BIOLOGICAL CONTROL OF LANTANA, PRICKLY PEAR, AND HĀMĀKUA PĀMAKANI IN HAWAI'I: A REVIEW AND UPDATE

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ABSTRACT

The biological control of noxious weeds in Hawai'i has been carried on intermittently since 1902, when insects and diseases of lantana (*Lantana camara*) were sought in Mexico by the Territorial Board of Agriculture and Forestry (now Hawaii Department of Agriculture). This approach was subsequently employed for the control of 20 other noxious weed pests between the 1940s and 1970s. Lantana was the first weed to be controlled by this method in the U.S. Results were very dramatic in some areas of the State, especially after later introductions by Hawaiian and Australian entomologists resulted in heavy stress on lantana. In addition to lantana, excellent results have been obtained in the biological control of cacti (*Opuntia* spp.), and Hāmākua pāmakani (*Ageratina riparia*). Prior to the introduction of cactus insects in 1949, 66,000 a (26,400 ha) of Parker Ranch range lands on Hawai'i Island were infested with cacti. By 1965, 7,610 a (<3,080 ha) remained infested, the result of three introduced insects and an accidentally introduced fungus disease; the red-fruited variety of cactus is particularly susceptible to the fungus. A spineless variety of the cactus occurs in the 'Āinahou-Poliokeawe Pali sector of Hawaii Volcanoes National Park, and biocontrol efforts are in progress. With the introduction of insects from Mexico and a foliar fungus disease from Jamaica, Hāmākua pāmakani is under excellent control on many ranch as well as privately owned and government lands on Hawai'i Island. The pathogenic fungus introduced into Hawai'i specifically for Hāmākua pāmakani represents the first successful attempt to establish a disease of this noxious weed.

INTRODUCTION

Biological control has been attempted on 20 species of alien plants in Hawai'i. Of these, 10, including the three examples discussed herein, have been judged successful in terms of control of the target weed. Biocontrol insects have established on eight additional weeds, but not enough stress on the target plant has been achieved for good control. Two attempts (firetree (*Myrica faya*) and Russian thistle (*Salsola kali*)) are considered failures so far, since no recoveries of the biocontrol insects

on target plants have been made. Biological controls achieved for the three weeds discussed below represent classical examples of success.

BIOLOGICAL CONTROL OF LANTANA

Introduction

Lantana (*Lantana camara*) is native to subtropical and tropical Central America and has become established as a weed in many countries of the world. It was introduced to Hawai'i as an ornamental in 1858 (Hillebrand 1888), and by 1902 very large areas were occupied, especially lower, drier areas (Perkins 1924). Perkins stated that "many of these dry areas are said to have afforded good pasture during the wet season before the coming of lantana." He attributed the spread of lantana on all islands largely to two introduced birds, the spotted or lace-necked dove, *Streptopelia chinensis*, and the Indian myna, *Acridotheres tristis*, both of which feed on the aromatic berries. Encroachment of this noxious weed into pasture lands was of much concern to ranchers, as it displaced valuable forage grasses, was costly to control, and reduced the carrying capacity of the range (Perkins 1924). A purposefully introduced plant without its native enemies and under very favorable climatic conditions was spreading throughout the Hawaiian Islands.

Insects on Lantana in Hawai'i Prior to Biocontrol Introductions

An alien scale insect known as the greenhouse orthezia, *Orthezia insignis*, was observed damaging lantana by Maui ranchers about the turn of the century; they named it Maui blight (Fullaway and Krauss 1945). Cattlemen spread the insect on O'ahu, but it was not host specific and became quite a nuisance on cultivated ornamentals. Other insects such as noctuids, probably *Chrysodeixis chalcites*; tortricids (leaf rollers); a native geometrid, *Scotorythra* sp. (looper) (Perkins 1924); and a phycitid, *Cryptoblabes aliena* (Fullaway and Krauss 1945), were recorded, but these were polyphagous (generalist herbivores) and had little if any effect on lantana.

Biological Control Efforts

In 1902, Albert Koebele, then an entomologist under the Commissioner of Agriculture of the Provisional Hawaiian Government, was sent to Mexico to investigate insect and disease enemies of lantana, with the object of introducing into Hawai'i insect species that he considered safe for trial. This was the first time the control of a noxious plant using insect enemies was attempted in what is now the United States. Large numbers of insects were found in Mexico attacking lantana flowers, seeds, flower stalks, leaves, stems, terminal branches, and roots. By the close of 1902, Koebele had shipped 23 different insect species to Hawai'i, many of which were found heavily parasitized upon arrival. Host specificity studies were not conducted, as Koebele shipped only those insects he considered safe for release (Swezey 1924). Of those insects liberated, eight species became established in the vicinity of Honolulu and from there spread to the other islands (Table 1). To quote Swezey (1924), "Just how they were distributed to the other Islands is not recorded but it is presumed that this was done shortly after they became established in Honolulu." Natural spread of

insects to neighbor islands has been recorded (Davis 1978). By 1905, introduced lantana insects were generally distributed throughout the Islands, and by 1924 the area occupied by lantana appeared to be much less than previously (Swezey 1924).

Swezey (1924) noted that "each of the eight introduced insects attacks the lantana plant in a somewhat different way and their combined attack results in greatly checking the production of seed and thus minimizes its chances for further spreading or reoccupying land from which it had been cleared." Although Spencer (in Hardy and Delfinado 1980) questioned the effectiveness of the seed fly *Ophiomyia lantanae* in controlling lantana, Swezey's reasoning for the combined effects of insect attack appears valid. Swezey regarded the larvae of the tortricid moth *Epinotia lantana* as probably the most beneficial of all insects in checking production of berries, because it bores into the flower stems, feeds in the receptacles of the flower clusters, and eats flowers and fruit.

