

Effective Biological Control Programs for Invasive Plants on Guam

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Abstract

Several biological control agents were imported and released in Guam for the control of siamweed (*Chromolaena odorata* (L.) King & H.E. Robins), ivy gourd (*Coccinia grandis* (L.) Voigt), and the giant sensitive weed (*Mimosa diplotricha* C. Wright ex Sauvalle). Substantial control of *C. odorata* was achieved using the moth (*Pareuchaetes pseudoinsulata* Rego Barros) (Lepidoptera: Arctiidae) and the gall fly (*Cecidochara connexa* Macquart) (Diptera: Tephritidae). There was a remarkable reduction of plant height caused by *C. connexa*. A biological control program on *C. grandis* has been effective, following the success achieved in Hawaii, through the introduction of the natural enemies *Melittia oedipus* Oberthür (Lepidoptera: Sesiidae) and *Acythopeus cocciniae* O'Brien and Pakaluk (Coleoptera: Curculionidae). At this moment, there are no infestations of *C. grandis* seen in Guam. Although *Heteropsylla spinulosa* Muddiman, Hodkinson & Hollis (Homoptera: Psyllidae) established successfully at release sites on Guam, it has yet to provide significant control of *M. diplotricha*. Presently, a biological control program has been initiated against *Mikania micrantha* (L.) Kunth. (Asterales: Asteraceae), using the rust fungus *Puccinia spegazzinii* De Toni (Basidiomycotina: Uredinales). Additionally, the biological control programs will be extended to neighboring Micronesian islands.

Introduction

Invasive and exotic pest plant species have become an escalating problem in Guam and other Micronesian islands. Non-native plant invasions can be seen in agricultural and residential areas, roadsides, rangelands, pastures, forests, wetlands and parks (Reddy, 2011). Control of invasive, non-native plant species involves difficult and complex procedures. Reddy (2011) listed the top 20 invasive plant species which have impacted Guam greatly and a strategic plan with several possible control measures was suggested.

Siam weed, *Chromolaena odorata* (L.) King &

H.E. Robins (Asterales: Asteraceae), is one of the most severe invasive weeds in Guam and other Micronesian Islands. It is a problem mostly apparent in plantations, pastures, vacant lots and disturbed forests (Cruz et al., 2006). It grows extremely rapidly, invading a wide range of vegetation types, forming dense monospecific stands and smothering other vegetation (Zachariades et al., 2009). Biological control using insects is considered an effective component of an Integrated Pest Management (IPM) program for this weed and has been incorporated into the IPM strategy in several countries where this weed is a problem. The moth *Pareuchaetes pseudoinsulata* Rego Barros (Lepidoptera: Arctiidae) was introduced from India and Trinidad and became established on

Guam in the 1980s (Zachariades et al., 2009). The gall fly *Cecidochara connexa* Macquart (Diptera: Tephritidae) was introduced from Indonesia in 1998 and established on Guam in 2002 and other Micronesian islands in succeeding years (Cruz et al., 2006; Zachariades et al., 2009).

Ivy gourd or scarlet gourd, *Coccinia grandis* (L.) Voigt (Violales: Cucurbitaceae), is an invasive and perennial vine which grows best under conditions of adequate rainfall and high humidity (Muniappan et al., 2009). Introduction of this vine in the 1980s resulted in invasion of over 100 hectares in different parts of Guam and almost one-third of Saipan (Bamba et al., 2009). It is also invading neighboring islands, Rota and Tinian (Muniappan et al., 2009). Based on the success of biological control in Hawaii, a program was initiated in the Mariana Islands using the natural enemies *Acythopeus cocciniae* O'Brien and Pakaluk (Coleoptera: Curculionidae), *Acythopeus burkhartorum* O'Brien and Pakaluk (Coleoptera: Curculionidae) and *Melittia oedipus* Oberthür (Lepidoptera: Sesiiidae) (Reddy et al., 2009a, b). The two weevil species, *A. cocciniae* and *A. burkhartorum*, were field released in various locations on Guam in 2003 and 2004, respectively (Bamba et al., 2009 and Raman et al., 2007), and *M. oedipus* was released in 2007 (Reddy et al., 2009b).

