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## Biological Control of Weeds in Mauritius: Past Successes Revisited and Present Challenges

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### Abstract

Ten insect species were introduced to control five weeds on the island of Mauritius from 1914 to 1982. Eight of these (80%) became established. The biocontrol programs against *Opuntia vulgaris*, *O. tuna* and *Cordia curassavica* were completely successful, with all three target plants now not considered as weeds, and requiring no management other than the ongoing, self-sustaining biological control. *Lantana camara* is under partially successful biological control, giving an overall full/partial success rate of 80%. No deliberately introduced insects have been reported attacking non-target plants. No weed biocontrol agents have been introduced since 1982 despite worsening weed problems, particularly in native vegetation. Two of the worst forest weeds on the main island are Chinese guava (*Psidium cattleianum*) and privet (*Ligustrum robustum*); both have recently been considered as biocontrol targets in other countries. *Lantana camara* is a serious weed on Rodrigues (574 km from the main island). No official attempts to introduce weed biocontrol agents onto Rodrigues have been made, although one, *Uroplata girardi*, is common there on *Lantana camara*. Despite past successes with biological weed control on Mauritius, and current invasive weed problems, it has been difficult to initiate new weed biocontrol programs. Obtaining funding for new programs is a major challenge, although some may use research conducted elsewhere and hence be relatively cheap. Prioritizing weeds as targets for biological control is important, and will depend on factors such as conflicts of interest in weed control, availability and sustainability of alternative control methods, significance of alien vertebrate dispersers, and the scale of the impact of the weeds in intact native vegetation or active restoration programs.

**Keywords:** biocontrol history, Mascarene Islands, success rates, non-target effects, forest weeds.

Mauritius is a small (60 x 45 km) tropical island country in the Indian Ocean, 880 km east of Madagascar. Mauritius has been an active centre for biological control, particularly against insect pests of sugar cane, coconuts, and other economically significant plants, and against weeds (Moutia and Mamet 1946, Greathead 1971). However, not all biocontrol programs have been well conceived, and Mauritius has had several misguided introductions. Examples of these include the Indian mongoose (*Herpestes auropunctatus Hodgson*) in 1900, which attacks native birds and poultry, and the predatory snail

(*Euglandina rosea Ferrusae*) in 1960, which attacks native snails (Cheke 1993, Griffiths *et al.* 1993, Staub 1993). In this paper we review the past weed biocontrol programs undertaken in Mauritius, assess the success rate and safety record, and include some current information on the status of the biocontrol agents. We then evaluate the prospects for future weed biocontrol programs in Mauritius, especially in areas where invasive alien weeds threaten the remaining indigenous biodiversity. Authority names for plants and agents are given in Table 1.

**Table 1.**  
**The weeds targeted for classical biological control in Mauritius (excluding Rodrigues), with the agents released and notes on their effect (see text for further details).**

