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MODELS FOR MINIMIZING RISKS OF DANGEROUS PESTS: THE PINK HIBISCUS MEALYBUG AND PAPAYA MEALYBUG

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ABSTRACT: The pink hibiscus mealybug (PHM), *Maconellicoccus hirsutus* (Green), and the papaya mealybug (PM), *Paracoccus marginatus* Williams & Granara de Willink, biological control programs were cooperatively developed in the Caribbean by various local and international agencies and organizations. Both programs served as models of proactive program action in the early stages of each invasive pest's introduction into a Caribbean island, and for minimizing losses to the U.S. and neighboring countries. The biological control technology for the PHM developed in St. Kitts and Nevis, W.I., between 1995 and 1997, has been successfully transferred within the last six years to the US Virgin Islands, Puerto Rico, Bahamas, Belize, California, and most recently to Florida, Haiti, and the Dominican Republic. The PM biological control technology developed in the Dominican Republic in 1999 has been transferred to Puerto Rico, Florida, Bahamas, and Guam within the last four years. In both programs, the introduction of exotic parasitoid species resulted in mealybug population density reductions ranging from 82 to 97%. Early program development allowed for swift technology transfer to newly infested islands and to the U.S. Mainland (California and Florida) within thirty days of being found infested. This swift transfer in turn significantly reduced the potentially high rate of geographical dispersal and averted disastrous economic losses in the Caribbean countries, and in the U.S. and its island territories.

KEY WORDS: *Maconellicoccus hirsutus*, *Paracoccus marginatus*, biological control

INTRODUCTION

Invasive agricultural pests continue to invade the Continental United States in record numbers of species. The U.S. Department of Agriculture, Animal and Plant Health Inspection Service had intercepted over 70,000 agricultural pests alone at ports of entry in the US by the close of 2002 (Figure 1) (Anon. 2003). Once a new pest is found in the US, a decision needs to be made whether to take no action, to implement an eradication program, or to develop an integrated pest management (IPM), a cultural, a chemical, or a biological control program.

During this last decade, a model for minimizing the risks of dangerous pests in the US has consisted of addressing the control of some of these pests offshore in a proactive mode prior to their introduction into the U.S. One option may be to develop a classical biological control program in cooperation with neighboring countries. This cooperation has successfully been accomplished for the pink hibiscus mealybug (PHM), *Maconellicoccus hirsutus* (Green), and the papaya mealybug (PM), *Paracoccus marginatus* Williams & Granara de Willink (both: Hemiptera, Coccoidea, Pseudococcidae).

The advantages of implementing an offshore classical biological control program are that: (i) it becomes a self-sustaining control program; (ii) it has high cost efficiency; (iii) it is environmentally sound; (iv) it "buys time" to develop the technology abroad before the pest invades another country; (v) it evolves into a cost-shared program with other countries and

international organizations; (vi) its level of control escalates as released exotic natural enemies increase in numbers and disperse geographically to new infested locations; and (vii) it reduces the population density of the pest, and thereby tend to slow its rate of dispersal, and thus defers the time when other countries in the region become infested; (viii) it is relatively easy to transfer to other countries; (ix) it reduces potential economic losses if ready to implement immediately upon detection of the pest after entry into a new country, i.e., no down time for a technology development phase; and (x) it takes advantage of resources and expertise in other countries.

THE PINK HIBISCUS MEALYBUG

The pink hibiscus mealybug was first found in the Western Hemisphere in Grenada in 1994. The economic risk to U.S. agriculture due to the invasion of the pink hibiscus mealybug was estimated by Moffitt (1999) to be approximately a US$ 750 million per year potential loss. Agricultural crops in the U.S. expected to bear most of the economic risk due to this pest included ornamental, vegetable and citrus crops, grapes, and avocados. The pest had spread rapidly to other Caribbean countries by 1999 (Figure 2) with the largest number of Caribbean countries confirming establishment of this pest by 1997 (Pollard, 1999). The infested area soon came to include more than 25 Caribbean Islands, and Guyana, and by August of 1999 southern California, by September 1999 Belize, and by November 2000 the Bahamas. The PHM was first detected and identified in Florida in June 2002, confirmed to be present in Haiti in May 2002, followed by the Dominican Republic in August 2002.

