporting research as well. The ongoing study, called "Selection and Evaluation of Field Resistant Leucaena in the Philippines" under management of ERDB has three projects:

Project 1 - A study of the biology and mass-rearing of two predators of H. cubana (UPLB)
Project 2 - Psyllid infestation: its socio-economic impact on leucaena tree farmers and end-users in the Philippines (ERDB)
Project 3 - Seed production and evaluation of psyllid-resistant leucaena selection (ERDB)

Because the leucaena psyllid is apparently now under control due to the influence of indigenous natural enemies and the accidental introduction of P. yaseeni, research on biological control of H. cubana is unlikely to receive high priority by the government of the Philippines.

The National Crop Protection Center in Los Banos was initially set up in 1976 with the support of USAID. Since then, crop protection centers in each region of the Philippines were

constructed, but have many responsibilities aside from biological control. According to Dr. Fernando Sanchez, entomologist and Vice Chancellor of Academic Affairs at UPLB, and first director of the National Crop Protection Center in Los Banos, biological control is not a priority for the Center, and, in fact, many of the staff originally trained in biological control have been assigned to other tasks. This is in part because the government of the Philippines has shown reluctance to commit funding to biological control efforts for solving agricultural pest problems.

15.6.2 Equipment and Facilities

The National Crop Protection Center in Los Banos and its regional crop protection centers throughout the rest of the Philippines provide adequate facilities for initiating serious biological control research and implementing biological control programs. It is doubtful that foreign assistance is needed in the Philippines for these purposes other than to exert influence on the government to promote the potential importance of biological control as a viable and sustainable pest management tactic. The institution of long-term and broad scope biological control programs would require the expansion of existing facilities to include rearing space and laboratory equipment. Such an endeavor could be supported by the government of the Philippines should it decide to commit resources and funds for the development and maintenance of biological control efforts.

15.6.3 Data and Information Management

The Philippines is unusually well-equipped to generate and manage information on biological control in comparison to most other Asian countries. There is a strong university system, and most campuses have a relatively large college of agriculture. IRRI is also headquartered in the Philippines and it has recently begun work on biological control. Although biocontrol is being officially encouraged by the government, biocontrol efforts lag behind much of the rest of Asia largely due to lack of funding.

There is access to a variety of entomological journals at many of the universities and at IRRI. However, as in any country, improvement of data accession from domestic and foreign sources remains a need and this applies as well to linkages between research and extension especially where IPM tactics are concerned. The biggest need in the Philippines regarding biological control is public and governmental awareness.

15.6.4 Environmental and Economic Assessment

Apparently, no environmental assessments on the impact of the leucaena psyllid, the use of C. coerulus, or the effect of P.

yaseeni have been conducted in the Philippines.

Available economic assessments on the damage inflicted by H. cubana on leucaena have been sketchy and often anecdotal (section 16.2), although ERDB has been focussing on the economics of the psyllid infestation. It can, however, be safely stated that the leucaena psyllid has had a very significant detrimental economic effect on projects for soil conservation and fuelwood, leafmeal, and fodder production. The most complete documentation on the economic impact of H. cubana in the Philippines is in the CAB International report (1989). In 1985, approximately 80% of the leucaena trees in the Philippines were adversely affected by H. cubana and this was estimated to be valued at about P 60 million. In 1986, 1987, 1988, and 1989, the levels of psyllid damage to the 200,000 ha of leucaena were 80%, 70%, 60%, and 50%, respectively, and the value of this damage over the four years was about P 5,200 million.

More recently indigenous natural enemies of H. cubana combined with the accidental arrival of P. yaseeni has resulted in normalization of leucaena wood production, and leafmeal production is recovering. The distribution and direct effects of P. yaseeni on leucaena production and on the ecosystem have not been systematically monitored.

15.6.5 Training Needs

There are a number of trained specialists in the field of biological control in the Philippines; unfortunately most of them have been diverted to concentrate on other agricultural concerns. It is suggested that the expertise these specialists can contribute toward enhancing biological control be more adequately directed. Training needs do exist, particularly at the technician level (e.g., taxonomy, mass rearing, release, monitoring), among extension agents, and at the farmer level. "Train the trainer" extension programs for villages would be appropriate for the dissemination of knowledge on biological control and other IPM tactics.

One of the most important training needs for the Philippines is for high level government administrators to become aware of the economic and environmental advantages of using biological control and other IPM tactics. The irony in the Philippines regarding the scant attention given to biological control can be seen most clearly in the case of leucaena and the leucaena psyllid. Of the countries studied in this EA, the Philippines relied on leucaena production for wood, fodder, shade, and erosion control to one of the greatest extents; perhaps second only to Indonesia. The arrival of H. cubana and its rapid infestation and destruction of leucaena was therefore quite serious. Control of the pest occurred by accident when P. yaseeni arrived without human intervention, and by the predatory activity of indigenous natural enemies. This clearly demonstrates both the cost effectiveness of biological control and the degree to which it can be self-sustaining once

introduced. Still, the government of the Philippines has done little in recognition of biological control as a possible solution to many of its pest problems. This is in sharp contrast to the efforts in Indonesia and the Indonesian government's acceptance and support of biological control and IPM.

16.0 THAILAND

16.1 Importance of Leucaena

Leucaena is used in Thailand primarily for fodder and fuelwood, occasionally for soil conservation and reforestation. Thailand first introduced fast-growing varieties of leucaena in the 1960s, but it has never been grown at a large enough scale to become an economically significant crop. Current interest in leucaena centers on the potential of leafmeal to improve feed quality and boost production of Thailand's livestock and dairy industries. Increased production is sought both to improve human nutrition and to generate foreign exchange, but is constrained by poor herd nutrition. Locally available feed tends to be low quality and scarce during the dry season, necessitating imports. Leucaena currently accounts for 3.5% of the total livestock feed in Thailand, and is grown primarily by smallholders on plots of 0.5 - 1.0 ha. Leucaena's potential as a feed source is limited because much of the land area available for production is unsuitable because of soil acidity, water logging, or high elevation. In terms of growers' preference, leucaena ranks behind other multipurpose species, including eucalyptus and acacia. Thailand's Royal Forest Department and the Thailand Institute of Scientific and Technological Development (TISTD) have tried to encourage the use of leucaena for production of fuelwood and charcoal and in agroforestry, but adoption has been low.

16.2 **Leucaena Psyllid Population in Thailand**

Thailand had been warned about the leucaena psyllid after it infested Hawaii in 1984. The leucaena psyllid was first detected in Thailand in September 1986 in Chachoengsao and Chumphong Provinces (both east of Bangkok) and in the Peninsular Region (south of Bangkok). Heteropsylla cubana did not reach the Northern Highland Region (Chiang Mai and Chiang Rai Provinces) until March 1987. By May 1987, all leucaena trees in Thailand were being attacked, although the leucaena trees showed varying degrees of susceptibility to psyllid damage (Northeast and Central Thailand were the most severely affected - in 1987, many leucaena trees were completely defoliated and it is estimated that 80% of them were infested). Later, in the summer, psyllid populations seemed to disappear altogether, but resurged in October 1988. This cycle of psyllid population fluctuation appears to be seasonal, as records from subsequent years have indicated. The annual infestation period for H. cubana in Thailand seems to be from October/November to April/May. Nevertheless, year-round "pockets" of leucaena psyllids exist in the Western Highland area of Kanchanaburi, the Northern Highland area of Chiang Mai, the rim of the Northeastern Plateau area at Muak Lek in Saraburi, Pak Chong in Nakhon Ratchasima, and in Buriram. It is also possible that such population pockets exist in the Southern Peninsular area. All known pocket areas share a common topography and microclimate; elevations from 100 to 500 meters and temperatures between 20° C and 30° C. It is speculated that these pocket areas serve as sources of

reinfestation after winter population declines in combination with typhoons from the South China Sea that move across infested islands to continental Southeast Asia. Similar observations on psyllid populations were made in Vietnam.

16.3 Past and Present Biological Control Efforts

Current pest control practices in Thailand are based on the use of synthetic pesticides, usually applied on a calendar basis rather than when pests have reached economic threshold levels. In spite of the apparent dependence on pesticides, awareness and use of biological control is increasing, but support for research on biological control does not compare with that for pesticide use. However, surveys for have identified several species which can be used for augmentative control or within existing IPM programs.

Exotic beneficial insects have been introduced to Thailand (Napompeth 1990b, 1989). This discussion, however, will be limited to the use of beneficial arthropods for the control of pest arthropods, and will not concentrate on the biological control of weeds or plant pathogens.

Thailand has an array of indigenous natural enemies, and has often been explored for natural enemies for introduction to other countries. In 1930, it was noted that rice stem borer, Scirpophaga incertulas (Lepidoptera: Pyralidae), eggs were parasitized by Tetrastichus schoenobii (Hymenoptera: Eulophidae). But Thailand was not identified as an important source for natural enemies until 1974, when the parasitoid, Apanteles erionatae (Hymenoptera: Braconidae), was introduced from Thailand to Hawaii for control of the banana skipper, Erionota thrax (Lepidoptera: Hesperiidae). Natural enemies of important crop pests in Thailand are listed and discussed in Appendix M.

There have been a few instances in which exotic insect biological control agents have been introduced to Thailand (note: classical biological control has not been implemented for pests of rice). Several generalist predators in the family Coccinellidae (Coleoptera) were imported to Thailand from Hawaii on various occasions from 1974-1982 for control of mealybugs and scale insects. The coccinellids (Azya obigera, Coelophora pupillata, Cryptolaemus montrozieri and Orcus chalybeus from Hawaii, and Chilomenes lunata from Kenya) have provided reasonably successful control of their target pests.

With regard to biological control of the leucaena psyllid, C. coerulus was introduced to Thailand in 1987 and 1988, O. abdominalis in 1989, and the parasitoid P. yaseeni in 1988 (while native to tropical America, they were imported from Hawaii).

Both C. coerulus and P. yaseeni have become established, but their effect on leucaena psyllid populations has not yet been determined.

Banpot Napompeth, head of Thailand's Center for Biological

Control, warns against the indiscriminate introduction of exotic generalist predators without first understanding their potential ecological impacts and the possibility of spread to neighboring countries. A cautious approach to release of exotic beneficial organisms has therefore been adopted in Thailand.

Among the indigenous natural enemies found in association with H. cubana in Thailand, all are generalist predators, and none are parasitoids. Of the predators, coccinellids are the most common, especially Menochilus sexmaculatus and M. discolor. However, it is doubtful that there will be a generalist predator efficient enough to control the leucaena psyllid. The indigenous predators in Thailand may have to be considered together as a predator complex, the role of which is yet to be determined in any sort of IPM approach. For this reason, although Thailand has opted in general to take a careful stand on the introduction of exotic natural enemies of H. cubana, the three previously mentioned exotic insect species have been released there.

16.4 Regulations on and Quarantine of Biological Control Agents

There are no regulations specific to the introduction and use of biological control agents in Thailand. It has been proposed that regulations be developed within the Department of Agriculture by making use of current Plant Quarantine Act regulations. At present, the National Biological Control Research Center takes responsibility for testing imported biological control agents, as authorized by the Department of Agriculture. Biological control agents are received by the National Biological Control Research Center at Kasetsart University where the exotic organism is raised through one generation to screen against hyperparasites or pathogens. After screening, the natural enemy is then mass reared and released.

Dr. Napompeth would like to divide introduced beneficial insects into two categories: primary exotics, which have not been introduced elsewhere, and secondary exotics, which have been used and researched in other countries. Secondary exotics should be screened according to the FAO Code of Conduct at the National Biological Control Research Center; primary exotics should be screened similarly, but also subjected to more rigorous research, especially with regard to their potential ecological interactions with indigenous flora and fauna and vulnerability to commonly used pesticides. It is suggested that research be conducted as recommended in section 13.4 for Malaysia.

16.5 Leucaena Psyllid Control Options

16.5.1 Pesticides

Thailand's Department of Agriculture does not have primary responsibility for research on H. cubana because leucaena is not considered to be an agricultural crop by the GOT. The Department's Entomology Division, however, has been conducting research on chemical control of the leucaena psyllid on behalf of the Department of Livestock Development. Pesticide efficacy was evaluated on a farm in Kanchanaburi Province in 1988. Results indicated that in order to reduce high levels of H. cubana, leucaena trees should be harvested for fodder as soon as possible after the rainy season so the plant can produce longer shoots that are more tolerant of psyllid damage before the pest population is able to build up in the dry season. Single or double dose applications of bifanthrin, lambda cyhalothrin, carbaryl, omethoate, carbosulfan, or dicrotophos at two week intervals were effective.

The Department of Agriculture developed a spraying program which they consider to be effective and economically feasible for controlling the leucaena psyllid. However, this raises concerns of pesticide residue problems and safety to the applicator, as well as other pesticide related problems (e.g., nontarget effects and pest resistance). The leucaena spray tactic relies on systemic pesticides applied at the beginning of the dry season before psyllid populations increase. This is largely impractical because leucaena is important as a dry season feed supplement when leaf meal prices are highest; chemical residues would make it dangerous to use the leaves shortly after harvest. Dry season harvests would have to be delayed at this most economically profitable time. And, because leucaena is mainly a small farmer crop, the safety of chemical applications is highly questionable.

Although it is most desirable in any IPM strategy to establish an economic threshold level for H. cubana, any such economic threshold level must be set according to the primary use of the leucaena tree in each given area. Threshold levels also cannot accurately be determined until practical and economically acceptable sampling techniques have been devised. Finally, an economic threshold level is purely academic and unrealistic until there is an available control tactic.

16.5.2 **Resistant Varieties of Leucaena**

In Thailand, resistance trials for L. leucocephala and L. diversifolia resulted in high levels of resistance to H. cubana in two varieties. A disadvantage of these varieties, however, is that the trees do not appear to produce seeds after two years. The Thailand Institute of Scientific and Technological Research (TISTR) is devoting efforts to determine the nature and effectiveness of different sources of psyllid resistant genotypes of L. leucocephala derived from existing stands in Thailand. It is possible that the development of resistant leucaena trees combined with the use of exotic natural enemies will be an effective IPM strategy for leucaena psyllid control.

Based upon the workshop "Biological and Genetic Control of

the Leucaena Psyllid" organized by NFTA and F/FRED, 3-7 November 1990 in Hawaii, TISTR is participating in the International Network of Leucaena Psyllid Tolerance (LPT) trials established in 1987, but due to lack of seed supply and funding, the scope of the experiment in 1987 was quite limited and the results were not conclusive.

16.5.3 **Grazing and Pruning**

Little work has been done in Thailand to establish the effectiveness of grazing and/or pruning leucaena for reducing psyllid damage. As was suggested in section 13.5.3, research on the timing of grazing and pruning infested leucaena trees deserves some attention. It is, however, unlikely that this tactic will prove to be universally effective, if at all.

16.5.4 **Alternative Crops**

Thailand can be divided into four major regions for agriculture, including fodder crop production, based broadly on physiographic characteristics and climate. The four regions are the south, the central plain, the northwest, and the north. In each region, a variety of fodder crops that can serve as alternatives or supplements to the limited leucaena production exist.

The Southern Region

Only a very small area of the total 110,000 ha under cultivation has been sown specifically for forage species - mostly *Brachiaria decumbens*, *Panicum maximum*, *Centrosema pubescens*, and *Macroptilium atropurpureum*. Also, legumes such as *Centrosema*, *Calopogonium*, and *Pueraria* are grown as cover crops in rubber plantations and they provide a source of fodder. Livestock are raised in association with paddy rice graze upland communal areas where *Digitaria* sp., *Chrysopogon* sp., and *Eragrostis* sp. *Stylosanthes hamata*, *S. guianensis*, *Brachiaria* sp., and *Paspalum plicatalum* have been used for fodder in some instances of controlled grazing. The primary use of leucaena in southern Thailand is as one of many browse trees and shrubs for goats. It is suggested that research be conducted to evaluate the utility of the various browse species for ruminants in southern Thailand to better assess the need for promoting *L. leucocephala*.

The Central Plains Region

The flat flood plain of the Chao Phraya River is composed of alluvial soils ideal for paddy rice cultivation. About 93% of all farm holdings are devoted to crop production with few areas available for grazing. Livestock rely heavily on crop residues, especially rice straw, which is often supplemented by natural or planted forage cut and carried from areas inaccessible to livestock. The use of forage legumes is not as widespread as in

other regions which is likely a result of the high fertility inherent to alluvial soils. Verano stylo and leucaena fodder are most commonly used as supplements to the straw.

The Northern Region

The northern region can be subdivided into three physiographic zones: the lowlands, the uplands, and the highlands. The lowlands comprise about 16% of the area and are flat and fertile alluvial basins where rice is grown. Livestock are fed rice straw and cut and carried fodder as described for the central plain region.

Uplands make up about 45% of the area; they are hilly and about 500 meters above sea level. Upland rice, maize, grain legumes and other field crops are grown there. Successful fodder crops are Verano stylo, Townsville stylo, siratro, Panicum maximum, and Urochloa mosambicensis (Sabi grass). Use of leucaena and other forage species are used in scattered plantings, and their use has been promoted by the Forage Division of the Department of Land Development.

The highlands comprise about 40% of the northern area and are characterized by rugged mountains and plateaus about 500 - 2,500 meters above sea level. Crops grown include rice, maize, and opium. Ruminant livestock are important in the culture of some hill tribe groups and are kept as a capital reserve for draught and sacrifice at special ceremonies. The main forage resources are low value grasses, mostly Imperata cylindrica, which occur as a result of shifting agriculture. Productivity of these grasslands is low, allowing support of less than one animal per 10 ha. In order to identify suitable forage plants which would allow increased animal stocking densities, the Thailand Australian Agricultural Project conducted research trials in collaboration with Chiang Mai University and the GOT Department of Welfare. The best legumes for grazed pastures above 1,200 meters included Desmodium intortum and Macrotyloma axilliare. At elevations of 600 - 1,200 meters, Stylo guianensis and D. intortum were the most productive. The best grasses at any altitude were Nadi setaria, Panicum maximum, Paspalum plicatulum, and Brachiaria decumbens. Leucaena was found to be poorly adapted to the upper highlands but grew well at altitudes below 1,000 meters, and yielded up to 500 tons of leaf fodder per ha.

The Northwest Region

The northwest region consists of a slightly elevated plateau of 17 million ha, 100 - 300 meters above sea level, with a tropical savannah climate and pronounced seasonal distribution of rainfall. At Khon Khaen, for example, more than 85% of the total annual rainfall, 1,250 mm, occurs from mid April to mid October.

Upland soils in this region are sandy, acid, low in organic matter and cation exchange, and contain few plant nutrients (e.g., nitrogen, phosphorus, and sulfur). Still, the northwest has the highest ruminant population of the four major regions and thus has the greatest potential for forage improvement. Feed

supply is governed by distinct seasonal livestock management patterns.

Forage capacity is sufficient for only one animal per ha in the wet season and 0.52 animals per ha in the dry season. Therefore, maintenance and growth of livestock production in the northwest region depends on increasing forage quantity and improving forage quality in a traditional low cost system for greater animal production. In the wet season, paddy land and some upland is cropped so that livestock are grazed on communal areas along roadsides, forest margins, and fallow lands. Late in the wet season, forage is cut and carried from areas inaccessible to livestock. During the dry season, after rice harvest, rice stubble and straw serve as the major fodder source. The poor quality of forage available during the long dry season is one of the primary reasons for low animal production. Research on forage species, pasture establishment, animal production, soil fertility assessment and seed production has been conducted by Khon Khaen University, the Department of Livestock Development, the Land Development Department, the Department of Public Welfare, the National Security Command, and the Northeast Agricultural Center.

The use of browse trees and shrubs has been viewed as a potential solution to the problem, particularly as deep root systems allow such trees to exploit moisture at greater depths than most annual plant species so that foliage can be produced even during the dry season. Research efforts have identified leucaena as being the most successful species with yields of 11 - 13 tons of green vegetation per ha. However, the slow establishment and poor growth on acidic soils have limited its use and alternative deep rooting forage species have been and should continue to be researched. Those species that show the most promise include *Sesbania sesban*, *S. formosa*, *Albizia falcataria*, and *Enterolobium cyclocarpum*. Table 9 shows the leaf yield of several potential forage species in comparison to leucaena at Khon Khaen.

Another dry season forage strategy being studied is growing forage crops during the dry season on stored moisture in paddy fields after wheat harvest. *Crotalaria juncea*, *Stylo scabra* cv. *seca*, and *S. viscosa* have been successfully produced in such a system.

It is clear that there are a number of areas in Thailand, especially at high elevations and/or in acid soil conditions, where leucaena is not an optimal forage crop. In other areas, however, leucaena may have potential as a tree legume for fodder, particularly if *H. cubana* can be controlled.

To date, research has been carried out under numerous projects is therefore fragmented and the methods used to evaluate fodder species have not been standardized. It is important that future research be conducted in a more systematic and coordinated manner. Trials should be performed to compare different systems for managing the fodder crops in combination with other farming systems that prevail from area to area. Such trials should be

linked with animal feeding tests to measure *in vitro* organic matter digestibility, live weight gain, fertility, and optimum and realistic feeding regimes.

Dissemination of forage production techniques to farmers is another area that deserves further attention, as the rate of voluntary acceptance of new methods and crops by farmers is low. The development of effective extension services in this regard is essential.

Adoption of more well adapted fodder species, particularly those that are indigenous to Southeast Asia, would likely serve as an efficient way of circumventing problems associated with H. cubana on leucaena. As reported by CABI (1990), there exist many species of plants which could be substituted for leucaena for fodder, fuelwood, erosion control, and nitrogen fixation purposes which are not attacked by the leucaena psyllid.

16.5.5 Biological Control

Similar to many Asian countries infested by H. cubana, only C. coerulus, O. abdominalis, T. leucaenae, and P. yaseeni are being considered or have been released in Thailand. While control of the leucaena psyllid is unlikely to be sufficient using the already established C. coerulus, and it is too early to determine the effectiveness of P. yaseeni, natural enemies native to Thailand should be researched to evaluate their potential for imposing adequate control. Dr. Napompeth emphasizes the need to explore for indigenous biological control agents before importing additional exotic organisms. Such caution is particularly rational in view of the availability of alternative fodder and fuelwood crops in Thailand that are not vulnerable to H. cubana attack. However, observations on natural predators of the leucaena psyllid in Thailand (includes an ant species, dragonflies, coccinellid beetles, and sparrows) indicate that their combined effect on the pest is negligible. It is for this reason that exotic natural enemies are still being contemplated.

16.6 Country Capacity

16.6.1 Institutional Responsibilities and Coordination

There are a number of institutions and organizations carrying out research and other activities related to the leucaena psyllid problem, but only one of these, the National Biological Control Research Center (NBCRC) at Kasetsart University, is devoting significant attention to biological control of the leucaena psyllid. The Department of Agriculture (DOA) is monitoring psyllid populations and investigating

Table 9. First year yield and chemical composition of leaf material of shrub legumes at Khon Khaen, Thailand.

Species	Leaf yield g/plant Season Wet	Dry	Crude protein (%)	IVDMD* (%)
Sesbania sesban, var. *nubica*	683.4	337.0	21.3	67.8
S. sesban	541.6	167.8	26.4	69.1
S. formosa	311.7	87.8	21.5	57.9
S. grandiflora	156.9	25.0	26.5	66.9
Enterolobium cyclocarpum	518.3	302.5	21.7	68.6
Albizia falcataria	321.8	101.7	19.5	61.5
A. lebbek	130.6	97.0	28.8	54.5
Leucaena leucocephala	236.6	168.6	19.7	52.7
Calliandra calothyrsus	215.9	82.5	15.7	48.0
Cassia siamea	90.5	83.6	18.8	65.5
Samanea samon	35.4	51.2	23.4	59.9
Pithocellobium dulce	28.1	39.0	19.1	59.6
Adenanthera pavonina	22.1	42.2	16.7	66.9

*In vitro dry matter digestibility

chemical control. TISTID is conducting trials with resistant varieties of leucaena. Coordination among these groups is promoted by the National Research Council's ad hoc Committee on Psyllid Control. The regional research network secretariat for F/FRED is located at Kasetsart University and, as a member of the research network, Thailand benefits from the information sharing made possible by the regional coordination of research. Currently there are no specific regulations governing the introduction and use of biological control agents. Regulations under Thailand's Plant Quarantine Act govern imports of plants and pests, but not potentially beneficial exotic biological control agents. The director of NBCRC, Dr. Banpot Napompeth, has suggested developing regulations for the introduction and use of biological control agents by building on existing Plant Quarantine Act regulations. The NBCRC currently conducts tests related to the introduction and use of biological control agents under the authorization of the DOA.

16.6.2 Equipment and Facilities

Screening, testing, and rearing of exotic biological control agents currently being used for psyllid control have been conducted at NBCRC's facilities at Kasetsart University. These activities are primarily the responsibility of Dr. Napompeth. Napompeth has successfully reared and released two exotic biological control agents for use against H. cubana: C. coerulus and P. yaseeni. Nevertheless, existing equipment, facilities, and staff should be improved to carry out quarantine activities and post-quarantine procedures that meet standards outlined in the proposed FAO code of conduct, and to mass rear and propagate biological control agents in sufficient numbers for an effective control program. Napompeth has proposed establishing a government funded national research center devoted to biological control activities, but the government has not yet responded to his proposal. Pest control in Thailand currently relies heavily on pesticides; while there is increasing interest in alternatives, government support for the necessary research and development is inadequate.

16.6.3 Data and Information Management

NBCRC coordinates its activities with other agencies and institutions, including universities, but currently no institution has assumed responsibility for synthesizing data and results from research activities related to different elements of a psyllid control strategy. These activities are currently fragmented between NBCRC (biological control), the DOA (psyllid population monitoring and chemical control), and TISTD (testing of resistant varieties). Data on the economic contribution of leucaena and the economic cost of psyllid infestation are limited; more baseline data and increased capacity to collect additional data on an ongoing basis would be required to evaluate

the benefits of instituting a biological control program.

16.6.4 Environmental and Economic Assessment

As noted above, there is little data on the economic value of leucaena or the economic impact of H. cubana on leucaena production. Thailand was among the countries included in CAB International's economic review of psyllid damage in southeast Asia and Australia; their study indicated limited impact, primarily borne by the smallholders who raise leucaena. After two years of significant losses (1987 and 1988) production has recovered to nearly match pre-infestation levels. Potential environmental impacts from introducing biological control agents for H. cubana were assessed in Thailand. NBCRC surveyed for indigenous natural enemies of H. cubana in 1986; based on laboratory tests and published reports on the biology and ecology of the two exotic biological control agents, NBCRC was confident that the likelihood of adverse environmental consequences from release of the two exotic natural enemies would be negligible.

16.6.5 Training Needs

Short term training in a variety of areas is needed for Thailand to establish an effective biological control program against the leucaena psyllid. Training aimed at longer term capacity building will be necessary to sustain current abilities, to develop the human resource base in terms of both numbers and skills, and to promote the integration of biological control as a component of broader IPM efforts. All activities related to development of a biological control program need strengthening, beginning with the need to formulate regulations governing the introduction, quarantine, and screening of exotic biological control agents. Additional skilled staff and facilities would be needed for mass rearing and propagation; supervision of releases, monitoring psyllid population dynamics, damage assessment, and estimation of economic impacts. Because psyllid damage in Thailand is limited, investment in training should be directed toward transferable skills to the degree possible; that is, toward general capabilities in biological control that are applicable to other pests. In-country capacity to supply such training is limited; Dr. Napompeth of NBCRC teaches a university course on biological control and has also been teaching extension agents, but additional similarly qualified individuals would be needed to train sufficient staff within a reasonable period of time.