The giant sensitive weed, *Mimosa diplotricha* C. Wright ex Sauvalle (Fabales: Fabaceae), also referred to in the literature as *M. invisa*, is a serious weed occurring mainly in vacant lots, roadsides, and crop lands (Kuniata, 2009). It has invaded most of the islands in Micronesia and the South Pacific (Esguerra et al., 1997). Recently, it has become established and spread to approximately two hectares in Guam, 120 hectares in Rota, 150 hectares in Tinian and 140 hectares in Saipan. After host specificity tests were conducted in Australia, *Heteropsylla spinulosa* Muddiman, Hodkinson & Hollis (Homoptera: Psyllidae) was released in Australia, Papua New Guinea, Samoa, Fiji, Cook Islands, Pohnpei, Yap and Palau (Esguerra et al., 1997; Wilson and Garcia, 1992), and it has effectively suppressed the weed in all the introduced countries. Because herbicidal control of *M. diplotricha* is expensive, labor intensive and requires frequent application, it is not a viable technique in the Marianas, and it was decided in 2005 to initiate biological control. Nymphs and adults of *H. spinulosa* were collected from Pohnpei and Palau and

were field released on Guam in 2008.

The objective of this project is to assess the impact and interaction of the established natural enemies of *Chromolaena odorata*, *Coccinia grandis* and *Mimosa diplotricha* at various locations on Guam.

Methods and Materials

Several sites with well-established stands of the three invasive plant species were selected for this study from villages in northern, central and southern Guam to represent the entire area of the island (Table 1). The sites were selected to include forested areas, suburban areas, waysides, and agricultural areas. A 12-channel global positioning system (GPS) (Garmin Corp., Taiwan) device was used to record longitude and latitude coordinates of each study site. Vegetation of each target weed was examined in randomly placed quadrats (1m²) (Reddy, 2011), with 2-4 replicates per site (Brower et al., 1998). The number of stems, leaves, and plant height of *Chromolaena odorata* was measured, *C. connexa* galls in each quadrat were counted, and number of *P. pseudoinsulata* larvae and adults and their feeding damage in terms of larval holes and yellow leaves were counted. Similarly, holes in leaves and stems of *Coccinia grandis* caused by *A. cocciniae* and *M. oedipus*, respectively, and number of larvae or adults of *A. cocciniae*, *A. burkhartorum* and *M. oedipus* were counted. Damaged leaves and dead branches of *M. diplotricha* caused by *H. spinulosa* feeding were counted, and number of nymphs and adults of *H. spinulosa* were counted. Sites were visited monthly.

All data were analyzed using the GLIMMIX procedure in SAS v.9.2. For yield data (by site), a one-way ANOVA was performed, and if treatment effects were significant ($P < 0.05$), mean pairwise comparisons were performed by the least-squares difference method. If the treatment and/or month effects were significant, pairwise mean comparisons were performed with log-transformed LSMEANS.

Results

Effect of natural enemies on *C. odorata*

There has been a significant increase in mean number of *C. connexa* gall formations on *C. odorata*

over the years and a corresponding significant decrease in growth of *C. odorata* (Figure 1). The average height of *C. odorata* was 65.2 cm in 2006 and decreased to 18.3 cm in 2010. Although larvae of *P. pseudoinsulata* were present in all five years we monitored, there was no significance in population build up (Table 2), except in the case of small larva holes, which were significantly higher in 2010 than in the previous years ($P < 0.05$). However, the leaves of *C. odorata* turned yellow due to larval feeding by *P. pseudoinsulata* in all the years.

Effect of natural enemies on *C. grandis*

The weevil *A. burkhartorum* has not become established, but population levels of *A. cocciniae* have increased significantly over the years (Table 3), and damage in terms of feeding holes on the leaves was observed to be significant in each year ($P < 0.05$). Similarly, the damage to the stems caused by larvae of *M. oedipus* increased significantly over the years ($P < 0.05$; Table 3), even though *M. oedipus* adults were not consistently observed.

Effect of natural enemies on *M. diplotricha*

Populations of nymphs and adults of *H. spinulosa* and incidence of damaged branches of *M. diplotricha* increased consistently between years, significantly from 2009-2010 (Table 4). However, incidence of dead branches remained low.