PHM attacks over 200 host plant species, but is most common on hibiscus and soursop (*Annona muricata*) in the Caribbean (Stibick, 1997). Hibiscus plants were used as a standard host for these studies except in California, where mulberry and carob trees were also studied. Two exotic parasite species were imported for control of PHM. One was *Anagyrus kamali* Moursi (Hymenoptera: Encyrtidae) imported from China, and a second was *Gyranusoidea indica* (Hymenoptera: Encyrtidae) imported from Egypt. Both parasites have a life cycle producing two generations for every one generation of the mealybug.

St. Kitts, W.I. Anagyrus kamali was initially released in St. Kitts in August of 1996. The second species, *Gyranusoidea indica,* was released in the spring of 1997. *Anagyrus kamali* became the dominant parasite and has been reported moving up to three miles from initial release points. By January of 1998, the parasites had reduced the PHM population density on hibiscus in St. Kitts by 92% (Figure 3).

US Virgin Islands. PHM was first found in the U.S.V.I. in St. Thomas and St. John in May 1997 and St. Croix in June 1997. The mealybug's population density on hibiscus shrubs at release study sites was reduced by an average of 91% in St. Thomas and over 97% in St. Croix during the period from July 1997 to February 1999 (Figures 4 and 5).

Puerto Rico. This same mealybug pest was first reported in Puerto Rico on the island of Vieques, June 24, 1997. Parasites were first released in Puerto Rico on January 8, 1998, first on Culebra; April 16, 1998 on Vieques; and May 22, 1998 on the main island. PHM densities were reduced by 96.3% on the main island during the period from May 1998 to January 2001 (Figure 6); 98% on Vieques from May 1998 to August 1999 (Figure 7); and 97.8% on Culebra from May 1998 to August 1999. Parasitization after the decline of the mealybug's population density remained at an average of 19.8% in Puerto Rico, 31.6% in Culebra and 24.8% in Vieques. The PHM has spread across Puerto Rico to date since the initial infestation in April 1998 moving from east to west much more slowly then anticipated, probably because of the early presence and impact of the exotic parasites.

Belize. The PHM was first reported in Belize, Central America, in September 1999. The above two parasite species were released by November 16, 1999, at a rate of 200 to 400 parasites

per release site. Within one year (November 1999 to November 2000) the PHM population densities had been reduced by 96.6% on hibiscus shrubs (Figure 8). Parasitization increased from 0% in November 1999, when the parasites were first released, to a high of 74% by November 2000.

California. This same mealybug pest was also discovered in Imperial County, California, in August 1999. The infestation was predominantly in the city of Calexico. In a cooperative effort among the California Department of Food and Agriculture, and the USDA, APHIS, PPQ, and the Puerto Rico Department of Agriculture Insectary, the latter shipped approximately 3,000 parasites for release in September 1999, only one month after PHM detection. An insectary was soon established in El Centro by the California Department of Food and Agriculture (CDFA) to mass produce *A. kamali* and *G. indica.* These species were released in the local area at newly infested sites. CDFA provided these beneficial species to Mexico, and later to USDA, APHIS, PPQ for releases in the Bahamas and the Caribbean. The infestation has remained confined to the southern end of Imperial County. The PHM population density on mulberry trees remained low throughout 2001, averaging only 3.9 mealybugs per terminal in September 2001 with 30.7% parasitization. This was an overall mealybug population density reduction of 98.4% (Figure 9).

Bahamas. The Bahamas were found to be infested in November 2000 on the Island of New Providence in the Nassau area. The PHM population density levels averaged 242.4 mealybugs per terminal in January 2001 with no parasites present. Following the established parasite release protocol, the PHM population density by February 2001 had declined by 82% (Figure 10). Additional parasite releases were made across the island of New Providence as the mealybug dispersed.

