Abstract. Strawberry guava — *Psidium cattleianum* Sabine (Myrtales, Myrtaceae) was introduced to Hawaii about 1825 and quickly escaped from cultivation. It is now found on all inhabited islands where it is one of the most important forest weeds. The small trees form extremely dense monotypic stands up to 10 m in height. Four insect species were found that have significant deleterious effects and, therefore, considerable potential. A leaf gall produced by *Tectococcus ovatus* Hempel (Homoptera, Eriococcidae) is the most promising due to the damage caused and the ease of handling. Bud galls, precocious developments of the bud that terminate shoot growth, are formed in response to *Dasineura gigantea* (Diptera, Cecidomyiidae). A seed gall induced by *Eurytoma psidii* Thuróczy and Wikler, *in ed.* (Hymenoptera, Eurytomidae) cements groups of seeds together and prevents germination of all seeds in the fruit. These latter two species have a significant impact but are more difficult to manipulate in quarantine. A shoot gall produced by *Eurytoma cattleianii* or *Eurytoma desantisi* (Hymenoptera, Eurytomidae) terminates further growth of the shoot. The species are difficult to handle in the laboratory. The biological control potential of three additional species is discussed: a leaf gall formed in response to *Neotrioza tavaresi* (Hemiptera, Psyllidae) which, though species specific, has little impact on the plants; a sawfly, *Haplostegus epimelas* Konow (Hymenoptera, Pergidae) is unsuitable because it attacks commercial guava occasionally; and, a chrysomelid *Lamprosoma azureum* Germar (Coleoptera, Chrysomelidae) is not recommended because it attacks a number of myrtaceous species.

Keywords: *Dasineura gigantea*, *Eurytoma*, *Haplostegus epimelas*, *Lamprosoma azureum*, Myrtaceae, *Neotrioza tavaresi*, *Psidium*, *Tectococcus ovatus*.

INTRODUCTION

Strawberry guava (*Psidium cattleianum* Sabine – Myrtales. Myrtaceae) was introduced in the Hawaiian Islands around 1825 (Wagner et al. 1990). Since then it has spread into mesic and wet environments from sea level up to 900 meters. Smith (1985) classified it as one of the top ten weeds of Hawaiian native forests, a status it still maintains. It is a weed of many tropical and subtropical islands throughout the world. It does not tolerate frost. Though it can be found in tropical continental environments and has naturalized in some places it only becomes a pest in insular ecosystems.

This fruit is eaten and occasionally made into a juice though the commercial 'strawberry guava juice' is a mixture of strawberry and guava juice. The plant is frequently featured in Japanese-style gardens for its smooth multicolored bark contrasting with shiny, dark green leaves and tolerance of pruning and snapping. These potential conflicts of interest are negated by its invasiveness, its tendency to form monotypic stands and the abundant fruit host several species of fruit flies. These flies
preclude the export of untreated soft fruit from the Hawaiian Islands, a serious impediment to the development of a tropical fruit industry in the Islands.

Manual control efforts are extremely labor intensive. The plants resprout readily from cut stumps. Grubbing it out of the ground is the only effective mechanical control, a method with profound, generally undesirable ecological consequences and impermissible in areas of archaeological interest. Using herbicides is not very effective. Spraying the trees requires the use of surfactants to wet the leaves but the shoots soon send out new shoots. Cut-stump and girdling techniques are not very effective except in areas where there is a drought season. Treatment of plants in wet areas appears to be effective but within two years shoots, initially distorted but later more normal, are produced. There are no known ecological techniques to control this weed. Biological control is, therefore, the last resort.

This report documents the results of the search for potential biological control agents of strawberry guava. One of the primary charges to the research team was that all agents must not attack the commercially important P. guajava. Initially, this stricture appeared to be insurmountable but three gall forming insects were discovered that were restricted to the target species. Preferred study sites had P. cattleianum and P. guajava growing in close proximity to one another. The laboratory and garden experiments were conducted at the Forest Protection Laboratory, Federal University of Paraná, Curitiba.

**Sampling & Observations**

*Psidium cattleianum* - yellow and red varieties, common guava (*Psidium guajava* L.) and other myrtaceous species including Surinam Cherry (*Eugenia uniflora* L.), gabirola tree (*Campomanesia xanthocarpa* Berg) and *Eucalyptus* spp. were studied in the field. These species were also grown in large park areas of the Centro Politecnico where the potential agents were later released for further host range evaluation under natural environmental conditions.