Discussion

Worldwide, biological weed control programs have had an overall success rate of 33 percent, with success rates considerably higher for programs in individual countries (Culliney, 2005). According to Reddy (2011), *C. odorata* has been rated the eighth most invasive weed on Guam. The two introduced natural enemies, *C. connexa* and *P. pseudoinsulata*, were well established on all parts of Guam. First and foremost, *C. connexa* has significantly affected

the height of *C. odorata*. Our results agree with Zachariades et al. (2009), who suggested that *C. connexa* may provide good control of *C. odorata*. The impact of *C. connexa* on growth and reproduction, in addition to the defoliation by *P. pseudoinsulata*, should provide successful control of *C. odorata* in other parts of the world. Although *P. pseudoinsulata* was established on Guam in 1985 followed by *C. connexa* in 2005, *C. odorata* is still among the top invasive weeds in Guam. Therefore, it is advisable to mass rear *P. pseudoinsulata* and release them at various locations in Guam to suppress *C. odorata*.

Coccinia grandis agents *A. cocciniae* and *M. oedipus* established well and provided effective control. Currently, there are no infestations of *C. grandis* on Guam. Although *H. spinulosa* was established at release sites, it has not yet provided a significant control of *M. diplotricha*. Esguerra et al. (1997) reported that a few months after release, *H. spinulosa* became well established and assisted in the control of this weed in both Pohnpei and Yap. Similarly, it is expected that *H. spinulosa* will reduce *M. diplotricha* populations by affecting all aerial parts, causing damage that can lead to the death of the entire plant. A biological control program is underway for mile-a-minute weed, *Mikania micrantha* (L.) Kunth. (Asterales: Asteraceae), the ninth most invasive weed in Guam, using a rust fungus *Puccinia spegazzinii* De Toni (Basidiomycotina: Uredinales) (Reddy, 2011).

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Table 1. Monitoring sites on Guam

Site	Invasive plant	Coordinates	No. of samples per site (n)
Yigo	<i>Chromolaena odorata</i>	13°31.869' N, 144°52.291' E	4
Agat		13°21.789' N, 144°39.001' E	4
Dededo		13°30.700' N, 144°51.173' E	4
Hagatña		13°28.161' N, 144°44.817' E	4
Mangilao		13°26.978' N, 144°48.737' E	4
Talofoto		13°23.025' N, 144°46.342' E	4
Inarajan		13°15.259' N, 144°43.300' E	4
Merizo		13°15.058' N, 144°43.071' E	4
Marbo Cave	<i>Coccinia grandis</i>	13°49.789' N, 144°87.001' E	3
Barrigada		13°28.385' N, 144°48.132' E	3
Inarajan Bay		13°28.395' N, 144°75.885' E	3
Yoña		13°24.359' N, 144°46.352' E	2
Merizo		13°15.063' N, 144°43.074' E	3
Mangilao		13°26.978' N, 144°48.737' E	3
Hagatña		13°28.598' N, 144°44.313' E	3
Tarja Falls	<i>Mimosa diplotricha</i>	13°24.348' N, 144°46.363' E	4
AES, Yigo		13°31.872' N, 144°52.297' E	2

Table 2. Effect of *Pareuchaetes pseudoinsulata* on *Chromolaena odorata*

Year	Mean number \pm SE (n=8) / one m ² quadrat				
	Larvae	Adults	Small larval holes	Large larval holes	Yellow leaves
2006	2.4 \pm 0.8a	0.0 \pm 0.0a	8.0 \pm 0.4a	3.2 \pm 0.8a	3.0 \pm 0.1a
2007	3.3 \pm 1.2a	0.0 \pm 0.0a	8.5 \pm 2.8a	4.0 \pm 0.3a	2.0 \pm 0.6a
2008	1.6 \pm 1.4a	0.0 \pm 0.0a	7.0 \pm 0.9a	3.0 \pm 0.5a	1.4 \pm 0.3a
2009	1.8 \pm 0.5a	0.0 \pm 0.0a	4.5 \pm 1.2a	0.0 \pm 0.0a	2.5 \pm 0.4a
2010	4.5 \pm 0.6a	3.5 \pm 0.7a	12.4 \pm 0.3b	8.5 \pm 0.6a	4.5 \pm 0.8a

Means within each column followed by different letters are significantly different at the P<0.05 level.