Target weed	Biological control (Order: Family)	Plant part attacked and type of attack	Year Agent Introduced	Outcome (further details in text)
<i>Opuntia vulgaris</i> Miller	<i>Dactylopius ceylonicus</i> (Green) (Homoptera: Dactylopidae)	Sucking insect (mealybug) on cladodes	1914	Initially successful, but the introduction of a predator reduced effectiveness
<i>Opuntia tuna</i> (L.) Miller	<i>Dactylopius opuntiae</i> (Cockerell) (Homoptera: Dactylopidae)	Sucking insect (mealybug) on cladodes	1927	Initially successful, but the introduction of a predator reduced effectiveness
<i>Opuntia vulgaris</i> and <i>O. tuna</i>	<i>Cactoblastis cactorum</i> (Bergroth) (Lepidoptera: Pyralidae)	Larvae bores into cladodes	1950	Re-established control of <i>Opuntia</i> spp.
<i>Cordia curassavica</i> (Jacquin) Roemer and Schultes	<i>Physonota alutacea</i> Boheman (Coleoptera: Chrysomelidae)	Larvae and adults feed externally on foliage	1947	Failed to establish.
	<i>Metrogaleruca obscura</i> (Degeer) (Coleoptera: Chrysomelidae)	Larvae and adults feed externally on foliage	1948	Completely successful control in conjunction with <i>E. attiva</i> .
	<i>Eurytoma attiva</i> Burks (Hymenoptera: Eurytomidae)	Larvae form gall, destroying seed	1949	Completely successful control in conjunction with <i>M. obscura</i> .
<i>Lantana camara</i> L.	<i>Salbia haemorrhoidalis</i> Guenée (Lepidoptera: Pyralidae)	Larvae feed externally on foliage	1965	Contributes to suppression of weed.
	<i>Diastemis tigris</i> Guenée (Lepidoptera: Noctuidae)	Larvae feed externally on foliage	1967	Established, at least initially. Impact unknown.
	<i>Uroplata girardi</i> Pic (Coleoptera: Chrysomelidae)	Larvae mine leaves, adults feed externally	1967	Widespread, but damage probably insignificant.
<i>Cyperus rotundus</i> L.	<i>Athesapeuta cyperi</i> Marshall (Coleoptera: Curculionidae)	Larvae internal, adults feed externally on foliage	1981	Probably failed to establish.

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## History and Success of Biological Control of Weeds in Mauritius

The first introduction of a biocontrol agent against a weed in Mauritius was the release of the mealybug, *Dactylopius ceylonicus*, to attack *Opuntia* spp. in 1914 (Greathead 1971). Since then, 9 more insect species have been released against 5 weed species (Table 1). Only 2 insect species released against weeds failed to establish populations, giving an 80% establishment rate of agent species. Success in biological control of weeds has been widely discussed (Crawley 1989, Cullen 1995, McFadyen 1998) but here we use the criteria employed by Hoffmann (1995): “full success” is where other control methods, e.g., mechanical or chemical, are now no longer required over any part of the range of the weed in the target country. Where biological control contributes to weed suppression, but other control methods are still required, the success is rated as “partial”. “Failure” is when the biocontrol agents make no significant contribution to weed suppression, thereby not reducing reliance on other control methods. Currently in Mauritius, the 2 *Opuntia* species and *Cordia curassavica* are under continuing, fully successful biological control, and *Lantana camara* can probably be described as under partially successful biological control. The overall full/partial success rate amongst weed species targeted for classical biological control is thus 80% (4 out of 5 species). It is noteworthy that the one weed biological control attempt in Mauritius that has completely failed was the one-off chance at establishing just one agent, with no existing track record of success, against *Cyperus rotundus*. Brief, under-resourced programs, using agents with no previous record of success, probably reduce apparent success rates of biological weed control in many countries across the world (S. Fowler, this volume).

The successful biological control of *Opuntia* spp. in Mauritius has an interesting history (Greathead 1971). The first agent introduced, the mealybug *Dactylopius ceylonicus*, successfully suppressed *O. vulgaris* but failed to attack *O. tuna*, so a second mealybug, *D. opuntiae*, was introduced in 1927. Successful control of both *Opuntia* species was then achieved, with both weeds being almost completely eradicated from the island (Moutia and Mamet 1946, Greathead 1971). The weeds remained rare until the late 1940s. Their increase in abundance has been linked to the deliberate introduction of the predatory coccinellid beetle, *Cryptolaemus montrouzieri* Mulsant, for the biological control of pineapple mealybug (*Dysmicoccus brevipes* (Cockerell)) (Greathead 1971). The predator appears to have interfered with the suppression of *Opuntia* spp. by the *Dactylopius* spp., allowing both plants to spread and begin to regain their weed status. This prompted the introduction of *Cactoblastis cactorum* in 1950, which restored the successful biological control of both *Opuntia* species. Indeed, wild *Opuntia* spp. are once again rare in Mauritius. A survey in 1998 found scattered, small plants of *Opuntia* spp. high on Montagne du Rempart, with signs of damage by the larvae of *Cactoblastis cactorum*. No *Dactylopius* spp. were seen during this survey, and it is possible that these biocontrol agents have become extinct. However, as wild *Opuntia* spp. are now apparently restricted to mostly inaccessible sites, conducting a thorough survey to detect the presence of *Dactylopius* spp. in Mauritius would be very difficult.