Table 1. Insects introduced in 1902 for lantana control that became established in the Hawaiian Islands.

Order	Species	Activity
Diptera (flies)	*Ophiomyia lantanae* (Froggatt) (agromyzid)	Fruit infesting
	Eutreta xanthochaeta Aldrich (tephritid)	Stem galling
Lepidoptera (moths)	*Epinotia lantana* (Busck) (tortricid)	Flower, shoot, seed feeding
	Cremastobombycia lantanella Busck (gracillariid)	Leaf mining
Lepidoptera (plume moth)	*Lantanophaga* (= *Platyptilia*) *pussillidactyla* (Walker) (pterophorid)	Flower feeding
Lepidoptera (butterflies)	*Strymon echion* (L.) (lycaenid)	Flower feeding
	S. bazochii gundlachianus (Bates) (lycaenid)	Flower feeding
Hemiptera (lace bug)	*Teleonemia scrupulosa* Stal (tingid)	Leaf feeding

Lantana was still a problem on many ranches in 1952. Surveys by Hawaiian and Australian entomologists indicated that earlier biological control agents were not providing sufficient stress for effective control. This may have been due to the effects of parasitism on some of the introduced insect species such as the braconid *Opius lantanae* on *Ophiomyia lantanae* (Bridwell 1919) and *Bracon mellitor* (Braconidae), *Perisierola emigrata* (Bethylidae), and *Pristomerus hawaiiensis* (Ichneumonidae) on *Epinotia lantana* (Zimmerman 1978). *Pachodynerus nasidens*, an eumenid wasp, may be an important predator of *E. lantana* (Fullaway and Krauss 1945). The eggs of the lantana butterflies *Strymon echion* and *S. bazochii gundlachianus* are often heavily parasitized by a tiny wasp, *Trichogramma* sp. (Fullaway and Krauss 1945).

Further exploration for biocontrol agents was undertaken in 1952 by the entomologist N.L.H. Krauss, who carried on investigations intermittently from 1952 to 1965 throughout tropical America and other regions. This work was followed by a cooperative arrangement in 1953 among Fiji, Trust Territory of the Pacific Islands; Queensland, Commonwealth of Australia; and Hawai'i. N.L.H. Krauss and J. Mann of Australia (during 1953-54) were the principal explorers (Davis and Krauss 1962a).

Thirteen candidate insects were received in the Hawaii Department of Agriculture quarantine facility, Honolulu, as a result of these explorations. Ten species were recommended for release after extensive host range tests by the Hawaii Department of Agriculture Advisory Committee and approved for release by the Board of Agriculture (Table 2). Three of the candidates, a cossid, *Langsdorfia franckii*, and the foliar chrysomelids *Octotoma plicatula* and *O. gundlachi*, failed to propagate sufficiently and died in quarantine. Of the seven remaining approved insects, six became established statewide. In addition, a foliar-feeding tingid from Peru, *Leptobyrsa decora*, was received in 1969 from K.L.S. Harley, an Australian entomologist, and is well established in certain areas on Kaua'i, Maui, and the island of Hawai'i. Strains of the tingid *Teleonemia scrupulosa* were introduced from Brazil, British Honduras, Trinidad, and Florida (Weber 1955) but are not included in the table because they are conspecific with the previously established strain from Mexico.

Caterpillars of the pyraustid *Syngamia haemorrhoidalis* denuded many acres of lantana at Mokule'ia, O'ahu, beginning in 1957. Up to 1958, this species was the only outstanding lepidopterous skeletonizer-defoliator of lantana (Davis and Krauss 1962a). The depredations caused by this insect were followed by the purposeful introduction of another lepidopterous leaf feeder, *Hypena strigata*. Establishment of *Hypena* was somewhat slower, but population irruptions occurred in Lāwa'i Valley, Kaua'i, in late 1958. Foliar devastation in thousands of acres throughout the State occurred between 1959 and 1961. In most lantana infestations, *Hypena* replaced *Syngamia* as the dominant control agent, building up very large populations during the winter months and leveling off during the summer, when *T. scrupulosa* replaced *Hypena* and *Syngamia* in importance from sea level to approximately 2,520 ft (763 m) elevation. In 1960, five

Table 2. Insects introduced into Hawai'i 1952-1969 to control lantana.

Name	Family	Date Introduced & Origin	Established	Site of Activity
Teleonemia vanduzii Drake	Tingidae	1952 (Cuba)	-	foliar
Blepharomastix acutangulalis (Snellen)	Pyraustidae	1953 (Mexico)	-	foliar
Octotoma gundlachi Suffrain	Chrysomelidae	1953 (Cuba)	-	foliar
Plagiohammus spinipennis (Thomson)*	Cerambycidae	1954-60 (Mexico)	+	stem
Octotoma plicatula (Fabricius)	Chrysomelidae	1954 (Honduras)	-	foliar
Octotoma scabripennis (Guer)*	Chrysomelidae	1955-59 (Mexico)	+	foliar
Aerenicopsis championi Bates*	Cerambycidae	1955 (Mexico)	-	branches
Catabena esula (Druce)	Noctuidae	1955 (California)	+	foliar
Langsdorfia franckii Hubner	Cossidae	1955 (Mexico)	-	roots
Syngamia haemorrhoidalis Guenee	Pyraustidae	1956 (Cuba, Florida)	+	foliar
Hypena strigata F.	Noctuidae	1957 (Kenya, E. Africa)	+	foliar
Uroplata girardi Pic	Chrysomelidae	1961 (Brazil)	+	foliar
Diastema tigris Guenee	Noctuidae	1962 (Panama Canal Zone)	-	foliar
Leptobyrsa decora Drake	Tingidae	1969 (Peru)	+	foliar

*Previously introduced in 1902 but did not become established.

years after its introduction from California, *Catabena esula*, another lepidopterous defoliator, began to increase on Hawai'i, Maui, and O'ahu and later caused extensive defoliation at South Point, Kohala, and other localities on Hawai'i Island (Davis and Krauss 1962b).