Florida. The pink hibiscus mealybug was first detected and identified in Florida in June 2002. By the end of December a total of 240 sections in Broward County and 133 sections in Miami-Date County had been formally surveyed. After parasite releases, population density of PHM declined from July to October of 2002 by 94% and was further reduced to 98.7% by April 2003 (Figure 11). Cooler temperatures could have contributed to the lower numbers counted in January. Parasites have been detected at new PHM infestations that are at least 3-4 miles away from the closest parasite release site, thus indicating that efficient parasite dispersal is occurring naturally. Homeowners are expressing their satisfaction with the biological control program of the PHM. Their hibiscus shrubs are returning to normal growth cycles with fully extended leaves and many flowers.

Haiti. The PHM was initially collected in Haiti May 9, 2002. A PHM biological control program similar to that of St. Kitts, U.S. Virgin Islands, Puerto Rico, and Belize was initiated in Haiti in July 2002. All parasites were shipped from the Puerto Rico Department of Agriculture's Insectary Operation. By February 11, 2003, a total of 106,300 parasites had been released in Haiti. From July 2002 to June of 2003, the PHM population density was reduced by 97% at the study sites (Figure 12). The PHM continues to disperse and now occupies over 1/3 of Haiti where parasites have been strategically released.

Dominican Republic. The Dominican Republic Ministry of Agriculture confirmed the presence of PHM on August 1, 2002. Initially the infestation was more or less confined to the Santo Domingo area, San Cristobal, Yamasa, and Monte Plata, and has now slowly begun to disperse in all directions throughout the country. Initial parasite releases were made in August at nine study sites and throughout the infested region. By the end of January 2003, a total of 79,400 parasites had been shipped from the Puerto Rico Department of Agriculture Insectary and released in the Dominican Republic. The PHM population density had significantly declined by 96.6% by June 2003 (Figure 13).

The common denominator in the success of this biological control program against the PHM has been the effectiveness of *A. kamali* and *G. indica*, which have demonstrated the

capability of successfully regulating PHM in tropical, subtropical, and semi-desert regions. Apparently the genetic variability of these two parasites has allowed them to adapt to a wide range of climatic habitats.

THE PAPAYA MEALYBUG

The papaya mealybug is believed to be indigenous to Central America and has been reported in Belize, Costa Rica, and Guatemala (Ben-Dov, 1994) and Mexico (Miller et al., 1999). In 1995, this mealybug species was first reported in the Caribbean in St. Martin. Since that time, it has spread to over 13 Caribbean countries as reported by Food and Agriculture Organization of the United Nations Office of the Sub regional Representative for the Caribbean. These include Antigua, Cuba, Guadeloupe, Montserrat, Puerto Rico, St. Kitts and Nevis, U.S. Virgin Islands, British Virgin Islands, Dominican Republic, Haiti, and St. Barthelemy (G. Pollard, personal communications; Ben-Dov, 1994). PM has also been found in the U.S., but only in Florida, where it was first detected and reported by the Florida Department of Agriculture in 1998 in Bradenton, Manatee County, and in Boca Raton, Palm Beach County. Both counties reported the mealybug on hibiscus plants in residential areas (Miller et al., 1999).

Over 55 host plants have been reported attacked by *P. marginatus* including: *Acacia* sp., *Acalypha* sp., *Ambrosia cumanensis*, *Annona squamosa*, *Carica papaya, Guazuma ulmifolia*, *Hibiscus rosa-sinensis*, *Hibiscus* spp., *Ipomoea* sp., *Manihot chloristica*, *Manihot esculenta*, *Mimosa pigra*, *Parthenium hysterophorus*, *Persea americana*, *Plumeria* sp., *Sida* sp., and *Solanum melongena.* The authors have observed heavy infestations on hibiscus and papaya.

Damage can be caused by direct feeding of the mealybug on the host plant resulting in defoliation, a bunching of the leaves at the terminal of the plant, distortion of the growing tip, heavy sooty mold, fruit discoloration, death of the plant, and heavy insect population densities on the fruit. It has been reported at times to cause damage to cassava in some areas of Mexico, and to papaya fruit, with so many mealybugs as to render the fruit inedible (Miller et al., 1999).