17.0 GENERAL CONCLUSIONS

Although H. cubana infestations were serious in each country studied in this EA, the present condition of leucaena production has been a function of each individual country's ability to impose control on the pest by biological methods whether through the deliberate introduction of exotic natural enemies, or by incidental control attained through indigenous natural enemies or the accidental arrival of an exotic natural enemy (e.g., P. yaseeni in the Philippines). Those countries that have been unable to mount an effective biological control program against H. cubana still suffer the effects of reduced or terminated leucaena production as a fodder, wood, and shade source.

Of the various tactics available for control of H. cubana, classical biological control is the only proven successful method. Classical biocontrol, however, must be implemented with a great deal of discretion. It is possible that deliberately introduced exotic biocontrol agents will result in adverse impacts on nontarget organisms and thus disrupt target sand/or nontarget ecosystems. For this reason, studies on the possible nontarget ecological impacts of exotic biocontrol agents should precede field releases (see section 7.0). In the case of using host specific parasitoids (e.g., Psyllaephaeus yaseeni and Tamarixia leucaenae) against H. cubana in Asia, the potential for causing adverse nontarget effects is very low; nevertheless, use of these wasps should be preceded by systematic ecological interaction studies. Use of generalist predators (e.g., Curinus coerulus) should involve more extensive ecological impact studies because of their ability to attack more than one species of organism (which is likely to involve nontarget species). It has been recommended in this EA that countries that plan to release exotic biocontrol agents against H. cubana conduct ecological impact studies prior to releases in order to determine the environmental soundness of using the selected biocontrol agent, and to conduct follow-up ecological studies for biocontrol agents that are released to determine the efficacy of the agent and to identify unexpected ecological impacts.

Ideally, biological control should be used in combination with psyllid-resistant leucaena varieties in an integrated approach to managing this pest. As a general rule, diversification of multipurpose tree species in agricultural systems would promote greater economic stability when unforseen devastating events, such as the H. cubana infestation of leucaena, befall one of the tree species. In areas where biological control agents and resistant varieties of leucaena are not viable, replacement of L. leucocephala with alternative and indigenous plant species seems to be the most prudent option.

Recommendations to strengthen each country's capacity to combat or circumvent the detrimental effects of H. cubana are provided in section 19.0.

As a final note, leucaena has become an important legume tree in East Africa. Although H. cubana has not yet arrived on the African mainland, it has invaded the islands of Mauritius and Reunion; it is only a matter of time before the African mainland is infested. It is therefore strongly suggested that, based upon the experience of southeast Asia and the Indian subcontinent presented in this EA, the application of biological control tactics be explored in Africa.

18.0 RECOMMENDATIONS

Agency for International Development

1. A.I.D. should develop policy, regulations, and environmental procedures for its programs, projects, and activities that involve the use of biological control agents and genetically engineered living organisms in developing countries.

2. A.I.D. should be flexible in its approach to promoting multipurpose tree species; species that are not indispensable (e.g., there exist many alternative species that can serve the same function and are not vulnerable to leucaena psyllid attack) should not be promoted.

3. A.I.D. should encourage work on developing alternative and indigenous fodder and fuelwood tree species (with respect to Leucaena leucocephala) and on the development of psyllid resistant leucaena varieties if leucaena is found to be an indispensable fodder and fuelwood source.

4. A.I.D. should continue to focus efforts on developing IPM strategies and provide appropriate technical assistance for strengthening biological control capacity in developing countries.

5. A.I.D. should encourage developing countries to strengthen their quarantine facilities, procedures, policies, and regulations for importation of plants and animals (including biological control agents) and genetically engineered organisms. In tandem, A.I.D. should encourage other donor countries and international development organizations to do the same.

6. A.I.D. should promote the integration of various government, private industry, and regional institutions and organizations (e.g., ASEAN PLANTI) in each developing country for more effective quarantine, production, release, and evaluation of exotic biological control agents.

7. A.I.D. should encourage the creation of regional organizations devoted to quarantine outside of the ASEAN member countries. In other words, the ASEAN PLANTI example should be promoted in other regions.

8. A.I.D. and other donor countries and organizations should urge that countries that harbor indigenous biological control agents that are being requested for use in other countries, exercise restraint in supplying these organisms to the countries that have expressed and interest in them unless effective/enforced quarantine and screening procedures are in place in the recipient country.

9. A.I.D. and other donor countries and organizations should encourage governments that desire to use biological control agents to conduct surveys for indigenous biological control agents prior to requesting exotic organisms for biological control purposes.

10. Prior to promoting exotic tree species in developing countries for agricultural, silvicultural, or other purposes, A.I.D. and other donors, PVOs, and NGOs should conduct or support thorough research on the pest complexes that attack such trees in the native habitat, and determine the probability of the pests' arrival in the country(s) to which the tree is to be introduced. Necessary precautions should then be taken before the tree is imported such that should a pest arrive from its original habitat, mitigative measures can be applied before damage to the tree can become pronounced and widespread. In the spirit of this recommendation, it is suggested that preventive action be taken, based upon the experience of leucaena production and its recent infestation by H. cubana in Asia, in Africa where L. leucocephala is also being grown but has not yet been attacked by the leucaena psyllid.

11. **A.I.D. should urge that exotic biocontrol agents be studied with regard to their interactions with nontarget organisms, as well as survivorship and ecology beyond the target ecosystem (e.g., in natural forests).**

All Countries

The introduction of biocontrol agents should be contemplated carefully, with consideration of efficacy of the agent against the target pest, adaptability of the exotic biocontrol agent to the new habitat, economic impacts of classical biocontrol, and the ecological impacts of the introduced biocontrol agent on nontarget organisms and systems (see section 7.0).

India

1. Quarantine procedures should be expanded to include study of possible nontarget effects that may result from the introduction of exotic biological control agents.

2. Research on alternative legume tree species should be continued to diversify wood, fodder, and shade tree sources.

3. Training is needed at research institutes involved with aspects of biological control, especially in microhymenoptera taxonomy and handling of parasitoids.

4. Information networking on biological control and IPM is needed at the international level.

5. India should conduct research on the effects of commonly used pesticides on potential biological control agents (both exotic and indigenous) and possible IPM strategies for leucaena psyllid control.

6. India should conduct systematic research to determine the best alternative crops to Leucaena leucocephala; if L. leucocephala, given the current leucaena psyllid infestation, is not as feasible for fodder and fuelwood production as other tree species, then alternative crops should be focussed upon in lieu of leucaena.

7. If resistance to the leucaena psyllid is to be pursued further, work should be conducted on identifying the mechanism(s) that impart such resistance such that screening trials can be directed with greater precision.

8. Quarantine procedures for biological control agents should be expanded beyond screening against the accidental introduction of hyperparasites and pathogens, and the possibility that biological control agents will cause injury to important crops. Tests should be conducted to determine the biological control agent's possible interactions and effects of commonly used pesticides on the efficacy of the biological control agent.

9. India should conduct systematic research to determine the best alternative crops to Leucaena leucocephala; if L. leucocephala, given the current leucaena psyllid infestation, is not as feasible for fodder and fuelwood production as other tree species, then alternative crops should be focussed upon in lieu of leucaena.

Indonesia

1. The Indonesian response to the infestation of H. cubana by rapidly promoting the use of C. coerulus using both research and extension effectively should continue and the principles brought to bear on other pest problems which could be alleviated with biological control agents.

2. Quarantine procedures should be expanded to include study of possible nontarget effects that may result from the introduction of exotic biological control agents.

3. Research on alternative legume tree species should be continued to diversify wood, fodder, and shade tree sources.

4. Biological control laboratory and rearing space should be expanded, and equipment provided (e.g., microscopes) to improve the quality of existing resources.

5. Training is needed at research institutes involved with aspects of biological control, especially in microhymenoptera taxonomy and handling of parasitoids.

6. Taxonomic keys are needed for parasitoid wasps.

7. Information networking on biological control and IPM is needed at the international level.

8. Training is needed in insect pathology, which would help to better identify, develop, and use potential microbial biological control agents, and to protect beneficial arthropods from entomopathogen epidemics.

9. Indonesia should be encouraged to export its successful experience in biological control to other Asian countries with similar needs.

Laos

The science of pest management in Laos is at a "ground zero" level, where even the most basic information (e.g., pest population dynamics and complexes, economic impacts of pests on crop production, identification of beneficial organisms) is lacking. With specific regard to leucaena production and infestations of H. cubana, information appears to be nonexistent. Therefore, recommendations must be reduced to the broadest of terms and at the most basic levels of agricultural production. This would require a complete assessment of the agricultural sector in Laos, and production of leucaena may not be identified as a high priority. Nevertheless, the current and potential importance of leucaena and other legume trees should be assessed in terms of their possible contributions toward the improvement of crop, livestock and forestry production and soil conservation.

This broad recommendation is made while bearing in mind that agricultural production in Laos still exists in a "time capsule" where both the positive and negative influences of agricultural "development" and "modern" methods have not as yet been introduced. Therefore, Laos represents a unique case in which environmentally friendly and sustainable pest management strategies can be developed and implemented early enough, if well planned and coordinated, to avoid many of the problems encountered in the development of pest management strategies in other Asian countries.

Malaysia

1. Malaysia's cautious approach to promoting leucaena cultivation is prudent in light of the leucaena psyllid infestation.

2. Malaysia's willingness to quarantine and study Tamarixia leucaenae for several years prior to its release is equally prudent.

3. Research on leucaena resistance, the effects of pruning and grazing, and biological control using indigenous organisms for Heteropsylla cubana control should continue with an aim for developing an integrated, nonchemical approach.

4. Quarantine screening procedures for exotic biological control agents should include studies on their interactions with local ecologies.

5. Malaysia should conduct research on crop diversification and its effects on leucaena psyllid populations and potential biological control agents (both exotic and indigenous).

6. Malaysia should also conduct research on the effects of commonly used pesticides on potential biological control agents (both exotic and indigenous) and possible IPM strategies for leucaena psyllid control.

7. There is a need to determine the importance of Leucaena leucocephala as a fodder, fuelwood, and shade source for Malaysia such that rational decisions can be made regarding the perceived need to promote cultivation of leucaena in light of the existing leucaena psyllid infestation.

8. If resistance to the leucaena psyllid is to be pursued further, work should be conducted on identifying the mechanism(s) that impart such resistance such that screening trials can be directed with greater precision.

9. Quarantine procedures for biological control agents should be expanded beyond screening against the accidental introduction of hyperparasites and pathogens, and the possibility that biological control agents will cause injury to important crops. Tests should be conducted to determine the biological control agent's possible interactions and effects of commonly used pesticides on the efficacy of the biological control agent.

10. Malaysia should conduct systematic research to determine the best alternative crops to Leucaena leucocephala; if L. leucocephala, given the current leucaena psyllid infestation, is not as feasible for fodder and fuelwood production as other tree species, then alternative crops should be focussed upon in lieu of leucaena.

Nepal

1. There is a need to assess the present and potential economic importance of leucaena such that realistic determinations can be made on whether or not its cultivation should be promoted further.

2. Nepal has a need to continue research on indigenous alternative plants to L. leucocephala.

3. There is a need for research on pruning and grazing effects on leucaena psyllid populations and how such tactics can be timed and incorporated into an IPM strategy.

4. NGOs need training on biological control; NGOs often promote such tactics but frequently do not understand them adequately enough to promote their safe and effective use.

5. NGOs should be doing psyllid resistance studies for leucaena rather than simply promoting existing psyllid susceptible varieties.

6. There is a need for policies and regulations on import of biological control agents and genetically engineered organisms that, at a minimum, conform to existing FAO Codes of Conduct on these topics.

7. Nepal needs to explore for and conduct research on indigenous potential biological control agents.

8. Development of regulations and policies on quarantine for both plants and animals (including biological control agents) should be encouraged, and mechanisms for enforcement should be devised and implemented.

9. The GON Department of Entomology scientists should not be overburdened with too many diverse responsibilities.

10. GON Department of Entomology biological control facilities must be upgraded, and staff increased with additional personnel will trained in biological control and IPM. Also, transportation to field sites must be available for biological control programs to be implemented and systematically evaluated.

11. Current entomological research results are largely unavailable in Nepal; efforts should be made by concerned NGOs and donor countries/organizations to rectify this paucity of scientific information.

12. Agricultural extension agents in Nepal should receive periodic training in all IPM tactics, and the extension agents should be provided with adequate transportation to make frequent visits to farmers in spite of the relatively poor infrastructure in Nepal.

13. Farmers from areas throughout Nepal should receive training to become trainers in the villages, similar to the training center (sponsored by the Netherlands) for apiculture.

14. The Japanese-built Horticulture Center in Kirtipur should be utilized for research as well as training, given the modern facilities there which appear to be of greater utility than those presently at the disposal of government and university researchers.

The Philippines

1. Studies should be conducted to determine the distribution and economic effect of P. yaseeni, and to determine whether or not farmers and plantation owners who grow leucaena need to be trained in on-site mass rearing of P. yaseeni.

2. The government of the Philippines should promote the concept and implementation of biological control, especially since staff trained in biological control and facilities for biological control already exist in-country.

3. Personnel with existing specialties in the field of biological control should be encouraged to maximize their potential for contribution in biological control rather than being diverted to unrelated tasks.

4. Extension agents should receive more intensive training in biological control and other IPM tactics, and a train the trainer program at the village level should be instituted to better disseminate this information to the farmer.

5. There should be closer linkages between research and extension entities.

6. Research on alternative legume trees indigenous to the Philippines should be continued to diversify sources for wood and leafmeal production.

7. There should be greater collaboration among institutions, agencies, donors, NGOs, and PVOs in the Philippines with regard to legume tree, livestock, and forestry promotion and production.

8. Quarantine procedures should be expanded to include study of possible nontarget effects that may result from the introduction of exotic biological control agents.

9. Development of psyllid resistant leucaena varieties, especially K784 and K785, should be continued to augment the control of H. cubana achieved incidentally with indigenous natural enemies and accidentally with P. yaseeni.

Thailand

1. Even though a National Biological Control Research Center exists in Thailand which carries out quarantine and screening tests for exotic biological control agents, Thailand still needs policy and regulation on the importation of biological control agents, and facilities that will be devoted to that purpose.

2. As recommended by Dr. Banpot Napompeth, the introduction of biological control agents should be contingent upon thorough surveys for potential indigenous biological control agents which may possibly preclude the need to import exotic organisms for this purpose.

3. Thailand's pre-release screening procedures should include research on potential interactions of exotic biological control agents with target ecosystems.

4. Thailand's research staff for implementing and assessing biological control agents should be expanded through increased training programs.

5. Thailand's agricultural extension service should continue to evolve more toward promotion of IPM, and away from the interests of agrochemical producers.

6. Research in Thailand should be directed increasingly at developing appropriate IPM strategies rather than being primarily focussed on pesticide use.

7. Research on leucaena resistance, the effects of pruning and grazing, and biological control using indigenous organisms for H. cubana control should continue with an aim for developing an integrated, nonchemical approach.

8. There is a need to research crop diversification and effects on leucaena psyllid populations and potential biological control agents.

9. Thailand should determine pesticide effects on biological control agents and integrated pest management strategies.

10. There is a need to determine the importance of *L. leucocephala* as a fodder and fuelwood source for Thailand such that rational decisions can be made regarding the perceived need to promote cultivation of leucaena in light of the existing leucaena psyllid infestation.

11. There is a need to focus research on identifying those crops that could be used as alternatives to *L. leucocephala*.

12. The distribution and effect of *P. yaseeni* in Thailand should be systematically monitored.

APPENDIX A

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APPENDIX B

Persons Contacted

India
Singh, S.P.
Biological Control Center
National Center for Integrated Pest Management
Bangalore, India

Indonesia
Bisson, Jerry
Natural Resources Officer
USAID/Indonesia
Jakarta, Indonesia

Oka, Ida N. Entomologist
Bogor Research Institute for Food Crops
Bogor, Indonesia

Two unidentified technicians
Bogor Research Institute for Food Crops
Bogor, Indonesia

Laos
Alton, Charles. Agricultural Economist
UNDP
Vientiane, Laos

Amaranthithada, Latsanivong. Head of Plant Research Division
Department of Agriculture and Extension
Ministry of Agriculture and Forestry
Vientiane, Laos

Bodhisane, Soukaseum. Vice Provincial Governor
Head of Agriculture and Forestry Service
Savannakhet, Laos

Keobounphanh, Sisavath. Member of the Central Committee of the Popular Revolutionary Party of Laos
Ministry of Agriculture and Forestry
Vientiane, Laos

Rasavanh, Chantihip. Agronomist
Department of Agriculture
Ministry of Agriculture
Vientiane, Laos

Saphangthong, Siene. Vice Minister
Ministry of Agriculture and Forestry
Vientiane, Laos

Malaysia

Amin, Mohd Najib. Agronomist, Livestock Research Division, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia

Chai-Lin, Tan. Research Officer, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia

Hamid, Mohd Norowi. Deputy Director, Basic Research Divsion, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia

Hong, Loke Wai. Senior Research Officer (Entomology), Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia

Ibrahim, A. Ghani. Department of Plant Protection, Faculty of Agriculture, Universiti Pertanian Malaysia, Selangor, Malaysia

Ilah, Ngiza. Horticulturalist, Plant Quarantine, Department of Agriculture

Kashyap, Arun. Forestry Information Specialist, CABI, Kuala Lumpur, Malaysia

Mohamed, Ahmad ZamZam. Director of Fundamental Research, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia

Mohammed, Khairi H. CABI, Kuala Lumpur, Malaysia

Muhammad, Khamsiah. Assistant Director, Plant Quarantine, Department of Agriculture, Kuala Lumpur, Malaysia

Ooi, Peter A.C. Entomologist, IIBC, Kuala Lumpur, Malaysia

Peng, Chen Chin. Senior Research Officer, Malaysian Agricultural Research and Development Institute, Kuala Lumpur, Malaysia

Sajap, Ahmad Said. Faculty of Forestry, University Pertanian Malaysia, Selangor, Malaysia

Sivanaser, M. Director, ASEAN-PLANTI, Selangor Darul Ahsan, Malaysia

Nepal

Arens, Thomas. Office Director, World Neighbors, Kathmandu, Nepal

Bowen, M. Roderick. Research Coordinator, Nepal-UK Forestry Research Project, Department of Forestry, Kathmandu, Nepal

Dickey, Alex. ADO, USAID/Nepal, Kathmandu, Nepal

Joshi, Samudra Lal. Entomologist, Entomology Division, National Agricultural Research Services Center, Kathmandu, Nepal

Manandhar, Dhruba H. Entomologist, Entomology Division, National Agricultural Research Services Center, Kathmandu, Nepal

Rechlin, Michael. Chief of Party, Institute off Forestry Project, Institute of Forestry, Pokhara, Nepal

Upadhaya, Batuk. Forestry Specialist, USAID/Nepal, Kathmandu, Nepal

The Philippines

Rushing, Kevin A. Environmental and Natural Resources Officer
USAID/Philippines
Manila, the Philippines

Sanchez, Ferndando. Entomologist and Vice Chancellor for Academic Affairs
University of the Philippines at Los Banos
Los Banos, the Philippines

Thailand

Awang, Kamis. Network Specialist, Winrock International - F/FRED, Bangkok, Thailand

Khemnark, Choob. Faculty of Forestry, Kasetsart University, Bangkok, Thailand

Lantikan, Celso. Winrock International - F/FRED, Bangkok, Thailand

Napompeth, Banpot P. Entomologist, National Biological Control Research Center, Kasetsart University, Bangkok, Thailand

APPENDIX C

Glossary

Coccinellidae	Taxonomic family (in Order Coleoptera) that includes ladybird beetles.
Coleoptera	Taxonomic order for beetles (Class Insecta).
Diptera	Taxonomic order for flies (Class Insecta).
Exotic	An organism originally from another area, country, or region.
Hemiptera	Taxonomic order for true bugs (Class Insecta).
Homoptera	Taxonomic order for psyllids, aphids, mealybugs, cicadas, leafhoppers, scale insects, etc. (Class Insecta).
Hymenoptera	Taxonomic order for wasps, bees and ants (Class Insecta).
Hyperparasite	A parasitoid of a parasitoid (usually a wasp).
Lepidoptera	Taxonomic order for butterflies and moths (Class Insecta).
Parasitoid	An organism that kills its host by using it as part of its reproductive cycle (usually wasps).

APPENDIX D

A.I.D. PLANS TO TRAIN ASIAN TECHNICIANS IN BIOLOGICAL CONTROL OF *HETEROPSYLLA CUBANA*

116

AID 1350-1 (3 87)

*PIO/T

AGENCY FOR INTERNATIONAL DEVELOPMENT

PROJECT IMPLEMENTATION ORDER/TECHNICAL SERVICES

1. Cooperating Country: Worldwide

Page 1 of 1 Pages

2. PIO/T No.

3. [X] Original or Amendment No. ____

4. Project/Activity No. and Title: 936-5517 PD&S FN

Environmental Planning and Management

DISTRIBUTION

5. Appropriation Symbol: 72-1101021.3

6. Budget Plan Code: DDNA-90-13600-KG11 043-36-099-00-20-01

7. Obligation Status: [X] Administrative Reservation [ ] Implementing Document

8. Project Assistance Completion Date (Mo., Day, Yr.): 3/31/91

9. Authorized Agent: M/SER/OP/W/R

10. This PIO/T is in full conformance with PRO/AG No. PAF s/ Date 2/26/90

11a. Type of Action and Governing AID Handbook: [ ] AID Contract (HB 14) [X] AID Grant or Cooperative Agreement (HB 13) [ ] PASA/RSSA (HB 12) [ ] Other

11b. Contract/Grant/Cooperative Agreement/PASA/RSSA Reference Number (If this is an Amendment)

12. Estimated Financing (A detailed budget in support of column (2) is attached as Attachment No. ____

		(1) Previous Total	(2) Increase	(3) Decrease	(4) Total to Date
Maximum AID Financing Available	A. Dollars		150,000		150,000
	B. U.S.-Owned Local Currency				

13. Mission References

14A. Instructions to Authorized Agent

M/SER/OP is requested to negotiate a grant with CAB International Institute of Biological Control (CIBC) in support of its unsolicited research proposal "Implementation of biological control for leucaena psyllid in Asia and Africa." Attached is Certification of Non-solicitation.

14B. Address of Voucher Paying Office: Agency for International Development
PFM/FM/AD, SA-2
Washington, D.C. 20523-0209

15. Clearances – Include typed name, office symbol, telephone number and date for all clearances

A. The Project Officer certifies that the specifications in the statement of work or program description are technically adequate.
S&T/FENR, Michael Bange — Phone No. 54063 — Date

B. The statement of work or program description lies within the purview of the initiating office and approved agency programs.
S&T/FENR, Twig Johnson (Actg.) — Date 4/3/90

C. S&T/EN, Jack Vanderryn — Date 4/4/90

D. Funds for the services requested are available
PFM/FM/AD, Gloria Craig — Date

E. S&T/FENR, Pat Bowen — Date 4/5/90
S&T/PO, Garland Standrod

16. For the Cooperating Country: The terms and conditions set forth herein are hereby agreed to

Signature _____ Date _____

Title

17. For the Agency for International Development

Signature _____ Date _____

Title Elizabeth P. Roche, Chief, S&T/PO/PR

*See HB 3, Sup. A, App. C, Att B, for preparation instructions. Note: The completed form contains sensitive information whose unauthorized disclosure may subject an employee to disciplinary action.

UNITED STATES OF AMERICA
AGENCY FOR INTERNATIONAL DEVELOPMENT

Name of Proposing Institution

CAB International
Institute of Biological Control
Silwood Park
Buckhurst Road
Ascot, Berks SL5 7TA
UK

Telephone: 011-44-990-872999
Facsimile: 011-44-990-872901
Telex: 9312102255 (BC G)

Title: Implementation of biological control for leucaena psyllid, *Heteropsylla cubana*, in Asia and Africa.

Date: 15 January 1990

Institutional Administrator	Research Projects Leader
Dr. D. J. Greathead Director, CIBC	Dr. J. K. Waage Deputy Director, CIBC

IMPLEMENTATION OF BIOLOGICAL CONTROL FOR LEUCAENA PSYLLID IN ASIA AND AFRICA

I. BACKGROUND

In 1985, a sucking insect, *Heteropsylla cubana*, appeared in Southeast Asia as a new and serious pest of the multipurpose leguminous tree crop, leucaena (*Leucaena leucocephala*). The pest, which was introduced accidentally from the tropical American homeland of leucaena, caused immediate and serious damage to leucaena production by defoliating and even killing trees over large areas.

In Indonesia, losses to cattle production dependent on leucaena for fodder rose in the first years of infestation to over $4 million pa, while losses of about $1 million pa were incurred in coffee, cocoa and other tree crops, where leucaena is grown as a shade tree. In the Philippines, where leucaena leaf meal was part of a growing animal food export industry, drops in production of over 50% were estimated. Beyond these commercial uses, leucaena had been widely accepted as an important fuel and fodder crop by many small farming communities and had an important role in reducing erosion losses and building soil nitrogen supplies. Losses to these farmers could not be estimated.

In 1987, consultation by national programmes and the Fuelwood and Forestry Research and Development (F/FRED) program of USAID led to the development of a regional control strategy for this pest based on two complementary approaches:

1. the use of natural enemies of the pest, including indigenous species and specialized, exotic species introduced from the pest's area of origin

2. the breeding of varieties of leucaena for resistance to the psyllid.

The first strategy, and particularly the introduction of exotic control agents, was seen to be the most promising in the short term, and on the basis of similar programmes in the past against exotic psyllids and other related sucking insects, had a good chance of success.

II. BIOLOGICAL CONTROL OF LEUCAENA PSYLLID

The first attempt at biological control of the psyllid in Asia involved the introduction of a predatory beetle, *Curinus coeruleus*, which was found to have some effect on the psyllid in Hawaii where it had appeared in 1984.

This insect proved to be effective in controlling the psyllid on leucaena in Indonesia plantations when it was mass produced and released in large numbers. However, on its own it does not reproduce with sufficient rapidity to control rapidly growing psyllid populations. Thus, while *C. coeruleus* can reduce the intensity of outbreaks, it is not effective in searching out low populations of psyllid and thereby preventing the initiation of outbreaks. It has now established in wetter climatic zones of Indonesia and efforts are

being made to establish it in other countries. Some countries, however, such as Papua New Guinea and Australia, have banned its introduction because, as a nonspecific predator, it puts at risk existing and planned biological control in key crops, and may also have undesirable effects on rare indigenous birds which depend on native psyllids.

Experience with biological control of psyllids and related insect pests indicates that specialized parasitic wasps exist which would be more effective than these predators and more specific to particular psyllids, thereby reducing the risk of detrimental effects to the environment (Greathead 1988).

II.1 Involvement of CIBC in leucaena psyllid biological control

The invasion of leucaena psyllid into Asia was seen by affected countries as a serious and immediate problem requiring urgent action. In early 1987, in response to requests for assistance in biological control from countries in the Pacific and Asia, the CAB International Institute of Biological Control (CIBC) initiated studies on leucaena psyllid and particularly the identification of suitable biological control agents from its area of origin.

In February 1988, CIBC based a research entomologist, Dr. Bob Brown, at its Caribbean and Latin American Station (CLAS) in Trinidad to study the ecology of the pest in its native region an to undertake exploration in the Caribbean and Central America for its natural control agents. This research was predicated upon the knowledge, from preliminary work by CIBC and the Hawaiian Department of Agriculture (HDOA), that the psyllid was not a pest in its native region and that it had a number of natural enemies there.