The impact of these lepidopteran introductions in the late 1950s and 1960s began to have an effect on lantana in some localities. Dieback to ground level was observed in the drier parts of the island of Hawai'i. At Kēōkea, Maui, lantana was defoliated continuously over many hundreds of acres despite heavy rains. Leaves that managed to appear temporarily on some plants were aborted; this appeared to be a prelude to dieback. On West Moloka'i, drought and heavy insect pressure by *Hypena* killed many acres of lantana (Davis and Krauss 1962a).

In the meantime, the foliar chrysomelids *Octotoma scabripennis* and *Uroplata girardi*, as well as the stem-boring cerambycid *Plagiohammus spinipennis*, became well established on the island of Hawai'i. These caused considerable damage to lantana in the wetter areas of Kona and Ka'ū (Davis and Krauss 1966). The tingid *Leptobyrsa decora* also attacks leaves, adding to the foliar problems of its host, and noticeable damage was reported recently at Pu'uanahulu, North Kona (Yoshioka, 1986 unpub. data).

Biocontrol of lantana by most established insects appeared to have attained an equilibrium by 1969. This may have been due to unfavorable weather conditions or lepidopterous parasitism, especially to the pupae of the California noctuid, *C. esula*, by the ichneumonid *Ecthromorpha fuscator*, and egg parasitism of the East African noctuid *Hypena strigata* by *Trichogramma* sp. (Yoshioka 1970).

The discovery of the stem- and trunk-boring cerambycid *Plagiohammus spinipennis* and the leaf-mining chrysomelid *Octotoma scabripennis* at 2,260 ft (914 m) elevation at Kahauloa and Pu'ulehua parcels of land, Kona, in February 1969 was a significant development. This represented a considerable natural spread from the original release point at lower Kahauloa, 680 ft (274 m) in elevation, a linear distance of approximately 6 to 10 miles (9.6-16 km) (Davis 1970). Thus far, there are no records of parasitism on *O. scabripennis* and *Uroplata girardi*. Larval parasitism on *P. spinipennis* by the braconid *Doryctes palliatus* (Cameron) has been recorded (Harley 1967).

Lantana in Hawaii Volcanoes National Park

Lantana occurs from sea level to approximately 2,350 ft (950 m) elevation in Hawaii Volcanoes National Park (much of it in dry habitats). It is generally scrubby in growth form. Most of the lantana insects are present, and at Hōlei Pali the butterfly *Strymon bazochii* has been frequently observed on lantana, where it feeds on the flowers and seeds (Williams 1980). In February 1986, severe foliar damage was observed at Poliokeawe Pali (1,520 ft or 615 m elevation) and at the approach to the 'Āinahou Ranch house (2,350 ft or 950 m elevation) (Davis, unpub. data). Defoliation was caused by *Hypena strigata* and *O. scabripennis*. At Poliokeawe Pali, sporadic dieback of lantana was also observed and was

perhaps due to incessant foliar damage by *T. scrupulosa*, *H. strigata*, and possibly *C. esula*. Stem galls initiated by *Eutreta xanthochaeta* were also observed, but the incidence of gall infestation was low and not considered important.

Present Status

Lantana is generally under partial to substantial control in the drier areas of Hawai'i (Table 3), but there are some areas such as Hawaii Volcanoes National Park and possibly others where biocontrol could be improved (Fig. 1). The foliar feeding bug *L. decora* has not been observed in the Park, and the chrysomelids *O. scabripennis* and *U. girardi* have not occurred at damaging population levels to date. In the wetter areas of Hawai'i, control has been improved by the work of *P. spinipenis*, *O. scabripennis*, *U. girardi*, *H. strigata*, and *L. decora*; but more continuity of depredation is needed.

Recommendations

For the State at large, no further introductions for biological control in the drier areas are recommended. For the wetter areas, the reintroduction of the chrysomelids *O. plicatula* and *O. gundlachi* and the introduction of a host-specific fungus are recommended. *O. gundlachi* was previously collected in Cuba, and unless it occurs in other

Table 3. Optimum climatic conditions for lantana insects.

Control Agent	Dry (20-40 in.)	Wet (50-100+ in.)	Wet and Dry Areas
Teleonemia scrupulosa Stal.	X		
Ophiomyia lantanae Froggatt	X		
Epinotia lantana Busck			X
Lantanophaga (=*Platyptilia*) *pussillidactyla* (Walker)	X		
Strymon echion (L.)	X		
Strymon bazochii gundlachianus (Bates)	X		
Octotoma scabripennis (Guerin)			X
Uroplata girardi Pic			X
Cremastobombycia lantanella Busck		X	
Eutreta xanthochaeta Aldrich			X
Plagiohammus spinipennis (Thomson)		X	
Hypena strigata Fab.		X	
Syngamia haemorrhoidalis Guenee			X
Leptobyrsa decora Drake			X
Catabena esula Druce	X		

countries, it may not be available. Since the established leafmining beetles are apparently free of parasites and predators, the beetles proposed for reintroduction would most likely not be parasitized and would put more stress on lantana when damaging population levels are reached.

The foliar bug *L. decora* should be collected and distributed in Hawaii Volcanoes to augment and provide additional stress to lantana in dry areas where other biocontrol agents are established.

