CLASSICAL BIOLOGICAL CONTROL OF *CLIDEMIA HIRTA* (MELASTOMATACEAE) IN HAWAI'I USING MULTIPLE STRATEGIES

Patrick Conant
Hawai'i Department of Agriculture, 16 E. Lanikaula St., Hilo HI 96720, U.S.A.
Email: *miconia@aloha.net*

Abstract. Biological control of *Clidemia hirta* in Hawai'i has been episodical in its application over the last 50 years driven more by economics than by biology. Four phases (mid 1950s, late 1960s, late 1980s, mid 1990s) are described. All but one was the result of lobbying by concerned interests. A number of strategies have been tried over the years and their contribution to the control of *C. hirta* is examined. Six different insect natural enemies and one pathogen have been released up to the present. Evaluation of effectiveness has been completed for only one of the insects and no study has been made of the combined effects of the agents on the growth or reproduction of the plant. Although better control is still needed in infested natural areas, the two most recently released moths that attack reproductive parts may have good impact potential.

Key words: biocontrol, *Antiblemma acclinalis*, *Ategumia matutinalis,* Buprestidae, Carposinidae, *Carposina bullata, Colletotrichum gloeosporioides* f.s. *clidemiae, Liothrips urichi, Lius poseidon,* Melastomataceae, Momphidae, *Mompha trithalama,* Noctuidae, Phlaeothripidae, Pyralidae.

INTRODUCTION

Biological control of *Clidemia hirta* D. Don (Myrtales, Melastomataceae) in Hawai'i began almost 50 years ago and has had a complex history of periodically active work. A variety of approaches have been employed, ranging from lobbying for funds to employing different release methods for the biocontrol agents. Over the decades, and as support has waxed and waned, time has allowed the testing of a wide variety of strategies. By examining the successes and failures, we can plan future weed biocontrol projects that are better tuned to unique problems inherent in Hawaiian ecosystems and in implementation of biocontrol programs.

Nakahara *et al.* (1992) summarized the history of the classical biological control program against *C. hirta*, commonly known in Hawai'i as clidemia or Koster's curse. Smith (1992) reported on the spread and ecosystem-altering capacity of this weed. These authors made recommendations regarding biological control of clidemia. I will review these recommendations later, but I especially want to emphasize what we have learned along the way in our efforts to control a well-established invasive forest weed in Hawai'i. A chronological account of the clidemia biocontrol effort shows that this program changed course several times as interest and funding came and went over the years. My purpose here is to show the various strategies tried and how they contributed to the classical biocontrol program for this weed.

BIOLOGICAL CONTROL

First Phase.
Clidemia was first reported as established in Wahiawa, O'ahu, (Krauss 1954) at a meeting of the Hawaiian Entomological Society. However, at the same meeting, a forester of the Board of Agriculture and Forestry, Mr. Karl Korte, reported seeing it there in 1941. Also reported in the meeting were personal observations by C. E. Pemberton of a noticeable reduction in clidemia between his visits to Fiji in 1920 and 1937 that he attributed to control by the thrips, *Liothrips urichi* Karny (Thysanoptera, Phlaeothripidae). Importation and release of the clidemia thrips in 1953 began the biological control program for clidemia that is still ongoing (Table 1).

Importation of the clidemia thrips is an example of what I will call "mail order classical biocontrol". It is a fast and generally cheap way to import natural enemies. For obvious reasons, there are some prerequisites to being able to "place the order", such as:

1. A known natural enemy that has somehow shown some potential for biocontrol; and,
2. A reliable, affordable, cooperator where the weed and natural enemy occur.

Fulfilling item two is not as easy as it might sound. It is usually not difficult to find cooperators in foreign countries, but it can be very difficult to find one that is both affordable and reliable. The thrips had given good results in Fiji (Simmons 1933) and a cooperator was available.

It was not until 1982, however, that Reimer and Beardsley (1989) conducted an evaluation of the effectiveness of the thrips. The insect only occurred in sunny or partly sunny areas and did not affect production of flowers or berries. However, it stunted vegetative plants, causing significant terminal leaf abscission, even killing some plants. Once the thrips was released, interest in further biocontrol work waned (perhaps because it was no longer considered a significant weed of pastures and plantations). This is a typical scenario for long-term biocontrol projects in Hawai'i and probably elsewhere.