The other fully successful weed biocontrol program in Mauritius targeted the woody shrub, black sage (*Cordia curassavica*) which, by the 1930s, was covering large tracts of the island in dense scrub. The first agent introduced from the native range of the target weed in the Caribbean was a chrysomelid beetle, *Physonota alutacea*, in 1947. Despite over 30,000 individuals being released as adults, larvae, or eggs, the insect failed to establish, possibly because of interference from ants (Williams 1950, Greathead 1971) A pro-

gressive feature of this program was the extensive host range testing of both this agent and the subsequently released chrysomelid *Metrogaleruca obscura*. For example, *M. obscura* was tested on 122 non-target plant species in the beetle's native range in the Caribbean, and 86 non-target plant species after the importation of the beetle into confinement in Mauritius (Simmonds 1950, Williams 1951). Extensive ecological studies were also carried out on *M. obscura*. These included a study of the life history and natural enemies of *M. obscura* in Trinidad (Simmonds 1950), experiments using simulated herbivory to examine the effect of *M. obscura* on the seed production of *C. curassavica* (Callan 1948), and trials using field cages to show that *M. obscura* was capable of severely defoliating the host plant in the absence of natural enemies, particularly 2 species of parasitoids (Simmonds 1948). Historically, it is noteworthy that prior to the introduction of *P. alutacea* into Mauritius, a highly critical article was published in *Nature* suggesting that this attempt at biological control was misguided and ecologically dangerous (Maulik 1947).

In contrast to *M. obscura*, relatively little ecological work was carried out with the second effective agent used against *C. curassavica*, the eurytomid gall wasp *Eurytoma attiva*, prior to its release in Mauritius. No safety testing was deemed necessary because "the insect's mode of development and close adaptation to its host-plant . . . was sufficient guarantee of its host specificity and harmlessness to other plants" (Williams 1960). The weed has been under successful, continuous biological control in Mauritius since the early 1950s (Williams 1960, Julien and Griffiths 1998).

Both the defoliating chrysomelid and the seed-destroying eurytomid are considered to contribute to the fully successful biological control of *C. curassavica* on Mauritius (Williams 1960), although no experimental studies have been carried out. The eurytomid gall wasp continues to destroy a large proportion of fruit, probably severely limiting the dispersal abilities of the plant, and seasonally the chrysomelid beetle can still achieve high levels of defoliation (S. V. F., unpublished data; J. Williams, personal communication). However, the initial effects of the chrysomelid *M. obscura* were spectacular, with almost total defoliation of the target weed over the entire island, and large numbers of beetles were even seen flying seaward from cliffs on the south coast (J. Williams, personal communication). The program against *C. curassavica* in Mauritius is regarded as one of the premier examples of successful classical biological control in the world (McFadyen 1998). The distribution and density of the target plant have been reduced to such an extent that it is no longer recognized as a weed. The program demonstrates long-term sustainability and apparently has been completely safe environmentally (see below).

**Table 2.**  
**Accidental introductions of insect herbivores onto Mauritius (excluding Rodrigues)**  
**that have an impact on invasive alien plant species targeted for biological control.**

Weed	Biocontrol agent	Plant part attacked and type of attack	Outcome
<i>Lantana camara</i>	<i>Hyphenalacera laceratalis</i> Walker (Lepidoptera: Noctuidae)	Larvae feed externally	Arrival or possibly native. Causes significant damage in drier periods.
	<i>Teleonemia scrupulosa</i> Stål (Heteroptera: Tingidae)	Sucking insects on stems and foliage	Accidental/unrecorded release. Causes extensive damage.
	<i>Orthezia insignis</i> Browne (Homoptera: Ortheziidae)	Sucking insect (errant scale) on stems and foliage.	Accidental arrival. Causes significant damage.