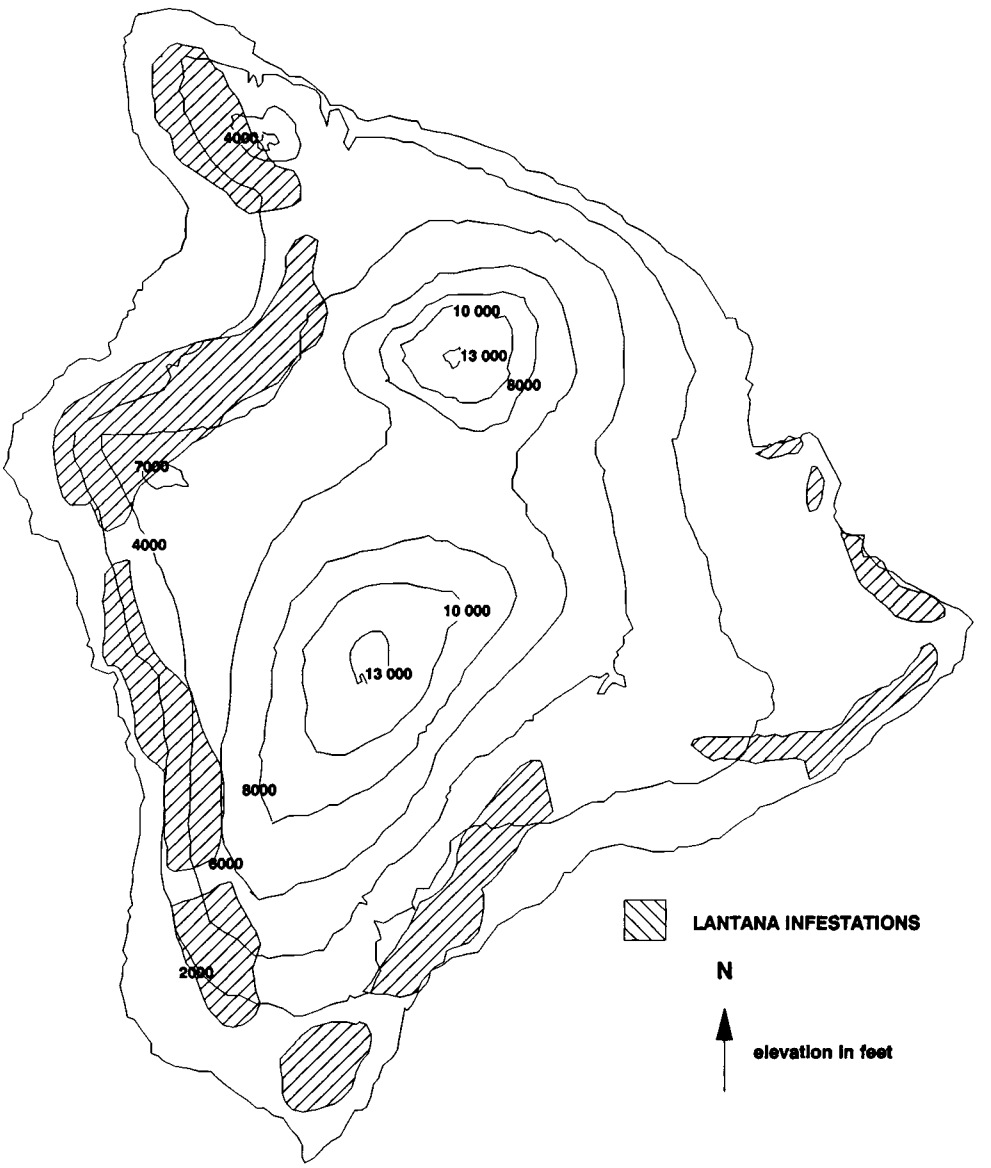

Figure 1. Distribution of lantana on the island of Hawai'i.

BIOLOGICAL CONTROL OF PRICKLY PEAR CACTUS (*OPUNTIA* SPP.)

Introduction

The prickly pear, or pānini as it is locally called, is represented by two species in Hawai'i, *Opuntia ficus-indica* (= *megacantha*) and *O. cordobensis*. These species are native to the drier parts of tropical America. Don Marin probably introduced *O. ficus-indica* to Hawai'i from Mexico about 1809 (Hosaka and Thistle 1954).

Cacti generally occur in the dry lowland areas on all islands, occasionally up to 2,640 ft (1,068 m) elevation such as on Parker Ranch, Hawai'i Island. Thick stands once occurred in the coastal areas between Puakō and Māhukona, inland from Kawaihae to lower Waimea, and from Waimea to Ke'āmuku, the last up to 2,640 ft (1,068 m) elevation. Prickly pear was also common in Ka'ū District, between Honu'apo and Punalu'u, on Hawai'i Island. A spineless cactus was introduced from the King Ranch, Texas, in 1937 and planted in the lower Keauhou-'Āinahou tract of Hawaii Volcanoes National Park at approximate elevations of 1,640 to 2,070 ft (500-630 m) (T. Lindsey, pers. comm. 1986).

Botanists disagree as to the identity and correct nomenclature of the *Opuntia* species common in Hawai'i. St. John (1973) listed *O. megacantha* as the common, established prickly pear cactus in Hawai'i. This plant has also been known by the name *O. tuna* (Hillebrand 1888). However, Benson (1982) considered *O. megacantha* to be a synonym of *O. ficus-indica* (India fig), which he recorded as escaped and naturalized on the dry leeward side of the Hawaiian Islands. He reported that spineless horticultural forms of *O. ficus-indica* are common and widespread. Much of the cactus in Hawaii Volcanoes is a spineless form, presumably a cultivar of *O. ficus-indica*. There is, however, some question as to the identify of some cacti in the Park (L.W. Cuddihy, pers. comm.), as hybrid forms may have been introduced into the 'Āinahou area of the Park during the time it was used as a cattle ranch.