Once the habits of the gall-forming insects were better understood, all associated plant species in the immediate environment of strawberry guava populations were examined for the insects or their galls. From this study, a checklist of species on which the galls were not found was produced thereby providing an initial evaluation of host range specificity.

The biology of each gall-forming insect included evaluations of hyperparasites and predators. The potential impact of natural control agents against the candidate species was assessed from observations but no quantitative studies were conducted. This information was then used in recommending the priority of each candidate for importation to the control area.

**Investigation in the area of origin**

Early exploration for strawberry guava was not encouraging. Hodges (1988) provided the first information on potential agents and recommended restricting further studies to southern Brazil, suggesting Paraná State as the best place for further research. Some of the species that he thought might be potential agent, (e.g., the bark beetle *Scolytopsis brasiiliensis* Eggers (Coleoptera, Scolytidae), were later found on other species.

The yellow-fruited variety of the plant is relatively common in the restingas as scattered individuals or in small groups, never in thickets as in Hawai‘i. The red-fruited variety was first found two years later and then only on the First Plateau. The plants are similar to several closely related species resulting in considerable initial uncertainty in determining the habitat and range of the species particularly when fruit are absent. It has been difficult to find large populations of *P. cattleianum*. 
RESULTS

Pathogens
Few pathogenic fungi were found on *P. cattleianum* and none of them were host specific. None had any significant impact on the plants (Hodges 1988). Subsequent fieldwork by Barreto (Federal University Viçosa, MG) has also proven negative.

There is a very common leaf spot disease that also occurs on *P. longipetiolatum*. It has not been identified nor has it been cultured. No similar disease has been reported previously on *P. cattleianum*. It has not been found on *P. guava* but its effects were minimal and it has no potential for biological control.

Hodges (1988) also found a tarspot fungus, *Phyllachora subcircinans* Speg. (Phyllachorales, Phyllachoraceae), on leaves of a few trees near Parana. This fungus was previously reported on *P. cattleianum* but we have not found it.

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Insects
During an initial survey 133 species from 80 families in 13 orders were found feeding on strawberry guava. The most common orders were Coleoptera, Diptera, Hemiptera, Hymenoptera, Orthoptera, Homoptera and Lepidoptera. The Coleoptera were the most diverse and abundant; 39% of all families, 47% of the species and 53% of the collections. The next most abundant were the Hemiptera with 14% of the families and 18% of species. Only 31 species were restricted to the Myrtaceae. Of these only five species are specific enough to be considered for biological control.

**Leaf Gall** - *Tectococcus ovatus* Hempel, 1900 (Homoptera, Eriococcidae). — The gall is convex oval on one side of the leaf, and acuminate oval on the other. The acuminate portion is generally on the upper side of the leaf, whether or not that is the abaxial surface. Occasionally galls may have acuminate or convex forms on both sides of the leaf. The size of the galls varies depending on the developmental stage and sex of the insect, those containing adult males are narrower and more acuminate than females. The galls are the same color as the leaf though the tips are frequently red (Vitorino 1995). The insect was easily handled in the laboratory and readily transferred from one plant to another. It is multivoltine.

*Tectococcus ovatus* is distributed throughout the range of *P. cattleianum* in Brazil but it is much more frequent on the red-fruited form on the First Plateau.

There is one parasitoid, *Metaphycus flavus* (Hymenoptera, Eucryptidae). The percentage parasitism in Brazil is 49%. There is also an ectoparasite *Aprosotocetus* sp. (Hymenoptera, Eulophidae) but the percentage parasitism is only 1%. Both species are present in Hawaii. There is also a predator, *Hyperaspis delicata* Massuti and Vitorino (Coleoptera, Coccinellidae) (Almeida & Vitorino 1997). Even with parasite levels as high as 50% the impact of the galls on leaves remains high. Consequently, *Tectococcus* is the most highly recommended of the potential agents against strawberry guava because of its impact on the host plant, its ease of handling and it multivoltine life cycle. Very heavy infestations can kill trees or branch systems but the most common result of infestation is a decrease in vigor, deformation of leaves that senesce prematurely and lack of flowering of infected shoots.
Bud Gall - *Dasineura gigantea* Angelo & Maia 1999 (Diptera, Cecidomyiidae).

Infestation of a bud results in the formation of small leafy rosettes up to 3 cm diameter somewhat like a double flower due to precocious production and development of the leaves that ultimately outpaces the ability of the meristem to produce embryonic tissue. The rosettes are initially green but turn yellow as they age and finally turn a deep magenta before drying out and turning brown. The insect attacks both the red and yellow-fruited forms (Angelo 1997) throughout the host's range.