Field characteristics of an adult female of *P. marginatus* include body color that is yellow under a white waxy secretion; no longitudinal depressions; short waxy filaments around the body of the adult female; short caudal filaments; yellow body fluid; egg sac produced under the body of the female; and specimens in alcohol turn a bluish-black color.

The potential for developing a successful biological control program was high. One reason is that this insect is not a major pest in Mexico, all of which implies that effective natural enemies attack it in Mexico. Secondly, five primary parasites had been collected from this mealybug in Mexico in 1999. Thirdly, mealybugs are highly amenable to classical biological control.

Hymenoptera parasites reported attacking *Paracoccus* spp. are *Adelencyrtoides* spp., *Aenasius* spp., *Alamella* spp., *Anagyrus* spp., *Aphycus* spp., *Clausenia* spp., *Gyranusoidea* spp., *Leptomastix* spp., *Prochiloneurus* spp., *Pseudectroma* spp., *Psedococcobius* spp., *Rhopus* spp. and *Pseudleptomastix* spp. (Noyes and Hayat, 1994). Parasites recovered from *P. marginatus* prior to any release in the Caribbean included *Anagyrus* spp. from Florida, St. Thomas (U.S.V.I.), Dominican Republic, and St. Kitts; *Acerophagus* spp. from St. Thomas, Dominican Republic, and St. Kitts; *Pseudleptomastix* sp. from the Dominican Republic; and *Prochiloneurus* sp. (hyper parasite) from St. Thomas, Dominican Republic, and St. Kitts.

The four primary parasites collected in Mexico by the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) and cooperators in Mexico in 1999 were *Anagyrus californicus* (Compere); *Anagyrus loecki* Noyes and Menezes; *Acerophagus papayae* Noyes and Schauff; *Pseudleptomadtix mexicana* Noyes and Schauff; and *Pseudaphycus angelicus* (Howard).

All five species were screened through the quarantine facility at the USDA, ARS Beneficial Insects Laboratory in Newark, Delaware. An environmental assessment was completed on all five species and specimens eventually shipped to San Juan, Puerto Rico, for field release. Here they were cultured and mass produced in a cooperative effort with the Puerto Rico Department of Agriculture and USDA, APHIS, PPQ.

Puerto Rico. Biological control programs were developed cooperatively in Puerto Rico with the Puerto Rico Department of Agriculture. Residential hibiscus and papaya plants were more commonly found to be infested in Puerto Rico. In Puerto Rico, prior to the release of any exotic parasites, the primary parasites already found attacking *P. marginatus* were *Anagyrus loecki* (90%); *Acerophagus* (unknown species) (10%); and an unknown species, which averaged 2.8% parasitization overall in May 2000. The *P. marginatus* population density at the study sites at that time averaged 447 mealybugs per hibiscus terminal and was not being effectively regulated by the local parasites. Within eleven months from the initial release of parasites, the mealybug population density decreased to an average of 16.3 mealybugs per terminal, a significant reduction of 96.3%. By February 2003 the PM population density had declined by over 99% (Figure 14). The parasite ratio shifted in two months with *Anagyrus loecki* at 18% and *A. papayae* at 75%. By December 2000, *A. papayae* was the only species recovered (100%), indicating a potential shift in parasite dominance by a potentially new exotic species from Mexico.

Dominican Republic. The PM biological control program in the Dominican Republic was a cooperative effort with the Ministry of Agriculture, USDA, APHIS, PPQ and IS and Junta Agroempresarial Dominicana (JAD). In the Dominican Republic, the parasite complex on *P. marginatus* prior to exotic parasite releases early in 1998 consisted of *Anagyrus loecki* (67%), *Acerophagus* sp. (11%) and *Pseudleptomastix* sp. (2%), and an unknown species (20%). Baseline data samples of the mealybug density on papaya initiated in May 2000 averaged 598 mealybugs per leaf with an average of 1% parasitization. After the release of the exotic species of parasites from Mexico, the parasite complex later shifted with *Acerophagus papayae* becoming dominant at 50% within six months, as compared to a reduction of *Anagyrus loecki* (11%). The percentage parasitization at that time reached 51%. The overall density of the mealybug on papaya over a nine-month period decreased to 16 mealybugs per leaf, a reduction of 97.3% (Figure 15), similar to that in Puerto Rico, and a 97% reduction on hibiscus.