Table 3. Effect of *Acythopeus coccinae*, *Acythopeus burkhardtorum* and *Melittia oedipus* on *Coccinia grandis*

Date	Mean number \pm SE (n=6) / one m ² quadrat					
	<i>Acythopeus coccinae</i>		<i>Acythopeus burkhardtorum</i>		<i>Melittia oedipus</i>	
	Feeding holes on leaves	Adults	No. of galls formed	Adults	Larval damage on stems	Adults
2006	43.2 \pm 2.2a	22.5 \pm 3.4a	0.0 \pm 0.0a	0.0 \pm 0.0a	not released	not released
2007	120.9 \pm 4.1b	34.2 \pm 1.8b	0.0 \pm 0.0a	0.0 \pm 0.0a	2.4 \pm 2.7a	0.0 \pm 0.0a
2008	223.6 \pm 3.4c	46.4 \pm 0.6c	2.4 \pm 1.3a	2.0 \pm 0.4a	12.5 \pm 1.2b	2.0 \pm 0.2a
2009	436.2 \pm 1.8d	48.6 \pm 4.2c	4.0 \pm 0.6a	0.0 \pm 0.0a	22.6 \pm 3.1c	0.0 \pm 0.0a
2010	all plants died					

Means within each column followed by different letters are significantly different at the P<0.05 level.

Table 4. Effect of *Heteropsylla spinulosa* on *Mimosa diplotricha*

Date	Mean number \pm SE (n=4) / one m ² quadrat		
	Nymphs/Adults	Damaged branches	Dead branches
2008	8.4 \pm 1.8a	1.5 \pm 0.2a	0.0 \pm 0.0a
2009	11.6 \pm 2.4a	6.4 \pm 0.1a	0.5 \pm 0.2a
2010	28.0 \pm 0.3b	13.0 \pm 2.8b	4.2 \pm 1.2a

Means within each column followed by different letters are significantly different at the P<0.05 level.

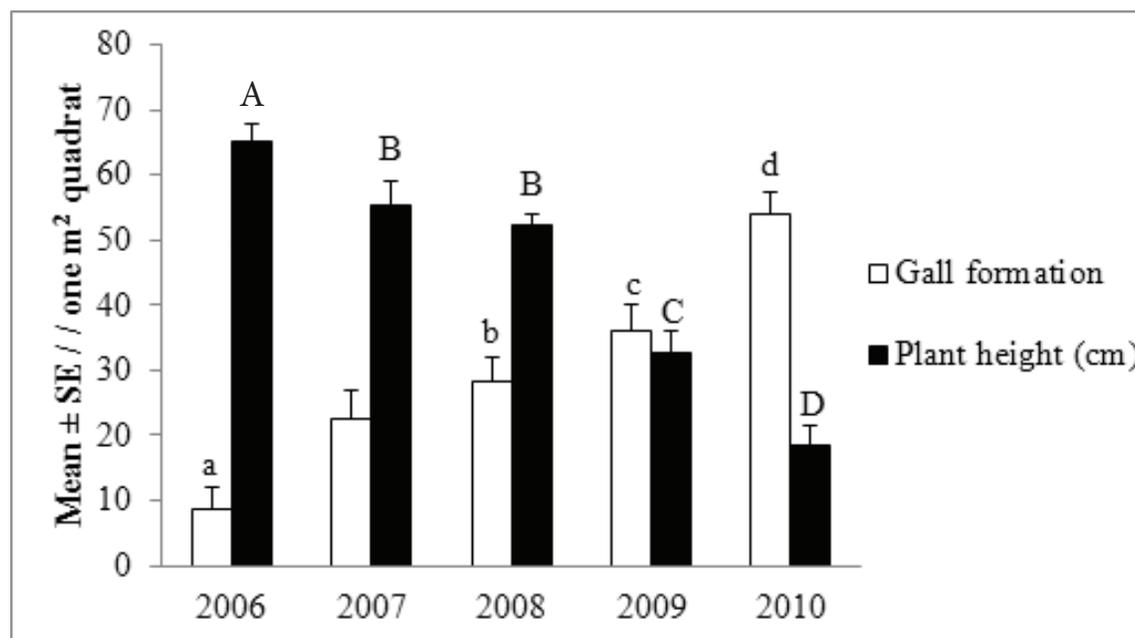


Figure 1. Effect of *Cecidochares connexa* on gall formation and plant height (n=8) of *Chromolaena odorata*. Means marked by different letters are significantly different at the P<0.05 level.