Galls are formed in both terminal and lateral buds of flushing shoots and occasionally in flowers and more rarely fruits. The production of the gall terminates the activity of the apical meristem of the affected shoot killing it. Heavily infested shoots do not grow any further. Any future activity of that branch results from the growth of a lower bud released from the apical dominance of the terminal parts. *Leptacis* sp. (Hymenoptera: Platygasteridae) was found associated to *D. gigantea* but it effects was not significant. This agent is very promising because it stunts the trees. It is relatively easy to handle the only problem being coordinating the emergence of the insects from galls with flushing shoots. It is essentially univoltine though a secondary flush of shoots during the year may be infested. Shipment of the galls requires no special precautions. The wide ecological range of the species makes it a generally useful agent. There is a potential cultural use of the galls in Hawai'i where they could be substituted for green roses frequently used in leis.

Seed Gall - *Eurytoma psidii* Thuróczy & Wikler, in ed. (Hymenoptera, Eurytomidae).

Fruit containing seed galls have a lumpy, blotched appearance and are generally larger than normal, smooth fruit. The seeds are cemented together in large masses or a few smaller masses. The pulp of galled fruit is substantially reduced and almost dry. Apparently normal seeds may be found in galls but they and the seed masses fail to germinate (Wikler 1999). Galled fruit falls to the ground at the same time as normal fruit. Galls can be found in the leaf litter under trees for at least two years after fruit drop.

The insect is found throughout the range of *Psidium cattleianum*. It does not demonstrate any preference for fruit type or ecological situation. It was also found in *Psidium longipetiolatum*.

There is one natural enemy, the parasitoid *Torymus psidii* Thuróczy and Wikler, in ed. (Hymenoptera, Torymidae).

The prospects of this insect as a biological control agent are good. However, only 10-50% of fruit are attacked (Wikler 1999). The level of infestation is weakly correlated with plant population size suggesting that the insects may have a much greater impact in the large monotypic stands in Hawai'i. An insect that reduces seed viability, however, is a long-term control agent that may not be suitable for managers looking for more immediate reductions in population levels of the weed. It should, however, have a strong effect in controlling dissemination in areas where range expansion is still occurring.

Difficulties should be anticipated coordinating the emergence of insects with floral bud production in quarantine. The insect lays its eggs in young buds and open flowers up until pollination but not those where the floral organs are beginning to deteriorate. The insects, however, emerge from infested fruit for several months after the first flush.

There is a potential conflict of interest with horticulturalists who grow the plant for its fruit. Galled fruit look distasteful and the rough texture of the seed masses is somewhat unpalatable. This markedly reduced pulp may make the fruit less suitable as a host for fruit flies, a potential benefit.
Stem Gall - \textit{Eurytoma caffleianii} Thuróczy & Wikler \textit{in ed.} and \textit{Eurytoma desantisi} Thuróczy & Wikler \textit{in ed.} (Hymenoptera, Eurytomidae). — The insect attacks emerging shoots producing a gall at the base of the shoot. The galls are predominantly lightly dilated to round, 2-3 times the diameter of the stem. It is the same color as the stem, initially green but slowly turning brown with age. Leaf development is normal but no flower buds are formed. At the end of the growing season the shoot distal to the gall dies terminating growth of that branch. Heavily infested plants, therefore, are somewhat stunted when compared with adjacent uninfected plants.

The species is confined to the First Plateau of Parana State (800-1100m). It is thought that \textit{E. desantisi} is parasitic on \textit{E. caffleianii}, the exact relationship is under investigation. After emergence, some generalist insects and birds attack the gall-former.

The gall-former is species specific attacking both the yellow and red-fruited forms but shows a marked preference for the red-fruited form.

This species is the lowest ranked of the recommended four potential biological control agents. It has not been managed through its life cycle under controlled conditions. Coordinating the availability of insects with plants with flushing shoots at the proper stage of development could prove difficult. Its restricted occurrence to the higher elevations of the distribution of \textit{P. caffleianum} means that it has limited potential as a universal agent against this plant. Hawaiian forest managers, however, may be interested because the critical areas for conservation of Hawaiian native forests are all at higher elevations where potential conflicts of interest with fruit fanciers and horticulturists are minimal. This is also the area where the weed is still spreading.