Preliminary studies indicate that the newly imported and released parasite species from Mexico possess the potential for significant impact on the population density of *P. marginatus* in papaya. The preexisting parasite complex in both Puerto Rico and the Dominican Republic, which is still being studied, appears to consist of similar species and genera found attacking *P. marginatus* in Mexico. It is believed that new species and/or biotypes of the same species introduced from Mexico may be more specialized and more adaptive to *P. marginatus* than the preexisting parasite species. The new forms caused a significant population density reduction of *P. marginatus*.

Guam. The report of papaya mealybug in Guam is the first record of this pest in the Pacific. It has been spreading actively from the Caribbean towards the North and South American continents. There is a threat of this mealybug spreading to the Commonwealth of the Northern Mariana Islands in the north, Federated States of Micronesia and the Republic of Palau in the south, and the Marshall Islands and the Hawaiian Islands east of Guam. Whereas economic losses caused by PM have yet to be documented in Guam, there was adequate justification for controlling this pest in the Caribbean and the U.S. mainland and its territories.

Baseline data surveys for evaluation of PM population densities on *Plumeria* spp. and *Hibiscus* spp. and their local natural enemies were conducted June 24, 2002. The overall population density of the PM was significantly reduced by 83% over a three-month period from

24 June until September 25, 2002 at eight *Plumeria* spp. study sites, and reduced by 96% at four Hibiscus study sites. The percentage parasitization at the beginning of this program was zero at both *Plumeria* spp. and Hibiscus spp. study sites, all of which indicated that no local parasites were parasitizing PM in Guam in June when the baseline data was collected. By July and August, percentage parasitization had increased to 30.0% and 33.4% on Hibiscus spp. and 2.9% and 1.9% on *Plumeria* spp. respectively. The percentage parasitization on *Plumeria* spp. was low with this sampling technique, because of large PM populations and the inability of the sampling technique to detect low numbers of parasites. The actual density counts of samples per leaf revealed an average of 11.6% parasitization in September and an 82.5% reduction of the PHM population density since June (Figure 16).

By October, the percentage parasitization had reached an average of 43.6%. A major typhoon passed directly over Guam in December 2002 causing some damage and defoliation to the study sites, and delayed the timing of the next collection of the field samples for determining the density of the PM and the parasites. Both *Anagyrus loecki* and *Acerophagus papayae* have become established in Guam and appear to be the major biological control agents regulating the population density of the PM.

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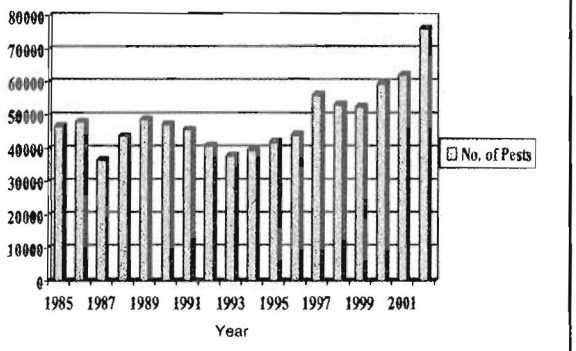