Part of this programme was supported by grants from the International Development Research Centre (IDRC - Ottawa) and the Australian Centre for International Agricultural Research (ACIAR - Canberra).

Over the following 18 months, exploration was made in 13 tropical American countries, yielding over 25 species of natural enemies of leucaena psyllid (Waage 1990). In addition, detailed population studies were carried out in Trinidad, and two promising control agents, both parasitic wasps, were brought into culture. Both species were new to science and were described by staff at the CAB International Institute of Entomology (CIE) and the British Museum of Natural History (BMNH) as *Tamarixia leucaenae* and *Psyllaephagus yaseeni*. *P. yaseeni* had previously been introduced into Hawaii by the HDOA under the name, *P.* sp. nr. *rotundiformis*, where it has been shown to attack low density populations of the psyllid and contribute to its control (Funasaki et al. 1990).

As of December 1989, both parasitoid species are in culture awaiting detailed biological studies to determine rearing methods and host specificity as a prerequisite to their provision to Asian national programmes.

II.2 The present status of leucaena psyllid biological control

Meanwhile in Asia, leucaena psyllid had spread to Sri Lanka, Nepal and India, causing there the same kind of severe defoliation as previously

observed in Southeast Asia. In its wake, leucaena had shown substantial recovery in countries like Philippines, with seasonal psyllid outbreaks being less dramatic than before. Nonetheless, losses to leucaena are considered continuing and serious. In Philippines, for instance, it is presently estimated that foliage production by leucaena is 50% of what it was before the psyllid.

In response to the continuing problem of leucaena psyllid, a meeting of national programmes in Asia and the Pacific was held in Indonesia in January 1989, supported in part by the F/FRED programme of USAID. This meeting recommended that:

"Biological control should be emphasized as one of the main components in management strategies to control H. cubana [and there is a need to] continue the search for natural enemies in the native range of leucaena psyllid until effective natural enemies become available for introduction."

Subsequent to this, an economic analysis of the impact of leucaena psyllid in Southeast Asia and the cost-benefit relationship of various control options (including biological control) was undertaken by CAB International's Development Services for the Australian International Development and Advisory Bureau (AIDAB). This analysis concludes that continuing damage caused by the pest is less than that indicated by initial infestations, but sufficient to recommend the expense (small relative to continuing losses) of introducing classical biological control agents, particularly for control of the pest on fodder leucaena, for which use an alternative tree species is not available.

II.3 The risk to Africa

Leucaena has been identified as a tree crop of much potential value to farming systems in Africa. Following research at the International Institute of Tropical Agriculture (IITA) in Nigeria, the use of leucaena in alley cropping is being widely promoted as a means to increase productivity and reduce fallow periods. Throughout Africa, leucaena is finding uses in agroforestry systems and as a fodder source for livestock, through national and regional programmes and the activity of international institutes such as IITA, the International Centre for Research on Agroforestry (ICRAF) and the International Livestock Centre for Africa (ILCA).

With the arrival of leucaena psyllid in India, the likelihood of its spread to Africa is much increased. Work by CIBC and the Overseas Development Research Institute (ODNRI) of the UK Government has identified the major means of dispersal of psyllid on the basis of its movement across the Pacific and Asia and the meteorological conditions which applied at the time. Applying this information to the African situation, it is possible, but unlikely, that airborne psyllids will reach the eastern African coast, where leucaena grows as a component of secondary vegetation. More likely is the psyllid's arrival by aircraft from India into such destinations as Nairobi and Addis Adaba, where leucaena is to be found in the vicinity of the airports.

The arrival of leucaena psyllid in Africa will jeopardize a number of existing and planned programmes of leucaena use, affecting small

farming systems in particular. Accordingly, a programme is planned with ICRAF and the African Phytosanitary Commission of the Organization of African Unity to develop an early warning system for the arrival of the psyllid, in order to bring biological control quickly to bear where a pest problem may first appear. Initial work in this area has involved the drafting of an information sheet for leucaena growers, which is awaiting funding for further development.

III. ADVANTAGES OF CIBC

The CAB International Institute of Biological Control (CIBC) is a non-profit, fully international, intergovernmental organization which aims to "promote through research, training and implementation the use of biotic agents for the supression of pests, as a component of pest management programmes and with emphasis on the needs of developing countries". Since 1927, it has provided the only truly international service in biological control, and today runs over 50 current biological control projects from bases in UK, Switzerland, Kenya, Pakistan, India, Malaysia and Trinidad. From its base in Trinidad established in 1945 and now the Caribbean and Latin American Station (CLAS), CIBC has undertaken many programmes of exploration for biological control agents of neotropical insects and weeds that have become pests elsewhere in the world.

CIBC's services are backed up by outstanding taxonomic institutes, including the CAB International Institutes of Entomology (CIE) and Mycology (CMI), whose expertise is essential for exploration programmes which invariably turn up new natural enemy species. It is also supported by CAB International's Information Service which annually scans about 10,000 serials and 5000 books, theses, reports, etc. to prepare a unique computerized database on world agriculture. This abstract database is presently growing by 135,000 records per year and is made available in 46 abstract journals and a number of other paper and electronic products.

CIBC has longstanding associations with many national and international programmes in biological control and pest management. Relevant to this proposal, CAB Interantional interacts closely with the Inter-American Institute for Co-operation in Agriculture (IICA) and the Caribbean Agricultural Research and Development Institute (CARDI), has established a Memorandum of Understanding with the University of the West Indies (UWI) and with the Consortium for International Crop Protection (CICP).

In Africa, CIBC maintains a station as part of the Kenya Agricultural Research Institute in Nairobi, where it bases regional programmes in pest management currently funded by ODA, IDRC and IITA. It has an active MoU with the International Centre for Insect Physiology and Ecology (ICIPE), involving interactions in many areas of research and information technology, and has recently developed cooperation with ICRAF on pest management in agroforestry. In 1988 CAB International co-hosted with ICRAF a workshop on this subject at its headquarters in the UK.

In Asia, CIBC works closely with national biological control programmes on a range of projects. In the past few years this has

included cooperative programmes and consultancies in biological control in India, Sri Lanka, Thailand, Malaysia, Philippines, Indonesia, Solomon Islands, Papua New Guinea and Australia. An MoU exists with the International Rice Research Institute (IRRI) which covers current cooperation in research and training.

CIBC's broad coverage and local expertise in biological control across the tropics facilitates its participation in pan-tropical programmes of biological control, such as that against leucaena psyllid. Its close working relationships with national and regional organizations at both ends of such a biological control effort will ensure efficient and rapid implementation of the leucaena psyllid natural enemies which CIBC has developed over the past two years.

IV. OBJECTIVES

This programme will implement available biological control for leucaena psyllid through the provision to Asian national programmes of properly quarantined cultures of the insect parasitoids, *Psyllaephagus yaseeni* and *Tamarixia leucaenae*. Where appropriate and desired, CIBC will provide assistance and training on the quarantine, production, release and assessment of these biological control agents.

In addition, CIBC will provide, through two international training courses, comprehensive training in biological control for Asian national programme staff, and will establish with ICRAF an early warning system and contingency plans for control of the leucaena psyllid in Africa.

V. PLAN OF RESEARCH

The programme would be conducted over a one year period, to begin in April 1990, as funds to maintain parasitoid cultures in Trinidad may not be available after that. The re-establishment of these cultures for a subsequent programme would be expensive.

V.1. Trinidad-based activities

The Scientist in Charge of CIBC's Trinidad station would supervise production of natural enemies and studies relevant to their provision to Asian national programmes, including host specificity studies on their mass rearing. He would be assisted by one full-time technician. He would organize shipments of *P. yaseeni* and *T. leucaenae* to UK for quarantine.

V.2. UK based activities and activities for Africa

Quarantine agreements between ASEAN countries recommend "third country quarantine" for living material of tropical and American origin, due to the risk of introducing rubber disease and other pests not presently in Southeast Asia. Quanrantine of parasitoids of leucaena psyllid would be carried out at CIBC's International Quanrantine Centre in UK, under the supervision of a CIBC quarantine specialist with experience of Asian requirements. Here it would be confirmed that material destined for Asia was free of hyperparasites, insect diseases and plant diseases.

A project co-ordinator would be identified at the UK Station who would be responsible for co-ordinating shipments into quarantine and forward shipments to Asia. The latter would involve liaison with the Scientist in Charge of CIBC's Malaysian Station and, where appropriate, national programmes.

The other role of the project co-ordinator would be to develop the African early warning system. This would involve establishment of an identification service for leucaena psyllid at the CIE, and a visit to ICRAF to plan the production of advisory leaflets and prepare an action plan in the event of the appearance of the pest on the continent. The CIBC Kenya Station would assist in logistical support for this activity.

V.3. Asian-based activities

In Asia, the Scientists in Charge of CIBC's Malaysian Station would visit national programmes to discuss procedures and timing of shipments of natural enemies from UK into their quarantine facilities. Where requested, he would provide on-site training for national programme staff assigned to the project in the laboratory rearing of the psyllid and its natural enemies, and on appropriate quarantine, release and assessment procedures. He would then co-ordinate shipments from CIBC UK and make follow up missions for trouble-shooting and determination of the need for further shipments.

In addition, provision will be made for three positions each on two training courses in biological control to be run by CIBC in Southeast Asia in 1990. A four-week training course on biological control in rice based cropping systems will be run at IRRI in September 1990. This course will provide training in methods for the assessment of natural enemies and their control by exotic and native agents which will be directly relevant to leucaena psyllid biocontrol. In addition, a portion of the course will be devoted specifically to leucaena psyllid biological control problem.

A second four week course on biological control for ASEAN quarantine staff will be run in December 1990 at ASEAN PLANTI in Malaysia. This course will also cover basic methodologies in biological control but will concentrate on the process of quarantine clearance of biological agents ny national programmes. The leucaena psyllid project will be a specific component of this course.

National programme staff attending these courses will receive specific instruction in leucaena psyllid biological control and broader instruction aimed at strengthening the capacity of their national programmes to carry out similar work in future.

Towards the end of the project, a detailed report will be made of the project and its achievements, including a country-by-country assessment of shipments received, their fate and the status of the local biological control programme.

VI. PERSONNEL

The project will be coordinated by Dr. Sean Murphy from CIBC UK headquarters. Dr. Murphy has eight years experience in the biological control of tropical pests, particularly on tree crops, and is presently responsible within CIBC for the development of a joint programme with ICRAF on pest management in agroforestry systems. Dr. Murphy will ensure the smooth movement of parasitoid material from Trinidad to Asia and will manage its quarantine in UK. He will also be responsible for the development of the African early warning system with ICRAF and associated institutions.

Dr. Murphy will be assisted in quarantine operations by Mr. Anthony Cross, Chief Technical Officer of CIBC UK Station. Mr. Cross has five years experience in the handling of tropical insects in quarantine and, for instance, has been responsible in recent years for the quarantine of biological control agents for the cassava mealybug and mite for the Africa-Wide Biological Control Program of IITA.

In Trinidad, Dr. Peter Baker, Scientist in Charge of CIBC's Caribbean and Latin American Station (CIBC-CLAS), will organize continuing studies on leucaena psyllid and provision of agents to CIBC UK. Dr. Baker has been in charge of CIBC's leucaena psyllid project for IDRC and ACIAR since 1989, and therefore is in a position to apply the considerable experience built up at CIBC-CLAS on this subject. Mrs. Sylvia Singh has been a technician at CIBC-CLAS for over 20 years, with specific responsibilities in the rearing of insect natural enemies and their shipment to other countries.

In Asia, Dr. Peter Ooi is the head of CIBC's Malaysian operation, based at CABI Asian Regional Office in Kuala Lumpur. He is a leading proponent and researcher into biological control in Southeast Asia and has conducted originally and highly valued research on biological control in rice, vegetables and plantation crops. Through close contacts with the Malaysian Agricultural Research and Development Institute (MARDI), and his many missions in Asia on behalf of CIBC, he has been closely involved with the development of leucaena psyllid work, and maintains close contacts with the relevant national programmes there.

VII. SIZE OF GRANT REQUIRED AND BASIS OF PAYMENT

A total sum of $US 149651 of S&T Bureau Small Activity funds for one year would be required to cover the cost of the work envisaged. This would include the cost of:

- part time employment of Drs. Murphy, Baker, Ooi and Mr. Cross
- full time employment of Mrs. Singh
- travel and subsistence costs for consultation and training
- equipment designated specifically for the project
- shipments of natural enemies and their quarantine
- preparation and publication of reports
- administration of the project

For provision of the services provided in the project, funding would be requested as indicated in the project schedule below. The costs are in American currency, using an exchage rate to pounds sterling of 1.65. An overhead charge of 30% on total project costs is made to cover administration of the project and of staff posted abroad.

CIBC's contribution to the project includes provision of laboratory facilities and equipment, office space and the use of vehicles for local travel at CIBC's stations in Trinidad, UK, Kenya and Malaysia, and provision of information services from CABI.

SUMMARY BUDGET

Salaries	
Existing staff	45652
Fringe benefits	10714
Travel	
International	9650
Local	500
Research expenses	25800
Training expenses	22800
Administrative costs	34535

TOTAL	149651

APPENDIX 1

PROJECT SCHEDULE

The proposed project shall commence on 1 April 1990

TABLE 1. DETAILED BUDGET (US DOLLARS)

SALARIES

TITLE	ANNUAL SALARY	% TIME DEVOTED TO PROJECT	SALARY CHARGED TO PROJECT
Existing Staff			
Dr. Baker	30441	50	15221
Mrs. Singh	6485	100	6485
Dr. Murphy	27061	25	6765
Mr. Cross	19543	30	5863
Dr. Ooi	22635	50	11318

FRINGE BENEFITS

Benefits covered (methods of calculation where applicable)

SA - superannuation (pension)
NI - UK national insurance (health insurance - UK govt scales)
FSA - foreign service allowance (UK civil service scales)
SLS - salary in lieu of superannuation (basic salary X 10%)

	SA	NI	FSA	SLS
Dr. Baker	1650		3582	
Mrs. Singh				649
Dr. Murphy	1184	486		
Mr. Cross	645	520		
Dr. Ooi	1998			

TRAVEL

Travellers/Purpose	No. trips	Cost/trip	Total
INTERNATIONAL			
Dr. Murphy collaboration with ICRAF on psyllid early warning system for Africa	1	1650	1650
Dr. Ooi consultation/training of Asian national programme staff in implementation	8	1000	8000
LOCAL			
Mrs. Singh collection of psyllids and natural enemies from Trinidad and Tobago	50	10	500

RESEARCH EXPENSES

Descriptions	
Taxonomic services (CIE, BMNH) for identification of African material	2000
Consumables	
- CIBC-CLAS for parasitoid production	1000
- UK for quarantine	1000
- Malaysia for coordination and local production	3000
Quarantine costs (220d@$40/rm/d)	8800
Publication	500
Telecommunication	1000
Shipments of parasitoids (10@$850)	8500
Subtotal	25800

TRAINING EXPENSES

Course fees/Travel/Subsistence for regional training courses	
- CIBC-IRRI (3 participants)	4950
- CIBC-ASEAN PLANTI (3 participants)	4950
Salaries/Travel/Subsistence for CIBC trainers	
- CIBC-IRRI (2 trainers)	8600
- CIBC-ASEAN PLANTI (1 trainer)	4300
Subtotal	22800

ADMINISTRATIVE COSTS (30% of total)	34535

APPENDIX E

JUSTIFICATION FOR USING EXOTIC NATURAL ENEMIES

4. CLASSICAL BIOLOGICAL CONTROL AND OTHER METHODS USING EXOTIC NATURAL ENEMIES

4.1 Justification for using exotic natural enemies

4.1.1 During the century since the introduction of the Vedalia beetle (*Rodolia cardinalis*) into California in 1888 some 5000 introductions of exotic natural enemies have been made chiefly for the classical control of insects and weeds (Table 1) but also mammals, molluscs, mites and other invertebrates. Other organisms, chiefly pathogens and nematodes, have been introduced for the development of biological pesticides by government and commercial laboratories. Several products are commercially available, some marketed internationally (Table 2).

4.1.2 Although only about one in four introduced biological control agents have become established and only a proportion of these make an important contribution to control of the pest, overall some 305 species of insect pests and 48 species of weeds have been controlled in at least one country. The pests which have been controlled include many of major importance throughout a region. Thus, prickly pear cactus (*Opuntia* spp.) was controlled over 60 million acres in Queensland and New South Wales by introduction of two insect species. Further, a number of successful biological controls have been repeated in other countries. For example, the cottony cushion scale (*Icerya purchasi*) has been controlled in at least 28 countries and the control of prickly pear cactus has been repeated in some 16 countries. In these instances the cost of control was minimal because the development work has already been done.

4.1.3 Unfortunately economic assessments of classical biological control are scarce. Too often, because the result is so obvious, cost/benefit analysis has been considered unnecessary. However, some rigorous assessments exist and show that the return on investment can be very high (Table 3), because control continues indefinitely without the need for further expenditure to maintain it. This characteristic of classical biological control makes it an unattractive commercial investment. Consequently most programmes have been carried out by governments or international organisations using public funds. On the other hand the farmer does not bear any direct financial or labour costs which makes the method especially attractive for resource poor farmers in developing countries.

4.1.4 In many instances classical biological control has been used where alternative controls were not feasible. Notable is the recent control of the South American cassava mealybug (*Phenacoccus manihoti*) in 34 affected African countries. Chemical control of mealybugs is difficult, too costly on a subsistence foodcrop and inadvisable in countries where the young shoots are gathered as food. Weeds of pasture and rangeland are also prime targets because of the low unit value of the land, which makes herbicides uneconomic, and because of the extent of the infestation to be controlled.

4.1.5 Thus, classical biological control is an economical and sometimes the only practicable control method for major introduced pests, especially in developing countries. Because of its achievements and potential for the future, given the likelihood of an increasing number of invasions by alien pests as the volume of international trade and travel increases and journey times are reduced, the regulation of biological control introductions should be designed so as to encourage its safe use while avoiding unnecessary restriction.

4.1.6 Importations of natural enemies for biological control involving periodic releases for short-term control are valuable when classical biological control

is not feasible. These biological control techniques share with classical biological control the advantage that their impact is more or less restricted to the target pest and so have minimal effects on populations of non-target organisms or on man since there are no toxic residues to pollute the environment or to contaminate food.

4.2 **Organisms used as biological control agents**

4.2.1 The range of organisms which has been proposed or used as biological control agents includes vertebrates and invertebrate predators, parasitic insects, and nematodes, as well as pathogenic microorganisms - protozoa, fungi, bacteria and viruses. Introductions of mongooses and other generalist vertebrate predators, chiefly on to oceanic islands during the 19th century for rodent control, were an ecological disaster because these animals are opportunists and take the most readily available prey. Therefore, not only did they frequently fail to provide adequate rodent control but they attacked chickens and native fauna, contributing to extinction of some endemic species. Although other generalist predators, including the giant toad (*Bufo marinus*)and predatory snails, continued to be introduced until recently, often with unfortunate side effects, introduction and liberation of such organisms is no longer recommended by responsible biological control practitioners and, indeed, is forbidden in some countries.

4.2.2 There remain special circumstances where generalists can be acceptable as biological control agents. Thus, predatory fish are used for mosquito control in wells and ornamental ponds where they are unable to escape into natural waterbodies. The restricted fauna of such habitats also ensures that mosquito larvae are the major component of the prey. Another exceptional situation is the use of herbivorous fish to control submersed waterweeds in ponds, reservoirs and irrigation canals. The Chinese grass carp or White Amur (*Ctenopharyngodon idella*) is attractive for this purpose because it requires very specific conditions for reproduction which are not met in the places where it is used, and so the numbers of fish can be controlled and, should they escape, the population will die out eventually. Also, in many situations sterile grass carp hybrids are used to avoid the possibility of reproduction.

Table 1

SUMMARY OF CLASSICAL BIOLOGICAL CONTROL RESULTS

USING INSECT AGENTS TO CONTROL INSECT PESTS AND WEEDS

NO OF:	INSECT PESTS	WEEDS
INTRODUCTIONS	4271	574
ESTABLISHMENTS	1307	327
PROJECTS	1361	96
TARGET PESTS	494	93
GOOD CONTROLS	305	48
COUNTRIES	138	48

From the IIBC BIOCAT databank (insects) and Julien (1987) (weeds)

Table 2

EXAMPLES OF PATHOGENS IN OPERATIONAL USE FOR ARTHROPOD PEST CONTROL

		FUNGI	
Beauveria bassiana	various	USSR	Boverin
Metarhizium anisopliae	froghoppers (*Aeneolamia* spp)	Brazil	Metaquino, Biomax
	rhinoceros beetle (*Oryctes rhinoceros*)	Pacific	Metapol
	brown plant hopper (*Nilaparvata lugens*)	SE Asia	Conbio, Metabio
Verticillium lecanii	aphids (*Aphididae*)	Europe	Vertalec
	whitefly (*Trialeurodes vaporariorum*)	Europe	Mycotal
	thrips (*Thrips tabaci*)	Europe	Thriptal
		BACTERIA	
Bacillus popilliae	Japanese beetle (*Popillia japonica*)	USA	Doom
B. thuringiensis	caterpillars (*Lepidoptera*)	Cosmopolitan	Bactospeine, Thuricide, Dipel, etc
	mosquitoes (*Culicidae*), etc.		Bactimos, Skeetal, Teknar, etc
		PROTOZOA	
Nosema locustae	grasshoppers (*Acrididae*)	USA	Nolo Bait
		VIRUSES	
Baculovirus	rhinoceros beetle (*Oryctes rhinoceros*)	Pacific	-
Nuclear polyhedrosis viruses	gypsy moth (*Lymantria dispar*)	USA	Gypchek
	boll worms (*Helicoverpa zea Heliothis virescens*)	USA	Elcar
	pine sawfly (*Neodiprion sertifer*)	Europe N. America	Neochek-S
Granulosis virus	codling moth (*Cydia pomonella*)	Europe N. America	Carpovirusine

NEMATODA

Steinernema bibionis	vine weevil (*Otiorhynchus sulcatus*)	UK, USA	Nemasys
Heterorhabditis sp.	vine weevil	Australia	Otinem Biosafe-N
Deladenus siridicola	woodwasp (*Sirex noctilio*)	Australia	-

Table 3

SOME ECONOMIC ASSESSMENTS OF CLASSICAL BIOLOGICAL CONTROL PROGRAMMES

(US $ millions)

PEST	REGION	SAVINGS *	COSTS OF CONTROL PROGRAMME
Cassava mealybug (*Phenacoccus manihoti*)	Africa (1984-2003)*	2205	14.8
Rhodes grass scale (*Antonina graminis*)	Texas (1974-8 mean)	194	0.2
Skeleton weed (*Chondrilla juncaea*)	Australia (1975-2000)	346.4	3.1
Wood wasp (*Sirex noctilio*)	Australia (1975-2000)	20.2	8.2
White wax scale (*Ceroplastes destructor*)	Australia (1975-2000)	2.2	1.4
Two spotted mite (*Tetranychus urticae*)	Australia (1975-2000)	22.9	0.9
Potato tuber moth (*Phthorimaea operculella*)	Zambia (1974-1980)	0.55	0.04
Alfalfa weevil (*Therioaphis trifolii*)	USA (1954-1986)	77.0	1.00
Water fern (*Salvinia molesta*)	Sri Lanka (1987-2112)	11.4	0.22

* The years in parenthesis are those of the period used by economists in calculating the discounted benefits shown in column 3 'savings'.

4.2.3 On the whole, the kinds of organisms used as biological control agents are now limited to species belonging to groups of organisms which experience has shown tend to have very restricted host ranges and do not readily exhibit switches in host preferences. These are principally:

Predators	Those insect predators such as some ladybirds, (Coccinellidae) specialist predatory mites etc. which are constrained by habitat preference and feeding behaviour to certain groups of pests in specific situations.
Parasitoids	Many of this diverse group of parasitic insects show a high degree of specificity to one or a few host species.
Parasites	Few are suitable except certain species of nematodes specialised as parasites of insects and weeds.
Pathogens	Pathogenic microorganisms with a narrow host range especially those with strains or species restricted to a single host.
Plant feeding insects etc.	Certain families of insects and a few other invertebrates exhibiting a high degree of host plant specificity.
Competitors and antagonists	Some harmless invertebrates and microorganisms which preclude the establishment of harmful pest species are used to inoculate crops or habitats prior to pest attack.

4.2.4 In practice, choice of biological control agents has to be related to the circumstances in which they will be used. Thus, where the pest has no close relatives either of economic importance or present in the native biota, less stringent host specificity screening is required than where there are valued species at risk.

4.2.5 Because screening cannot usually include all species at risk, for cost or logistic reasons, and the precise behaviour of an introduced species cannot be predicted from pre-introduction studies, no absolute guarantee of safety can be given. Therefore the degree of specificity required in a control agent should depend on circumstances. Consequently each proposed introduction should be judged on its merits. A comprehensive assessment should be made by the regulatory authority which should include a review of the economic importance of the pest, the benefits and disadvantages of alternative control measures and their costs as well as the potential benefits and risks of introducing a biological control agent. Only when this is done is it possible to make an informed decision on where the greater benefit lies and to determine if any possible negative effects are sufficiently offset by the advantages.

4.3. Targets for biological control and available agents

4.3.1 The suitability of different pests as targets for biological control depends on many factors. The economic and social justification for biological control has been reviewed above (4.1). The feasibility of biological control also depends on the origin of the pest, the group of organisms to which it belongs and the

existence of suitable natural enemies. These biological factors should be evaluated before a research programme is initiated.

4.3.2 Traditionally, introduced species are considered prime targets for biological control using introduced natural enemies on the premise that they have arrived accidentally in small numbers with a low probability that they were accompanied by their natural enemies, especially if the pest is scarce in its area of origin. However, native or other long established pests may also be good targets if it can be shown that their importance as pests varies in different parts of their range and this is due to the action of natural enemies present in some areas but not in others. Good prospects for biological control may also exist when a pest species has a close relative in another region which has effective natural enemies.

4.3.3 Pests must also belong to groups of organisms which have effective natural enemies that are also safe to other organisms. Few vertebrate pests satisfy these requirements; their predators are mostly opportunists, their parasites are non-specific or have stages affecting unrelated non-target organisms, and many of their diseases are also not specific. An exception which has been exploited is the myxoma virus from South American relatives of the European rabbit (*Oryctolagus cuniculus*) which provided effective control of rabbits in Europe and Australia until the pathogenicity of the virus became attenuated.

4.3.4 Similarly, pest molluscs have not proved to be ideal targets. Their parasites tend to have vertebrates as their final hosts and the pathogens discovered so far are not sufficiently host specific. Predators have been used but do not meet current standards of specificity and were not very successful.

4.3.5 Many insect pests present ideal targets and are the subject of the majority of successful biological controls reported to date. Some 66% of the successes relate to Homoptera - aphids, plant hoppers, scale insects, mealybugs etc. The success rate with other insect orders is lower (Table 4) but some excellent results have been obtained for most of them. Success rates are higher for insects feeding in exposed positions; those with larvae boring into plant tissue may escape natural enemies and consequently success rates against these are lower. Soil pests present the most difficult targets. The list of successful agents for insect control is dominated by parasitic wasps and flies but some groups of specialised insect predators have also proved effective. Diseases have been chiefly useful as biological pesticides but, where an efficient dispersal mechanism exists, they have provided classical biological control agents - for example the rhinoceros beetle virus in the South Pacific which is dispersed by infected beetles.