The suppression of *C. curassavica* raised concerns that this weed would be replaced by *L. camara*. The subsequent introductions of 3 biocontrol agents against *L. camara*, together with the impact of some accidentally introduced insect herbivores (Table 2), do appear to have prevented the emergence of *L. camara* as a major weed on Mauritius, although again, no experimental studies have been conducted. In contrast, *L. camara* has become a very serious weed on the island of Rodrigues (part of Mauritius, but 574 km further east into the Indian Ocean). No deliberate releases of biocontrol agents against *L. camara*, or any other weed targets, are recorded for Rodrigues. However, recent surveys have revealed that the hispine beetle, *Uroplata girardi*, is common but probably not having any significant impact on *L. camara* (J. M. and S. V. F., unpublished data).

### **Non-target Effects of Biocontrol Agents Attacking Invasive Weeds in Mauritius**

No insects deliberately introduced for biological control of weeds have been reported attacking non-target plants in Mauritius, including ornamental *Opuntia* spp. However, ornamental *L. camara* are regularly treated with insecticide. *Orthezia insignis*, one of the insects recorded as damaging to *L. camara* (Table 2), is a polyphagous scale insect and a common tropical pest. In Mauritius it is a pest of some crops such as *Solanum melongena* L. There are no records of *O. insignis* damaging native plant species in Mauritius, but it would not be surprising if this occurred occasionally.

Recent surveys of several common invasive weeds (*Psidium cattleianum* Sabine, *Ligustrum robustum* Blume, and *Lantana camara*) revealed no non-target attack by deliberately released biocontrol agents (S. V. F., unpublished data). However, one adult *M. obscura* was found on a plant of *P. cattleianum* with none of its correct host plant (*C. curassavica*) apparent within at least a radius of 1 km. The lack of any juvenile stages and of any visible damage suggests that the adult beetle was merely a 'tourist', using the plant for shelter. There are plans to investigate the current laboratory and field host-range of the successful biocontrol agents released against *C. curassavica*, to test whether their host ranges could have been modified over the hundreds of generations that these insect populations will have gone through since their release over 50 years ago.

Despite the excellent record of success and safety of classical biological control of weeds in Mauritius, some people within the Government of Mauritius, non-government organisations and potential international funding agencies, have concerns over the safety and usefulness of biological control. These are some of the current barriers to implementing further programs against key environmental weeds in Mauritius.

### **Weed Threats to the Indigenous Biota of Mauritius and the Potential for their Amelioration through Classical Biological Control**

The indigenous biota of Mauritius, which is of global significance because of its high endemicity, is under extreme threat from habitat loss and invasive alien animals and plants (Strahm 1993). Today less than 5% of the island comprises native vegetation (Safford 1997). The Government has established nature reserves and the 6,574 ha Black River Gorges National Park, but these measures alone are insufficient because of the threat from invasive alien animals and plants. Deer (*Cervus timorensis* Blainville) and pigs (*Sus scrofa* L.) are preventing regeneration of native plants and disturb the ground. Monkeys (*Macaca fascicularis* (Raffles)) and rats (*Rattus* spp.) also damage native plants and are important predators of native birds, reptiles, and invertebrates. Madagascan tenrecs (*Tenrec ecaudatus* (Schreber)) and toads (*Bufo gutturalis* Power) are also major predators

of invertebrates. Introduced birds, especially the bulbul (*Pycnonotus jocosus* L.) distribute fruit of alien plants, facilitating weed invasion into remnant native vegetation. Alien plant species displace and dominate the native flora, and the worst of these alien plants are capable of invading and destroying the last intact areas of canopy forest (Lorence and Sussman 1986). Much of the land within the Black River Gorges National Park is dominated by invasive alien weeds, and all the remaining patches of intact canopy forest are being degraded, apart from the small fenced and hand-weeded Conservation Management Areas (CMAs). The CMAs, comprising 40 ha in total, are restricted in size by available resources and technology. Sustainable restoration and conservation requires methods to control weed and animal pests that are appropriate for much larger areas than the current laborious and expensive techniques used in the CMAs. Major weeds of the upland forest include *Psidium cattleianum* and *Ligustrum robustum* which, with dispersal and/or disturbance by introduced vertebrates, can invade canopy forest and prevent regeneration of native vegetation (Lorence and Sussman 1986).