The cochineal cactus, *Nopalea cochenillifera*, is also present in Hawai'i (Degener 1946). The cladodes or "pads" of this species are usually spineless. Luther Burbank introduced this plant to Santa Rosa, California, from the Hawaiian Islands and Mexico for his experiments with spineless cactus (Burbank 1914).

Uses

There are many uses for cacti in tropical America, such as food, drink, and medicine; in Mexico a commercially valuable red dye is derived from the cochineal insect *Dactylopius coccus*, which breeds on *Nopalea cacti*, *N. nopalnocheztli*, and *N. nocheznopalli* (Ross 1986). In the low, dry areas of Hawai'i, cattle used the common wild cactus *O. ficus-indica* for moisture, and the Hawaiians made a fermented drink from the fruits and also ate them raw (Neal 1965).

Recorded Enemies of Cacti Prior to Hawai'i State Introduction of Biocontrol Agents

A form of the fungus *Fusarium oxysporum* destroys the red-fruited cactus and was recorded from Kaua'i, Ni'ihau, O'ahu, Moloka'i, and Maui (Carpenter 1944). A cactus scale, *Diaspis echinocacti*, infests *Opuntia* spp. (Zimmerman 1948) but is relatively unimportant. A dipterous scavenger, *Copestylum* (= *Volucella*) *tamaulipana*, was frequently found in rotting cactus pads (Swezey 1932). An undetermined scab (fungus) is present on spineless cactus, sometimes occupying much of the pad surface, but is also relatively unimportant (C.J. Davis, pers. observ. 1985).

The Problem

Prior to 1949, tree cactus, *O. ficus-indica*, spread at an alarming rate on the island of Hawai'i, covering the lowlands almost solidly in many areas and spreading into upper elevations and better pastures. Attention was drawn to this menace as early as 1930 by the former manager of Parker Ranch, W.W. Carter. The mechanical destruction of cactus appeared too costly in those days. Hearing of the great success of the Australian government in tackling the cactus problem there by the biological control method, Carter turned to the local government agency, the Hawaii Board of Agriculture and Forestry (now Hawaii Department of Agriculture) to conduct a similar program, if feasible (Fullaway 1952).

Introductions for Biological Control

At first, ranchers responsible for lands with poor water supplies opposed the introduction of cactus insects. They believed that cactus was an asset to them in times of drought. It took years to overcome this opposition. In the interim, a joint project to effect destruction of the red-fruited variety of cactus by the fungus disease spores of *Fusarium oxysporum* was undertaken by Parker Ranch and the Board of Agriculture and Forestry. This project continued until 1949 (Fullaway 1954).

In 1949, the Board of Agriculture and Forestry approved the introduction, testing, and release of a number of biocontrol agents for Hawai'i Island only (Table 4). In addition, two species of coreid bugs, *Chelinidea tabulata* and *C. vittiger*, were received from Riverside, California in June 1949. However, in host range testing, positive results on pineapple (*Ananas comosus*) were obtained, and the remaining bugs were ordered destroyed.

The 66,000 a (26,400 ha) of cactus infestation on Parker Ranch in 1949 was reduced to 7,610 a (3,080 ha) by 1965 (H. Kimura, pers. comm. 1986). Sequential photo documentation of cactus destruction by *Cactoblastis cactorum* and *Dactylopius opuntiae* between 1954 and 1965 showed partial to complete destruction of cacti at Ke'āmuku between 2,000 and 3,500 ft (609-1,067 m) elevation (Fig. 2A and 2B). *Opuntia* spp. were totally eliminated from Kawaihae to the lower limit of Waimea (*ca.* 1,700 ft or 518 m elevation) in three to four years by *Dactylopius* and *Cactoblastis*. *Archlagocheirus funestus* replaced *Cactoblastis* and *Dactylopius* in effectiveness off the Kohala Road at 3,000 ft (914 m) elevation and below the Kawaihae-Kohala Junction. In Ka'ū between

Figure 2. Destruction of cactus at Ke'āmuku between 1954 (upper) and 1979 (lower) by *Cactoblastis cactorum* and *Dactylopius opuntiae*.

Table 4. Biocontrol agents introduced to control cactus in Hawai'i.

Date Intro.	Name	Source	Results
1949	*Dactylopius* sp.	California	Failed to establish
1949	*Dactylopius opuntiae* CKLL	Australia, "Mexican strain"	Established
1949	*Melitara doddalis* Dyar	Texas	Failed to establish
1949	*M. prodenialis* Walker	Texas	Failed to establish
1950	*Cactoblastis cactorum* (Berg)	Australia (Uruguay)	Established
1950	*Moneilema armatum* Le Conte	Texas	Failed to establish
1950	*M. crassa* Le Conte	Texas	Failed to establish
1950	*Archlagocheirus funestus* Thomson	Australia	Established

Honu'apo and Punalu'u, pānini has nearly disappeared, due to biocontrol agents. The 1987 distribution of Cactaceae on the island of Hawai'i is much reduced (Fig. 3).

Current Efforts toward Biocontrol of *Opuntia* in Hawaii Volcanoes National Park

Opuntia sp. occurs in the Park in the lower 'Āinahou Ranch area from nearly sea level to 3,100 ft (945 m) elevation. The single most-dense stand occurs on the slope of Poliokeawe Pali and covers an area of approximately 161 ft^2 (15 m^2). Outlying individuals occur singly or in small clumps and are sparsely distributed in the open grassland areas of lower 'Āinahou. Considering the difficult terrain and widely scattered plants, control by means other than biocontrol would seem economically unfeasible.