Figure 1. Reportable Interceptions of Agricultural Pests at US Ports of Entry

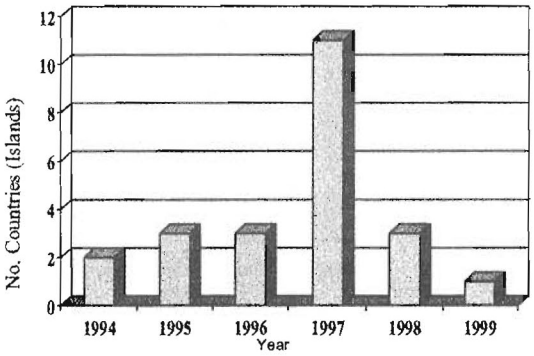

Figure 2. Spread of *M. hirsutus* in the Caribbean

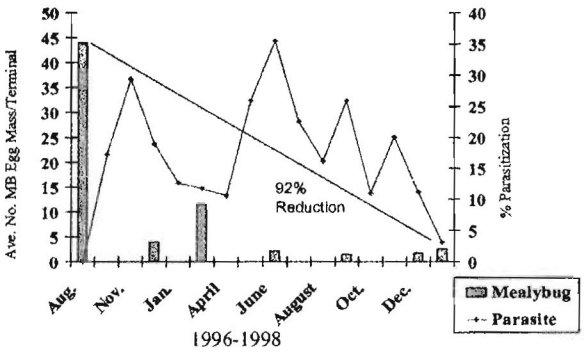

Figure 3. Impact of parasitoids on PHM in St. Kitts, West Indies (Hibiscus)

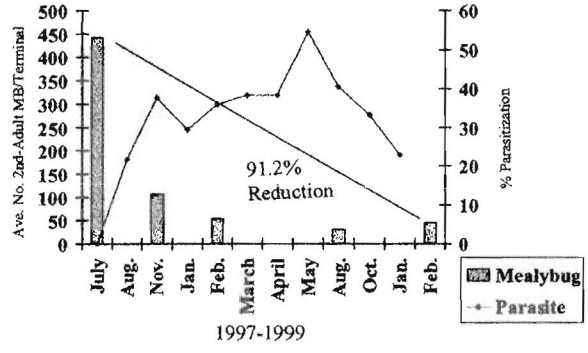

Figure 4. Impact of Parasitiods on PHM in St. Thomas, U.S.V.I. (Hibiscus)

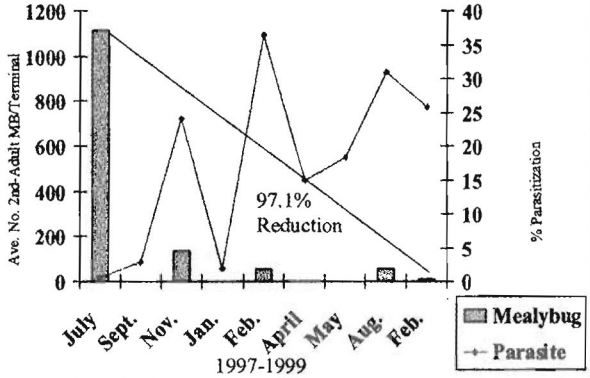

Figure 5. Impact of parasitoids on PHM in St. Croix, U.S.V.I. (Hibiscus)

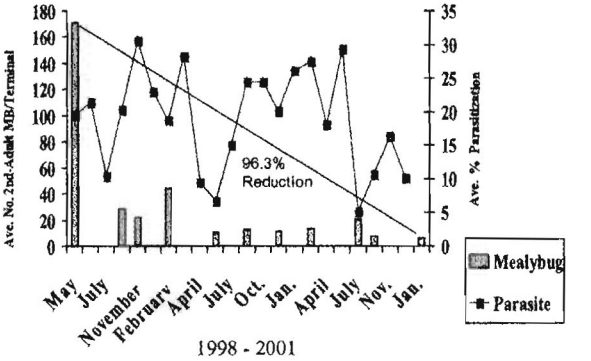

Figure 6. Impact of parasitoids on PHM in Puerto Rico (Hibiscus)

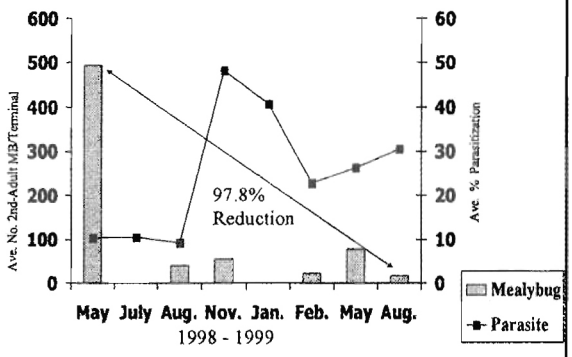

Figure 7. Impact of parasitoids on PHM in Vieques, Puerto Rico (Hibiscus)