\textit{Lamprosoma azureum} Germar, 1824 (Coleoptera, Chrysomelidae). — Both larvae and adults damage the plants feeding on the young, un sclerified bark of the shoots frequently girdling it (Caxambú 1998). Even if the girdling is incomplete the shoot is severely stunted and very susceptible to attack by pathogens. The beetles attack young trees only and have never been observed on plants above 1.8 m tall. The highest number of insects recorded on one plant was 8 where they caused extensive damage.

Unfortunately, this species is not specific to strawberry guava. It has been found feeding on other species of Myrtaceae, e.g., \textit{Eugenia uniflora} L., \textit{Campomanesia xanthocarpa} Berg, \textit{Psidium guajava} L., \textit{P. spathulatum} Mattos and \textit{Acca sellowiana} Berg. The scatoshell were also found on two species of Melastomataceae: \textit{Tibouchina sellowiana} (Cham.) Cogniaux and \textit{T. urvilleana} (DC.) Cogniaux.

\textit{Neotriozza tavaresi} Crawford, 1925 (Hemiptera, Psyllidae). — The insect produces large, round, green galls on leaves and is found throughout the range of \textit{P. caffleianum}. The gall is round up to 5 mm average diam. The maximum number of galls observed was 70/leaf but most leaves have fewer than 20. Psyllids emerge during October-November (Spring). They copulate 5-10 minutes after emergence. The adults live around 5 days and feed on sap in leaves. Oviposition occurs mainly in the leaf margin where the eggs are attached by a pedicel. The nymphs hatch and after short dispersal they attach themselves to the adaxial surface and start feeding (Butignol, pers. comm.).

Wasps, ants, flies, spiders and birds attack the adults. The nymphs are protected inside the galls but can be attacked by parasitoids also, as yet unidentified.

This species, though apparently confined to \textit{P. caffleianum}, will not be an effective biological control agent. The damage that it causes does not result in premature leaf drop or any reduction in flowering or growth of the plants except in extreme infestations.

\textit{Haplostegus epimelas} Konow, 1901 (Hymenoptera, Pergidae). — This sawfly can cause extensive damage to young shoots and mature leaves of \textit{P. caffleianum}. Eggs are laid
subepidermally along one side of a young shoot slowing growth of that side considerably. Damage and fungal growth can kill twigs. Young nymphs feed on the underside of leaves that in conjunction with oviposition kills a larger percentage of shoots. Later instars consume large quantities of mature leaves defoliating shoots (Pedrosa-Macedo, 1998). Sawflies can be found throughout the range of *P. cattleianum*.

An unknown mite damages the eggs. The potential of this sawfly as a biological control agent is poor. Previous reports indicated that the sawfly also attacks *P. guajava*, a result confirmed as a rare event in this study.

**DISCUSSION**

**Exploration.**
Strawberry guava is not a very common plant in Brazil. It is normally a minor subcanopy species except in the restinga. Its physical similarity to a number of related species caused considerable confusion and it was not until the second year of exploration that sizeable populations of the plant were found. Even then the red-fruited form was discovered only in the third year of the study. Though found in disturbed areas and abandoned fields these areas were poor study sites because the trees were cut back occasionally. Plants in disturbed areas were generally infested with only one gall-forming insect, if at all.

The requirement that potential biological control agents not attack the congeneric common guava was a constraint that was counterproductive initially because the two species are sympatric only as weeds in abandoned fields and disturbed areas. Though the focus was always on strawberry guava considerable time was wasted looking for common guava in gardens and small farms. Consequently, the full complement of galls was not discovered until the third year of the project and it was only then that the potential of the project was clearly understood.

The ability to support year-round studies in native habitat was instrumental to the success of the project. As insects were discovered populations were established on plants in a small orchard on the university grounds where they were able to attack several closely related species. The fact that there were insects that did not attack a closely related species suggested that the host-specificity of these gall-forming insects was highly discriminating.

Two potential agents, *Lamprosoma azureum* and *Haplostegus epimelas*, that did not form galls were studied in great detail because of their significant impact. It was discovered later that under certain conditions they would attack common guava so they are not recommended as potential agents.

**Cost.**
The total cost of the Brazilian studies was $500,000.00 ($300,000 from US sources and $200,000.00 from CNPq and CAPES (Brazilian equivalent of NSF) who provided 2-year M. Sc. Scholarships for 5 students and one for Ph. D. including 1 year at IIBC-UK.