Second phase.
It is unclear what spurred Davis to collect a pyralid leaf roller, *Ategumia matutinalis* (Guenee) (Lepidoptera, Pyralidae) on clidemia in Puerto Rico and Trinidad, West Indies but it was released in Hawai'i in 1969 (Davis 1972). Perhaps the growing publicity about invasive forest weeds that came with early 1970's environmental consciousness and determined lobbying efforts at the state legislature by the Sierra Club, the Conservation Council for Hawai'i and others gained popular support for control of invasive forest weeds during the mid 70's. The continued spread of clidemia in recent decades (Wester and Wood 1977) has made it a high priority target. Newspaper articles appeared and chronicled the releases of clidemia natural enemies by members of the Sierra Club and its High School Hikers. Without the determined lobbying efforts of several people (e.g., Betsy Gagné, Lorrin Gill, Dana Peterson), the dormant clidemia biocontrol program might not have been revitalized. Keeping the broad conservation community informed and involved in natural area weed biocontrol can make a big difference in funding allocations.

Funding obtained by the lobbying effort and the publicity generated led the governor to issue a mandate requiring the use of available departmental funds to find effective methods of control, including biocontrol. By 1978, the University of Hawai'i and the Department of Land and Natural Resources (DLNR) were involved in clidemia research and control and the Hawai'i Department of Agriculture (HDOA, formerly the Board of Commissioners of Agriculture and Forestry) was designated the lead agency (Nakahara *et al.* 1992).

Third phase.
A classical biocontrol exploration program was proposed by HDOA and implemented in 1979. Robert Burkhart conducted a typical exploratory trip of three months duration in South America. A number of natural enemies were sent back but could not be kept alive in quarantine. Dead specimens of each species were retained in the HDOA collection. Insects attacking reproductive parts could not be cultured due to the poor ambient light in the 1960's vintage quarantine building. Clidemia plants did not thrive, flowers aborted and fruit dropped. The inadequacy of the quarantine facility for growing certain target weeds through their life cycle led to another change in the approach to clidemia control. Virtually all classical biocontrol exploration done by the HDOA previously was based typically on a 3-month or less collecting trip. In contrast, the 1980 exploratory trip was a 6-month trip to Trinidad jointly funded by DLNR and HDOA. A local technician was hired there and trained to ship insects to Hawai'i after Burkhart left. Unfortunately, for the second time, none survived in quarantine in Hawai'i. Then in 1982, Burkhart set up house-keeping in Trinidad at the Commonwealth Institute of Biological Control (CIBC) for a longer stay to collect, rear and test the specificity of the natural enemies of clidemia. Burkhart was a welcome guest because he had taken natural enemies of crop pests to Trinidad for exchange.

On this trip, a new, almost revolutionary approach for HDOA was tried: The host specificity tests were performed outdoors under natural conditions to avoid all the problems associated with the dark and highly artificial quarantine environment. Was this "country of origin" method of exploration effective in this case? Was it worth the cost? To answer the first question, yes it was indeed effective. Regarding cost, this trip was a somewhat special case in that the costs were minimized by exchanging natural enemies for services and by combining funding from other exploratory biocontrol projects he performed simultaneously. This same country-of-origin work today can be quite expensive.

In his clidemia work at CIBC Burkhart used two basic approaches:

1) choice and no choice tests in outdoor cages; and,
2) exhaustive sampling of representative taxa of sympatric non-target plants to delineate the natural host range of the more promising natural enemies.

His studies identified 14 species that appeared to have potential for Hawai'i (Nakahara *et al.* 1992). Two of these, *Eurytoma* sp. "black" (Hymenoptera: Eurytomidae) and *Penestes* sp. (Coleoptera: Curculionidae), were found to be of no value (Burkhart 1986, 1988). His tests led to the eventual release of four more species. Within this small complex of insects lie more lessons to be learned from this project.

Among the myriad dilemmas facing an exploratory entomologist working alone in a foreign country is "the quick fix vs. the long slow, difficult, but presumably more effective fix" dilemma. The two approaches are not mutually exclusive but the quick fix does tend to favor species that are easy to handle in quarantine and which have not been evaluated as the most effective of the suite of species available. However, an experienced biological control specialist can often choose effective agents after a short visit to the native country of a target weed. The evaluation of all host-specific species for impact and then working out their biology and conducting host screening experiments prior to their introduction into quarantine can be extremely expensive and time-consuming. Administrative pressure to justify spending money out of state as well as the need for success in order to justify the foreign travel are never far from one's thoughts.