Methods. *Opuntia* pads heavily infested with the larvae of *C. cactorum* and *D. opuntiae* were collected from the Parker Ranch area of Hawai'i Island and were subsequently set out by National Park Service personnel at two release sites. The primary release site was at Poliokeawe Pali, on the Ka'ū side of the Keauhou Trail in the lower 'Āinahou area of Hawaii Volcanoes National Park at 2,000 ft (610 m) elevation. The second release site was on a single *Opuntia* individual occurring approximately 130 ft (40 m) south of the 'Āinahou Ranch house at an elevation of 3,100 ft (945 m). Four releases totalling approximately 40 infested pads occurred through January 1987 at the primary site. Releases were made in May and September 1985, October 1986, and January 1987. A single release of approximately seven infested pads was made at the 'Āinahou Ranch house site in September 1985. At both sites, pads of collected infested cactus were lashed with twine or flagging tape directly to apparently healthy pads so that infested and healthy surfaces were in maximum contact. Additionally, at the 'Āinahou Ranch house site, holes were drilled into host pads with a brace and bit. Infested pads were lashed onto the drilled pads so that

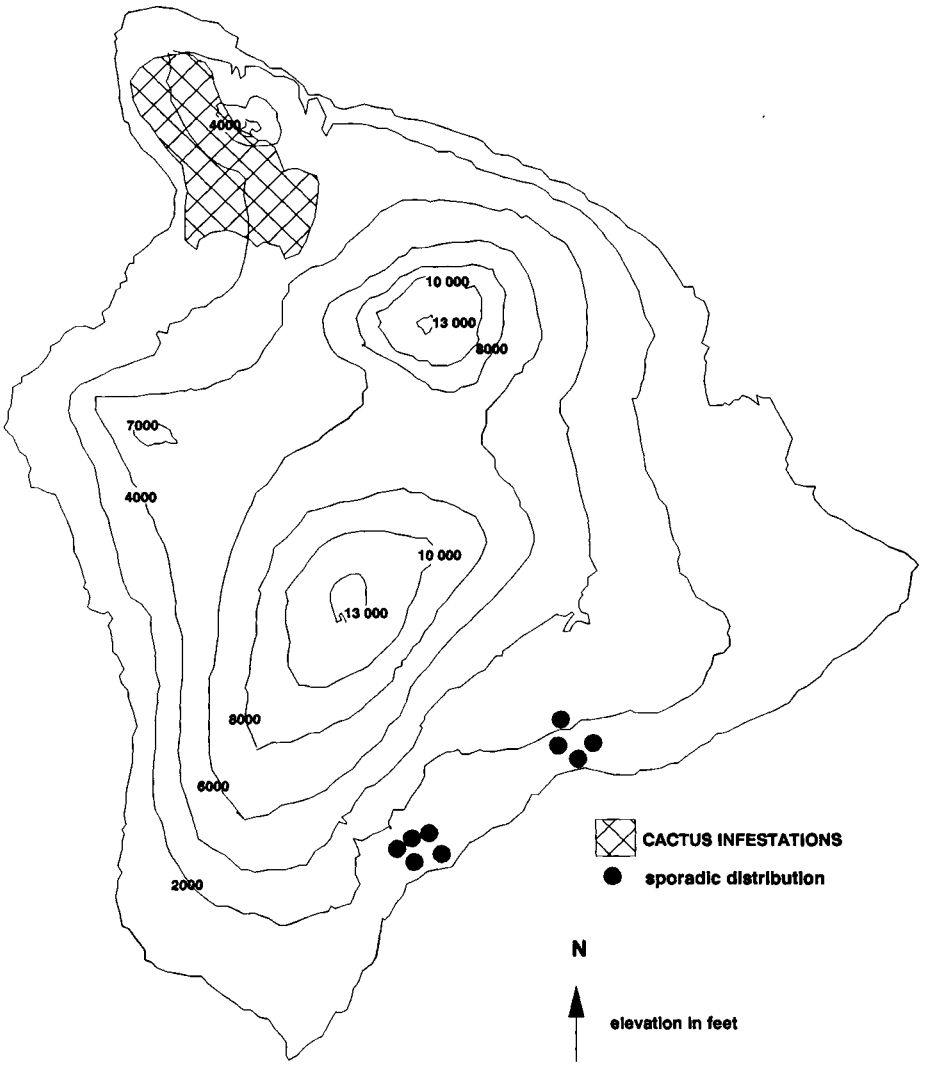

Figure 3. Distribution of cactus on the island of Hawai'i.

newly introduced *Cactoblastis* larvae could transfer to the new host through the holes provided.

Cactoblastis moths lay their eggs on the spines of cactus (Fullaway 1954). Since the cactus in the Park is primarily a spineless variety, prevention of the establishment of *Cactoblastis* populations was a concern. To enhance establishment, wooden toothpicks were placed in two host cactus pads in close proximity to larval release sites. Round and flat toothpicks were tested as surrogate spines. Toothpicks were cut in half with clippers, and the blunt end of the wooden pick was stuck through the epidermal layer to a depth of 0.4 to 0.8 in. (1-2 cm). Approximately 10 surrogate spines were inserted in the test pads.

Six permanent photopoints were established at the Poliokeawe site to monitor the long-range vigor or decline of the cactus plants and to follow the spread of the insect populations.

Results. Poliokeawe Site -- Results at the primary release site on Poliokeawe Pali at nine months showed fresh *Cactoblastis* infestations apparent in at least six pads, and *Dactylopius* colonies active on approximately 12 pads. Furthermore, fresh *Cactoblastis* activity was observed on an outlying cactus individual 165 ft (50 m) from the primary release site. However, 13 months after first release, neither species had become well established. At that time, three old *Cactoblastis*-infested pads were observed, but there was no evidence of fresh activity. Similarly, *Dactylopius* infestation was minimal, with only one colony observed. At 20 months after the first release and at the time of the fourth release, fresh *Cactoblastis* activity was observed in three cactus individuals located 65 to 100 ft (20-30 m) from the primary release site. No fresh *Cactoblastis* activity was observed within the release site. In the approximately 10 colonies observed, low levels of *Dactylopius* activity were noted in the release site.