4.3.6 Mites do not have parasites but their specific mite predators provide effective control agents and some fungal pathogens are being developed as biological pesticides.

4.3.7 Many weeds have proved to be good targets for biological control, especially dominant species which have a major impact in pastures, rangeland or in perennial crops. To date most effort has been applied to perennial weeds and has involved introduced arthropods or more recently pathogens, notably rust fungi. Annual weeds of arable land provide a less attractive target because in many instances a large number of species are present and all of them must be controlled at the same time. Also, because of their short life span and the unstable environment in which they grow they do not provide ideal targets for long-term biological control, so host specific strains of pathogens are being developed as biological herbicides for short-term suppression of the seedlings of these weeds.

Table 4

RELATIVE SUCCESS RATE OF CLASSICAL BIOLOGICAL CONTROL OF INSECT PESTS BY ORDER

ORDER	SUCCESS RATE (%)
Homoptera	66
Lepidoptera	18
Coleoptera	7
Diptera	5
Hymenoptera	1
Heteroptera	1
Others	2

From BIOCAT Databank.

4.4 Outline of steps in a classical biological programme

4.4.1 Biological control research, being directed at controlling single pests, is relatively expensive and should not be initiated without prior assessment of feasibility and the potential return on investment. The economic analysis should include estimation of the current level of damage caused, a comparison of the costs of alternative control procedures including the frequency at which they will be needed and a forecast of the likely future extent of the problem if no action is taken. For example, for European knapweeds (*Centaurea* spp.) invading Canada, factors favouring a biological control campaign included the high cost of repeated herbicide applications and the estimation of the extent of infestation when the weed had reached the limits of its potential distribution. It is also pertinent to consider the side effects of action in terms of pollution, loss of amenity, threat to native fauna and flora as well as the direct costs to the farming community.

4.4.2 Biological control programmes can be conveniently costed in 'scientist years' to obtain a measure of the resources required independent of currency values. It has been estimated that for the knapweed programme the supply and screening of an agent requires 2 - 3 scientist years and that 6 agents might need to be processed to obtain control of the weed. Such calculations provide a guide to the investment needed and can be used in reaching a decision on whether initiation of a programme is justified.

4.4.3 The evaluation stage should also include the preparation of a dossier on the pest which not only assists in judging feasibility but provides the essential background information for a research proposal. This should include as much of the following as possible:

1) Accurate identification of the pest and information on its world distribution.

2) An opinion on the probable area of origin of the pest and proposals for search areas where candidate agents are likely to be encountered.

3) A digest of what is known of the ecology and biology of the target pest.

4) A critical list of records of natural enemies of the pest and if appropriate those of its close relatives highlighting species or groups likely to be good candidate control agents.

5) Any information on biological control results achieved on related pests.

4.4.4 The programme will probably include the following steps:

1) Surveys in selected source areas, preferably within the area of origin or where this is not feasible in areas where the pest is reported to be of minor importance

2) Ecological studies on natural enemy impact at selected sites with emphasis on the role of potential control agents

3) In-depth life history studies on selected candidate agents including development of rearing techniques

4) Host specificity screening, especially for weed control agents

5) Preparation of a screening report to be the basis for an application for an import permit

6) Collection and multiplication of the candidate agent, including screening for disease and parasites

7) Shipment into quarantine into the receiving country and screening for purity of the culture after granting of import permit

8) Further host specificity screening if required to apply for a release permit

9) Multiplication and release after approval has been obtained

10) Evaluation of the outcome of releases.

4.4.5 Usually one agent is imported at a time so that the steps from 7-10 may be repeated. Where agents are already known and have been successfully used elsewhere the work in steps 1-4 will already have been completed so that, unless additional host specificity screening is required, the programme can start at step 5 provided a source of agents has been identified.

5. RISKS ASSOCIATED WITH INTRODUCED BIOLOGICAL CONTROL AGENTS

5.1 Background

5.1.1 The foregoing analysis has indicated areas of risk in biological control. The risks related to the manufacture and application of biological control agents chiefly concern the health of those working in insectaries, pathogen production and when applying formulated pathogens. These have been dealt with elsewhere by WHO (1981) and FAO (1988). This document is concerned with the risks to non-target organisms and the environment from

the introduction of exotic organisms. All introduced organisms present a potential hazard, and proposals for introductions should be subject to scrutiny, but the greatest risk relates to those introductions made in the expectation that the biological control agent will become permanently established. Experience with invading species has shown that eradication is seldom feasible, or indeed possible, once an organism has spread beyond its point of entry. Thus, it is important that biological control introductions are made only after an evaluation of the advantages, disadvantages and risks. The advantages have been reviewed here (4.1) and it is shown that very considerable economic benefit can result from successful biological control. The possible negative effects are summarised as a background to the formulation of guidelines for the regulation of biological control introductions.

5.2 Direct damage to non-target species of economic importance and native fauna and flora

5.2.1 Screening programmes are designed to assess the risk that non-target organisms will be attacked and provide the data for a risk assessment. The procedures are outlined in section 6. As indicated, the level of acceptable risk must be decided by the importers (4.2.5).

5.3 Indirect environmental damage

5.3.1 Reduction in the abundance of pests may leave empty niches which can be occupied by other noxious species. For example, destruction of stands of major weeds may leave bare ground which is then colonised by another weed or results in soil erosion. These dangers must be assessed by the importing country which should consider measures to ensure that the pest is replaced by useful or other non-controversial species. Thus, pasture grasses may be seeded to replace a weed. However, prior analysis should have been carried out to assess the economic value of a proposed biological control programme which should not have been sanctioned unless the removal of the pest problem was expected to result in economic or environmental benefits of value to the community (4.4.1).

5.4 Conflicts of interest

5.4.1 An organism may be a pest to part of the community but valued by another part, as in the Australian Patterson's Curse/Salvation Jane controversy (1.2.3). Such problems should be settled in advance of approval of a biological control programme on the basis of where the greater benefit lies for the community as a whole.

5.5 Environmental pollution

5.5.1 Biological control agents do not normally pollute the environment. However, following introduction, successful agents may become temporarily very abundant and become a nuisance. For example, successful weed control agents may leave large amounts of decaying biomass which may be offensive. These problems are transient, and if the public is informed of their temporary nature and the long-term benefits which will ensue, complaints can be minimised.

5.6 Damage from contaminants

5.6.1 Biological control agents for shipment should be screened to ensure that they are free from their own natural enemies which might limit their effectiveness, and from contamination with plant and animal pathogens. Further, they should be packed using sterile or otherwise inert materials free of contaminating organisms. As with host-specificity screening cost/benefit considerations should be taken into account so that precautions are appropriate and not excessive. Thus, elimination of all pathogens from insects can be expensive and ineffective if the pathogen is widespread and non-specific so that the agent will soon become reinfected in the receiving country. The shipping authority should be responsible for taking sensible precautions but the receiving authority should specify any special needs and conditions. For example, intermediate quarantine in a third country may be specified to ensure that major diseases of the crop host of the pest are eliminated. Where possible, agents should be shipped as resting stages (insects) or *in vitro* cultures (pathogens) and inclusion of living host plant or animal material avoided.

5.6.2 As an added precaution, all shipments should be opened in quarantine or other secure premises for inspection on receipt and all packaging and other extraneous material destroyed or sterilised promptly. Any suspect material of the control agent or contaminated shipments should also be destroyed at once.

5.7 Concern of neighbouring countries

5.7.1 Natural enemies are not constrained by political boundaries and may spread out of the country in which they are released into neighbouring countries. Importing countries should be aware of this and, where appropriate, inform their neighbours or regional organisation acting on behalf of their governments of the intention to introduce biological control agents.

5.8 Conclusions

5.8.1 Thus, the dangers requiring international guidelines relate to the safety of the biological control agent to non-target organisms and the avoidance of contaminants. The issues relating to the level of acceptable risk and conflicts of interest are the province of the importing country alone.

6. SAFETY PROCEDURES

6.1 Screening tests

6.1.1 The potential dangers posed by introduced plant-feeding organisms to crops have long been recognised. Consequently, it has been a requirement for many years that agents for weed control should be rigorously screened to ensure, as far as possible, that they will not damage crops and other useful plants. Thus, safety procedures for weed control agents began to be developed early this century and the procedures developed over the years provide a model for devising screening procedures which are being introduced for other categories of biological control agents. Further, concern for native flora and fauna has now resulted in many countries requiring screening of endangered native species as well as economically important non-target organisms. Therefore, safety screening of all biological control agents proposed for introduction is now being demanded by many countries. Because, of the pioneering work done on weed control agents and the greater

experience gained with them, procedures for screening organisms attacking plants will be outlined first. 142

6.1.2 All screening tests on candidate biological control agents should employ the strain which would be released so as to ensure that intraspecific variation does not invalidate the tests (2.3). Likewise, it is advisable to use the same strain of the pest which is to be controlled in tests to avoid the possibility of incompatibility which might lead to failure.

6.2 Weeds

6.2.1 Initially, screening of insect agents for weed control was done by carrying out 'no-choice' feeding (starvation) tests and oviposition tests on a range of economically important plant species in which the test agents were held isolated in small containers with the test plant until it died or fed (oviposited) on the plant offered. It was soon realised that under the highly artificial conditions of these tests where insects are confined in small containers, abnormal results are frequent and lead to the rejection of species which are host plant specific under field conditions. Accordingly, more realistic procedures were developed and protocols for their use were debated by participants in successive International Symposia on Biological Control of Weeds. The outcome has been the adoption of agreed protocols by IIBC, CSIRO and USDA for the selection of test plants and the conduct of screening tests. These incorporate a centrifugal testing sequence first proposed by Wapshere in 1975 (Wapshere, 1989) which seeks to determine the host range of the candidate agent by tests on varieties of the target weed, species in the same genus as the weed, genera in the same tribe and so on until only negative results are obtained. As a check on these results other plants selected on the following criteria are also tested:

1) Other recorded host plants of the candidate agent, however dubious such records may be

2) Host plants of species closely related to the candidate biological control agent

3) Unrelated plants with biochemical or morphological characteristics in common with the target weed

4) Crop plants grown in the area where control of the weed is desired, but having a poorly known pest fauna and disease complex, and those that for geographic, climatic or ecological reasons have not been exposed to attack by the candidate agent.

6.2.2 The degree of specificity which needs to be demonstrated and the level of risk which is acceptable depend on the importance of the weed and the presence of non-target species closely related to it in the environment where the weed is to be controlled. Thus, less specificity can be tolerated for cactus insects in countries such as Australia where there are no native cacti than for natural enemies of wild blackberries, because other species and hybrids of the genus *Rubus* are cultivated for soft fruit production. However, agents are usually rejected if there is evidence that other plant species are at risk.

6.2.3 The nature of the screening tests depends to an extent on the life cycle of the agent and the stage, or stages, which select the host plant. For insects, feeding tests are carried out except for those species where the ovipositing parent is the sole determinant of where the offspring will feed, e.g., gall makers and leaf miners. Similarly, oviposition tests are carried out for all

species which oviposit in or on the host plant. Both tests are usually carried out as multiple choice tests in the presence of the weed host as control using excised plant parts or potted plants, as appropriate, for species which fail no choice screening. Where positive results are obtained, further tests are carried out to determine whether the candidate can complete its life cycle on the plants in question. These may be further supplemented with field experiments in the area of origin in which test plants are exposed in a stand of the weed infested by the candidate and observations are made on the candidate's host range under natural conditions. Sometimes it is also possible to set up a garden of test plants including examples of the target weed imported from its invasion area, in order to carry out screening outdoors - provided that there are no restrictions on importing noxious plants back into the area of origin. These additional tests may demonstrate host specificity in the early stages of host finding which are circumvented under cage conditions, e.g., the mite for the control of gorse (*Ulex europaeus*) now released in New Zealand is never found on non-hosts outdoors but does attack some varieties of French beans (*Phaseolus vulgaris*) in captivity.

6.2.4 Recently, fungi have been successfully used in weed control and the protocols developed for insects have been adapted for safety testing of pathogens. Infectivity tests are carried out in which infective stages are applied to test plants in the laboratory and plants are exposed to natural infection in the field.

6.2.5 These procedures appear to provide a reliable guide to the performance of weed control agents because no unanticipated attacks on non-target plants have been reported for agents released after being screened using the above protocols.

6.3 Insects

6.3.1. Until recently, control agents for insects were not rigorously tested, it being deemed sufficient if they were not known to attack economically important insects (bees, silkworms, lac insects) or other beneficial species. However, more rigorous requirements are being introduced in some countries to protect native fauna.

6.3.2 For some insect parasitoids and predators, the protocols developed for weed agents can be adapted and used, but many more of these insects behave abnormally under cage conditions than plant feeding insects. Since entomophagous species respond to a complex of chemical and physical cues from the environment, host plant and pest hosts, key determinants of host specificity may occur at any of these levels and be eliminated in highly simplified test environments. Consequently, greater reliance on other measures of host range will be required in making safety assessments of entomophagous insects, viz. field studies in the country of origin to determine the natural host range with special regard to determining the environmental and biological factors which delimit the niche occupied by the candidate insect. Unfortunately test insects, being mobile, cannot be used in the kind of field experiments which can be used in screening test plants in the field. Therefore, these observations may be supplemented by laboratory studies on host identification behaviour, olfactory cues used in locating hosts, developmental parameters including nutritional requirements and modelling of the life cycle and phenology in relation to that of species at risk.

6.4 Micro-organisms

6.4.1 Micro-organisms and parasites for insect control can be screened using the same procedures as micro-organisms for weed control by carrying out infectivity tests and following these when necessary with in-depth studies on the course of infection in the laboratory. However, as with insect control agents, screening in the field is not feasible and recourse has to be made to study of the epidemiology of the pathogen in relation to the ecology of non-target species of insects which may be at risk.

6.4.2 Antagonists, principally micro-organisms used for control of plant diseases, can be screened using the same principles as for pathogens to be used for weed control to ensure that they are not pathogenic to plants. Similarly, competitors can be screened in this way when they are micro-organisms. Invertebrate competitors can be processed using the techniques for parasitoids and predators.

6.4.3 Pathogens of vertebrates present a potential risk to human and animal health. Therefore it is strongly advised that WHO should be consulted before they are considered as candidate biological control agents for vertebrate pests.

APPENDIX F

A CODE OF CONDUCT FOR THE INTRODUCTION OF BIOLOGICAL CONTROL AGENTS

7. A CODE OF CONDUCT FOR THE INTRODUCTION OF BIOLOGICAL CONTROL AGENTS

7.1 Prior considerations

7.1.1 Introductions of natural enemies for biological control of pests should only be carried out with the consent of the national government of the country where liberations are to be made. Governments are advised to consider designating an authority with powers to issue permits for the introduction and liberation of biological control agents. The chosen authority in countries with legislation in place is usually that charged with regulating plant quarantine by the Ministry of Agriculture or that charged with regulating introductions by the Ministry of Environment. The Ministry of Health may also regulate introductions of agents for disease vector control. It would be appropriate to involve officials or advisors from all three areas to ensure that all potentially interested parties are consulted. It would also be appropriate to seek advice from outside agencies with experience in biological control when new initiatives are proposed. The FAO can assist in identifying sources of expertise.

7.1.2 Biological control agents should only be introduced when a clear benefit to the community is to be expected (5.4.1). Therefore, the authority responsible for issuing permits for importing of biological control agents should determine in advance if control of the pest is in the public interest, and provide those parties likely to be affected with an opportunity to put their case for or against biological control. Neighbouring countries or regional quarantine authorities should also be consulted to clarify any potential conflicts of interest between countries as well as those that may arise within countries (5.7). If the decision is in favour of implementing biological control, guidance should be provided to the agency undertaking the introduction programme as to the level of allowable risk of damage to non-target species and should be specified (5.2).

7.1.3 The agency proposing to carry out the control programme against the pest is advised to obtain government approval before investing money in research. To provide the information on which a decision can be based as to whether

to invest in biological control, as much of the following information should be obtained as is possible (4.4.3):

1) Accurate identification of the pest to provide full scientific name and details of its classification

2) Summary of available information on the origins, distribution, biology, natural enemies damage and impact of the pest, actual and potential, on the economy

3) Indication of the likely cost of biological control and the prospects of its success

4) A work plan for exploration and importation of natural enemies if suitable species are identified.

7.2 **Information required on candidate biological control agents**

7.2.1 The agency carrying out exploration and investigations on candidate agents and the agency managing the control programme, if different should prepare a dossier on the candidate agent for submission to the regulatory body to include as much of the following information as possible:

1) Accurate identification of the candidate agent to provide full scientific name and its classification or, if a formal name is not yet available, sufficient characterisation of the agent to allow its unambiguous recognition

2) A summary of all available information on the origins, distribution biology, natural enemies and impact in its area of origin of the candidate agent; also any other appropriate data to indicate the known host range

3) Instructions for its breeding or culture under laboratory conditions

4) A screening report based on laboratory tests, field observations and any other appropriate data to indicate the known host range of the candidate agent 6)

5) Information on natural enemies of the candidate agent and procedures required to ensure their elimination from laboratory colonies 5.6.1)

6) For micro-organisms, information should also be supplied indicating any risks to those who may be handling them under laboratory and field conditions 3.2.3).

7.2.2 The regulatory body should provide information on tests to be carried out to determine host range including a list of organisms to be screened.

7.3 Recommended screening procedures

7.3.1 A tiered exploration of the host range of the candidate agent is recommended. This should proceed from simple no choice/maximum challenge tests to more complex investigations as appropriate to the nature of the agent and the reason for failure to satisfy the previous tier of tests (Table 5). Testing should cease passes tests at a given tier. It is important

that all screening tests should be carried out using the strain of the candidate agent which it is proposed will be used in the field. Likewise, the samples of the target pest used in these tests should be of the same strain as that to be controlled (6.1.2).

7.4 Recommended procedures for granting import permits

7.4.1 The regulatory body should require submission of a dossier of information on the candidate agent including the screening report (4.4.3) and a statement on the reasons for requesting an import permit, i.e., the nature of the pest problem and its importance to the country.

7.4.2 Giving due regard to the importance of the pest problem the regulatory body should evaluate the dossier in relation to the degree of acceptable risk (4.2.5). If the agent is apparently completely host specific, or if there are no potential hosts in the country, an unconditional permit could readily be granted. If there are potential hosts among non-target species the regulatory body should consider whether the possibility of damage to non-target species of economic or conservation value is of greater importance to the community than control of the pest, and make its decision accordingly.

7.4.3 Import permits should state the conditions to be fulfilled by the dispatcher and importer. These may include a specified source, precautions to be taken against the inclusion of natural enemies of the agent, exclusion of contaminants, packaging to allow inspection without escape of the contents, port of entry, agency to receive the consignment, conditions under which the package may be opened, and the facilities in which the culture may be held. The purpose should be to ensure as far as possible that only a pure culture is received (5.6) and that, if it is to be held in quarantine, the package is taken into quarantine before it is opened for inspection even if its contents are not to be held in quarantine thereafter.

7.5 Shipping procedures

7.5.1 The shipper must follow any conditions specified on the import permit but should always take steps to ensure that the culture of the agent is free of natural enemies, contaminants and other organisms. Packaging should be chosen from inert materials and every effort made to ship material at a stage which does not need food on the journey. The package should be packed and secured in such a way that it can be inspected without fear of the escape of its contents (5.6).

7.5.2 Advance notice with full details of routeing should be provided to the receiver to minimise the chance of delays and enable officials at the port of entry to be alerted.

7.5.3 Shipments should not be despatched until the import permit is received as well as any other documentation which may be required such as quarantine labels. Suitable information should be prominently displayed on the outside of the package to inform those handling it of the nature of the contents and how it should be handled.

Table 5

A TIERED HOST SPECIFICTY TESTING SEQUENCE FOR BIOLOGICAL CONTROL AGENTS.

	WEED ARTHROPODS	PARASITOIDS & PREDATORS	PATHOGENS
Tier I Preliminary Screen Screen of full range of test organisms using no choice maximum challenge principle	**Starvation tests** Exposure to plant parts until feeding/oviposition observed or death	**'Starvation' tests** Exposure to test organism until feeding or oviposition takes place or death	**Infectivity and toxicity tests** Inoculation with massive dose and observe if infection takes place
TIER II Critical Screen Screen species attacked at I in presence of host	**Multiple choice tests** Exposure to test plants and normal host in cages. Check for feeding/oviposition	**Multiple choice tests** Exposure to test organisms & normal host in semi-natural' arena in cages	(not applicable) go to Tier III
TIER III Physiological compatibility Attempt to rear through entire life cycle on species attacked at II and test fertility of offspring	**Rearing tests** Attempt to rear, noting mortality at each stage, size of F_1 adults and test fertility on test plant	**Rearing tests** Attempt to rear noting mortality at each stage and test fertility of F_1, on test organism	**Life cycle** Attempt to obtain complete life cycle using test organisms and to infect a sub-sequent generation
TIER IV Ecological compatibility Biological analysis using field observation, lab. tests, climate comparisons etc. to determine if species on which life cycle completed at III could become hosts	**Field trials** Expose test plants among infested hosts in field and examine for attack **Epidemiology** Analyse phenology, habitat preference in relation to that of attacked plants	**Behaviour analysis** Test responses to host finding cues from test organisms **Epidemiology** Analyse phenology, habitat preference in relation to that of attacked organisms in its country of origin	**Field trials** Expose test organisms to pathogen in natural infestations in field **Epidemiology** Analyse phenology, climate etc. in relation to that of organisms attacked in its country of origin

7.6 Intermediate quarantine

7.6.1 Countries lacking secure quarantine facilities for receiving shipments of biological control agents direct from the country of origin, or those concerned about the special dangers from importations from regions where quarantine pests of major significance exist, may consider importation through intermediate quarantine in a third country for added safety (5.6.1). Such a procedure is particularly valuable for the exclusion of plant diseases which may contaminate shipments. Organisations offering intermediate quarantine will be situated in countries where the particular risks are of no significance, and will be equipped to test for contamination and elimination of hyperparasites or disease from natural enemy cultures.

7.7 Quarantine procedures on receipt

7.7.1 After port formalities are completed the package should be taken unopened to a quarantine unit to be opened and inspected (5.6.2). Where no quarantine unit exists and a pure culture has been imported for immediate release it may be sufficient to open and inspect the package in a secure laboratory (i.e., a closed room equipped with facilities for sterilising or autoclaving extraneous or suspect material).

7.7.2 The biological control agents should be examined and any dead, diseased or contaminated material destroyed immediately. All extraneous material and packaging should be sterilised or destroyed. Only healthy agents or pure cultures should be passed on for subsequent processing.

7.7.3 Agents should be cultured in quarantine for at least one generation or as long as has been specified by the authorities. Exceptionally, the agents may have been passed for release, e.g., if intermediate quarantine has been used or certified pure cultures have been imported from a reliable source.

7.8 Procedures for release into the environment

7.8.1 Further safety tests may be required after receipt, especially if it has not been possible to meet all requirements before shipment. These must be carried out and reported to the regulatory authority before release can be contemplated.

7.8.2 If not agreed under the terms of the import permit, approval for releases must be obtained. The application may require information on any further tests carried out and a report on the material received, its condition on arrival and any subsequent screening for disease and contaminants.

7.8.3 The release programme should be fully documented as to numbers liberated, dates, localities, crops, weather and any other data relevant to assessing the outcome.

7.8.4 Advance arrangements should be made for evaluation of releases to continue until establishment is confirmed or failure is certain, and for continued assessment of the impact of the established natural enemy on the target pest and on non-target organisms. If necessary, technical assistance should be sought to ensure that the outcome is fully documented and is published.

7.8.5 Authoritatively identified voucher specimens of the pest organisms and natural enemies studied in a biological control programme should be deposited in the collection of appropriate institutions where they will be freely available for reference. These voucher specimens should include

examples of agents taken at all stages of the investigation and include samples from the source area, the founder culture shipped the country where biological control is to be effected and also recoveries from the field after release and establishment.

APPENDIX G

REARING THE LEUCAENA PSYLLID AND ITS PARASITOIDS

6. PRODUCTION OF LEUCAENA PSYLLIDS AND ITS PARASITOIDS

Following a decision to introduce natural enemies of leucaena psyllid, there will be a need to raise the psyllid and its natural enemies in the laboratory. Some natural enemies may be reared in quarantine for a few generations, as recommended above. Ultimately, natural enemies will have to be produced on a fairly large scale if it is planned that releases will be made in different parts of the country. It may take many, large releases to achieve establishment of the agent. Following this, the site where the agent is established can also be a source for agents to introduce elsewhere.

In this section, we describe methods for rearing leucaena psyllid and two of its natural enemies most likely to be introduced into Asia, *Psyllaephagus yaseeni* and *Tamarixia leucaenae*. These methods have been developed in Trinidad, which has a similar climate to much of tropical Asia. The methods are designed to be carried out easily in a small, well run insectary. Most of all they indicate that the successful rearing of exotic pests and natural enemies in quarantine **requires intensive work and attention to detail on a daily basis.**

6.1 Outline of rearing procedure.

The secret of rearing the psyllid is to provide an abundance of healthy leucaena with actively growing shoots. In the tropical conditions of Trinidad, it proved fairly easy to grow the plant from seed in pots (20 to 30 seeds/pot) outdoors in field cages covered with fine netting to protect the plants from psyllid attack. The plants are transferred to the indoor

psyllid culture when about two months old. Adults are added to a cage of four pots which is referred to as the oviposition cage. Eggs begin to be laid within 24 hours and plant pots are periodically removed to adjacent cages marked '1st & 2nd instar'; subsequently pots from these cages are moved on to other cages marked, '3rd & 4th instar' and then '5th instar & emerging adults'.

If the plants are to be grown indoors (for instance in quarantine) they require a high light intensity; hence above each cage is suspended a row of fluorescent strip lights in between which are placed tungsten incandescent bulbs to improve the light spectrum. A temperature of no more than 24°C is maintained in the culture room by air-conditioners.

Each cage of parasitoids is maintained by introducing one pot per week of leucaena with newly emerged psyllid nymphs, and removing the oldest pot in the cage, so that each pot stays in the cage for one month. This gives ample time for the parasitoids to complete their life cycle. After the pot is removed from the cage the shoots are drastically pruned and returned to the outdoor cages where they re-grow in about 6 to 8 weeks and can be reused.

6.2 Optimal rearing conditions

The rearing of insects is often developed on an ad-hoc basis and can depend much on the intuitive skill of a particular laboratory technician. Problems can arise when trying to transfer the skills to other rearing units, especially in temperate countries where ambient conditions can be very different.

Hence some studies have been initiated to try to quantify optimal rearing conditions. This work is still underway, but the following data can be provided:

A simple frame cage covered with fine mesh is satisfactory for rearing psyllids, and preferable to an all-glass or plastic (eg perspex) cage, due to the need to have good circulation of air to prevent condensation and mold. Mesh cages have the advantage of being cheap and simple to make, and provides good conditions for the plant and insect without the need for extensive manipulation.

Studies on optimal humidities for psyllid survival reveal that humidities between 75%RH and 100%RH at 25°C gave similar, good survival and growth, but rearing can be achieved below this.

It is thought that psyllids, like many sucking insects, depend on nitrogen in plant sap for growth and, particularly reproduction. Efforts were made, therefore, to increase psyllid numbers by fertilizing potted plants, to see if this would encourage laying of more eggs. Nitrogen fertilizers did not significantly increase egg laying by psyllids.