Lius poseidon Napp (Coleoptera: Buprestidae) and *Antiblemma acclinalis* Hubner (Lepidoptera: Noctuidae) are examples of the "quick fix". *Lius poseidon* is a buprestid beetle that mines the leaves in the immature stage while adults are defoliators. *Antiblemma acclinalis* larvae roll up leaves and feed within. Unfortunately both species are attacked by parasitoids already present in Hawai'i.

Mompha trithalama Meyrick (Lepidoptera: Momphidae) and *Carposina bullata* Meyrick (Lepidoptera: Carposinidae) are examples of the long, slow method. *Mompha trithalama* larvae feed primarily on the seeds within berries and *C. bullata* larvae feed primarily on flowers, (these roles overlap somewhat). The former is established in Hawai'i but it is too early to determine any impact. The latter has not been established.

Biotic interference is a significant problem in biological control programs, particularly in Hawai'i. Its effects have been studied in the Hawaiian program against clidemia. Reimer and Beardsley (1986) found that larvae of the leaf roller (*A. matutinalis*) were parasitized by 4 species of hymenoptera. Their sampling methods did not include egg or pupal parasitiods, although they did rear out one species of *Trichogramma* from an egg. Percent parasitization of the larvae was consistently high suggesting that "These high levels of parasitization by parasitoids may be a major and at the very least an important factor contributing to low (*A. matutinalis)* field populations" (Reimer and Beardsley 1986). Effectiveness of the leaf roller has never been evaluated, but its rarity in the field suggests that it has little impact on the plant. Damage in the field is readily recognized by the rolled up sub-terminal leaves in which the larvae feed. Reimer (1988) found that ants and an anthocorid bug preyed on the thrips and caused significant mortality.

The two control agents released and evaluated for biocontrol of clidemia both suffer from biotic interference. *Antiblemma acclinalis* Hubner (Lepidoptera, Noctuidae), first released in 1995, may be suffering a similar fate since the moth and its damage are rarely seen, even at former release sites. Young larvae feed on leaves at night, and rest under leaves during the day. Third instar and older larvae migrate down to the ground during the day and climb back up to feed on foliage at night (Burkhart 1987).

My collections of *Lius poseidon* larvae produced adults of *Chrysocharis parksi* Crawford (Hymenoptera: Eulophidae), a purposefully introduced parasitoid of *Liriomyza* (Diptera, Agromyzidae) leaf miners on vegetable crops. It is possible that other leaf miner parasitoids are attacking this beetle and they may be attacking a Gracillariid moth that has been released to control *Myrica faya* Aiton (Myricales, Myricaceae). How much biotic interference occurs with other natural enemies released for biocontrol of weeds in Hawai'i? More field collections of immature stages of biological control agents are needed to assess this problem. In fact, it is a significant need in the evaluation of all Hawaiian biocontrol introductions.

In 1985, the Hawai'i State Legislature adopted another tactic, the use of a plant pathogen. A leaf spot fungus (*Colletotrichum gloeosporioides* f. sp. *clidemiae* Trujillo (Deuteromycotina, Melanconiaceae) from Panama appeared to have good potential (Trujillo, Latterell and Rossi 1986). It was only the second time a pathogen had been used in classical weed biocontrol in Hawai'i, and the first one against a natural-area weed. There always had been considerable resistance to the use of pathogens but the demonstrated potential of the fungus overcame opposition. The fungus is now established on most islands infested with clidemia. Defoliation can be extensive over contiguous areas when weather conditions are favorable (cool, windy and rainy). Its effects on the weed have not been quantitatively evaluated as yet so it is difficult to assess its long-term impact, but it does appear to defoliate and stress the plant at least seasonally.

Lius poseidon was approved for release by the Board of Agriculture in early 1988. Specimens from each shipment were first sent to Dr. Minoru Tamashiro, University of Hawai'i, to check for pathogen infection of the agents prior to their release. The insect is now established on Maui, O'ahu, Kaua'i and Hawai'i. The effectiveness of neither the leaf feeding adults nor leaf-mining larvae has been quantified. Damage to young plants appears to be greater than to mature plants, particularly in combination with thrips damage.

Fourth phase.

The clidemia project became dormant again after the release of *L. poseidon*. The fourth attempt to use biological control began in the mid 1990s. Hurricane Iniki (1992) caused extensive damage to forested areas on Kaua'i, which became vulnerable to weed invasion. U.S. Forest Service (USFS) funds became available in 1995 for forest restoration with control of invasive forest weeds a high priority. Since clidemia already infested the wetter low to mid elevation forests there, some of these funds were used to import another natural enemy for clidemia. *Antiblemma acclinalis* had been approved for release years earlier but no funds had been available to import it. It was first released in 1995 but remains uncommon, probably due to parasitism.