'Āinahou Ranch House Site -- Three *Cactoblastis* egg sticks were observed on cactus pads at the 'Ainahou Ranch house site in August 1986, 15 months after release. Two of the egg sticks were approximately 1.6 in. (4 cm) in length, while the third egg stick was approximately 0.8 in. (1.5 cm) in length. The egg sticks occurred on the tips of small spines and were not observed on the surrogate spines. At 20 months after release, fresh or recent *Cactoblastis* activity was apparent in four pads, with approximately 12 pads showing old activity. Fewer than five pads remained uninfested. A single *Cactoblastis* larva was observed on a detached pad on the ground beneath the host cactus. No *Dactylopius* colonies were observed.

Discussion. Reasons for the fluctuation in populations of *Cactoblastis* and *Dactylopius* at the Poliokeawe Pali site are not known. Possible factors may include seasonally or climatically controlled reproductive cycles of the biocontrol agents, low population levels, or other conditions. Additionally, a *Dactylopius* predator, *Cryptolaemus montrouzieri* (family Coccinellidae, order Coleoptera), was observed at the release site and may be a contributing factor in the fluctuation of *Dactylopius* populations.

Additional introductions of *Cactoblastis* and *Dactylopius* will probably increase probabilities of distribution and mating among biocontrol agents. Observations at release sites will continue, and further documentation of biocontrol efforts will be forthcoming. Since most of the cacti in Hawaii Volcanoes National Park are spineless, the cochineal insect on spineless cactus in Mexico, *Dactylopius coccus*, may be more suitable for control than *D. opuntiae* and should be considered for introduction.

BIOCONTROL OF HĀMĀKUA PĀMAKANI

Introduction

Hāmākua pāmakani, or spreading mistflower (*Ageratina riparia* (= *Eupatorium riparium*), is an aggressive, fast-spreading, noxious weed of no forage value on ranchlands. Pāmakani means "windblown" in the Hawaiian language and originally referred to Maui pāmakani, *A. adenophora*, a former pest of Maui rangelands. Hāmākua pāmakani is a native of Mexico, and as with Maui pāmakani, the seeds are windblown.

Hāmākua pāmakani was first observed naturalized in the vicinity of Hilo, Hawai'i in 1926. By 1930 it had spread to Mountain View and along the Hāmākua Coast (Degener 1946). It was recorded as infrequent in the Hawaii Volcanoes National Park residential area and at Makaopuhi Crater (Fagerlund and Mitchell 1944). By 1960, this noxious weed was prevalent in many moist areas of the Park as well as the Volcano Village district and in Ka'ū and Kona, especially in upper ranch areas. In addition to Hawai'i Island, *A. riparia* is present on O'ahu and Maui but is not considered a problem. A large population exists on Tantalus on O'ahu. In Hawaii Volcanoes it is now an undesirable weed, competing with native plants and occupying disturbed areas.

Data assembled by the Hawaii Cattlemen's Association supplemented by Hawaii Department of Agriculture personnel indicated that in 1972, 128,500 a (52,000 ha) were infested with Hāmākua pāmakani, of which 98,840 a (40,000 ha) were ranchlands and 29,650 a (12,000 ha) were governmental or other privately held lands (Matayoshi 1981). As the carrying capacity of ranges deteriorated due to invasion by *A. riparia*, chemical control became impractical for most if not all ranchers, and other solutions were sought by the Cattlemen's Association. A spittle bug, *Philaenus spumarius*, was recorded (E. Yoshioka, slide taken at Hualālai Ranch, Kona, May 1977), but damage by this bug and other general feeders such as *Brevipalpus phoenicis*, a red and black flat mite, was insignificant. *B. phoenicis* was found on *A. riparia* in Hawaii Volcanoes National Park at 2,165 ft (660 m) elevation in 1986 and apparently had not been recorded from this host previously.

Biological Control

Ranchers impressed by the successful control of lantana, cacti, and Maui pāmakani urged the State to follow a similar approach for Hāmākua pāmakani. At a meeting held in Honolulu attended by representatives of the Cattlemen's Association, the Hawaii Department of Agriculture, and University of Hawaii personnel, it was unanimously agreed that further exploration for natural enemies be undertaken, with funds provided by ranchers and with a general plan of action, including: 1) insect exploration, by Hawaii Department of Agriculture; 2) plant disease search, University of Hawaii; 3) propagation, testing, and distribution of approved insects and pathogens, Hawaii Department of Agriculture and University of Hawaii.

Exploration in Mexico and neighboring countries was undertaken by a Hawaii Department of Agriculture entomologist and a University of Hawaii plant pathologist beginning in 1972. A plume moth, *Oidaematophorus*

beneficus, was found in Mexico, tested in Department quarantine facilities, approved for release by the Board, and liberated on a Kona ranch in October 1973 (Nakao and Funasaki 1976). Subsequent releases were made in the Volcano area and other localities on Hawai'i Island.

In 1973, a stem-galling fly, *Procecidochares alani*, from Vera Cruz, Mexico (*ca.* 2,000 ft or 610 m elevation), was brought to Hawai'i by a Hawaii Department of Agriculture entomologist. Propagation of the fly was very successful in the Honolulu quarantine facility, and upon the conclusion of the host range tests, approval for release was obtained. The first release was made in Kona in April 1974 at 3,400 ft (1,036 m) elevation, and subsequent island-wide releases were made (Nakao and Funasaki 1976).