Being able to use students to study the life histories of gall-forming insects as graduate student thesis topics was very important. Not only were the costs low but students were also able to study the insects over several years. For gall-forming insects this is the best way to approach the problem. During the first year the study established the possible life cycle that is confirmed or corrected during more focused studies in the second year. During the second year it was also possible to try to manipulate the insect in the laboratory or laboratory garden. These latter studies are an important element in the development of the management techniques that are necessary for later manipulation of the insects in quarantine.
Host ranges.
Once the habits of the gall-forming insects were understood and the potential of the insect as a biological control agent established, associated plant species in the immediate environment of populations were examined for galls. Searches for each insect were conducted particularly when the galls were developing on the strawberry guava plants. From this study, a checklist of species on which the galls were not found was established. This list can be used as a broad host range screening. For strawberry guava the list contains over 198 species in 59 families.

Insect biology.
The biology of each gall-forming insect was studied in the field and the university gardens. Hyperparasites and predators were studied in similar detail. The potential impact of natural control agents against candidate species was established which should enable entomologists in Hawaii to estimate the potential of known Hawaiian parasitoids. This information was important in establishing the priority of candidates for importation. Release from parasitoids, etc., should enable a potential agent to be more effective. *Tectococcus ovatus*, however, is parasitized by two species, congeners of which are already present in Hawaii. Even with parasite levels as high as 50% in Brazil the impact of the galls on leaves remains high. Consequently, *T. ovatus* is still the most highly recommended of the potential agents.

Life cycle studies.
Host-range testing of the potential agents has been conducted with species that are easily manipulated such as *Tectococcus*. However, there are major problems with several other gall-forming species that require narrow windows of the plant phenophase in order to infect the plant. There are major problems coordinating the emergence of the insects in the laboratory with the necessary phenophase of potential hosts. It is extremely difficult to expose even strawberry guava to the gall-forming insects at the correct stage in a laboratory or greenhouse whereas garden plants are much easier to handle. This problem suggests that manipulating some of the potential agents in quarantine is going to be a severe challenge.

Quarantine priorities.
Our approach to establishing the priority of each insect was to consider the following criteria:

- **Impact** - the greater the impact of the insect on some aspect of the plant's biology the higher the recommendation.
- **Handling** - The greater the ease of experimental manipulation of the insect the higher the recommendation.
- **Parasitism and predation** - The greater the number of parasitoids and predators the lower the recommendation.

The priority is:

- *Tectococcus ovatus* (leaf gall). Already in quarantine in Hawaii and has passed all host range challenge tests to date;
- *Dasyneura gigantea* (bud gall). Plan to attempt to establish this species in quarantine in 2001;
- *Eurytoma* sp. (seed gall). One attempt made to introduce it into quarantine failed; and,
- *Eurytoma* sp. (stem gall). No quarantine studies anticipated at present.
Comprehensive evaluation of biological control potential.
We were not able to evaluate the impact of these potential agents on the target plant quantitatively. Vandalism was a continual problem during the study even within the school compound. The cost of increasing the security of the area was too high. Qualitative assessments in the field and of garden plants were relatively easy for defoliators. *Tectococcus ovatus* infestation results in premature leaf drop as the population increases on the plant. Major branches and even whole trees can be defoliated. *Neotrioza tavaresi* infestation, however, does not result in premature leaf drop and is, therefore, not recommended for further consideration. The impact of species affecting the shoots was entirely subjective. We were unable to manipulate the insects sufficiently to conduct controlled studies of impact. The stunting of growth by these insects was pronounced enough to suggest that the competitiveness of infect plants would be reduced considerably. No attempt was made to assess the impact of the seed gall.

Insects have been the focus of this biological control study. The identification of five gall-forming insects all of which displayed considerable host specificity suggested that there was adequate potential for the development of a successful biological control program without further studies. Pathogens were evaluated early in this project but were excluded when it became apparent that most were not specific. The one species, a leaf spot fungus, that might have been considered was never found fertile and was only found in one population for a brief period. We did encourage plant pathologists to continue searching for potential agents but subsequent studies by Barreto have proven negative also.

The prospects for a successful biological control program against *Psidium cattleianum* are considered to be very good. The four gall-forming insects recommended attack different aspects of the biology of the plant offering a multi-faceted approach to plant control. The insects are relatively free from attack by hyperparasites and predators though novel attacks in other countries should be anticipated. The host range specificity of the insects is very narrow; they do not attack the commercially important *P. guajava*. It appears that this weed, so widespread particularly on tropical and subtropical islands, can be controlled by the introduction of a few insects.

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LITERATURE CITED