References

- Bamba, J.P., Miller, R.H., Reddy, G.V.P. & Muniappan, R. (2009) Studies on the biology, host specificity, and feeding behavior of *Acythopeius cocciniae* O'Brien and Pakaluk (Coleoptera: curculionidae) on *Coccinia grandis* (L.) Voigt (Cucurbitaceae) and *Zehneria guamensis* (Merrill) Fosberg (Cucurbitaceae). *Micronesica* 41, 70–82.
- Brower J.E., Zar, J.H. & von Ende, C.N. (1998) *Field and Laboratory Methods for General Ecology*, Fourth Edition, MCB/McGraw-Hill Companies, Inc. 273p.
- Cruz, Z. T., Muniappan, R. & Reddy, G.V.P. (2006) Establishment of *Cecidochares connexa* (Diptera: Tephritidae) in Guam and its effect on the growth of *Chromolaena odorata* (Asteraceae). *Annals of the Entomological Society of America* 99, 845–850.
- Culliney, T.W. (2005) Benefits of classical biological control for managing invasive plants. *Critical Reviews in Plant Sciences* 24, 131–150.
- Esguerra, N. M., William, J. D., Samuel, R. P. & Diopulos, K. J. (1997) Biological control of the weed, *Mimosa invisa* Von Martius on Pohnpei and Yap. *Micronesica* 30, 421–427.
- Kuniata, L.S. (2009) *Mimosa diplotricha* C. Wright ex Sauvalle (Mimosaceae),). In *Biological Control of Tropical Weeds Using Arthropods* (eds. Muniappan, R., Reddy, G.V.P. & Raman, A.), pp. 247-255, Cambridge University Press, Cambridge, UK.
- Muniappan, R., Reddy, G.V.P. & Raman, A. (2009) *Coccinia grandis* (L.) Voigt (Cucurbitaceae). In *Biological Control of Tropical Weeds Using Arthropods* (eds Muniappan, R., Reddy, G.V.P. & Raman, A.), pp. 175–182, Cambridge University Press, Cambridge, UK.
- Raman, A., Cruz, Z.T., Muniappan, R. & Reddy, G.V.P. (2007) Biology, host-specificity of gall-inducing *Acythopeus burkhartorum* (Coleoptera: Curculionidae), a biological-control agent for the invasive weed *Coccinia grandis* (Cucurbitaceae) in Guam and Saipan. *Tijdschrift voor Entomologie* 150, 181–191.
- Reddy, G.V.P. (2011) Survey of invasive plants on Guam and identification of the 20 most widespread. *Micronesica* 41, 263–274.
- Reddy, G.V.P., Cruz, Z.T., Braganza, N. & Muniappan, R. (2009a) The response of *Melittia oedipus* (Lepidoptera: Sesiidae) to visual cues is increased by the presence of food source. *Journal of Economic Entomology* 102, 127–132.
- Reddy, G.V.P., Cruz, Z.T. & Muniappan, R. (2009b) Life-history, host preference and establishment status of *Melittia oedipus* (Lepidoptera: Sesiidae), a biological control agent for *Coccinia grandis* (Cucurbitaceae) in the Mariana Islands. *Plant Protection Quarterly* 24, 27–31.
- Wilson, B. W. & Garcia, C. A. (1992). Host specificity and biology of *Heteropsylla spinulosa* (Hom.: Psyllidae) introduced into Australia and Western Samoa for the biological control of *Mimosa invisa*. *Entomophaga* 37, 293–299.
- Zachariades, C., Day, M., Muniappan, R. & Reddy, G.V.P. (2009) *Chromolaena odorata* (L.) King and Robinson (Asteraceae). In *Biological Control of Tropical Weeds Using Arthropods* (eds. Muniappan, R., Reddy, G.V.P. & Raman, A.), pp. 130–162, Cambridge University Press, Cambridge, UK.