Potential of classical biological control for banana weevil, *Cosmopolites sordidus* Germar, with natural enemies from Asia (with emphasis on Indonesia)

A. Hasyim[1] and C.S. Gold[2]

Potential for biological control of banana weevil

General basis and protocol for classical biological control

Biological control is defined as "the action of parasites (parasitoids), predators or pathogens in maintaining another organism's population density at a lower average than would occur in their absence" (Debach 1964). Thus, biological control represents the combined effects of a natural enemy complex in suppressing pest populations. The concept of biological control arose from the observed differences in abundance of many animals and plants in their native range compared to areas in which they had been introduced in the absence of (co-evolved) natural enemies. As such, populations of introduced pests, unregulated by their natural enemies, may freely multiply and rise to much higher levels than previously observed. Biological control is a component of **natural control** which describes environmental checks on pest buildup (Debach 1964). In agriculture, both the environment (i.e. farming systems) and natural enemies may be manipulated in an attempt to reduce pest pressure.

Classical biological control concerns the search for natural enemies in a pest's area of origin, followed by quarantine and importation into locations where the pest has been introduced. One underlying assumption is that herbivores are under natural biological control by co-evolved natural enemies and may be inconspicuous (i.e. non-pests) in their endemic range. These herbivores may reach pest status when they move into areas when freed from control by their natural enemies. Chances of natural enemy establishment

[1] Research Institute for Fruits, Solok, West Sumatra, Indonesia
[2] IITA/ESARC, Kampala, Uganda

and success are greatest when ecological conditions are similar between the areas of collection and release.

The objective of a classical biological control programme is the establishment of an equilibrium between pest and natural enemy populations such that damage levels are below economic threshold. Pest eradication is neither a sustainable nor a desirable outcome. The most effective natural enemies are monophagous or narrowly oligophagous (i.e. have narrow host or prey ranges) and they would quickly disappear if they were to exterminate their hosts. This would create new problems should the pest be reintroduced from a nearby area.

An example of a successful biological control programme involved the introduction of natural enemies (most notably the encyrtid wasp *Epidinocarsis lopezi* De Santis) into Africa for the control of the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero 1977 (Herren and Neuenschwander 1991). The cassava mealybug was accidentally brought into sub-Saharan Africa during the 1970s. It quickly spread across the cassava growing belt, causing devastating losses. Searches were undertaken in Latin America (the area of origin for cassava) for the mealybug (where it was virtually unknown) and its natural enemies. These were eventually found on cassava in Paraguay and Brazil. Release of *E. lopezi* and several predacious coccinellids quickly brought the mealybug under control throughout most of Africa.

Biological control is only one of many approaches available to reduce the abundance of pests and the damage they cause. In some cases, biological control may be sufficiently effective that no other control measures are required. Quite often, however, only partial control may be achieved and it is necessary to integrate biological control with other measures. Biological control may require an initial research expenditure, but has the advantages that it is permanent, ecologically sound, compatible with most farming practices (except the use of pesticides) and requires little or no investment on the part of the farmer. Occasionally, modification of farm management practices might be encouraged to enhance the efficacy of natural enemies.

In general, parasitoids are more effective than predators. Parasitoids tend to have narrower host ranges while many predators (including all known enemies of banana weevil) are opportunistic predators. Specialist natural enemies are likely to have more efficient searching behaviour in locating their hosts, and to be more adapted to the range of conditions under which the host lives. Ants might be an exception: although opportunistic predators, they are very effective foragers.

It is also important to ensure that candidate natural enemies do not attack other beneficial insects such as herbivores which control undesirable weeds (e.g. water hyacinth). In South Africa, for example, two coccinellids (the native *Exochomus flavipes* and the imported *Cryptolaemus montrouzieri*) effectively control *Leucaena* pysillid (*Heteropsylla cubana*), while at the same time interfering with the biological control of prickly pear cactus by the introduced cochineal insect *Dactylopius tomentosus*. Natural enemy host or prey range is normally ascertained through a careful review of the literature (on what is known about the candidate natural enemy and other species in the same genus or family), and by testing in the laboratory. A careful study of the biology and behaviour of selected natural enemies, including detailed observations in their original home, often permit sound conclusions to be drawn as to their probable host range in a new site.

The primary advantage of a classical biological control programme is that exotic natural enemies (from the area of origin) most often tend to be far more effective at controlling introduced pests than endemic natural enemies already present in the pest's new range. Natural enemies from the area of origin have had a long period of association with the pest during which both have co-evolved together. Such natural enemies are often specialists well adapted to locate the host plant and/or the pest insect. Though this line of reasoning is sometimes contested (Pimentel 1961), the fact remains that most successful biological control programmes have used natural enemies from a pest's area of origin.