Rearing and release of *A. acclinalis* was still ongoing in 1998 when USFS Special Technology Development Program funds were obtained to import *C. bullata* and *M. trithalama*. Burkhart had finished all the host specificity tests in Trinidad many years earlier, but the results and petition to release had never been prepared because funding had lapsed. State and Federal approval was obtained for release of both species in 1995 and releases began that year. However, releases were very small and establishment was doubtful. Funding from the U.S. Army coincidentally became available in 1997 for Burkhart to rear both species in Tobago, West Indies and ship them to the HDOA in Honolulu as pupae. Samples were sent to Dr. Gerard Thomas in Berkeley for pathogen diagnosis prior to release. Releases of *M. trithalama* were made at Schofield Barracks East Range (Schofield-Waikane Trailhead), Lyon Arboretum and Kahana Valley on O'ahu, and at Pohoiki and Waiakea Forest Reserve on the island of Hawai'i. *M. trithalama* now appears to be established at Kahana Valley and Pohoiki. *C. bullata* has yet to be recovered, but surveys will continue at all release sites. Redistribution will be made to other islands and other clidemia infestations within islands once either moth is firmly established.

FUTURE PROSPECTS

The consensus among environmentalists and land managers appears to be that clidemia is still not under adequate control. It is too early to know the effects of the two most recently released lepidoptera (Table 1). No formal impact evaluation studies are underway other than checking for establishment. Importation and release of new agents in the future may warrant consideration. Nakahara *et al.* (1992) mention five species (among others) of clidemia natural enemies in Trinidad identified by Burkhart as having potential for biocontrol in Hawai'i. Two of these are lepidoptera that attack both clidemia and *Miconia* sp. (Melastomataceae) flowers. The remaining three are a eurytomid gall-forming wasp that attacks the berries, an unidentified cecidomyiid midge that attacks flowers and an unidentified stem-boring cerambycid beetle, which proved difficult to work with. All three of these might be at low risk of biotic interference and the former two could be useful additions to the complex of natural enemies now established. However, the use of plant pathogens should be reconsidered now that HDOA has a quarantine facility with a plant pathologist on staff. Pathogens have some advantages over insects: they can be tested more quickly than insects, take up less space and are, in general, easier to propagate.

Table 1. Natural enemies of *Clidemia hirta* (Melastomataceae) released in Hawai'i.

Species	Part of plant attacked	Year Released
Liothrips urichi	TERMINALS	1953
Ategumia matutinalis	LEAVES	1969
Colletotrichum gloeosporioides f.s. *clidemiae*	LEAVES	1986
Lius poseidon	LEAVES	1988
Antiblemma acclinalis	LEAVES	1995
Mompha trithalama	FLOWERS/FRUIT	1995
Carposina bullata	FRUIT/FLOWERS	1995

Using biological control against any plant in the family Melastomataceae in Hawai'i could also be beneficial to the control of clidemia. Since virtually all of these species are known to be weeds in Hawai'i, host specificity of a biocontrol agent needs only to be limited to the family of the host plant. The biocontrol program for *Miconia calvescens* could conceivably aid in control of clidemia as well as other melastomataceous weeds in Hawai'i.

SUMMARY OF STRATEGIES USED AND LESSONS LEARNED IN CLIDEMIA BIOCONTROL

1) Education and publicity can lead to popular support and funding of individual programs.
2) "Mail order" natural enemies (biocontrol agents readily available from a foreign cooperator) can be a quick method of importing agents, if a reliable cooperator at a reasonable cost can be found.
3) Traditional short-term (three months or less) classical biocontrol exploration can be useful if natural enemies that can be reared easily in quarantine are found.
4) Long-term work in country of origin by a Hawai'i-based explorer can be effective but may be expensive. This strategy allows host-range and specificity tests to be done under natural conditions.
5) The advantages and disadvantages of "Fast-tracking" easy-to-rear foliar feeders vs longer-term efforts for harder-to-rear flower/fruit feeders should be evaluated
6) The likely impact of biotic interference should be evaluated. Leaf feeding lepidoptera with exposed diurnal larvae may have lower

probability of success due to biotic interference by parasitoids. Leaf mining larvae may also be at risk from parasitoids.

7) Plant pathogens should be considered seriously in any biological control program against weeds.

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