A phytopathogenic fungus, *Cercosporella* (now *Entyloma* sp., according to Trujillo *et al.* 1988), was collected on *A. riparia* in Jamaica, in 1974 by the University exploratory pathologist. After host range tests it was approved for release by the Board of Agriculture, and cooperative liberations were made by University and Hawaii Department of Agriculture personnel beginning in November 1975 (Nakao and Funasaki 1979).

Results

The establishment of the plume moth defoliator and the stem gall fly in Volcano in 1974 led to a steady build-up of both insects, and by 1975 Hāmākua pāmakani was under heavy stress. At one particular site (3,800 ft or 1,165 m elevation), the weed began to disappear (Davis, pers. observ. 1975). The foliar pathogenic fungus *Cercosporella* (now *Entyloma*) sp., which was released in November 1975 (Trujillo 1985), is established in Volcano, but disease formation at this elevation appears to be limited. However, the disease has done exceptionally well in some Kona ranching areas and is especially devastating between 2,000 and 3,500 ft (610-1,067 m elevation) (Matayoshi 1981) (Fig. 4A and 4B). These agents have significantly reduced infestation of Hāmākua pāmakani on Hawai'i Island (Fig. 5).

CONCLUSIONS

Based on year-round observations of lantana and its imported enemies on ranch, government, and private lands statewide, and on sequential photo documentation of cactus and Hāmākua pāmakani on the Island of Hawai'i at fixed photographic stations, biological control of all three weeds has been dramatic. For lantana, this control ranges from partial to substantial; for cacti, substantial to complete; and for Hāmākua pāmakani, substantial to complete. In addition to purposely introduced insects, an introduced pathogen has contributed to the successful biocontrol of Hāmākua pāmakani.

All three weeds are present in Hawaii Volcanoes National Park. Most of the introduced insects are present on lantana, but the degree of control has not been determined. Introduced insects for spineless cactus at Poliokeawe are barely established, and the status of control cannot be assessed at this time. Hāmākua pāmakani is under partial control at 'Āinahou at 3,100 ft (945 m) elevation, and control is substantial to complete at 3,800 ft (1,159 m) elevation.

Figure 4. Biocontrol of an infestation of Hāmākua pamakani in North Kona (1974, upper photo) by *Entyloma* sp. (1978, lower photo).

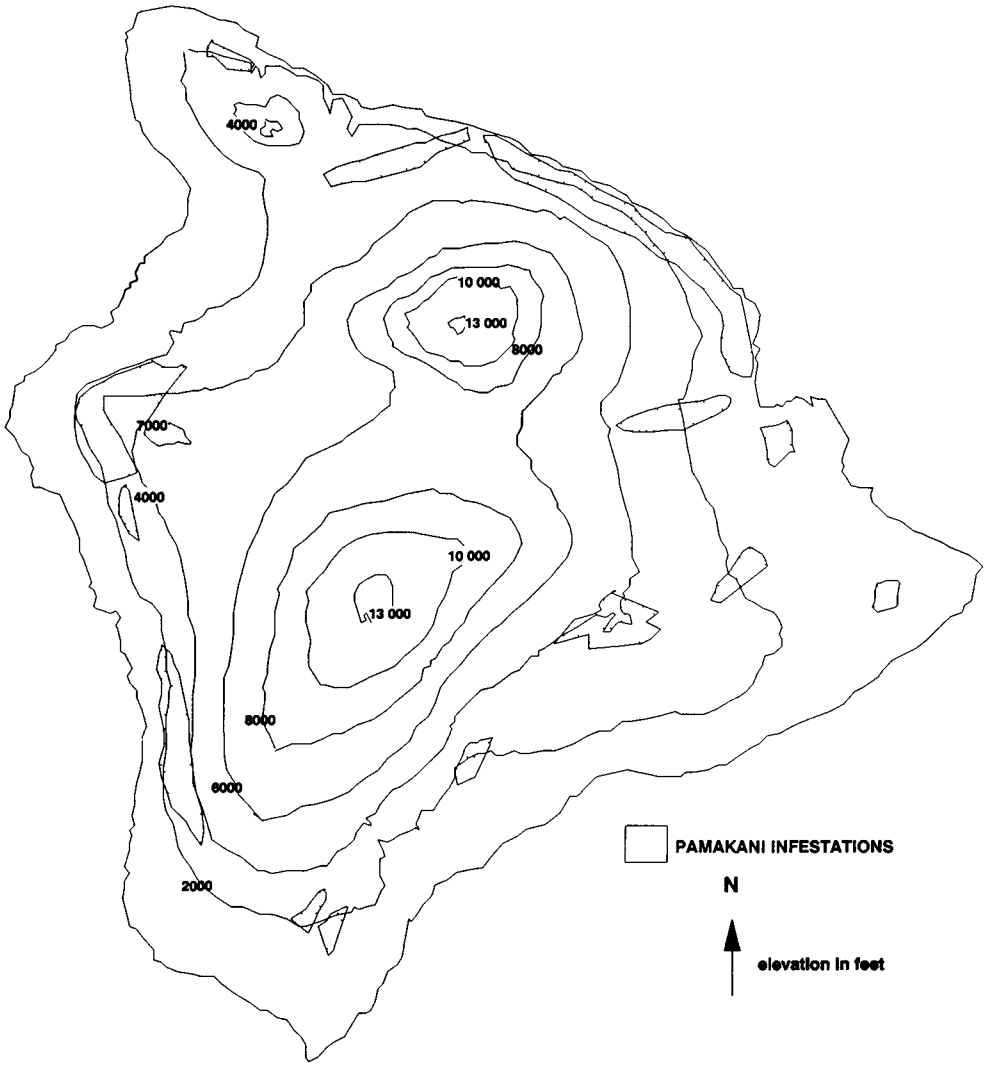

Figure 5. Infestation of Hāmākua pāmakani on the island of Hawai'i, 1987.

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