Sampling both the pest and its natural enemies is necessary to determine pest density and whether adequate numbers of natural enemies are present to control the insect. For example, natural enemy numbers may initially lag behind those of pests. Thus, in some cases, pest numbers may be nearing action levels (e.g. a threshold for pesticide application), while natural enemy populations may also be increasing such that they will overtake and suppress the pest before it effects serious damage. However, it is often necessary to demonstrate to producers, accustomed to using pesticides on a timetable or at first sight of a pest, that natural enemies may bring the pest under control if they refrain from applying chemicals.

Area of origin of banana and banana weevil

The genus *Musa* originated in Southeast Asia and has a centre of diversity in Assam-Burma-Thailand-Indonesia-Papua New Guinea, with a minor centre on the Southeast African Highlands (Simmonds 1966). Edible bananas originated in South and Southeast Asia from two wild progenitors, *Musa acuminata* (donor of A genome) and *Musa balbisiana* (donor of B genome), and have spread throughout the humid tropics (Stover and Simmonds 1987). Secondary centres of crop diversity exist in East Africa (highland cooking bananas, unique to the region) and West Africa (plantains) (Stover and Simmonds 1987).

The banana weevil (*Cosmopolites sordidus* Germar) is believed to be a native of the Indo-Malaysian region (Zimmerman 1968, Clausen 1978). However, bananas (and the weevil) have long been disseminated throughout the world; therefore, the centre of origin of the weevil remains obscure. Furthermore, the existence of but a single congeneric species (*C. pruinosus*, reported from Borneo and the Philippines (Zimmerman 1968) makes it difficult to use taxonomic evidence to speculate on the origin of banana weevil.

Pest status of banana weevil in Asia

The banana weevil egg, larval and pupal stages all occur within the host plant or crop residues. The eggs are placed superficially within the host, but are at low density and often below the soil surface (Abera *et al.* 1999). The damaging larvae live in galleries within the banana corm, making them largely inaccessible to parasitoids and opportunistic predators. This suggests that the most likely natural enemies would either be specialized parasitoids or predators which can attack eggs or enter crop residues.

The weevil appears to be unimportant in much of Asia, although it may be among the most destructive banana pests in certain parts of the region. Other important banana herbivores include the banana pseudostem borer, *Odoiporus longicolis* (Olivier) and banana leaf roller, *Erionota thrax* L. In Indonesia, for example, the banana weevil is considered a major problem in some lowland and highland zones, yet many clones and areas have low levels of damage. In general, banana weevil pest status in Asia is unclear, with most reports being subjective rather than based on conclusive data (Table 1).

Table 1. Banana weevil pest status in Southeast Asia.

Country	Pest importance (*)	Data on incidence	Data on yield loss
Burma	?	-	-
Thailand	+	-	-
Laos	?	-	-
Cambodia	+	-	-
Malaysia	+++	-	-
Vietnam	++	-	-
Brunei	++	-	-
Indonesia	++	-	-
Philippines	++	-	-
India	+	-	-
Sri Lanka	++	-	-

(*) +++ Important / ++ Moderately important / + Present.

Sources: Viswanath (1977), Geddes and Iles (1991), Waterhouse (1993); adapted from Gold (1998).

The pest status of banana weevil outside of Asia is also controversial (Purseglove 1972, Ostmark 1974, Waterhouse and Norris 1987) and may be related to the genome group and management practices (Gold *et al.* 1994, 1999). In New South Wales, Lobel (1975) controlled banana weevils over a 2-year period in experimental plots using insecticides, yet failed to find improved growth or yield. He concluded that heavy infestations by this weevil in New South Wales are a symptom, rather than a cause, of declining plantations. However, Rukazambuga *et al.* (1998) found that yield losses to banana weevil in highland banana increased with crop cycle and reached 44% in the third ratoon of an on-station yield loss trial.

Prospects for biological control for banana weevil

Classical biological control of banana weevil in Africa may be possible. The banana weevil evolved in Asia, from which it has spread to all of the world's major banana-growing regions (Neuenschwander 1988). Introduced pests, unimportant in native habitats, often reach damaging levels when released from the control of co-evolved natural enemies. The banana weevil appears to fit this pattern, although there is some belief that the weevil might reach pest status in parts of Asia (Waterhouse 1993). Nevertheless, exploration for banana weevil natural enemies in Asia followed by selection, quarantine and release of suitable species could establish an herbivore equilibrium below economic thresholds.