When ages of leaves presented for egg laying was studies, it was found that substantially higher numbers of eggs were laid per female when presented with 0 to 5 day old leaves leaves older than 5 days.

6.3 Culturing of *Heteropsylla cubana*

The following is a precise procedure, used by IIBC, for culturing this insect. It may require modification in other laboratories, depending on availability of materials.

Leucaena leucocephala (variety K8) seeds are scarified in sulphuric acid for 13 minutes. A volume of acid about 1.5 times that of the seeds is used. The seeds are thoroughly rinsed afterwards in tap water. The seeds can be planted immediately, though it appears they can be kept in this condition for several days at least if stored dry.

At IIBC Trinidad, seeds are planted in local clay soils to which powdered limestone has been added in a ratio of about 7:1 (leucaena does not grow well in acid soils). The seeds are scattered on the surface of 6" pots of soil, then another half inch of soil added and firmed down. About 20 to 30 seeds per pot are used. The seeds are watered twice a day and should germinate in a couple of days. Normal germination is about 95%.

The seeds are germinated in full sunlight, where they spend the rest of their time. They should be placed in a fine net cage to prevent attacks by insects. The cage should have a solid bottom (concrete is ideal) to prevent contamination from insects on grass, etc. and to stop competition from other plants.

At first the leucaena grows distressingly slowly, but seems to 'take-off' after about 8 weeks. The plants are fertilized two weeks after germination with a slow release fertilizer. They must also be watered TWICE a day unless there has been substantial rain immediately before. They are watered first thing in the morning and last thing in the afternoon.

To maintain a minimum healthy psyllid culture 20 pots should be planted every two weeks.

At about an age of two months the leucaena is transferred to the stock psyllid culture (maintained out of doors in a cage). To maintain a good culture 10 pots a week should be added. They MUST be plants which are growing VIGOROUSLY.

The number of pots in the psyllid culture should be maintained at around 100. These are kept in a 6' by 6' by 6' mesh cage on a framework of plastic piping (one needs pressure pipe for strength). It is important to locate this cage in strong sunlight to promote plant growth.

About 5 pots of leucaena, with heavy psyllid infestation, can be removed from the colony each week.

IIBC also maintains a psyllid culture in the lab, where it is safer from the vagaries of nature and attack by parasites. This culture is maintained in netting cages containing 4 to 6 pots of leucaena.

One of the cages contains plants just brought in from the outdoor leucaena culture cages and adult psyllids for oviposition. The adults in these cages are obtained from any other culture cages. They are caught with a miniature sweep net, from which all other insects are removed with a pooter before the adults are transferred to this cage. The plants are left in here for at most two to three days and then transferred to a second cage. If after three days there is still insufficient oviposition, then there are either insufficient adults or the plants are unsuitable i.e. not having enough young growth. As the psyllid nymphs develop they are moved from cage to cage so as to maintain one cage with instars 1 & 2, one with instars 3 & 4 and one with instar 5 & emerging adults. As needed, infested pots are also removed to maintain cultures of the natural enemies.

To maintain the necessary growth rate of the leucaena the cages are placed about 80cm below a rack of 8 standard daylight fluorescent lamps and 6 100W incandescent lamps. If too many lamps are used the psyllid eggs will desiccate and fail to hatch. On the other hand if the humidity is too high the Leucaena is attacked by fungus and dies. Because of the drying effect of the lamps it is necessary to water the plants twice daily. At the time of watering any undesirable insects are also removed.

6.4 Culturing of parasitoids

Parasitoids are all cultured in the laboratory in netting cages 50cm on each side. They are approximately 80cm beneath a bank of 8 standard 6' daylight fluorescent tubes and 6 100W incandescent bulbs. They are in air conditioned rooms with a daytime max. temp. of 25°C and min. R.H. of 40% and a night-time min. temp. of 13°C and max. R.H. of 55%

Each cage contains 4 pots of *L. leucocephala* seedlings about 8 to 12 weeks old. One of these is replaced once a week in rotation, so that pots spend a total of 4 weeks in a cage. The new pots introduced have been exposed to adult psyllids and are heavily laden with newly hatched and unhatched eggs. The parasitoids attack these young psyllids and complete their development within the 4 weeks the pot spends in the cage. Any mummified psyllids still remaining on a pot to be discarded are removed to small tubes for emergence and reintroduction to the culture.

The main limit to parasitoid production is the reliable provision of large numbers of suitable psyllid nymphs. *Psyllaephagus* requires 1st and 2nd instar nymphs, while *Tamarixia* required 3rd and 4th instar nymphs.

Strict quarantine is also important as *Tamarixia* in particular appears to be highly invasive and quickly contaminates other cultures if given any chance.

6.5 Culture protocol

The following notes give the day by day procedures to be followed in maintaining the cultures of the psyllid and two of its parasitoids. In addition to the notes on these sheets the following should be noted.

All cages should be clearly labelled with their number and contents. The cages and the lab should be kept clean and tidy at all times.

Note that some of the figures used are only estimates and may need some alteration with experience and as conditions change. This is particularly true of the number of cages of ovipositing psyllids and the number of seeds planted. In this as in many aspects of the culturing common sense and careful thought are required.

Growing Leucaena leucocephala (out of doors)

Daily

1. Remove any psyllids, caterpillars, etc. from plants twice daily. You should look for psyllid adults on young shoots and kill them with a rapid movement of thumb and finger. Also look for young leaves with eggs or nymphs - these leaves should be removed (if in any doubt as to the presence of psyllids remove the leaf.

2. Check cages for holes, which should be repaired. Also ensure that base of cage is tucked under and is tightly sealed as possible. Be careful not to introduce unwanted insects into cages on your clothes and keep cages zipped except when entering and exiting.

3. Water copiously twice daily. Be sure not to miss any plants. Too much water is better than too little.

Weekly

1. Plants will be removed for psyllid cultures (also at other times for experiments).

2. Plants returning from psyllid cultures should be cut back to leave about 8cm of stem. This stem length should not bear leaves, but should have buds from which

the plant can re-sprout. These pots should then go into the leucaena culture cages, being very careful not to introduce any psyllids. The excess foliage should be destroyed.

Every 2 weeks

1. Plant 20 pots of *Leucaena leucocephala* K8 seeds. Follow detailed instructions on separate sheet.

Culturing of H. cubana outdoors

Daily

1. Remove any parasitoids, predators and other herbivores (e.g. caterpillars or crickets) from plants twice daily (need to spend about 15 min on each cage - I suggest 0800 - 0830 & 1430 - 1500). You should look for both mummies and adult parasitoids. Leaflets bearing the former should be removed and the latter killed with a rapid movement of thumb and finger.

2. Check cages for holes, which should be repaired. Also ensure that base of cage is tucked under and as tightly sealed as possible. Be careful not to introduce unwanted insects into cages on your clothes and keep cages zipped up except when entering and exiting.

3. Water plants copiously twice daily; once first thing in morning and once last thing in afternoon. Be sure not to miss any plants. Too much water is better than too little.

Weekly

1. The cage should contain about 80 pots. The 10 oldest should be removed and cut back to leave about 8cm of stem. This stem length should not bear leaves, but should have buds from which the plant can re-sprout. These pots should then be put into the leucaena culture cages for regrowth, being very careful not to introduce any psyllids. These 10 pots should then be replaced with 10 new pots from the Leucaena culture.

Other

1. As needed psyllids will be removed for experiments and to top up the indoor culture.

Culturing of leucaena psyllid (in the laboratory)

Daily

1. Check cages for holes, which should be repaired. Leave cages open as little as possible - be careful not to introduce unwanted insects into cages on clothing. Sleeves of the cages should be sealed with a loop of wire at all times when access to cage is not required.

2. Check and replace any failed light bulbs. Check function of air conditioning and reading on thermohydrograph to ensure proper temperature and humidity.

3. Check cage and plants for contaminants. Ideally there should be only leucaena and the psyllid present. Any parasitoids MUST be rigorously exterminated. It is essential that all mummies of parasitoids are found and destroyed and you must spend several minutes on each cage checking for them. Ants must be tracked to their nest and destroyed (if need be by discarding a plant pot).

4. Check general healthiness of culture. Are plants healthy? Are plants producing plenty of new growth? Are there plenty of adult psyllids? Are there plenty of eggs being laid? Are there good numbers of all nymphal instars present? If the answer to any of these questions is no there is probably a problem which MUST be rectified. (Note - it is especially important to check that there are sufficient adults and sufficient new growth in cages where egg laying is occuring). Also note that a CONSTANT supply of good numbers of all the nymphal instars is needed for any experiments on natural enemies).

5. Water twice daily - once in the morning and once last thing in the afternoon. Be sure not to miss any plants. Too much water is better than too little - about 1 litres per cage

6. Check all the cages containing psyllids (other than those allocated for oviposition) for adults and remove as many as possible with the miniature sweep net and transfer them to the cages for oviposition. Before

introducing them remove any adult parasitoids with pooter and return them to their own cage. Note that the transferring of adult psyllids is a critical task and will probably require an hour a day to do this. If insufficient are available indoors, more will have to be found from the outdoor culture or from the field.

Every two days

1. Twelve pots of Leucaena should be maintained in the cages allocated for oviposition by adult psyllids. Every two days (i.e. Mon, Wed & Fri) these should be moved to cages containing cultures of parasitoids and to cages for rearing psyllids, as required. They must then be replaced by new pots from the outdoor leucaena culture. These new plants must have plenty of fresh flushing leaves, which are required by the psyllids for oviposition. Before removing the old plants, sweep them with the miniature sweep net to capture the adult psyllids - these can then be reintroduced to the cage with the new pots.

2. Transfer plants from egg laying cages to cages designated for the next stages, and so on. Remove plants from cages for adult production, trim of leaves and return to leucaena culture cage, as discussed earlier.

Every week

1. Re-wind thermohydrograph.

Culturing of Psyllaephagus yaseeni

Daily

1. Check cages for holes, which should be repaired. Leave cages open as little as possible - be careful not to introduce unwanted insects into cages on clothing. Sleeves of the cages should be sealed with a loop of wire at all times when access to cage is not required.

2. Check and replace any failed light bulbs.

3. Check cage and plants for contaminants. Ideally there should be only leucaena, psyllids and *Psyllaephagus* present. Any *Tamarixia* present MUST be rigorously exterminated. It is essential that all mummies of *Tamarixia* are found and destroyed - you must

spend several minutes on each cage checking for them. Ants must be tracked to their nest and destroyed (if need be by discarding a plant pot).

4. Check general healthiness of culture. Are plants healthy? Are there plenty of adult parasitoids? (Are you sure they are *Psyllaephagus* and not *Tamarixia*?) Are there plenty of mummies? Are there plenty of suitable (i.e. 1st and 2nd instar) psyllid nymphs available for parasitism. If the answer to any of these questions is not, there is probably a problem which MUST be rectified.

5. Water twice daily - Be sure not to miss any plants. Too much water is better than too little.

Every week

1. Each cage should contain 4 or 5 pots of leucaena. Once a week the oldest pot should be removed and replaced with a pot from the psyllid oviposition cages with numerous newly hatched nymphs. Mummies should be removed from the old plant and stored in 6 X 1.5cm glass tubes. As the parasitoids emerge from the mummies they can then be released back into the culture. Note that in order for the mummies to emerge, approximately the correct humidity must be maintained in the tubes - this is achieved by keeping 2 or 3 mummies in each tube, still attached to a single leaflet. The old plants can then be trimmed back to about 8cm and put in the outside leucaena culture.

Culturing Tamarixia leucaenae

Daily

1. Check cages for holes, which should be repaired. Leave cages open as little as possible - be careful not to introduce unwanted insects into cages on clothing. Sleeves of the cages should be sealed with a loop of wire at all times when access to cage is not required.

2. Check and replace any failed light bulbs.

3. Check cage and plants for contaminants. Any *Psyllaephagus* present must be RIGOROUSLY EXTERMINATED. You must spend several minutes in each cage checking for these. Ants must be tracked down to their nests and destroyed

4. Check general healthiness of culture. Are plants healthy? Are there plenty of adult parasitoids? (Are you sure they are *Tamarixia* and not *Psyllaephagus*?) Are there plenty of mummies? Are there plenty of suitable (i.e. 3rd and 4th instar) psyllid nymphs available for parasitism? If the answer to any of these questions is not, there is probably a problem which MUST be rectified.

5. Water twice daily.

Every week

1. Each cage should contain 4 or 5 pots of leucaena. Once a week the oldest pot should be removed and replaced with a pot from the psyllid oviposition cages with numerous newly hatched nymphs. Mummies should be removed from the old plant and stored in 6 X 1.5cm glass tubes. As the parasitoids emerge from the mummies they can then be released back into the culture. Note that in order for the mummies to emerge approximately the correct humidity must be maintained in the tubes - this is achieved by keeping 2 or 3 mummies in each tube, still attached to a single leaflet. The old plants can than be trimmed back to about 8cm and put in the outside leucaena culture.

APPENDIX H

SUCCESS AND CHALLENGES OF THE INDONESIA NATIONAL INTEGRATED PEST MANAGEMENT PROGRAM IN THE RICE-BASED CROPPING SYSTEM

ipm indonesia

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THE INDONESIA NATIONAL INTEGRATED PEST MANAGEMENT PROGRAM: SUCCESS AND CHALLENGES

Dr. Ida Nyoman Oka

IPM Steering Committee Member at the

National Development Planning Agency of the

Republic of Indonesia

UNDP Seminar/Workshop on Integrated Pest Management,
New York, 26 - 27 July 1990

THE INDONESIA NATIONAL INTEGRATED PEST MANAGEMENT PROGRAM: SUCCESS AND CHALLENGES *)

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I. NATIONAL FOOD PROGRAM

Since her independence in 1945, Indonesia has been struggling hard to fulfill the three basic needs for her rapidly expanding population : food, clothing and shelter. This effort has been intensified and better planned by the government of the New Order which came into power about 25 years ago. The overall agricultural development of Indonesia is being carried out through four main programs i.e intensification, diversification, rehabilitation and extensification.

The food intensification program is an integral part of the total agricultural development as a whole. The objective of the program is not only to achieve and maintain self sufficiency in food but as equally important to increase farmers income, increase foreign earnings through export of agricultural products, to provide equity for job opportunities, to provide strong support for the rapidly expanding industrial and business sectors and last but not least to maintain a healthy environment, which has been more and more emphasized during these last five years.

Diversification is a program to enable the farmers to produce diversified food and other agricultural products, for their own use and for market and thereby making them less dependent on only one commodity to their income.

Rehabilitation programs emphasized among others things on rebuilding the broken and outdated irrigation system and rejuvenation of old age estate crops plantations, while extensification is a program to turn certain forest areas and unproductive wasteland into productive agricultural areas.

Food production technically is being increased mainly through massive intensification program with high yielding modern varieties, increased inputs of chemical fertilizers, improved and expanded irrigation system, higher crop intensities, and intensive use of pesticides. Along with these technical inputs socioeconomic environments are also being improved including better pricing policy and marketing of agricultural products, improved infrastructures, establishment of farmers cooperatives and farmer water users associations and extension efforts. The responsibility for implementing the intensification food program rests with a body called BADAN PENGENDALI BIMBINGAN MASSAL (BIMAS) = Directive Agency for Mass Guidance. At the central government the program is directly under the command of the Minister of Agriculture, while at the Provincial and Kabupaten (county) level the Program is chaired by the Governor and the Bupati (County Chief), respectively.

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*) Presented at the UNDP Seminar/Workshop on Integrated Pest Management, New York, 26-27 July 1990.

The program was able to increase the rice production by an average annual rate of about 4,5% over two decades-well above the annual population increase of 2,3 %. Self-sufficiency in rice was achieved for the first time in history in 1983 and this has been maintained until this year.

II. INCREASING PEST PROBLEMS AND THEIR CONTROL

Highly intensified food agriculture with various inputs brought with it various problems socioeconomic, agronomic and environmental. Among the environmental problems that limit production or even cause entire crop losses are attacks of various pests (insects, mammals, diseases and weeds). In addition, pest problems are responsible for yield instability.

Increasing pest problems are observed particularly in the highly intensified areas. For example, the brown planthopper, Nilaparvata lugens, which was listed as a very minor rice pest, changed its status into the most important pest since 1972. In 1976-1977 rice season alone more than half a million hectare of rice field were heavily damaged by the pests, causing a loss of around 350,000 ton of milled rice valued at more than US $ 100 million. Assuming the annual consumption per capita was only 120 kg, this loss would have been able to feed around 3 million people for an entire year. The Rice Tungro Virus (RTV) transmitted by the green leafhopper, *Nephotettix virescens* remains a threat in some highly intensified rice centers.

Rats remain a very important pest not only attacking food crops while it is still in the field, but it is also a serious storage pest. Conservative estimates of crop losses due to rats range between 200 - 300,000 ton of rice annually.

Recently an outbreak of the white stem borer, *Scirpophaga innotata* took place in the Northern part of West Java, attacking around 75,000 hectare which caused yield loss of about 40 %.

During the early years of the mass intensification program pest problems were controlled using a unilateral method, i.e with only pesticides, applied at regular intervals 3 to 4 times throughout the growing season. Not only ground sprays were introduced using knapsack and power sprays but in case of large scale pest outbreaks the government also used aerial sprays, which were first introduced around 1967 - 68 to control white stem borer in parts of West Java. When BPH broke out more than one million rice fields were totally blanketed with air sprays in Java and North Sumatra. Outbreak of RTV in Bali in 1981-1982 covering and area of around 12,000 hectare were also air sprayed to knock down the population of the green leaf hopper, the vector of the disease. Pesticides were believed as an insurance to success of production. Farmers were intensively taught several techniques of pesticide applications. Pesticides were already expensive, but since it were heavily subsidized, farmers could buy them at relatively "low" prices and they were easy to obtain because of the extensive distribution network.

III. INTRODUCING THE IPM CONCEPT

1. Beginning of IPM implementation

The result of the massive sprays were questioned by our scientists because inspite of applying higher pesticide concentration and more frequent applications the pests remained in abundance. In addition, other environmental problems were unavoidable such as death of non target species (fish, snakes, frogs, eels, ducks, worms) pesticide residues in food, water, and soil, and hazards to men (poisoning and death).

This gradually changed the government policy of pest control from a unilateral method to a comprehensive approach known as the Integrated Pest Management, which should be based on a through understanding of the intricate interrelationships of the component of the ecosystem. The concept was officially adopted in 1979, and was followed by strengthening the plant protection service personnel, more emphasis on using cultural controls, resistant varieties, and monitoring for more judicious use of pesticides. Pest outbreaks became less abundant, but still threatened the crops in many of the production centers, due to many problems encountered during its implementation in fields :

a. pesticides were still used in abundance;

b. the pesticide subsidy remained massive, which made the farmer continue using pesticides at low prices;

c. the farmers were too used to grab pesticides, because they have been taught to use the poisons for more than a decade;

d. the extension efforts on IPM to farmers were very limited due to lack of a sound extension program on IPM and the inadequate knowledge of the extension personnel;

e. massive campaigns by pesticide companies on pesticide use;

f. externality factors continued to exist.

2. Presidential Decree no. 3, 1986 and its impact

The promulgation of the Presidential Decree no. 3, 1986 in November was a consequence of the fact when massive BPH outbreaks occurred in Central Java medio 1986 where around 75.000 ha paddy field were lost, and it was simultaneously proven by scientists that a number of the pesticides caused

resurgence of BPH. The green leafhopper population showed a 10 to 20 fold resistance increase to most of the pesticides.

The Decree declared that IPM should be the strategy for pest control on rice. It further outlines the following principles :

a. The type of insecticide used and the method of application must take into account the protection of natural enemies of the BPH and other insect species of rice;

b. The development of insect resistance to insecticides must be avoided through insecticide resistance management;

c. Insecticides are to be used only if other control methods are not effective, and then in a judicious way. To achieve these goals, the decree further stated;

d. The knowledge and skills of crop protection field personnel should be improved;

e. Results of field observations by this personnel should determine pest management recommendations to farmers;

f. Agricultural extension officers should provide information for farmers based on directives laid down by crop protection field personnel in such a way that farmers are aware of, and are willing to and capable of, practicing correct pest control;

g. Agricultural extension officers, farmers groups, and farmers are to be trained to increase their skills.

- At last the Decree order to stop using 57 registered brands of broad spectrum insecticides on rice. Only a few very narrow spectrum insecticides are allowed to be used against rice pest.

- Following the Decree the pesticide subsidies were gradually decreased from 70-75 per cent in 1986 down to around 40-45 per cent in 1987 and in January 1989 the subsidies were totally withdrawn.

The Decree demonstrates the strong political will of the Government and her commitment to maintain rice self-sufficient, while protect the environment and human health. The crash program on IPM was immediately launched. Coordination was established starting from the central government down to sub-district level. The number of pest field observers was doubled from 1500 up to 3000 each of them provided with a motorcycle to ensure mobility.

The impact of the Decree was highly positive in terms of:

a. Awakening and shaking the officials, particularly those concerned with plant protection that they should work more diligently following the IPM concept;

b. For those engaged in pesticide enterprises it felt like a serious earthquake;

c. It is considered as a strong measure to reorientate the nation that the basis for the overall agricultural development program should be man power development, environmental preservation, and human health;

d. Other neighboring countries are steadily watching Indonesia concerning how successfully she is implementing the Decree;

e. Research in plant protection have been stimulated to gear their program to strengthen IPM;

f. Drastic reductions in the use of pesticides. Before the Decree in the 1985-86 fiscal year around 14,200 metric tons of organophosphate insecticides were distributed throughout the intensification areas. Shortly after the Decree the use of the organophosphate insecticides dropped by around 60 percent;

g. Government savings of her precious foreign currency for purchases of pesticides are substantial, around US $ 100-150 million/year.

IV. NATIONAL PROGRAM ON IPM

1. People first

As mentioned in the Presidential Decree, developing manpower capabilities through training of pest field observers, extension personnel and farmers in IPM should be given highest priority. In the long run this policy is highly appropriate to continuously ensure large scale implementation of IPM in the field. The farmers themselves are expected to be able to carry out proper IPM in their own fields.

2. Operating mechanism

To implement this policy the National Program on IPM has been launched which started in 1989 through 1991. The Program is being coordinated by the Badan Perencanaan Pembangunan Nasional (= National Development Planning Agency). A steering committee was established consisting of memberships from the Ministry of Agriculture (Directorate General of Education and Training, Directorate General of Food Crops, Agency for Mass Guidance Program), Ministry of Environment and Population, Leading Universities, Ministry of Home Affairs and FAO. The terms of reference of the committee is to identify and discuss general issues and outline policy guide lines for proper implementation of the IPM training.

The Steering Committee is assisted by a Working Group, consisting of a limited number of IPM experts and administrators who are also members of the Steering Committee. The task of the Working Group is to see to it that the daily program of the IPM training is carried out according to the schedule. The arising problems during the execution of the program are discussed in the SC regular meetings for immediate solution.

The financial support of the IPM National program is provided by the USAID funds. FAO is requested to provide full assistance in the execution of the Program.

At the Provincial and Kabupaten (County) levels the National Program is fully supported by the Governors and Bupati respectively. Full assistance and help were secured from the Kakanwils (a representative of the Ministry of Agriculture at the Province), the heads of the agricultural services, training, and plant protection, respectively.

3. How many people to be trained

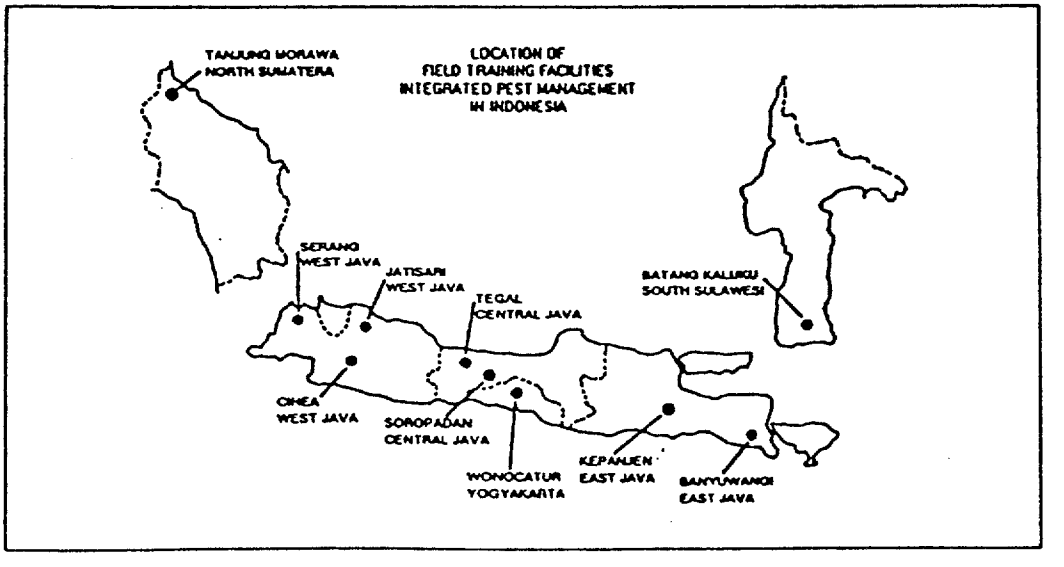
Within the two years of the Program (1989-1991), it is planned to train 1000 field pest observers, 2000 field extension workers and 100.000 farmers. This will be only about 1/3 of the existing field pest observers, about 1/15 of the 30.000 field extension workers. If there were 15 million farmers engaging mainly on food crops production the 100.000 farmers that enjoyed IPM training would be only about 0,67 cent of the total food crops farmers of the country.

At the start of the Program 20 trainers then called Field Leaders I, have been given extensive rice IPM training for the whole rice season. In addition, 90 trainers were given a 2 week thorough rice IPM training who were become Field Leaders II. They are the key people who start the mass IPM program to train the field observers, the extension workers and the farmers.

From the stand point of the limited existing IPM expertise in the country this program is a bold undertaking, but looking at the millions of the farmers needed to be trained, the program is just a beginning.

To effectively carry out the Program and to obtain maximum outputs, it is necessary to set up priorities in terms rice ecology, location of the training facilities, qualifications of the trainers and trainees and the groups of the farmers to be trained.

Rice centers within six provinces (West-Central-East Java- Yogyakarta, North Sumatra and South Sulawesi) are chosen because these regions contributing about 75 per cent of the total rice (food) production of the country. These centers are highly intensified with 2-3 crops/year and in between non rice crops (soybean, mungbean, peanut, cassava, lowland vegetables) are raised.



Today there are 1800 Farmers Field Schools scattered in 6 provinces, each of which consists of around 25 farmers, a total of 45.000 farmers are enjoying the IPM training.

4. Methodology

The training approach use Experiential, Discovery Learning Processes carried out in the field where the trainers are being exposed to the reality what is actually going on in the field. They are practicing how to grow a healthy crop, how to manage them, how to observe and distinguish between pests/diseases and natural enemies, how they are interacting, studies of action threshold levels as a base for judicious use of pesticides, action of pesticides and its environmental consequences, etc. Discussions among the trainees with the help of their own drawings of their findings in the field after each observation, is an important part of the method.

The sphere of the training is made very informal so that each of the trainee is willing to speak up freely, give his own opinion, thereby building up his confidence and the subject remain interesting for them. It is a sort of "bottom up" method rather than a "top down" method where the trainer do almost all the talking while the trainees are expected to carefully listen.

The training modules are prepared by FAO experts with inputs from IRRI, leading national Universities, Research Institutions and Directorate General of Agriculture.