There is a need to prioritize significant weeds for potential biological control. Understanding aspects of the ecology of the weeds, in particular their modes of dispersal and impact on indigenous ecosystems, is an important step. For example, the current fencing programs that exclude large vertebrates such as pigs and deer from the CMAs provide evidence that these animals facilitate weed invasion through ground disturbance and seed dispersal. The higher rate of dispersal of *L. robustum* into these fenced areas compared with *P. cattleianum* probably means that *L. robustum* is the highest priority for potential biological control. This may be fortuitous, because the public use of wild fruit of *P. cattleianum* may make it difficult to start a biocontrol program against this plant.

The cost of biocontrol programs against weeds that have not previously been targeted is always high because of the extensive research required to discover potential agents and ensure their safety (Julien and White, 1997). Both *P. cattleianum* and *L. robustum* are examples of weeds for which some research has already been carried out for other countries where these plants are serious weeds. The former is a major forest weed in Hawai'i, and initial surveys in the native range of *P. cattleianum* in southern Brazil suggest that potential biocontrol agents exist that are both damaging to the plant and sufficiently host specific to not present a risk to cultivated guava *P. guajava* (Wikler *et al.* 1996). There is a current research program investigating the potential for biological control of *L. robustum* for the island of La Réunion (part of the Mascarene Archipelago, 150 km SW of Mauritius). This was the first biological control program worldwide to target a *Ligustrum* species, so it illustrates well the scale of the resources needed to tackle a new target weed: in this case, the field surveys for potential agents, and host range testing in this program, is costing FF 5.8 million (US \$1 million) over 5 years. However, the resources needed to include Mauritian plant species in the host range testing for potential biocontrol agents for *L. robustum* will be only a very small fraction of this.

Where weeds have been successfully controlled biologically elsewhere in the world, biocontrol agents with a proven track record of safety and success can be transferred to new countries much more economically. An example is mist flower, *Ageratina riparia* Regel (King and Robinson), where only a minimal amount of additional safety testing would be required before agents already released and successful in Hawai'i (Trujillo 1985, Morin *et al.* 1997) and New Zealand (Fröhlich *et al.* in press) could be considered for release in Mauritius. Mist flower can be a major riparian weed, and is present in streams in forested areas of Mauritius, but it is not clear whether its current or future

potential as a weed would warrant a biocontrol program.

Perhaps the first practical step to rekindle interest in biological control of weeds in Mauritius, and help to break down political and logistical barriers, could be to introduce additional biocontrol agents to attack *Lantana camara* on the island of Rodrigues (where the plant is a major weed, unlike on Mauritius where it appears to be largely under successful biological control). There appears to be an opportunity to promote this as the first release of a weed biocontrol agent in the country of Mauritius (which includes Rodrigues) for nearly 20 years.

Clearly, biological control of weeds is a long-term solution, and alternative management methods for invasive weeds are needed in the short term. More efficient weeding methods, and new fencing technologies, could improve the exclusion of invasive aliens from the protected areas, allowing these areas to be expanded. However, classical biological control is still the best solution for key weed species that are increasingly dominating and destroying the valuable native ecosystems in the Black River Gorges National Park. Mauritius has some of the worst examples of impact of invasive weeds on indigenous flora found anywhere in the world. However, it also has an admirably successful and safe history of the use of classical biological control against major weeds. Despite political and logistical challenges, there is great potential for biological control to ameliorate the impact, in the long term, of several of the key environmental weeds affecting indigenous Mauritian biodiversity.

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