Possibilities and considerations for classical biological control of banana weevil have been reviewed by Greathead (1986), Waterhouse and Norris (1987), Neuenschwander (1988), Greathead *et al.* (1989), Kermarrec (1993) and Koppenhofer (1993a,b) while Schmitt (1993) provides a partial list of arthropod natural enemies. Koppenhofer *et al.* (1992) and Koppenhofer (1993a) found that endemic natural enemies of the weevil in Kenya did not show much promise. In contrast, ants (i.e. *Tetramorium guinensee, T. bicarinatum* (Nylander) and *Pheidole megacephala* Fabricius) contribute to control of banana weevil in Cuba (Roche 1975, Roche and Abreu 1983, Castineiras *et al.* 1991). Based on the weevil's biology, Greathead *et al.* (1989) give a 30% chance for a complete success in biological control.

In Asia, a large number of beneficial organisms (parasites, predators and pathogens) occur naturally in banana plantations and may provide some degree of pest control. Predatory spiders, coccinellids, lacewings, reduviids, ants, and parasitic flies and wasps are the most important beneficial insect groups active in banana plantations. Cane toads feed on beetle weevil and other insects near the ground. Tree frogs, which frequent the banana plants also, feed on insects. Many natural enemies appear small and insignificant, or are nocturnally active, and may go largely unnoticed. Their real value is only appreciated when they are destroyed by inappropriate use of insecticide.

Previous searches for natural enemies of banana weevil in Asia have produced a number of generalist predators. These have been largely unsuccessful in biological control attempts (Waterhouse and Norris 1987). In contrast, egg parasitoids may be effective against banana weevil (Neuenschwander 1988). The existence of parasitoids can only be determined from extensive surveys. As of yet, no parasitoid has been reared from any banana weevil stage in Asia or anywhere else.

Natural enemies of banana weevil in Southeast Asia

Natural enemies of banana weevil observed in Asia include predatory beetles (histerids, staphylinids, silvanids and hydrophilids) and larvae of a rhagionid fly (Jepson 1914, Frogatt 1928, Cuille 1950, Waterhouse and Norris 1987) (Table 2). Most of these occur in banana residues. In addition, unidentified ants, elaterid larvae, carabid larvae and earwigs in crop residues have been observed (Hasyim and Gold, personal observation). All are generalist, opportunistic predators and may feed on banana weevil. The most important banana weevil predator identified to date is the histerid *Plaesius javanus*. Both larval and adult *P. javanus* will attack banana weevils and they are often found inside of crop residues.

Table 2. Common natural enemies of banana weevil in Southeast Asia.

Coleptera	
Histeridae	*Plaesius javanus* Erichson
	Hyposolenus (Plaesius) laevigatus (Marseul)
	Hololepta quadridentata (F)
	Hololepta spp.
Staphylinidae	*Belonuchius ferrugatus* Erichson
	Leptochirus unicolor Lepeletier
Silvanidae	*Cathartus* sp.
Hydrophilidae	*Dactylosternum hydrophiloides* MacLeay
Diptera	
Rhagionidae	*Chrysopilus ferruginosus* (Wied.)

Successful biological control attempts require establishment of the insect in a new environment and repression (control) of a pest population. To date, biological control attempts against banana weevil have met little success (Table 3). Most attempts were made before 1940, using limited numbers of predators. *Plaesius javanus* has been successfully introduced into both the Pacific region and Trinidad, but failed to establish following introduction attempts into Australia, Cameroon, Jamaica, Japan, Samoa, Tanzania and Uganda (Waterhouse and Norris 1987). Among other predators, only *Hyposolenus laevigatus*, *Hololepta quadridentata* and *Dactylosternum hydrophiloides* have been established outside of Asia.

In Fiji, *P. javanus* successfully established following introduction from Java and reportedly provided control in an area severely infested by banana weevil (Kalshoven 1981, Waterhouse and Norris 1987). However, it took eight years for the predator species to become fully established. Otherwise, there are no reports of any introduced natural enemy controlling banana weevil.

Table 3. Introductions of natural enemies for the biological control of banana weevil.