V. ACHIEVEMENTS AND BENEFITS OF IPM IN INDONESIA

Achievements since the Presidential Decree no. 3/86 and the results of the IPM training:

- The yearly rice production of the country are steadily increasing well above the population increase. Yield during 1987/1988 crop year averaged 7 ton/ha, as compared to only 6 ton/ha in 1986;

- No serious or large scale pest outbreaks, particularly BPH, were encountered. Cases of light BPH attack were observed in some rice centers, but it can be contained well below economic damage. Recent outbreak of white stemborer in part of West Java could be immediately contained through IPM principles;

- Savings by the farmers in terms of pesticide purchases are very significant. Before the decree and with 80% subsidy of the pesticides, the farmers had to spend at least around Rp. 10,000/ha/season. Without subsidy they had to spend as much as Rp. 40,000/ha/season. After the Decree with at least 60% reduction of pesticidal applications (in many cases more than 60%), they can use their cash for something more urgent, like paying school tuition for their children. The Governments savings of her foreign currency is very substantial, around US $ 100-150 million/year;

- The environmental health (water, soil, plants, air) can be more secured. This is very important, because most of the farmers use irrigation water for bathing, cooking and drinking;

- Biological life components of the agroecosystems are preserved (non-target species, natural enemies and beneficial creatures) and gradually are increasing in number;

- Those pest field observers, field extension workers and in particular the farmers after the training evidently become much more confident on how to properly manage their crops and handle potential pest problems;

- The farmers become aware that in their respective fields they have an array of "allies" (predators : lady birds, carabids, spiders, tiny parasites and insect pathogens) that are of great help to them and they know that these creatures should be protected from unscrupulous use of pesticide poisons;

- The farmers realize that growing a healthy crop can better withstand attacks of insects and diseases;

- The farmers are well informed that pesticide are really poisons, and therefore it should be handled with utmost care and their use should be based on a "when necessary program";

- Visits to a limited numbers of the field schools strongly indicated that after the training the farmers are eager to convey the informations obtained to other farmers groups who did not (yet) have the chance to participate in the training program;

- Especially for the pest field observers the IPM training is being combined with University enrollment for one semester. If they pass the courses they obtain a D1 diploma in pest control. This enable them to promote one step in their carrier as government servant;

- Other rice growing provinces (Bali, Lampung, West Sumatra) are expecting to also receive the same kind of training;

- A few respected Directors, who are responsible for extension and training of the Ministry of Agriculture are much impressed by the way the field training is being conducted and are thinking about adopting this approach for other subject matters;

- Both the Minister of Agriculture and the Junior Minister of Agriculture, after discussions with the farmers right in the field were happy to note that the farmers could clearly distinguish between the insect pests and their natural enemies.

- During the extensive outbreak of the white stemborer that occurred in the Northern part of West Java attacking around 63.000 ha from which more than 13.000 ha were totally lost, the National IPM program were able to train more than 75.000 farmers within only 5 days how to properly cope with the pest using IPM principles;

- IPM strongly stress on rational and judicious use of pesticides.

VI. CHALLENGES

The significant progress that has been made in the large scale implementation of IPM is not without challenges in the future that needs to be overcome:

1. It is planned to train all the remaining pest field observers working in all provinces. There are about 2000 more people. This need careful and detailed planning;

2. More farmers should be trained beyond 1991, including those from the provinces other than the 6 major ones mentioned above. This also needs careful planning;

3. The officials in the Provinces, Kabupatens and Kecamatans working as seniors to the pest field observers and extension workers also need to be informed and made aware of the new approaches of pest control. Otherwise the already trained pest observers and the extension workers will face difficulties with their superiors. Plans are being made by the Agency of Training and Education to overcome these problems. Technically they need assistance from the IPM program;

4. Various research aspects to strengthen the IPM control tactics should be identified and carried out, such as development of durable plant resistance in the palawija and vegetable crops against important pests; control threshold levels need further research; identification and assessment of the natural enemies of pests attacking the palawija and vegetable crops;

5. As IPM technologies are more refined in the future it needs to be conveyed to the practitioners to be applied in field. Therefore, it is anticipated that training of this kind should be a continuous process;

6. IPM trainings need adequate funding to support the activities in order to properly meet the challenges. Our Government is determined to continue and strengthen the implementation of the IPM concept at farmers field level, because the benefits are highly significant economically, environmentally, as well as socio culturally.

APPENDIX I

SECONDARY METABOLITES IN LEUCAENA AFFECTING RESISTANCE TO *HETEROPSYLLA CUBANA* CRAWFORD

SECONDARY METABOLITES IN LEUCAENA AFFECTING RESISTANCE TO *HETEROPSYLLA CUBANA* CRAWFORD

Jinadasa Darma and Irawan Sutikno

Research Institute for Animal Production
P.O. Box 123, Bogor 16001
Indonesia

Abstract

Plant secondary metabolites have a functional role in plant defense mechanisms. A study has been carried out to search for the secondary metabolite(s) that may be responsible for the resistance of some leucaena cultivars to *Heteropsylla cubana* Crawford. This report compares the contents of mimosine, total phenolics, flavonoid glycosides, tannins and "saponin" in the sap of resistant and non-resistant leucaenas. Only the compounds that are tentatively identified as saponin distinguish resistant and non-resistant leucaenas.

Introduction

The outbreak of the leucaena psyllid (*Heteropsylla cubana* Crawford) showed that resistance is a distinguishing characteristic among leucaenas. Based on the size of psyllid populations and the amount of damage, leucaenas can be classified into resistant and non-resistant groups. The classification can be based on monitoring the effect of the psyllid infestation on various leucaena accessions or, on experimental results obtained from research with a systematic design.

Whether a monitoring or a systematic research design is used, the effect of leucaena psyllids on leucaena accessions may vary with the location and the physiological states of the trees. An explanation of why certain leucaena accessions are resistant under certain conditions is lacking. Knowledge about the factor(s) that confer resistance, how the factor works and how it is expressed will enable us to understand the mechanisms underlying resistance and to exploit these mechanisms in psyllid management. The identification and quantification of chemicals that confer resistance to psyllids can be used to predict whether a leucaena accession is resistant and to substantiate results from resistance trials that monitor pest populations and damage.

The resistance of plants to pests and diseases can be related to their physical characteristics, physiological responses or biochemical properties.

Plant secondary metabolites can repel, deter, or be toxic to insect pests. Several secondary metabolites have been identified in leucaena, including mimosine, phenolics, tannins, flavonol glycosides (Lowry *et al.* 1984) and saponin (Acamovic *et al.* 1986). A comparison of the contents of these compounds in resistant and non-resistant leucaena accessions will be discussed in this paper.

Because adults of leucaena psyllids tend to congregate on non-resistant leucaenas but not on resistant leucaenas, the possibility of the presence of volatile attractants or repellents on leucaena will also be discussed.

Materials and Methods

Since leucaena psyllids are sap-suckers, the comparison is based on secondary metabolites contained in the sap, which was obtained by pinching the tip of the leucaena shoots.

Results and Discussion

Mimosine

The toxicity of leucaena was first reported by Morris (1897), who found that the ingestion of the seeds and foliage of leucaena caused hair loss, especially in the mane and tail of horses, pigs and donkeys. Mimosine, as the toxic principle, was isolated from leucaena by Kostermans (1946), who investigated the cause of hair loss in humans who ate the seeds.

The insecticidal action of mimosine was demonstrated by Mendoza and Ilag (1980) by spraying aphids with mimosine solution. In higher animals, the targets of mimosine toxicity are hair follicles and particular organs, such as the thyroid gland and the reproductive organs. Since it is poisonous to many organisms,

including plants, animals, and microbes, and it inhibits DNA, RNA and protein synthesis (Reisner *et al.* 1979), mimosine can be classified as a broad spectrum toxin. Thus, mimosine also could be deleterious to leucaena psyllids. Leucaena accessions that contain higher amounts of mimosine in the sap might be less susceptible to psyllid damage.

A comparison of mimosine content in the sap of resistant and susceptible leucaena accessions is presented in Table 1. The mimosine analyses indicate that a highly resistant accession, BPTL 003, did not contain a higher amount of mimosine in the sap than did tolerant or susceptible accessions. This suggests that mimosine is not a defensive compound against leucaena psyllids. In fact, the mimosine concentration in the sap of more than 10 percent (fresh weight) represents a concentration that is greater than its solubility in water. Such a high mimosine content has been reported previously by Tangendjaja (1983).

The ability of leucaena psyllids to flourish on sap with such high mimosine concentrations indicates that leucaena psyllids have adapted well to mimosine. Cattle can also feed on leucaena containing mimosine without toxic effects (ter Meulen *et al.* 1979) due to the rumen microorganisms, which are able to degrade mimosine efficiently and rapidly.

Mimosine degrading activity was also exhibited by leucaena psyllid extract (Figure 1). A descending mimosine concentration which evolves an ascending 3-hydroxy-4(1H)-pyridone (DHP) concentration indicates that leucaena psyllids are able to degrade mimosine to DHP. As shown in Figure 1, the leucaena sap does not demonstrate mimosine degrading activity, since mimosine solution incubated with sap did not produce higher concentrations of DHP over time.

DHP was also detected in leucaena psyllid bodies (Table 2). Since DHP is not naturally

Table 1. Mimosine content* of the sap of leucaena accessions.

No.	Accessions	Mimosine (% DW ± S.D.)	R/S
1.	*L. diversifolia* BPTL 003	51.22	R
2.	*L. diversifolia* CIAT 17388	41.34±2.09	T
3.	*L. pulverulenta* CPI 22964 x *L. leucocephala* cv Cunningham	54.49±1.78	T
4.	*L. leucocephala* K636	49.45±1.69	T
5.	*L. collinsii*	36.73±1.93	T
6.	*L. leucocephala* K8	52.29±2.67	S
7.	*L. leucocephala* cv Peru	43.55±2.32	S
8.	*L. leucocephala* K28	36.73±2.31	S
9.	*L. leucocephala* cv Cunningham	40.80±1.63	S
10.	*L. pulverulenta* CPI 23145 x *L. leucocephala* cv Cunningham	34.47±1.89	S

* Mean of 4 tree replicates, except for BPTL 003, which was unreplicated.

R = resistant, less than 5 adult psyllids per 20 cm shoot. Nymphs, if any, do not develop into late instars. Sometimes a few punctures were found on leaflets.
T = tolerant, psyllids proliferate well. Trees still retain more than 50 percent of leaves (clonally propagated K8 were heavily damaged).
S = susceptible Trees were heavily damaged.
DW = dry weight.

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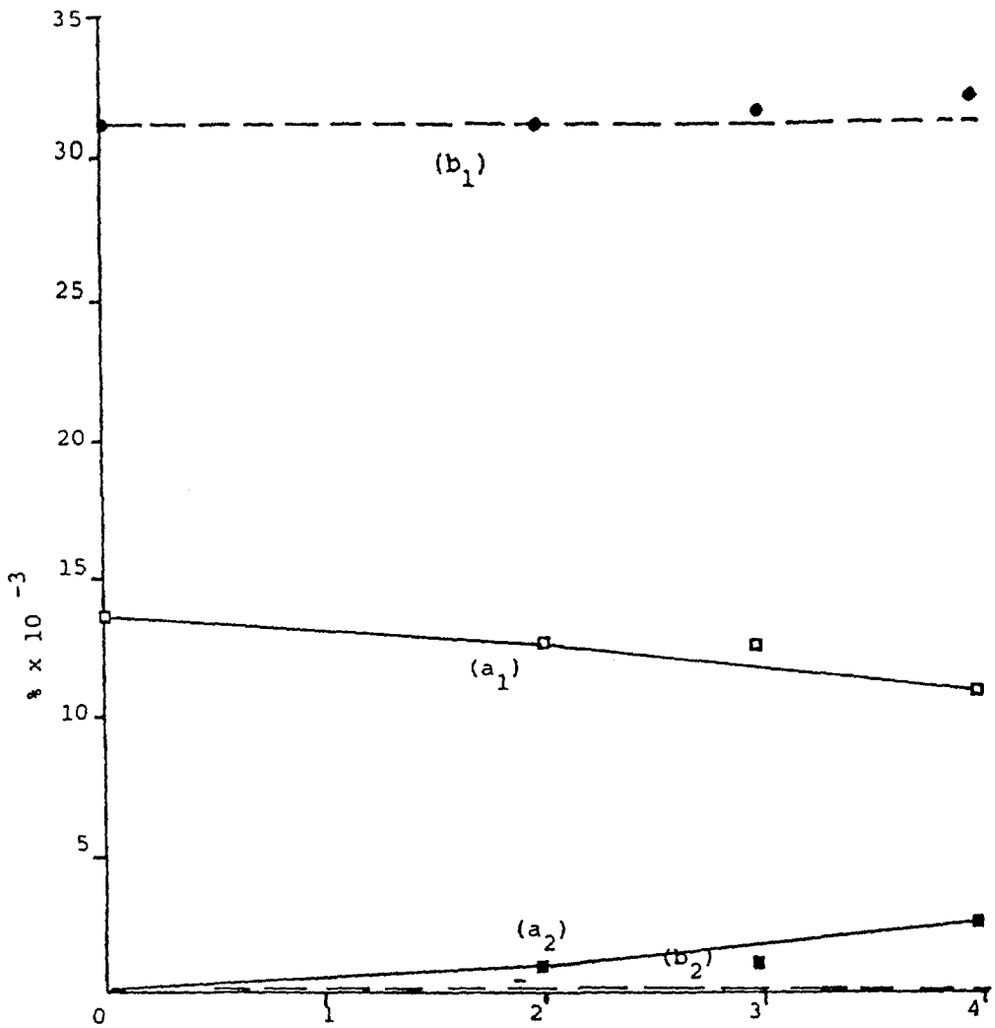

Time of incubation (hr).

Figure 1. Mimosine degrading activity of leucaena psyllids extract.
a_1 : Mimosine incubatd with psyllids.
a_2 : Mimosine incubated with sap.
b_1 : DHP formed in a_1.
b_2 : DHP formed in a_2.

Table 2. Mimosine and DHP contents* in Leucaena psyllids and their excreta.

Sample	% FW ± SD	
	Mimosine	DHP
Leucaena psyllids		
Adults	.050 ± .01	.010 ± .006
Nymphs	.020 ± .003	.002 ± .003
Honey dew	.070 ± .2	.001 ± .002
Solid excreta	.200 ± .08	+
Leucaena sap	7.830 ± 3.0	-

* Mean of 4 replicates
\+ = detected
\- = not detected
FW = fresh weight

found in leucaena sap, the presence of DHP in psyllid bodies indicated that mimosine degradation occurs in psyllids. The presence of mimosine and DHP in psyllid excreta indicates that the mechanism of adaptation also involves excretion of undegraded mimosine.

The ability of leucaena psyllids to thrive on high mimosine-containing sap, to degrade and to excrete this toxic amino acid suggest that it is unlikely that mimosine plays a crucial role in defensive mechanism against leucaena psyllids.

Phenolics, flavonol glycosides and tannin

Flavonol glycosides and tannin are the major constituents of leucaena leaf phenolics. The total phenolics in leucaena leaves account for 5 percent of dry weight, of which 1 percent is tannin and 3-4 percent is flavonol glycosides (Lowry *et al.* 1984).

Condensed and hydrolyzable tannins are both powerful precipitants of protein. Although there are several mechanisms to explain growth inhibition, all explanations involve protein binding. (Singleton and Kratzer 1969). By binding proteins, tannins can impair herbivore nutrition and physiological function. The astringent property of tannins may also be a deterrent to psyllids.

Like tannins, the phenolic hydroxyl group of flavonol glycosides has a strong affinity for proteins. Thus, the mechanism of toxicity to insects is indirect, through their interaction with proteins.

Tannin

The contents of total phenolics and tannins in the sap of resistant accessions were generally higher than that of non- resistant accessions Table 3. Phenolics content was available for only one resistant species, *L. diversifolia* BPTL 003(710 ppm dry weight). All non-resistant accessions contained lower amounts of phenolics ranging from 380 to 580 ppm dry weight. The tannin content of one non-resistant accession, *L. diversifolia* X, was as high as that of some resistant accessions. If this accession is ignored, resistant accessions have tannin contents ranging from 1,797-2,800 ppm dry weight, and non-resistant accessions have lower tannin contents ranging from 131 to 1,314 ppm dry weight.

To obtain more conclusive results on whether resistance is related to tannin content a further study must be carried out to compare a larger number of accessions with adequate replication. Since different types of tannin vary in toxicity,

Table 3. Total phenolics and tannin contents* in the sap of resistant and non resistant leucaenas.

No.	Accessions	ppm ± SD DW		R/S/T*
		Phenolics	Tannin	
1.	*L. diversifolia* BPTL 003	710	2,800	R
2.	*L. diversifolia* BPTL 005	-	2,435±95	R
3.	*Leucaena* BPTL 007	-	202±25	R
4.	*Leucaena* BPTL 010	-	1,797±8	R
5.	*L. leucocephala* BPTL 011	-	1,854±17	R
6.	*L. diversifolia* CIAT 17388	570±40	158±16	T
7.	*L. pulverulenta* CP1 22964 x *L. leucocephala* cv Cunningham	450±30	1,142±41	T
8.	*L. leucocephala* K636	550±90	1,056±24	T
9.	*L. collinsii*	490±90	-	T
10.	*L. diversifolia* BPTL 001	-	596±84	T
11.	*L. diversifolia* BPTL 002	-	131±84	T
12.	*L. diversifolia* X	-	2,265±12	S
13.	*L. leucocephala* K8	580±50	-	S
14.	*L. leucocephala* cv Peru	450±40	732±76	S
15.	*L. leucocephala* K28	410±40	-	S
16.	*L. leucocephala* cv Cunningham	430±60	1,314±407	S
17.	*L. pulverulenta* CP1 23145 x *L. leucocephala* cv Cunningham	360±30	718±66	S

* Mean of 4 replicates, except BPTL 003, which was unreplicated.
- = undetermined
* R = resistant; S = susceptible; T = tolerant;

only three closely related hexanoic acids (Kafka 1970).

That leucaena psyllids which can be found on a hidden and isolated leucaena may be related to the sensitivity of their olfactory systems to the olfactory attractants emitted by the host. Adults of leucaena psyllids congregate on the tips of shoots of non-resistant leucaenas, but not on other host species or some resistant leucaena accessions. These varied preferences may be related to the presence of olfactory attractants or repellents.

To determine whether attractants or repellents are present in resistant and non-resistant leucaenas, the volatile compounds of leucaena leaves were analyzed. Eight components were detected and designated as Component 1, Component 2 (trans-2-hexanol), Component 3, Component 4, Component 5 (1-hexanol), Component 6 (cis-3-hexenol), Component 7 (trans-2-hexenol) and Component 8 (methyl salicylate).

The number and quantify of volatile components varied among the different accessions of leucaena (Figures 2 and 3). No distinctive compound, which could be interpreted as a repellent, was found in resistant accessions. Similarly, no distinctive compound, which could be interpreted as an attractant, was found in susceptible accessions. Therefore, leucaena susceptibility or resistance to psyllids does not appear to be related to the presence or absence of attractants or repellents.

Saponins

Applebaum and Birk (1972) suggested that, in plants, saponins may impart resistance to insects. Medicagenic acid (a sapogenol) was shown to be toxic to the potato leafhopper (*Empoasca fabae*), the pea aphid (*Acyrthosiphon pisum*) and the grass grub (*Castelytra zealandica*). Soya saponin was highly toxic to *Sitophilus oryzae* and less so to the larvae of *Tribolium castaneum* (Price *et al.* 1987). Sutherland *et al.* (1975) found that crude extract of alfalfa root contains a strong feeding deterrent for the larva of *C. zealandica*. Saponin also has been reported to impair the function of the digestive tract, particularly water absorption (Applebaum and Birk 1972).

The toxicity of alfalfa saponin, however, can be reversed by incorporating appropriate amounts of cholesterol in the diet. This suggests that the detrimental effect of alfalfa saponins is due to the medicagenic acid in saponins, which complexes with sterol (Shany *et al.* 1970).

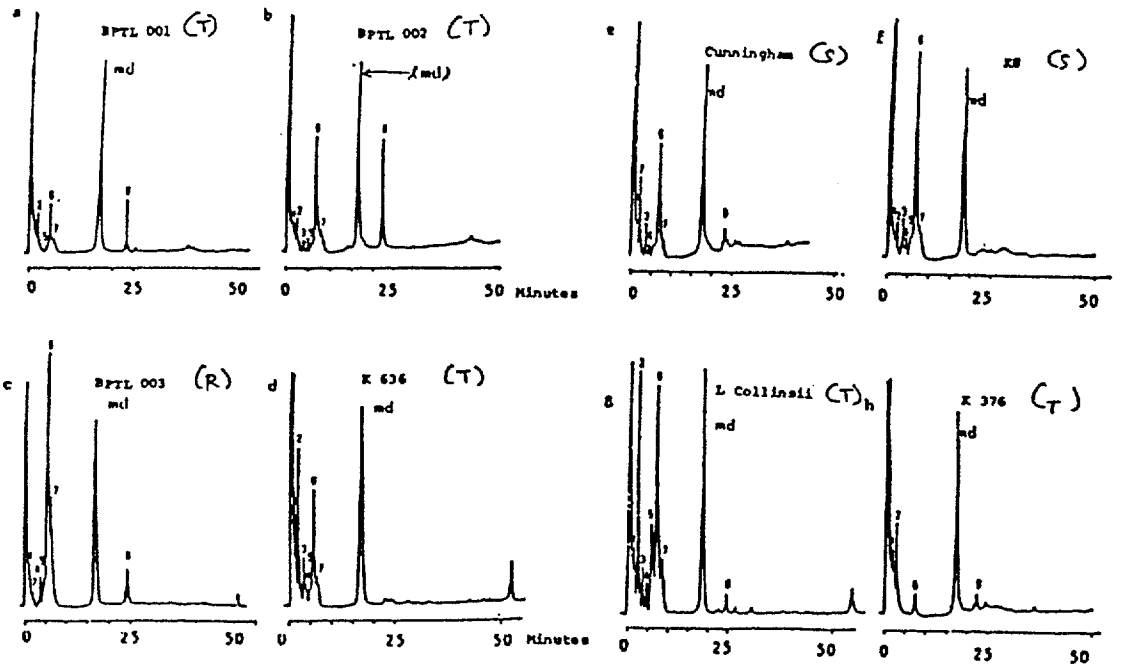

Figure 2. Chromatogram of volatile compounds of leucaenas.
Md = Methyl decanoic (internal standard).

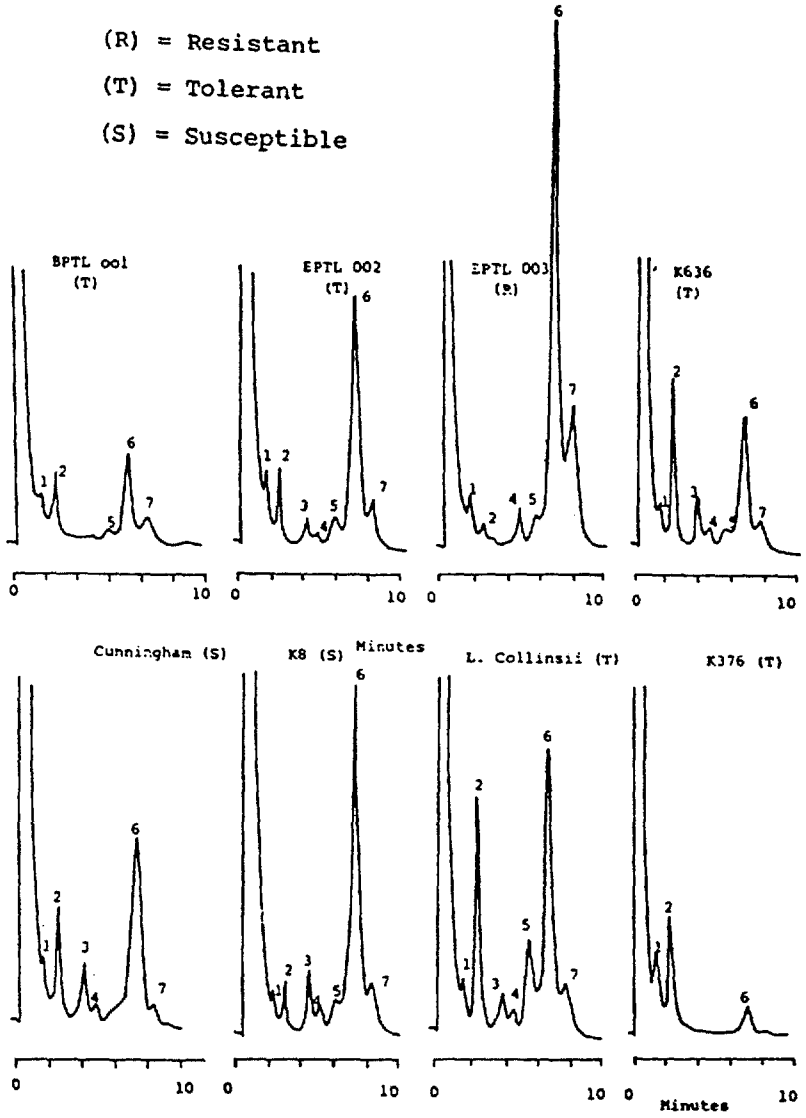

Figure 3. Chromatogram of volatile compounds of leucaenas with isothermal elution.

Insects are unable to synthesize sterols and absolutely require cholesterol or a closely related sterol in the diet.

That leucaena may contain saponins was suggested by Acamovic and D'Mello (1982), who found that chickens fed leucaena leaf meal deposit less fat than those fed on soybean

control diet. Using thin layer chromatography, one isolate, tentatively identified as saponin, has been detected (Acamovic *et al.* 1986).

Using a similar method, the saponins of our leucaena accessions were analyzed (Table 4). It appears that the number of saponin fractions and their intensities differ among resistant and non-resistant accessions. Resistant accessions possess three fractions with Rf values (n-butanol : ethanol : ammonia = 7:2:5) of fraction I = 0.24; fraction II = 0.45 and fraction III = 0.47. The Rf value of fraction I is similar to the Rf value of leucaena seed saponin (Rf = 0.26) reported by Acamovic and D'Mello (1986).

Non-resistant accessions possess only two fractions, I and II, in a lesser amounts than the resistant accessions. This difference may indicate that the saponins of leucaena may confer resistance to leucaena psyllids.

Further analytical studies are needed to confirm whether these are truly saponin and to develop a quantitative analysis. Whether leucaena saponins confer resistance can only be elucidated with bioassays. Ginseng saponins agglutinate red blood cells (Utsumi *et al.* 1984). How leucaena saponins interact with cells requires further study.

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Table 4. Saponins in the sap of resistant and non resistant leucaena accessions.