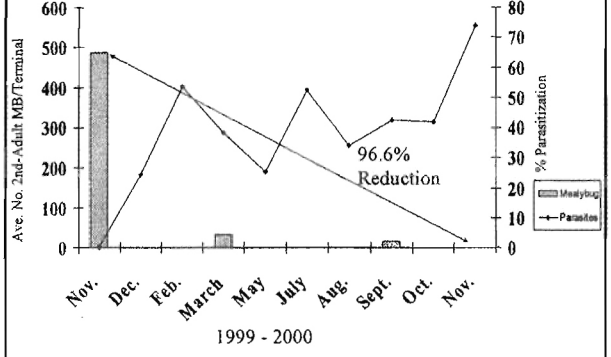

Figure 8. Impact of parasitoids on PHM in Belize, Central America (Hibiscus)

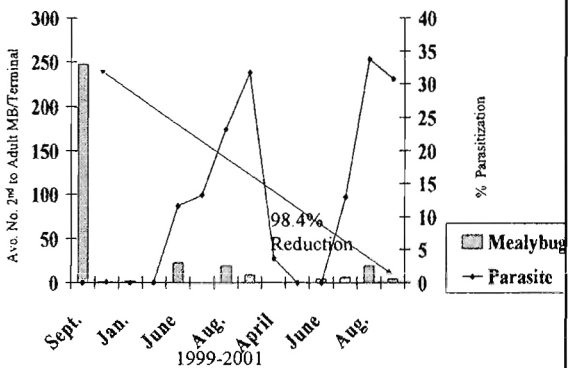

Figure 9. Impact of parasitoids on PHM in California (Mulberry)

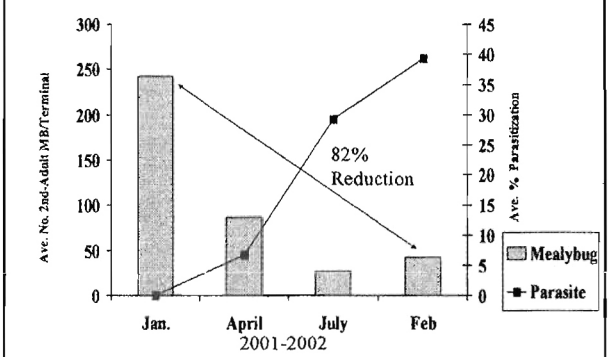

Figure 10. Impact of parasitoids on PHM in the Bahamas (Hibiscus)

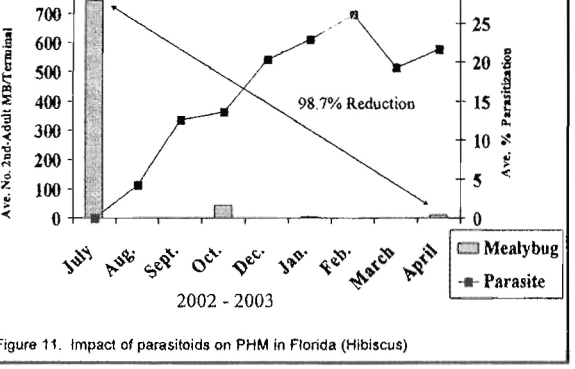

Figure 11. Impact of parasitoids on PHM in Florida (Hibiscus)

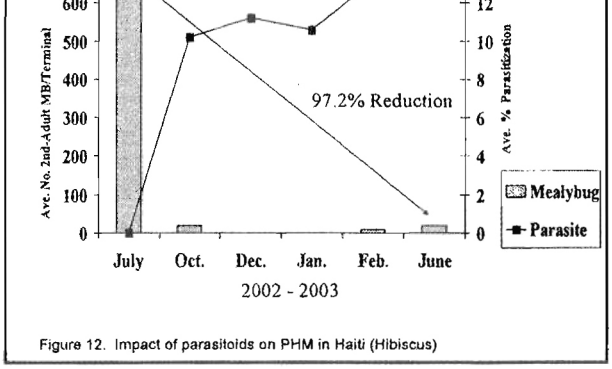

Figure 12. Impact of parasitoids on PHM in Haiti (Hibiscus)

