Field release of *Tectococcus ovatus* (Homoptera: Eriococcidae) for biological control of strawberry guava, *Psidium cattleianum* Sabine (Myrtaceae), in Hawai'i

Draft Environmental Assessment
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Proposed Action: The USDA Forest Service Institute of Pacific Islands Forestry proposes field release in Hawai'i of *Tectococcus ovatus* Hempel (Homoptera: Eriococcidae) for classical biological control of strawberry guava, *Psidium cattleianum* Sabine (Myrtaceae), under permits from the Hawai'i Department of Agriculture, Hawai'i Department of Land and Natural Resources, and USDA Animal and Plant Health Inspection Service.

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Summary

The U.S. Department of Agriculture (USDA), Forest Service, Institute of Pacific Islands Forestry, in collaboration with the Hawai'i Department of Agriculture and Hawai'i Department of Land and Natural Resources, proposes the environmental release in Hawai'i of a scale insect from Brazil, *Tectococcus ovatus* Hempel (Homoptera: Eriococcidae), for classical biological control of strawberry guava, *Psidium cattleianum* Sabine (Myrtaceae). *Tectococcus ovatus* is a highly specific insect that produces leaf galls on strawberry guava in its native range in Brazil. The purpose of establishing this insect species in Hawai'i is to reduce growth and reproduction of strawberry guava, thereby limiting this weed's ability to invade native forests and reducing an important source of agricultural pest fruit flies.

Initial release of the biocontrol agent is proposed for the Ola'a Forest Reserve on the island of Hawai'i, however the eventual impact of this agent is expected to extend statewide following redistribution of the agent by state and federal agencies. Conditions for environmental release of *Tectococcus ovatus* in Hawai'i have been established by the Hawai'i Department of Agriculture following review and approval by the Hawai'i Board of Agriculture in consultation with the Advisory Subcommittee on Entomology and Advisory Committee on Plants and Animals. The proposed action requires Plant Protection and Quarantine permits from the USDA, Animal and Plant Health Inspection Service (APHIS); a permit for import and liberation of restricted organisms from the Hawai'i Department of Agriculture, Plant Quarantine Branch; and a special use permit from the Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife.

Evidence from host specificity testing and observations of the host range of *Tectococcus ovatus* in Brazil indicate that this biocontrol agent will attack only the target weed *P. cattleianum* in Hawai'i. Populations of *Tectococcus ovatus* are expected to increase to damaging levels on the target plant within a few years at release sites. Spread of the insect from the initial release site will occur naturally via wind dispersal and artificially via redistribution efforts by state and federal agencies involved in strawberry guava management. *Tectococcus ovatus* is expected to cause reduced vegetative growth and reduced fruit and seed production, decreasing the spread of strawberry guava over a period of years. Impacts of *Tectococcus ovatus* on strawberry guava are expected to have major economic benefits including improved control of pest fruit flies, increased effectiveness of mechanical and herbicidal control, and long-term protection of vulnerable native forest ecosystems from one of their most serious threats. Impacts on native Hawaiian species, including many endangered rainforest species, are expected to be highly beneficial due to significant reduction in the threat of strawberry guava to native forests in Hawai'i.

An alternative to the proposed action considered in this assessment is no action. Under this alternative the insect would not be released, and management of strawberry guava would be limited to existing methods.

Because *Tectococcus ovatus* is host specific on strawberry guava, and the environmental consequences of its release are expected to be highly beneficial to the native forests and agricultural economy of Hawai'i, the anticipated determination from this EA is a Finding of No Significant Impact (FONSI).