Insect	Attempts	Established	Location established
Plaesius javanus	23	8	Fiji islands
Hyposolenus laevigatus	1	1	Cook island
Dactylosternum abdominale	1	0	
D. hydrophiloides	4	2	Australia, Jamaica
Hololepta quadridentata	6	1	Saint Vincent
Hololepta sp.	3	0	
Chrysophylus ferruginous	1	0	
Total	**39**	**12**	

Source: Waterhouse and Norris (1987); adapted from Gold (1998)

Current research activities on banana weevil in Indonesia

Banana production systems in Indonesia

Indonesia is one of the most important banana growing countries in Asia, with production spread across Sumatra, Java, Bali and Sulawesi. These areas are hot and humid, with mean temperatures ranging from 27.5ºC at sea level to 20°C at 1000 masl. Relative humidity in these areas varies between 60-95%, while annual rainfall ranges from 1200-4250 mm.

Most banana production can be categorized into four systems. These are backyard production, mixed crop production, commercial smallholder production, and corporate farm (agribusiness) plantations. The majority of banana growers are smallholders, with most field management done with household labour and by hand. The banana is advantageous because of its year-round nonseasonal fruit production. The leaves also have an economic value as wrapping material for traditional food in areas near the cities.

The backyard production is the dominant system and attractive to smallholders because of the availability of land around the homestead, the ease of crop establishment, minimum capital investment, and easy monitoring. The system is characterized by high diversity of clones (which vary by region) and primary use of bananas for home consumption. As a result, clone selection is based on family preferences rather than market demand. Management demands include weeding, removal of dried leaves, and harvesting. House wastes, animal manure, and compost are commonly used as soil amendments. Generally, commercial fertilizers and chemical pesticides are not applied.

Mixed production systems may be complex. Banana may be planted as a primary or secondary crop and as either a perennial or short-term crop. As a primary perennial crop, banana can be intercropped with rice, cassava, or vegetables. Banana may also serve as the primary (short-term) crop during the first 2-3 years in a cocoa plantation during which it provides shade to the young cocoa. As a secondary crop, banana is often associated with coconut, cocoa, clove and coffee. Banana is a popular choice for mixed farming systems because it is relatively easy to propagate, and provides both food and cash for household.

Indonesia possesses a great wealth of banana germplasm. Nationally, the most important commercial clones in Indonesia are dessert bananas: Pisang ambon, Pisang ambon lumut, Pisang raja serai, Pisang raja, Pisang berangan, Pisang mas, and cooking bananas: Pisang tanduk, Pisang oli, Pisang nangka and Pisang kepok. In West Sumatra, the main clones are Pisang kepok, Pisang buai, Pisang ambon randah, Pisang ambon, Pisang raja, Pisang raja serai and Pisang manis.

Farmer management of banana weevil

In areas where banana weevil is viewed as important, farmers employ a variety of cultural methods to reduce pest incidence. These include selection of clean planting material, regular removal of old leaf sheaths, and digging up and drying of old corms. However, the use of clean planting material to prevent dissemination of weevils is only recognized by a few farmers. Trapping is viewed as too labour-intensive with unclear benefits. Farmers at most sites expressed a desire to use pesticides against banana weevil although, in fact, only a few of commercial growers do so.

Research activities on banana weevil

Population dynamics of banana weevil borer in West Sumatra

This study was carried out from September 1997 to February 1998 in Sitiung, located inland (110 masl). The annual rainfall was 2884 mm. The main study field (50 m x 50 m) contains 225 mats of banana. Adult weevils were trapped, sexed, marked on their elytra with lacquer and released on the same plant. Figure 1 shows the fluctuation in the adult numbers, as estimated using the formula of Jolly and Seber (Jolly 1965, Seber 1973). The results show that weevil abundance at Sitiung fluctuated with distinct peaks. Field data suggest that weevils populations were negatively correlated with numbers of *Plaesius javanus* and that *P. javanus* may be inherently capable of regulating weevil populations (Fig. 1).

Twenty plants were evaluated 1-2 weeks after harvest on each visit. In spite of using a susceptible clone, banana weevil damage (Table 4) at this site was probably lower than elsewhere in Sumatra (Table 6), because of the site's low elevation.