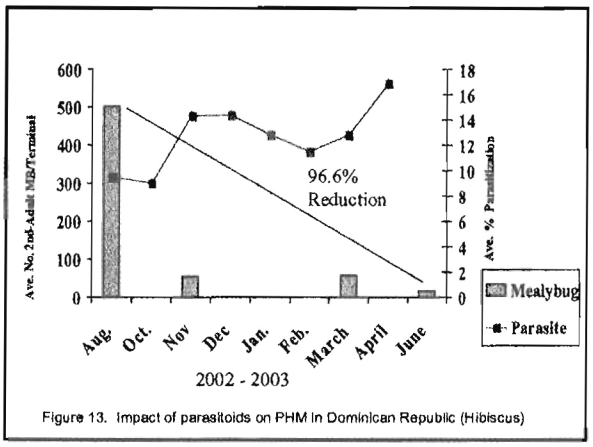

Figure 13. Impact of parasitoids on PHM in Dominican Republic (Hibiscus)

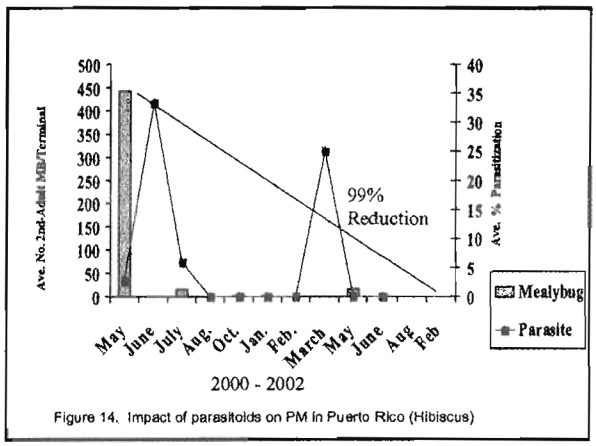

Figure 14. Impact of parasitoids on PM in Puerto Rico (Hibiscus)

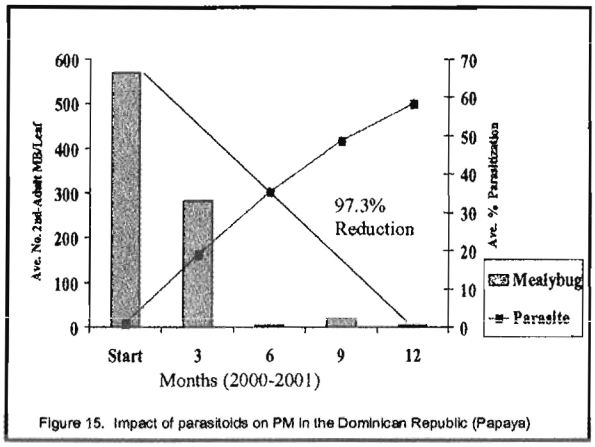

Figure 15. Impact of parasitoids on PM in the Dominican Republic (Papaya)

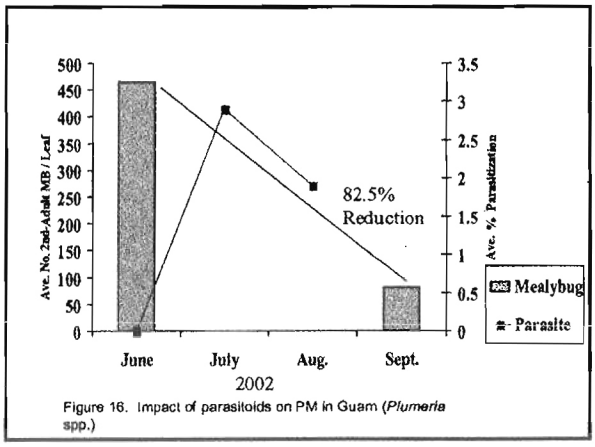

Figure 16. Impact of parasitoids on PM in Guam (*Plumeria* spp.)