No.	Accessions	Saponin I	II	III	R/S/T*
1.	*L. diversifolia* BPTL 003	+/10	+/3	+/5	R
2.	*Leucaena* BPTL 005	+/5	+/3	+/5	R
3.	*Leucaena* BPTL 007	+/5	+/3	+/5	R
4.	*Leucaena* BPTL 010	+/5	+/3	+/5	R
5.	*Leucaena* BPTL 006	+/5	+/3	+/2	R
6.	*Leucaena* BPTL 011	+/5	+/3	+/2	R
7.	*L. diversifolia* CIAT 17388	+/3	+/2	-	T
8.	*L. leucocephala* K 636	+/3	-	-	T
9.	*L. pulverulenta* CPI 22964 x *L. leucocephala* cv Cunningham	+/3	+/2	-	T
10.	*L. diversifolia* BPTL 001	+/3	+	-	T
11.	*L. diversifolia* BPTL 002	+/3	+	-	T
12.	*L. leucocephala* cv Cunningham	+	-	-	S

\+ = present, higher quantities are represented by higher numbers.
\- = undetermined
* R = resistant; S = susceptible; T = tolerant

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APPENDIX J

SOME EXPERIENCES IN MASS BREEDING, RELEASE, AND EVALUATING THE ESTABLISHMENT OF *CURINUS COERULUS* MULSANT IN YOGYAKARTA AND CENTRAL JAVA

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SOME EXPERIENCES IN MASS BREEDING, RELEASE AND EVALUATING THE ESTABLISHMENT OF *CURINUS COERULEUS* MULSANT IN YOGYAKARTA AND CENTRAL JAVA

Soeprapto Mangoendihardjo and F.X. Wagiman

Faculty of Agriculture
Gadjah Mada University
Yogyakarta, Indonesia

Abstract

Curinus coeruleus Mulsant has been mass produced, released and evaluated since 1986. The results varied over time and in different locations in Central Java and Yogyakarta. Laboratories from eight stations in both provinces have mass-produced 350,000 adults during the last two years. Mated adults were the most suitable stage for release and the beginning of the dry season, coincided with the increase of the psyllid population, was the most favorable time for releases. After periodic releases from 1987, it was estimated that 30-40 million eggs, larvae, pupae and adults occupied the areas in the release sites and its vicinities by the beginning of 1989. When laboratory mass-production programs end, *C. coeruleus* will be field collected and released in certain locations to accelerate its dispersal and to ensure the establishment of the predator.

Introduction

Curinus coeruleus Mulsant was introduced to Indonesia to control leucaena psyllid because the pest is of exotic origin. About 8,300 adults of the predator *C. coeruleus* were imported from Hawaii in July-August 1986 to control the leucaena psyllid. Some of them and their progeny were subsequently distributed to North Sumatra, Yogyakarta, Semarang, Surabaya, Denpasar and Kupang to be mass-reared. One hundred and ninety seven adults were brought to the Laboratory of Biological Control in the Faculty of Agriculture at the Gadjah Mada University (UGM) in Yogyakarta in August 1986. These were used to set up a mass rearing program in the laboratory with some modification of existing rearing techniques. A portion of the larvae and adults produced were then delivered to the Laboratory of Estate Crops Extension Service in Yogyakarta and Jollong Coffee Estate for a mass-rearing program under the supervision of UGM entomologists (Managoendihardjo 1986).

C. coeruleus was released periodically in rural areas of Yogyakarta and Central Java, and continuously in Jollong and Assinan Coffee Estate in Central Java. Official releases were made by the Vice Governor of Yogyakarta Special Territory on May 9, 1987 and by the Governor of Central Java Province on May 22, 1987. The techniques of release and evaluation were described by Mangoendihardjo (1987).

Mass breeding

Generally mass-rearing of the predator has be successful in Indonesia. Most laboratory staff under the Directorate of Plant Protection for Estate Crops and Estate Crop Enterprise used the guidelines in the booklet issued by the National Team For Lamtoro Jumping Plant Lice, while the staffs in the Jollong and Assina Coffee Estates followed the guidance of UGM entomologists.

Modifications of equipment and techniques

The equipment and rearing techniques recommended by the National Team (Figure 1 were modified in one laboratory of the Estate Crops Extension Service in Yogyakarta. The leucaena twigs, which carry the eggs and nymphs of the psyllid, were not thrown away after replacing them with new twigs. They wer kept in plastic baskets (Figure 2) and allowed dry. The dried materials were covered with white muslin and tied with string to prevent th escape of newly hatched predator larvae. Usually the larvae were found crawling on the underside of the muslin where they could easil be collected and transferred to plastic jars. More than 200 larvae could be collected in 2-4 days.

The recommended material for predator oviposition sites was also modified. Knotted bamboo sticks were preferable to pleated plas or notched bamboo sticks (Figure 3). The number of eggs laid in knotted bamboo sticks and notched bamboo sticks was nearly equal, but egg mortality on the knotted bamboo was

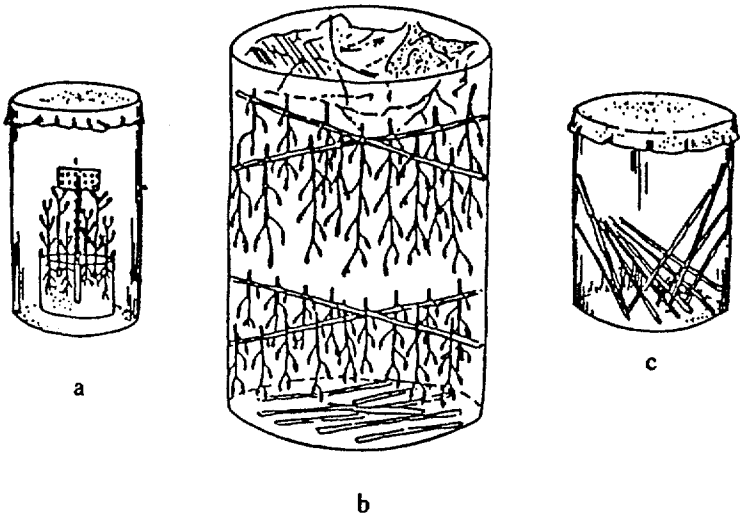

Figure 1. Mass breeding equipment for *Curinus coeruleus* Mulsant. a. Plastic cage with a notched bamboo stick as an oviposition site stuck into a plastic pot planted with leucaena seedlings and a piece of carton dropped with pure honey. b. Plastic cage or basket with 4 bamboo sticks as hangers of leucaena shoots infested by the jumping lice, and c. Bamboo sticks containing eggs of *C. coeruleus* kept in the plastic jar.

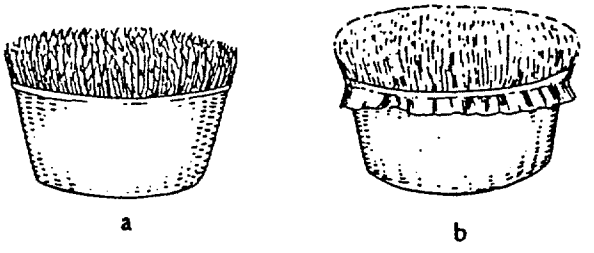

Figure 2. Baskets used for drying leucaena shoots after use as sources of psyllid eggs for rearing adults of *Curinus* a. Uncovered, b. Covered with muslin.

lower (67%) than on the notched bamboo (83%).

The plastic baskets used for rearing larvae were also modified. Plastic baskets with four screened windows on the side and one on the bottom were stored on racks made of perforated materials to reduce humidity in the rearing chambers. In the well-aerated baskets, 30-40 percent of the eggs developed into the last instar, while in the non-aerated baskets, only 10-20 percent of the larvae survived due to a fungal attack (Yuniastuti and Mahrub 1987).

Handling of eggs and larvae

The most critical factor in mass-rearing of *C. coeruleus* is the handling of eggs and young larvae. Oviposition sites should be handled carefully, especially when the knotted bamboo sticks are used. A dry environment is essential because many eggs did not hatch in damp jars. Eggs and larvae of different ages should be placed in separate jars, because the older larvae prey on younger ones and eggs (Irianti 1980). Cannibalism may occur at all larval instars and adult stages, and at all population densities. Transferring first and second instar larvae using a brush may injure the larvae; allowing the larvae to move by themselves reduced larval mortality.

Production

Production of adults varied from about 10,000 to almost 100,000 individuals per mass-rearing station, depending on staff skill, equipment, and availability of food for the predators. Development and production of the predators were much better at higher elevations (400-800 m) than at lower elevations. By the end of 1988, about 350,000 adults had been produced and released from the stations in Yogyakarta and Central Java.

Release

Optimal stage for release

Trials to determine the optimal stage to be released were conducted in Jollong Coffee Estate by Wijayanti (1988). Mated adults were more successful in becoming established than third and fourth instar larvae. After release, mated females soon laid their eggs and new progenies were rapidly found. Larvae require time to develop into pupae and adults after release and since adults emerge at different times, they may not find mates.

Environmental conditions

Certain environmental conditions retard development of *C. coeruleus*. Windy or extremely hot, dry, or humid conditions, the isolation of leucaena among other crops or natural vegetation, and frequent insecticide applications by spraying discourage reproduction, survival, and dispersal of the predator. In extreme conditions of drought and very wet weather, the psyllid population is low and establishment of the predator can fail. The predator should be released when eggs and young nymphs of the psyllid are abundant. *C. coeruleus* should not be released at night, because they are inactive and other predators, such as ants and lizards can prey on them.

Evaluation

The evaluation should be based on the recovery, reproduction and effectiveness of the predator.

Recovery

Larvae, pupae and adults of *C. coeruleus* are usually easy to find. The adults are active in seeking prey. Since adults may survive for 1-4 months, recovery of adults is not the most important indicator of predator establishment. However, recovery of adults one or two months after release is a good indicator of predator survival.

Reproduction

Recovery of larvae and pupae in the field reflects successful reproduction of *C. coeruleus*. Eggs and newly hatched larvae were difficult to observe; older instars, pupae and adults could be found more easily. The population in an area near a release site was estimated by counting larvae, pupae, and adults collected from twigs sampled at the height of the observer. This per twig count multiplied by the average total number of twigs on each stem of leucaena and the number of leucaena plants in the area provided an estimate of the total population. *C. coeruleus* should be counted between 8.00 and 10.00 hr in the morning when its vertical and horizontal distribution on the plant is observed to be nearly even.

Using this procedure, it was estimated that at Jollong Coffee Estate in Central Java, at an

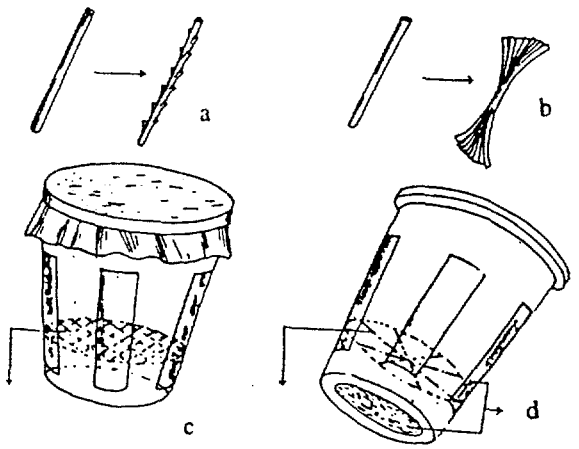

Figure 3. Bamboo sticks as oviposition sites and plastic baskets with 5 screened windows. a. Notched bamboo stick, b. Knotted bamboo stick, c. and d. Plastic baskets with different bamboo stick arrangements.

elevation of 500 to 900 m., the *C. coeruleus* population gradually increased from about 100 individuals in December 1986 to 25,000 in March 1987, 250,000 in June 1987, 600,000 in September 1987, 1.5 million in December 1987, 6.3 million in March 1988, 12.2 million in June 1988, 19.0 million in September 1988, and 25.0 million in December 1988. In Yogyakarta and Central Java, there were 30-40 million *C. coeruleus* at various life stages in January 1989 (Wagiman *et al.* 1988, Suparman, pers. comm.).

Efficacy

Finally, efficacy of the predator was evaluated by monitoring psyllid populations and recovery of leucaena.

Reduction of psyllid populations

Nymphs and adults of the psyllid were sampled periodically before and after release of the predator. The psyllids were collected by enclosing the tip of a leucaena shoot in a plastic bag, tapping the plastic bag and removing the tip carefully. Chloroform dropped on a piece of cotton killed the psyllids in the bag. The psyllids were counted using a hand counter and a piece of paper marked with a grid (Figure 4).

Suparman (pers. comm.) found no significant relationship between population density, of the psyllid and *C. coeruleus*; the correlation coefficient was only -0.2. Perhaps a higher population of the predator is needed to control the psyllid or perhaps other environmental conditions override the effect of the predator on the psyllids.

Recovery of leucaena

Although there was no significant correlation between the populations of *C. coeruleus* and psyllids per twig, *C. coeruleus* population growth was followed by the recovery of the leucaena trees. Recovery of leucaena was documented by taking photographs of damaged leucaena plants before the release of the predator and several months after the release during the dry season.

Another indicator reflecting the degree of control by *C. coeruleus* was the production of estate crops with leucaena as shade trees. Data collected during 1986 - 1988 by Mangoendihardjo *et al.* (1988) showed that at Jollong Coffee Estate, where *C. coeruleus* was released and became established in 1986, there

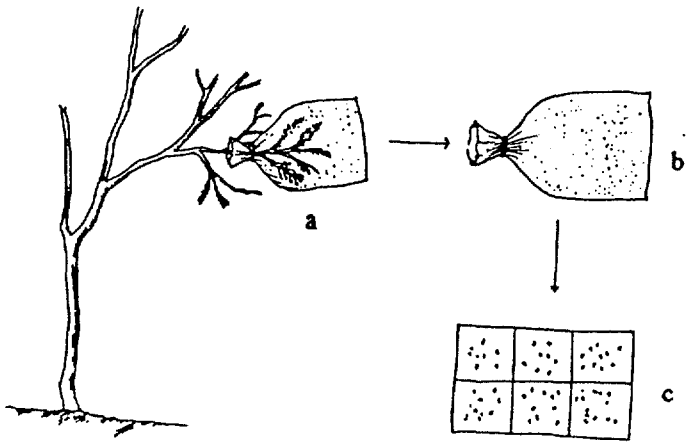

Figure 4. Plastic bag and paper used for collecting and counting the population of nymphs and adults of leucaena psyllid. a. Plastic bag used for snarling at the tip of leucaena, b. Plastic bag and a piece of cotton dropped with chloroform to kill the psyllid, and c. Paper with grid to spread the psyllids before counting.

collected during 1986 - 1988 by Mangoendihardjo *et al.* (1988) showed that at Jollong Coffee Estate, where *C. coeruleus* was released and became established in 1986, there was no reduction in coffee production. In the Public Coffee Estate near Jollong Coffee Estate, where no *C. coeruleus* was released, coffee production in 1987 and 1988 was only 50 percent of the production in 1986.

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APPENDIX K

STUDY ON ARTIFICIAL DIET FOR THE REARING OF *CURINUS COERULUS* MULSANT IN INDONESIA

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STUDY ON ARTIFICIAL DIET FOR THE REARING OF *CURINUS COERULEUS* MULSANT

Soeprapto Mangoendihardjo, F.X. Wagiman
and Agnes Tutik Purwani Irianti

Faculty of Agriculture
Gadjah Mada University
Yogyakarta, Indonesia

Abstract

Four formulae of artificial diet consisting of chicken egg or chicken liver were tested on the larval instars of *Curinus coeruleus* Mulsant. The development of the third and fourth instar larvae into adults ranged from 24 to 40 percent, and the females produced fertile eggs. A dough consisting of the powder of egg white or chicken liver, sugar, yeast, pure honey, vitamin C, agar, and aquadest was a good artificial diet. However, the developmental period of the larval instars was longer and the adults that emerged were smaller for larvae fed the artificial diet than for the larvae fed with natural prey.

Introduction

Curinus coeruleus Mulsant (Coleoptera: Coccinellidae) has been easily reared on its natural prey, the eggs and young nymphs of leucaena psyllid, *Heteropsylla cubana* Crawford (Anon. 1987). While producing eggs, the adult predator could be reared on artificial diets, such as raisin and pure honey. It has also been reared on a diet of natural prey and pure honey and females produced 957 eggs (maximum 2,159 eggs), about 6 times as many eggs as the females fed eggs and nymphs without honey (Irianti 1988).

At some *C. coeruleus* mass rearing centers in Central Java and Yogyakarta Special Territory, the mass rearing failed because of the lack of natural prey during the rainy season. Preliminary studies showed that older instar larvae of *C. coeruleus* could be reared on an artificial diet consisting of raisins and a dough made of fruits and pure honey (Mangoendihardjo 1987). This result encouraged the investigators to develop artificial diets which could be produced easily and cheaply. Preliminary results of the study are presented in this paper.

Materials and Methods

Four formulae of artificial diet made of chicken eggs or chicken liver were tested. The primary ingredients, (1) egg white, (2) egg white and yolk, (3) yolk, and (4) chicken liver, were steamed, dried and ground. A dough was prepared consisting of 5 g of the protein powder, 5 g of cane sugar, 5 g of yeast, 2.5 ml of honey, one tablet of vitamin C, 0.1 g of agar, and 18 ml aquadest.

The diets were placed in a petri dish lined with paper to prevent dampness on the bottom. Five larvae of each instar were released in each petri dish. The dishes were arranged in a completely randomized design and replicated five times. The parameters were larval, prepupal and pupal period, percentage of adults emerged and egg production.

Results and Discussion

The percentage of larvae that developed into adults ranged from 0 to 40 percent (Table 1). In general, older instars developed better than younger instars. No first instar larvae fed with artificial diet developed into adults, and no second instar larvae fed with egg yolk or chicken liver developed into adults. Four to 40 percent of third and fourth instar larvae developed into adults.

Larval, prepupal and pupal periods were longer for larvae fed with artificial diets than for larvae fed with natural prey (Table 2). Adults of *C coeruleus* reared on artificial diets were smaller than adults reared on natural diets (Table 3).

Adults that were fed artificial diet produced eggs (Table 4) and some eggs hatched. Further investigation of egg viability is still needed. The highest number of eggs produced was from females fed with chicken liver or egg white and yolk. Females fed with yolk alone produced the lowest number of eggs (Table 4).

Irianti (1988) reported that the total number of eggs and nymphs of leucaena psyllid consumed by the first to third instars of *C. coeruleus* was

Table 1. The average percentage of larvae that developed into adults when fed with artificial diets.

Artificial diets	Larval instar			
	L1 (%)	L2 (%)	L3 (%)	L4 (%)
1. Egg white	0	8	20	36
2. Egg white mixed with yolk	0	16	8	32
3. Egg yolk	0	0	4	20
4. Liver	0	0	4	40

Table 2. Larval, prepupal and pupal periods of larvae fed with various artificial diets (days).

Larval diets	Stages						Total
	L1	L2	L3	L4	PP	P	
L1 Egg white	3.75	-	-	-	-	-	-
White egg + Egg yolk	-	-	-	-	-	-	-
Egg yolk	2.0	-	-	-	-	-	-
Liver	2.0	-	-	-	-	-	-
Natural prey	2.9	2.2	3.2	5.1	1.7	4.7	19.8
L2 Egg white	-	6.38	21.5	14.0	2.0	7.0	50.88
White egg + Egg yolk	-	3.09	12.75	8.5	2.0	7.0	33.34
Egg yolk	-	3.3	-	-	-	-	-
Liver	-	6.3	10.0	-	-	-	-
Natural prey	-	2.2	3.2	5.1	1.7	4.7	17.6
L3 Egg white	-	-	8.63	16.0	2.6	7.0	34.23
White egg + Egg yolk	-	-	10.67	11.5	1.5	8.5	32.17
Egg yolk	-	-	10.67	11.0	4.0	5.0	30.67
Liver	-	-	10.33	10.0	1.0	7.0	28.33
Natural prey	-	-	3.2	5.1	1.7	4.7	14.7
L4 Egg white	-	-	-	12.1	2.0	6.9	21.0
White egg + Egg yolk	-	-	-	12.3	1.9	7.9	22.1
Egg yolk	-	-	-	10.0	2.17	8.0	20.17
Liver	-	-	-	13.83	2.25	7.8	23.88
Natural prey	-	-	-	5.1	1.7	4.7	11.5

Table 3. The size of adult *Curinus coeruleus* fed with various artificial diets.

Diets	Male			Female		
	length (mm)	width (mm)	n	length (mm)	width (mm)	n
1. Egg white	4.75	4.11	8	4.8	4.06	7
2. Egg white + yolk	4.86	4.22	8	4.9	4.17	9
3. Egg yolk	4.6	4.25	2	4.4	3.9	1
4. Liver	4.58	3.98	6	4.58	3.88	5
5. Natural prey	5.09	4.46	10	5.35	4.63	10

Table 4. Egg productivity of *Curinus coeruleus* fed with various artificial diets for 70 days.

Artificial diets	Number of females	Total number of eggs produced	Number of eggs per female
1. Egg white	7	536	76
2. Egg white + yolk	9	1,112	123
3. Egg yolk	1	2	2
4. Liver	5	731	146

lower than that of fourth instar larvae and adults. When offered psyllids eggs only, the first to third instar larvae of *C. coeruleus* consumed 511 eggs per individual, while fourth instar larvae and adults consumed 536 eggs per individual. If eggs and nymphs were offered together, the number of individuals consumed by younger and older stages were 391 and 474 respectively.

When psyllid nymphs were offered alone, the number of individuals consumed by the younger and older stages were 111 and 232 respectively. This means that we can reduce the number of psyllid eggs and nymphs by more than one half by substituting artificial diet at the fourth instar larvae and adult stages. During the rainy season, when the population of the psyllid was low and sometimes quite difficult to obtain, this procedure would be more economical.

Conclusion

Artificial diets consisting of chicken egg or chicken liver powders, sugar, honey, yeast, vitamin C, agar and aquadest, can be used to rear 4th instar larvae and adults of *C. coeruleus*. About 20-40 percent of the larvae developed into adults and the females produced fertile eggs.

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APPENDIX L

MALAYSIA PLANT QUARANTINE ACT, 1976

KERTAS MAKLUMAT KUARANTIN BIL. 14/89

PLANT QUARANTINE REQUIREMENTS FOR THE INTRODUCTION OF BENEFICIAL ORGANISMS INTO MALAYSIA

Kementerian Pertanian
Jabatan Pertanian
Semenanjung Malaysia

November, 1989

FOREWORD

The Plant Quarantine Act 1976 was promulgated with the primary objective of protecting Malaysia's agriculture from pests, be they domestic or foreign. Besides restricting the entry of exotic pests, the Act provides for suitable preventive measures to be undertaken on pest carriers which range from host plants to non-plant materials. A beneficial organism as defined under the Act falls under the category of a non-plant pest carrier and possibly as a pest per se. Hence, the entry of beneficial organisms into Malaysia is controlled with the objective of ensuring that the organisms do not carry contaminants, hyperparasites or other organisms which are harmful to plants. Furthermore, an organism whilst beneficial as a biocontrol agent against one pest species, a noxious weed or as a pollinator should not be a pest to another beneficial organism or to any economic crop.

This information booklet is prepared as a general guideline for research scientists especially those involved in biological control of pests. As the range of organisms which can be considered beneficial to agriculture is wide and varied, the entry of each species shall be considered on its own merit. Details of specific requirements would be spelt out in the permit issued for each introduction.

Director-General of Agriculture,
Malaysia.

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PLANT QUARANTINE REQUIREMENTS FOR THE INTRODUCTION OF BENEFICIAL ORGANISMS

INTRODUCTION

The introduction of beneficial organisms into Malaysia is controlled under the Plant Quarantine Act 1976. Under the Act "a beneficial organism" is defined as "any invertebrate animal (including the eggs of such animal), fungus, bacterium, virus or any other organism which is beneficial to agriculture and which is not capable of being injurious to plants". Biological control agents of insect pests, natural enemies of weeds, microbial agents, pollinators, honey bees, silkworms, compost accelerators, rhizobium inoculants, earthworms and mushrooms amongst others, fall within the above definition of beneficial organisms. Importation of beneficial organisms into Malaysia requires an import permit from the Director-General of Agriculture, Peninsular Malaysia, the Director of Agriculture Sabah or the Director of Agriculture Sarawak. In addition to the permit the organisms must be certified as pure cultures and free from contaminants and hyperparasites by the relevant authority from the exporting country.

CATEGORIES OF BENEFICIAL ORGANISMS

A. Biological Control Agents of Insect Pests
- (i) Proven parasitoids
- (ii) Unproven parasitoids
- (iii) Vertebrate predators
- (iv) Proven insect pathogens
- (v) Unproven insect pathogens

B. Natural Enemies of Weeds
- (i) Proven phytophagous insects
- (ii) Unproven phytophagous insects

(iii) Proven pathogenic organisms
(iv) Unproven pathogenic organisms
(v) Phytophagous vertebrates

C. Other Beneficial Organisms

(i) Insect pollinators
(ii) Silkworms
(iii) Honeybees
(iv) compost accelerators
(v) Rhizobium innoculants
(vi) Earthworms
(vii) Mushroom spawn

QUARANTINE REQUIREMENTS

A. Biological Control Agents of Insect Pests

(1) Proven parasitoids

(a) An importer is required to submit to the Department of Agriculture (DOA) the following data and reports:-

(i) Reports of status of local natural enemies of target pest in Peninsular Malaysia, Sabah or Sarawak based on actual surveys.

(ii) Research data proving the effectiveness of the parasitoid on the target pest in the country of export or any other country.

(iii) Reports of successful application of the parasitoid in the control of the target pest.

(iv) Established data on host specificity tests.

(b) The parasitoid to be introduced should be obtained from laboratory bred pure cultures.

(c) Preferably the pupal stage of the parasitoid is to be introduced and these are to be packed individually in properly stoppered clear glass vials.

(d) In the country of export, the pupae should be surface sterilised by dipping in 0.1% sodium hypochlorite or any other suitable disinfectant.

(e) On importation, the introduced parasitoid shall be screened for species purity, and freedom from hyperparasites or any other foreign contaminants.

(f) Rejected parasitoids and packing materials shall be disposed off only after autoclaving or soaking in formalin solution or by incineration.

(g) All post-entry screening of the parasitoids are to be carried out in the quarantine insectary of the DOA or any other approved facility.

(h) Host specificity studies on previously tested plants as well as any additional local species not tested shall be carried out under quarantine.

(i) Post-entry quarantine screening will be carried out by the DOA in conjunction with the research entomologist/plant pathologist. A joint report shall be prepared for presentation to the

Director-General of Agriculture/Director of Agriculture. After presentation of the results of the post-entry screening tests, the Director-General shall decide on its release into the field.

(j) Only the F_1 and subsequent generations of the parasitoid shall be released. Any surviving parental insects shall be destroyed.

(k) All waste materials used in the post-entry studies should be destroyed by incineration or autoclaving or with formalin within the insectary.

(2) Unproven parasitoid

(a) Research by biocontrol entomologist must be carried out in the laboratory as well as in the field to prove the effectiveness of the parasitoid on the target pest in the country of origin or any other place outside Malaysia. Results of such research must be submitted to the DOA. If only laboratory studies are required, such studies may be carried out in the DOA quarantine insectary under the supervision of the Department of Agriculture.

(b) Status of natural enemies of the target pest in Peninsular Malaysia, Sabah or Sarawak to be established and report of such survey be submitted to the DOA.

(c) Host specificity studies are to be carried out outside Malaysia or in the DOA quarantine insectary.

(d) All other quarantine measures and requirements under (b) - (k) as described under "proven parasitoids" apply.

(3) Invertebrate predators

(a) Research data on the host range of the predator and its effectiveness on target pests must be produced to the DOA. If such data are not available, the researcher concerned will be required to carry out necessary studies in the country of origin.

(b) The predator must be host specific and known not to predate on beneficial insects or mites or cause any nuisance to human or domestic animals.

(c) Quarantine measures (b) - (k) as described under "proven parasitoid" apply.

(4) Vertebrate predators

(a) Importation of vertebrate predators is prohibited unless well proven to be host specific, effective and harmless to beneficial insects or mites and do not cause any nuisance to human and domestic animals, or disrupt the ecology of the environment.

(b) Importation is subjected to approval by the Veterinary Department, and other relevant authorities besides the DOA.