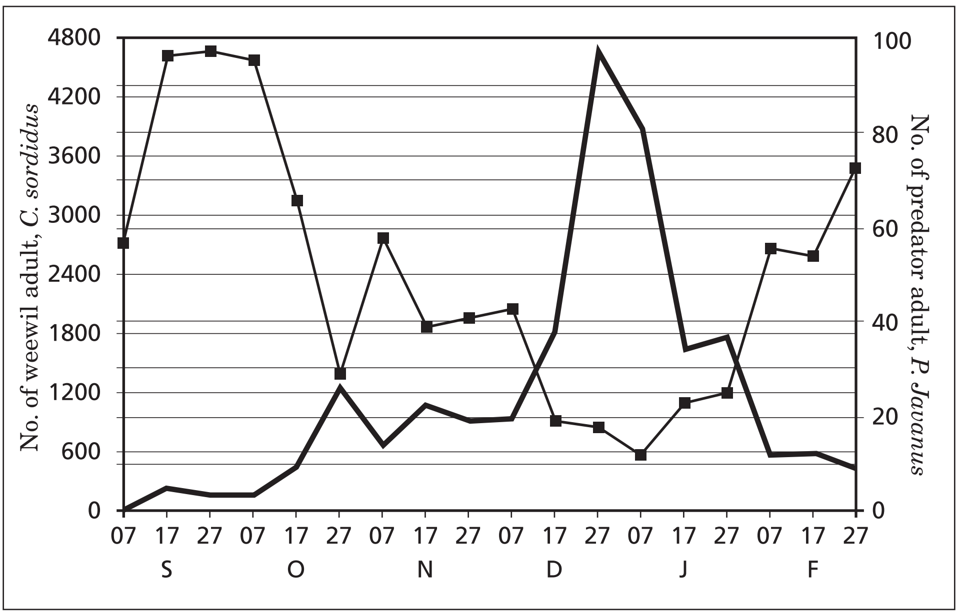

Figure 1. Seasonal fluctuations in adult banana weevil (estimated by Jolly-Seber method) and predator Plaesius javanus (■) in a banana field in Sitiung, West Sumatra, Indonesia.

Table 4. Banana weevil damage source for Pisang kepok (AAB) at Sitiung location, diagnostic survey for site at 110 masl (September 1997 - February 1998).

Date (month)	Surface damage		Cross-section damage	
	PCI	DP	Inner	Outer
September	10.9	3.6	0.0	0.7
October	11.1	4.6	0.1	1.5
November	13.4	5.4	0.1	1.5
December	18.8	7.6	0.1	2.1
January	18.2	7.5	0.2	1.9
February	14.9	6.0	0.2	1.5
March	14.5	5.8	0.1	1.5

PCI = Percentage coefficient of infestation. Presence/absence on grid of 20 section

DP = Damage to periphery. Percentage area in galleries

Source: Hasyim and Harlion (1998)

Mortality agents of immature banana weevils

Preliminary experiments were undertaken to assess mortality of banana weevil immatures at two sites in West Sumatra. Banana weevil eggs, larvae and pupae were collected from field sites in Sitiung and Baso and transferred to the entomology laboratory of the Research Institute for Fruit (RIF) at Aripan-Solok where they were reared under ambient temperatures. Egg mortality was largely attributed to fungus (which may have been from laboratory contamination). Both the larval and pupal stages were attacked by phorid parasitoids.

Table 5. Mortality factors of egg and immature stages of field-collected banana weevil during rearing in the laboratory.

Stage	Initial number reared	Mortality			
		Parasites	Fungi	Dried/rotten	Recruitment to next stage
Egg	210	0.0	19.0	2.8	78.1
Larva 3-5	637	5 a	3.5	16.5	79.6
Pupae	115	1 a	4.5	13.0	81.7

a. Phoridae

Candidate natural enemies for biological control programme

Hymenopterous parasitoids were absent from weevil immatures, while larval and pupal parasitism by phorids was low. Nevertheless, a more intensive search in the Indonesia-Malaysian region may reveal more promising arthropod natural enemies. Currently the only promising predator for the control of banana weevil is *P. javanus*. Both the larvae and adults prey on weevil larvae in banana residues. The larvae are very voracious. In the laboratory, they will attack all larval instars and may consume 30-40 per day. In natural surroundings, the larvae are omnivorous and cannibalistic.

Research on microbial antagonists of banana weevil is currently being undertaken in Indonesia. In Sumatra, the fungi *Beauveria bassiana* and *Metarrhizium* sp. attack the larvae and adult of *C. sordidus* more frequently in highland sites than lowland.

Factors required for developing a microbial control programme and influencing the efficacy of entomopathogens have been described by Falcon (1971). An understanding of pest biology, ecology and behaviour as well as life table parameters can be used as a foundation for knowing when and where to apply entomopathogens. Naturally occurring fungal infections are dependent upon a high host density and favourable temperature and moisture. The banana weevil tends to occur in low population densities and it is unclear to what degree fungal spores might be passed from one individual to another.

Falcon (1971) also notes that ideal microbial agents pose no human health hazard, are easy to produce, have a narrow host range and do not attack beneficials, and are sufficiently virulent against the host. Many strains of *Beauveria bassiana* and *Metarrhizium anisopliae* have effected high mortality of banana weevils in the laboratory, but problems in cost-effective delivery systems, field persistence and efficacy in controlling banana weevils under field conditions remain to be demonstrated. Pathogen virulence, persistence and dispersal are likely to be affected by abiotic and biotic environmental factors (Falcon 1971).

Both *B. bassiana* and *Metarrhizium* sp. have been isolated from banana weevil adults in Indonesia. While these entomopathogens may have an important role in controlling banana weevil within Indonesia, it remains unclear whether or not these fungi would be more effective then local strains in controlling banana weevil biotypes found in Africa. Protocols do exist in Uganda and elsewhere for the importation of microbial agents but determination of pathogen host range remains a critical concern.

Host plant resistance to banana weevil

Host plant resistance might be integrated with biological control to form an integrated pest management strategy for the control of banana weevil. Partial control by a natural enemy might be sufficient if farmer clones are resistant or tolerant to attack. Similarly, it is important to understand factors influencing weevil population dynamics under field conditions when selecting sites for searches for natural enemies. Low weevil populations may be due to resistant clones rather than natural enemy control.

To date, little information is available on the susceptibility or resistance of Indonesian banana clones to banana weevil. In order to search for resistance to banana weevil borer, a screening trial on the response of various clones of banana is necessary. Under field conditions in West Sumatra, *Musa* genome group AAB was most susceptible to banana weevil attack, while AA clones were relatively resistant with little damage and limited penetration into the corm (Hasyim *et al.* 1997, see Table 5). In Uganda, plantain (AAB) and highland banana (AAA-EA) were most susceptible to banana weevil attack, while Gros Michel (AAA) demonstrated peripheral damage similar to highland cultivar but penetration into the corm was limited (Gold *et al.* 1994). The introduced beer type (AB, ABB) was relatively resistant with peripheral damage and limited penetration into the corm.

Table 6. Banana weevil damage for different banana genome groups in diagnostic survey of West Sumatra (Indonesia) banana-based cropping system (April 1995 - March 1996).

Genome group	Banana type	Surface damage PCI	Surface damage DP	Cross-section damage Inner	Cross-section damage Outer
AAB	Jantan, Raja, Raja serai	38.6 b	17.7 b	6.3 b	10.7 b
ABB	Kepok, Kalek, Awak	51.0 a	36.6 a	12.6 a	19.7 a
AAA	Buai, Ambon, Randah	32.6 ab	18.8 b	7.5 b	11.6 b
AA	Rotan, Lidi dan Mas	10.0 c	4.0 c	0.5 c	2.8 c

PCI = Percentage coefficient of infestation. Presence/absence on grid of 20 section
DP = Damage to periphery. Percentage area in galleries
Cross-section damage = Percentage area in galleries
Data collected from 20-40 days after harvested plant
Source: Hasyim *et al.* (1997)

Research needed

A successful biological control programme is based on a solid foundation of ecological research and studies on population dynamics for both the pest and candidate natural enemies. In order to study the feasibility of biological control against banana weevil, we propose that the following studies be undertaken in Asia:

1. Seasonal fluctuations in abundance of banana weevils should be documented in detail. The cause of fluctuation should be analyzed in relation to the change in climatic conditions and the action of natural enemies.
2. Determine areas where the weevil indeed is of minor importance and whether cultural methods and biological agents may be responsible for this low pest incidence.
3. Ecology of banana weevil adults especially longevity and fecundity under field and laboratory conditions.
4. Biology of natural enemies including host specificity, searching behaviour, fecundity and generation time, intra- and interspecific competition.
5. Quantitative data relating life table parameters to environmental and food conditions are needed in order to develop efficient techniques for rearing and for predicting population development.
6. Experimental methods should be applied for evaluating the impact of natural enemies. This information should provide insight into when natural enemies should have maximum effect.

In Indonesia, environmental conditions are extremely diverse. Therefore, the results obtained from one geographical location can rarely be applied elsewhere. The high diversity of habitat conditions in which crop-pest-natural enemies systems exist, is not only essential to develop effective control measures, but also provide a fascinating arena for ecological study in general. It is hoped that this workshop will provide the foundation for establishing a network for exploration of candidate natural enemies in Asia so that they may be introduced in other countries.

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