(5) Proven insect pathogens - Insect pathogens which are included in this category are bacteria, fungi, viruses, nematodes, protozoa, etc.

(a) The importer must submit to the DOA the following data and reports.

(i) Report of status of local entomogenous pathogens on the target insect pest through actual surveys or from literature.

(ii) Research data indicating its effectiveness on the target pest in other countries.

(iii) Host specificity data (in relation to its effect on beneficial insects or other non-pest organisms).

(b) The pathogens to be imported must be obtained from laboratory bred pure cultures.

(c) On importation, the introduced pathogen shall be screened for species purity and freedom from other contaminants.

(d) Rejected cultures and packing materials shall be disposed off by autoclaving.

(e) Verification on host specificity to be carried out in the post-entry quarantine station by the relevant researcher in conjunction with staff of the DOA.

(f) Results of post-entry quarantine screening must be submitted to the Director-General of Agriculture/ Director of Agriculture who shall decide on its release into the field.

(g) All waste materials used in post-entry screening shall be destroyed by autoclaving.

(6) Unproven insect pathogens

Similar requirements as for "unproven parasitoids" except that all preliminary studies on the effectiveness and host specificity are to be carried out outside Malaysia.

B. Natural Enemies of Weeds

(1) Proven phytophagous insects

(a) An importer is required to submit to the DOA the following data and reports:-

(i) Reports of status of natural enemies of the target weed in Peninsular Malaysia, Sabah or Sarawak as the case may be based on actual survey.

(ii) Research data on host-specificity tests.

(iii) Reports of successful application of the natural enemy in the control of the target weed.

(b) Other quarantine requirements or measures (b) to (k) as described under "proven parasitoids" apply.

(2) Unproven phytophagous insects

(a) Research by biocontrol entomologist to be carried out in the country of origin to (i) prove the effectiveness of the insect on the target weed; (ii) determine its host specificity - including all economic crops of Malaysia. Results of such studies to be submitted to the DOA. If only laboratory studies are required, such studies may be carried out in the DOA quarantine insectary under supervision of the DOA.

(b) Status of natural enemies of target weed in Peninsular Malaysia, Sabah or Sarawak to be determined through surveys and reports of such surveys to be submitted to the Department of Agriculture.

(c) Other quarantine requirements or measures (b) to (k) as listed under "proven parasitoids" apply.

(3) Proven pathogenic organisms - Pathogenic organisms which are included in this category are bacteria, fungi, viruses, nematodes, protozoa, etc.

(a) The pathogen must be specific to the target weed. Data proving its specificity must be produced. Factors such as races of the pathogen and environmental conditions must be taken into consideration when testing for host range.

(b) The culture to be imported must be pure which shall be re-examined on importation for species purity.

(c) Verification and additional host specificity tests shall be carried out in the post-entry quarantine station in conjunction with the DOA.

(d) Results of post-entry screening to be submitted to the Director-General of Agriculture/Director of Agriculture who shall decide on its suitability for field release.

(e) Other quarantine measures pertaining to disposal of materials as described under "proven insect pathogens" apply.

(4) Unproven pathogenic organisms

Similar requirements as described under "unproven phytophogous insects" applies, with the exception that importation for preliminary studies locally on its effectiveness and host specificity is prohibited.

C. Other Beneficial Organisms

Other organisms which do not fall under the above categories may be considered beneficial as long as they are not plant pests within the context of the definition of the Plant Quarantine Act but beneficial to agriculture.

(1) Insect pollinators - An importer is required to submit to the DOA the following data and reports:-

(a) Status of insect pollinators or nature of pollination of target crops in Peninsular Malaysia, Sabah or Sarawak based on actual surveys.

(b) Research data proving the effectiveness of the pollinator on similar crops in the country of origin.

(c) Results of host-range studies conducted in the country of origin. Host-range studies shall be repeated at the post-entry quarantine station in conjunction with the DOA.

(d) Other procedures and quarantine measures (b-k) as described under "proven parasitoids" apply.

(2) Silkworms

(a) The eggs, prior to import, must be soaked in 1% formalin solution for 20 minutes, rinsed in water and dried under shade before packing.

(b) The consignment must be accompanied with an approved certificate from the country of origin to certify that the eggs are produced from moths which are free from the following diseases:-

(i) Pebrine disease, Nosema bombycis

(ii) White musscardine, Beauveria bassiana
Green muscardine, Spicaria prasina
Yellow muscardine, Isariopsis farinosa

(iii) Viral diseases namely Grasserie (grasserie-virus), Cytoplasmic Polyhedrosis (polyhedral virus), Infectious flacherie (morator-virus)

If adequate certification is not provided, the consignment shall be destroyed upon arrival.

(c) Post-entry quarantine inspection shall be conducted at the importer's premise by DOA. Immediately after hatching, the first instar larvae shall be examined for presence of diseases.

(d) All diseased larvae shall be destroyed and the rearing containers and tools disinfected with 3% formalin and sun-dried.

(3) Honeybees (Apis spp.)

(a) Importation of hives or combs is not permitted.

(b) It is prohibited to import used bee equipment.

(c) Containers used for approved importation must be destroyed by incineration.

(d) The bees must be accompanied with an approved certificate from the country of origin to prove that the bees and the original colony are free from the following pests and diseases:-

(i) American Foul Brood - Bacillus larvae

(ii) European Foul Brood - Streptoccus pluton

(iii) Nosema disease - Nosema apis

(iv) Sacbrood - Sacbrood virus

(v) Mite - Acarapis woodi

(e) Only Apis mellifera from Australia, New Zealand, Taiwan and the United States (Hawaii) are allowed entry on condition they are certified as specified under (d).

(f) The worker bees accompanying the queen bee must be packed in escape-proof screen cages with necessary food supply.

(g) Bees found to be infested or inadequately certified will be destroyed upon arrival.

(h) Semen of honey bees from the African and American continents (North and South America) is strictly prohibited.

(4) Compost accelerators

(a) Technical data on the pathogenicity to plants of all the organisms contained in the product is to be submitted to the DOA for evaluation.

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(b) If any of the organisms or strains of the organisms is/are exotic and known to be pathogenic to plants, importation will not be permitted.

(5) Rhizobium innoculants

Phytosanitary certificate to certify that the

(a) organisms are from pure laboratory-cultured source.

(b) medium has been sterilised or do not carry any plant pest(s).

(6) Earthworms

Phytosanitary certificate or any other approved certificate to certify that the organic medium on whic the earthworms are cultured is free from plant pests.

(7) Mushroom spawn

(a) Phytosanitary certificate to declare that the mushroom cultures are pure and free from pathogenic organisms.

(b) The mushroom spawn species must not be pathogenic to local economic crops.

(c) Spawn bottle to be properly labelled and sealed.

Plant Quarantine Section
Crop Protection Branch
Department of Agriculture
Kuala Lumpur
AUGUST 1989

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APPENDIX M

LISTS OF NATURAL ENEMIES IN THAILAND

Table 1. Some important natural enemies of insect pests of rice in Thailand

Insect pest species	Natural enemies
Rice stem borer complex:	
Scirpophaga incertulas (Walker)	**Egg parasites:**
Chilo suppressalis (Walker)	*Telenomus dignus* Gahan
Chilo polychrysa (Meyrick)	(Scelionidae)
Sesamia inferens (Walker)	*Telenomus rowani* Gahan
	(Scelionidae)
	Tetrastichus ayyari Rohwer
	(Eulophidae)
	Tetrastichus schoenobii Ferrière
	(Eulophidae)
	Trichogramma australicum Girault
	(Trichogrammatidae)
	Trichogramma japonicum Ashmead
	(Trichogrammatidae)
	Larval Parasites:
	Amauromorpha accepta schoenobii
	(Viereck) (Ichneumonidae)
	Bracon chinensis Szepligeti
	(Braconidae)
	Cotesia flavipes (Cameron)
	(Braconidae)
	Ischnojoppa luteator (F.)
	(Ichneumonidae)
	Temelucha philippinensis (Ashmead)
	(Ichneumonidae)
	Temelucha stangli (Ashmead)
	(Ichneumonidae)
	Tropobracon schoenobii (Viereck)
	(Braconidae)
Leafhopper and planthopper complex:	
Nephotettix virescens Distant	**Egg parasites:**
Nephotettix nigropictus Ishihara	*Anagrus optabilis* (Perkins)
Nilaparvata lugens Stal	(Mymaridae)
	Gonatocerus sp.
	(Mymaridae)
	Mymar taprobanicum Ward
	(Mymaridae)
	Oligosita sp.
	(Trichogramatidae)
	Oligosita brevicauda Girault
	(Trichogrammatidae)
	Oligosita yasumatsui Viggiani
	(Trichogrammatidae)
	Paracentrobia garuda Subba Rao
	(Trichogrammatidae)
	Paracentrobia yasumatsui Subba Rao
	(Trichogrammatidae)
	Tetrastichus formosanus Timberlake
	(Eulophidae)
	Nymphal and adult parasites:
	Elenchus yasumatsui Kifune & Hirashima
	(Elenchidae)
	Pipunculus (Eudorylas) javanensis de Meijère

Table 1. Some important natural enemies of insect pests of rice in Thailand

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Insect pest species	Natural enemies
Rice stem borer complex:	
Scirpophaga incertulas (Walker)	**Egg parasites:**
Chilo suppressalis (Walker)	*Telenomus dignus* Gahan
Chilo polychrysa (Meyrick)	(Scelionidae)
Sesamia inferens (Walker)	*Telenomus rowani* Gahan
	(Scelionidae)
	Tetrastichus ayyari Rohwer
	(Eulophidae)
	Tetrastichus schoenobii Ferrière
	(Eulophidae)
	Trichogramma australicum Girault
	(Trichogrammatidae)
	Trichogramma japonicum Ashmead
	(Trichogrammatidae)
	Larval Parasites:
	Amauromorpha accepta schoenobii
	(Viereck) (Ichneumonidae)
	Bracon chinensis Szepligeti
	(Braconidae)
	Cotesia flavipes (Cameron)
	(Braconidae)
	Ischnojoppa luteator (F.)
	(Ichneumonidae)
	Temelucha philippinensis (Ashmead)
	(Ichneumonidae)
	Temelucha stangli (Ashmead)
	(Ichneumonidae)
	Tropobracon schoenobii (Viereck)
	(Braconidae)
Leafhopper and planthopper complex:	
Nephotettix virescens Distant	**Egg parasites:**
Nephotettix nigropictus Ishihara	*Anagrus optabilis* (Perkins)
Nilaparvata lugens Stal	(Mymaridae)
	Gonatocerus sp.
	(Mymaridae)
	Mymar taprobanicum Ward
	(Mymaridae)
	Oligosita sp.
	(Trichogramatidae)
	Oligosita brevicauda Girault
	(Trichogrammatidae)
	Oligosita yasumatsui Viggiani
	(Trichogrammatidae)
	Paracentrobia garuda Subba Rao
	(Trichogrammatidae)
	Paracentrobia yasumatsui Subba Rao
	(Trichogrammatidae)
	Tetrastichus formosanus Timberlake
	(Eulophidae)
	Nymphal and adult parasites:
	Elenchus yasumatsui Kifune & Hirashima
	(Elenchidae)
	Pipunculus (Eudorylas) javanensis de Meijère

Table 1. (Contd.)

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Insect pest species	Natural enemies
	(Pipunculidae) *Pipunculus (Eudorylas) mutillatus* Loew (Pipunculidae) *Pipunculus (Eudorylas) orientalis* Koizumi (Pipunculidae) *Pseudogonatopus hospes* Perkins (Dryinidae) *Tomosvaryella oryzaetora* Koizumi (Pipunculidae) *Tomosvaryella subvirescens* (Loew) (Pipunculidae) **Predator:** *Cyrtorhinus lividipennis* Reuter (Miridae)
Rice gall midge: *Orseolia oryzae* (Wood-Mason)	**Larval-pupal parasites:** *Neanastatus cinctiventris* Girault (Eupelmidae) *Neanastatus gracillius* ? (Eupelmidae) *Neanastatus oryzae* Ferrière (Eupelmidae) *Obtusiclava oryzae* Subba Rao (Pteromalidae) *Platygaster foersteri* (Gahan) (Platyfgasteridae) *Platygaster oryzae* (Cameron) (Platygasteridae)
Rice leaffolder: *Cnaphalocrocis medinalis* Guenée	**Egg parasites:** *Trichogramma* sp. (Trichogrammatidae) *Trichogramma chilonis* Ishii (Trichogrammatidae) **Larval parasites:** *Brachymeria excarinata* Gahan (Chalcididae) *Cotesia angustibasis* (Gahan) (Braconidae) *Copidosoma (= Litomastix)* sp. (Encyrtidae) *Elasmus claripennis* (Cameron) (Elasmidae) *Goniozus* sp. nr. *hanoiensis* Gordh (Bethylidae) *Macrocentrus* sp. (Braconidae) *Stenomesius japonicus* (Ashmead) (Eulophidae) **Pupal parasites:** *Brachymeria* sp. (Chalcididae)

Table 1. (Contd.)

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Insect pest species	Natural enemies
	Trichospilus pupivora Ferrière (Eulophidae) *Xanthopimpla flavolineata* Cameron (Ichneumonidae)
Armyworm and cutworm complex: *Mythimna loreyi* (Dup.) *Mythimna separata* (Walker) *Mythimna venalba* (Moore)	**Larval parasites:** *Apanteles taragamae* Viereck (Braconidae) *Blepharella paradosum* (Tachinidae) *Brachymeria euploeae* (Westwood) (Chalcididae) *Copidosoma (= Litomastix)* sp. (Encyrtidae) *Eocarcelia kockiana* (Townsend) (Tachinidae) *Exorista civiloides* Baranov (Tachinidae) *Exorista sorbillans* (Wiedemann) (Tachinidae) *Microbracon* sp. (Braconidae) *Nemorilla anomala* (Walker) (Tachinidae) *Palexorista solensis* (Walker) (Tachinidae) *Pseudogonia jacobsoni* (Tachinidae)
Rice skipper: *Pelopidas mathias* (F.)	**Larval parasites:** *Apanteles baoris* Wilkinson (Braconidae) *Charops brachypterum* Gupta & Maheswary (Ichneumonidae) *Halidaya luteicornis* Walker (Tachinidae) *Thecocarcelia (= Arhyrophylax) nigrotibialis* (Baranov) (Tachinidae)
Rice bug: *Leptocorisa acuta* (Thunberg)	**Egg parasite:** *Gryon nixonii* Mashner (Scelionidae)
Rice grasshopper: *Hieroglyphus banian* (F.)	**Egg parasites:** *Scelio facialis* Kieffer (Scelionidae) *Scelio hieroglyphi* Timberlake (Scelionidae)

Table 2. Some important natural enemies of insect pests of agricultural crops other than rice in Thailand 220

Insect pest species	Natural enemies
FIELD CROP PESTS:	
Castor bean	
Castor semilooper: *Ophiusa janata (L.)* (Lepidoptera: Noctuidae)	**Predator:** *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae)
Corn	
Asiatic corn borer: *Ostrinia furnacalis* (Guenée) (Lepidoptera: Noctuidae)	**Egg parasites:** *Trichogramma australicum* Girault (Hymenoptera: Trichogrammatidae) *Trichogramma chilotraeae* Nagaraja & Nagarkatti (Hymenoptera: Trichogrammatidae) **Predator:** *Proreus similans* (Stal) (Dermaptera: Chelisochidae)
Bombay locust: *Patanga succincta* (L.) (Orthoptera: Acrididae)	**Egg parasites:** *Scelio facialis* Kieffer (Hymenoptera: Scelionidae) *Scelio hieroglyphi* Timberlake (Hymenoptera: Scelionidae) **Nymphal and adult parasite:** Unidentified mermithid nematode **Fungus disease:** *Entomophaga grylli* (Fresenius) Batko (Entomophthorales: Entomophthoraceae)
Corn leaf aphid: *Rhopalosiphum maidis* (Fitch) (Homoptera: Aphididae)	**Nymphal and adult parasite:** Unidentified aphelinid **Predators:** *Menochilus sexmaculatus* (F.) (Coleoptera: Coccinellidae) *Micraspis discolor* (F.) (Coleoptera: Coccinellidae)
Corn ear worm: *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae)	**Egg parasites:** *Trichogramma australicum* Girault (Hymenoptera: Trichogrammatidae) *Trichogramma chilotraeae* Nagaraja & Nagarkatti (Hymenoptera: Trichogrammatidae) *Trichogrammatoidea bactrae* Nagaraja (Hymenoptera: Trichogrammatidae) **Predator:** *Proreus similans* (Stal) (Dermaptera: Chelisochidae)
Corn thrips: *Frankliniella williamsi* Hood (Thysanoptera: Thripidae)	**Predator:** *Orius persequens* (Hemiptera: Anthocoridae)

Table 2. (Contd.)

221

Insect pest species	Natural enemies
Cotton	
Cotton aphid:	
Aphis gossypii (Glover)	**Predators:**
(Homoptera: Aphididae)	*Menochilus sexmaculatus* (F.)
	(Coleoptera: Coccinellidae)
	Micraspis discolor (F.)
	(Coleoptera: Coccinellidae)
American bollworm:	
Heliothis armigera (Hubner)	**Egg parasites:**
(Lepidoptera: Noctuidae)	*Trichogramma chilonis* Ishii
	(Hymenoptera: Trichogrammatidae)
	Trichogramma confusum Viggiani
	(Hymenoptera: Trichogrammatidae)
	Trichogrammatoidea bactrae Nagaraja
	(Hymenoptera: Trichogrammatidae)
	Larval parasites:
	Cotesia sp.
	(Hymenoptera: Braconidae)
	Carcelia rutilla Rondani
	(Diptera: Tachinidae)
	Erioborus argenteopilosus (Cameron)
	(Hymenoptera: Braconidae)
	Exorista sorbillans (Wiedemann)
	(Diptera: Tachinidae)
	Phorcida sp.
	(Diptera: Tachinidae)
	Predators:
	Chrysoperla basalis (Walker)
	(Neuroptera: Chrysipidae)
	Chrysoperla ochracea Alb.
	(Neuroptera: Chrysopidae)
	Coccinella transversalis F.
	(Coleoptera: Coccinellidae)
	Eocanthecona furcellata (Wolff)
	(Hemiptera: Pentatomidae)
	Eumenes sp.
	(Hymenoptera: Eumenidae)
	Geocoris sp.
	(Hemiptera: Lygaeidae)
	Hapactor tristicolor Reuter
	(Hemiptera: Reduviidae)
	Harmonia arcuata F.
	(Coleoptera: Coccinellidae)
	Macranthopsis nodipes Reuter
	(Hemiptera: Reduviidae)
	Menochilus sexmaculatus (F.)
	(Coleoptera: Coccinellidae)
	Micraspis discolor (F.)
	(Coleoptera: Coccinellidae)
	Nabis sp.
	(Hemiptera: Nabidae)
	Ropalidia faciata
	(Hymenoptera: Vespidae)
	Sycanus collaris (F.)
	(Hemiptera: Reduviidae)

Table 2. (Contd.)

Insect pest species	Natural enemies
Cotton leafworm: *Spodoptera litura* (F.) (Lepidoptera: Noctuidae)	**Egg parasites:** *Chelonus* sp. (Hymenoptera: Braconidae) *Telenomus nawai* (Ashmead) (Hymenoptera: Scelionidae) **Larval parasites:** *Cotesia* sp. (Hymenoptera: Braconidae) Predator: *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae)
Cotton leafhopper: *Amrasca biguttula* Ishida (Homoptera: Cicadellidae)	**Predators:** *Geocoris* sp. (Hemiptera: Lygaeidae) *Menochilus sexmaculatus* (F.) (Coleoptera: Coccinellidae) *Micraspis discolor* (F.) (Coleoptera: Coccinellidae)
Sorghum **Sorghum shoot fly:** *Atherigona soccata* Rondani (Diptera: Muscidae)	**Egg parasite:** *Trichogrammatoidea bactrae* Nagaraja (Hymenoptera: Trichogrammatidae) **Larval parasite:** *Tetrastichus nyemitanus* Rohwer (Hymenoptera: Eulophidae) **Pupal parasites:** *Psilus* sp. (Hymenoptera: Diapriidae) *Trichopria* sp. (Hymenoptera: Diapriidae)
Soybean **Bean fly:** *Ophiomyia phaseoli* (Tryon) (Diptera: Agromyzidae)	**Larval parasites:** *Biosteres* sp. (Hymenoptera: Braconidae) *Plutarchia giraultii* (Hymenoptera: Eurytomidae) Unidentified cynipid Unidentified eulophid Unidentified pteromalid
Green stink bug: *Nezara viridula* (L.) (Hemiptera: Pentatomidae)	**Egg parasites:** *Telenomus* sp. (Hymenoptera: Scelionidae) *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae)
Leaffolder: *Hedylepta indicata* (F.) (Lepidoptera: Pyralidae)	**Larval parasite:** *Cotesia* sp. (Hymenoptera: Braconidae) **Pupal parasites:** *Brachymeria excarinata* Gahan (Hymenoptera: Chalcididae) *Xanthopimpla flavolineata* (Cameron) (Hymenoptera: Ichneumonidae)

Table 2. (Contd.)

Insect pest species	Natural enemies
PLANTATION CROP PESTS	
Sugarcane	
Sugarcane borer complex: *Chilo infuscatellus* Snellen *Chilo sacchariphagus* (Bojer) *Scirpophaga excerptalis* (Walker) (Lepidoptera: Pyralidae) *Sessamia inferens* (Walker) (Lepidoptera: Noctuidae)	**Egg parasites:** *Telenomus rowani* (Gahan) (Hymenoptera: Scelionidae) *Tetrastichus shoenobii* (Ferrière) (Hymenoptera: Eulophidae) *Trichogramma australicum* Girault **Larval parasite:** *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) **Pupal parasites:** Doryctinae (Hymenoptera: Braconidae) *Temelucha philippinensis* (Ashmead) (Hymenoptera: Ichneumonidae) *Tetrastichus* sp. (Hymenoptera: Eulophidae) *Xanthopimpla* sp. (Hymenoptera: Ichneumonidae)
Sugarcane scale insect: *Aulacaspis tegalensis* (Zehntner (Homoptera: Diaspidae)	**Nymphal parasite:** *Adelencyrtus miyarai* Subba Rao (Hymenoptera: Encyrtidae) **Predators:** *Chilocorus circumdatus* (Gyllenhal) (Coleoptera: Coccinellidae) *Chilocorus nigritus* (F.) (Coleoptera: Coccinellidae) *Coccinella transversalis* (F.) (Coleoptera: Coccinellidae) *Menochilus sexmaculatus* (F.) (Coleoptera: Coccinellidae)
Sugarcane whitefly: *Aleurolobus barodensis* Maskell (Homoptera: Aleurodidae)	**Larval and pupal parasites:** *Azotus* sp. (Hymenoptera: Aphelinidae) *Encarsia ochai* Viggiani (Hymenoptera: Aphelinidae) *Prospatella* sp. (Hymenoptera: Aphelinidae)
Coconut	
Rhinoceros beetle: *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae)	**Larval parasite:** *Scolia oryctophaga* (Coquillett) (Hymenoptera: Scoliidae)
Coconut slug caterpillar: *Parasa lepida* Cramer (Lepidoptera: Limacodidae)	**Larval parasites:** *Chaetexorista javana* Brauer (Diptera: Tachinidae) *Chrysis shanghaiensis* Smith (Hymenoptera: Chrysididae) *Cotesia parasae* (Rohwer) (Hymenoptera: Braconidae)

Table 2. (Contd.)

Insect pest species	Natural enemies
	Euderastichus sp. (Hymenoptera: Eulophidae) *Systopus polistoides* Westwood (Diptera: Bombyliidae) **Predator:** *Eocanthecona furcellata* (Wolff) (Hemiptera: Pentatomidae)
Banana **Banana skipper:** *Erionota thrax* (L.) (Lepidoptera: Hesperidae)	**Egg parasites:** *Anastatus* sp. (Hymenoptera: Eupelmidae) *Ooencyrtus erionotae* Ferrière (Hymenoptera: Encyrtidae) **Larval parasite:** *Apanteles erionotae* Wilkinson (Hymenoptera: Braconidae) **Pupal parasites:** *Brachymeria euploeae* (Westwood) (Hymenoptera: Chalcididae) *Brachymeria marginata* Cameron (Hymenoptera: Chalcididae) *Scenocharops* sp. (Hymenoptera: Ichneumonidae) *Xanthopimpla* sp. (Hymenoptera: Ichneumonidae)
FRUIT PESTS	
Oriental fruit fly: *Dacus dorsalis* Hendel (Diptera: Tephritidae)	**Larval parasites:** *Biosteres arisanus* (Sonan) (Hymenoptera: Braconidae) *Biosteres javanus* (Hymenoptera: Braconidae) *Biosteres longicaudatus* Ashmead (Hymenoptera: Braconidae) *Opius makii* Sonan (Hymenoptera: Braconidae) *Biosteres vandenboschi* (Fullaway) (Hymenoptera: Braconidae) *Spalangia* sp. (Hymenoptera: Pteromalidae)
Mango leafhopper complex: *Amritodus atkinsoni* Lethierry *Chunrocerus niveosparsus* Lethierry *Idioscopus clypealis* (Lethierry) (Homoptera: Cicadellidae)	**Egg parasite:** *Centrodera idioceria* Ferrière (Hymenoptera: Aphelinidae) **Nymphal and adult parasites:** *Epipyrops fuliginosa* Tams (Lepidoptera: Epipyropidae) *Pipunculus annulifemur* Brun. (Diptera: Pipunculidae)
Lemon butterfly: *Papilio demoleus* L. (Lepidoptera: Papilionidae)	**Egg parasites:** *Ooencyrtus* malayensis Ferrière (Hymenoptera: Encyrtidae)

Table 2. (Contd.)

Insect pest species	Natural enemies
	Tetrastichus sp. (Hymenoptera: Eulophidae) **Larval parasite:** *Erycia nymphalidophaga* Baranov (Diptera: Tachinidae) **Pupal parasites:** *Brachymeria marginata* Cameron (Hymenoptera: Chalcididae) *Pteromalus puparum* (L.) (Hymenoptera: Pteromalidae)
Longan stink bug: *Tessaratoma papilosa* (Drury) (Hemiptera: Pentatomidae)	**Egg parasites:** *Anastatus* sp. (Hymenoptera: Eupelmidae) *Encyrtus* sp. (Hymenoptera: Encyrtidae) *Microphanurus* sp. (Hymenoptera: Scelionidae)
VEGETABLE PESTS	
Diamondback moth: *Plutella xylostella* (L.) (Lepidoptera: Plutellidae)	**Egg parasite:** *Trichogrammatoidea bactrae* Nagaraja (Hymenoptera: Trichogrammatidae) **Larval parasite:** *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae)
Thrips: *Thrips palmi* Karny (Thysanoptera: Thripidae)	**Egg parasite:** *Megaphragma* sp. (Hymenoptera: Trichogrammatidae) **Larval parasite:** *Ceranisus menes* (Walker) (Hymenoptera: Eulophidae) **Predators:** *Bilia* sp. (Hemiptera: Anthocoridae) *Orius* sp. (Hemiptera: Anthocoridae) *Campylomma* sp. (Hemiptera: Miridae) *Franklinothrips vesiformis* (Crawford) (Thysanoptera: Aeothripidae) *Amblyseius* sp. (Acarina: Phytoseiidae) *Phytoseius* sp. (Acarina: Phytoseiidae)