I. Proposed Action

The U.S. Department of Agriculture (USDA), Forest Service, Institute of Pacific Islands Forestry, has submitted applications for permits to the Hawai'i Department of Agriculture, Plant Quarantine Branch, for environmental release of a scale insect from Brazil, *Tectococcus ovatus* Hempel (Homoptera: Eriococcidae) into the State of Hawai'i under the provisions of Hawai'i Revised Statutes (HRS), Chapter 141, Department of Agriculture, and Chapter 150A, Plant and Non-Domestic Animal Quarantine; and to the Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife, for release of this insect on state forest lands under HRS Chapter 171, Public Lands, Chapter 183, Forest Reserves, and Chapter 195, Natural Area Reserves System. *Tectococcus ovatus* will be used for classical biological control of strawberry guava, *Psidium cattleianum* Sabine (Myrtaceae), an invasive weed that is a critical threat to native forests throughout the state.

This Draft Environmental Assessment (DEA) was prepared by the applicant for the Office of Environmental Quality Control (OEQC), Department of Health, State of Hawaii, to comply with the provisions of Hawaii Revised Statutes Chapter 343, addressing Environmental Impact Statements. This DEA is required because the applicant intends to release the biological control agent on state lands with the assistance of state employees and funding. The initial environmental release is planned for Ola'a Forest Reserve on the island of Hawai'i (Appendix 8). Release and initial monitoring of the biocontrol agent will be supported with funds ($50,000) from the Watershed Partnership Program administered by Hawai'i Department of Land and Natural Resources. This DEA examines the potential effects on the environment that may be associated with the release of *T. ovatus* to control infestations of strawberry guava on state lands, including Forest Reserves and Natural Area Reserves. This EA considers the potential effects of the proposed action and its alternatives, including no action. It has been prepared in accordance with USDA's National Environmental Policy Act (NEPA) implementing procedures (Title 7 of the Code of Federal Regulations (CFR), part 372).

Conditions for environmental release of *Tectococcus ovatus* have been established by the Hawai'i Department of Agriculture following review and approval by the Hawai'i Board of Agriculture in consultation with the Advisory Subcommittee on Entomology and Advisory Committee on Plants and Animals (Appendix 7). Environmental release of this insect would occur under permits from the USDA Animal and Plant Health Inspection Service (APHIS); Hawai'i Department of Agriculture, Plant Quarantine Branch; and Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife.

II. Purpose and Need for the Proposed Action

The applicant's purpose for releasing *Tectococcus ovatus* is to reduce the damaging effects of infestations of strawberry guava in Hawai'i. Strawberry guava (*Psidium cattleianum*), a small tree from Brazil introduced to Hawai'i in 1825, is considered one of the state's most disruptive alien weeds (Hosaka and Thistle 1954, Smith 1985, Huenneke and Vitousek 1990, Wagner et al. 1990, Loope 1998). The biological control agent *T. ovatus* is expected to reduce impacts of this invasive tree by slowing its growth and spread in native forests, and reducing a key food source of alien frut fly pests of agriculture in Hawai'i.

Strawberry guava infests thousands of acres of forest on all the major Hawaiian Islands. It forms dense thickets up to 30 ft. in height and suppresses native species, including many which are rare and endangered. Strawberry guava is also a wild host of fruit flies, including the oriental fruit fly and Mediterranean fruit fly, which cost taxpayers and farmers millions of dollars annually in quarantine and eradication efforts (Vargas et al. 1983a&b, Vargas et al. 1990, Harris et al 1993, Kaplan 2004). Attempts at management of fruit fly pests in Hawai'i are severely constrained by the abundance of fruiting strawberry guava (Vargas and Nishida 1989, Vargas et al. 1995).

There is a need to release a host-specific agent for biological control of strawberry guava because chemical and mechanical controls are too expensive to apply effectively over large areas. Because it is host specific, *T. ovatus* is expected to affect directly only the target weed, strawberry guava, in Hawai'i. Populations of *T. ovatus* are expected to spread gradually on the target plant, reaching damaging levels within a few years at each release site. *T. ovatus* is expected to reduce vegetative growth and reduce fruit production of strawberry guava, decreasing its spread over a period of years. Impacts of *T. ovatus* on strawberry guava are expected to have major economic benefits including improved control of pest fruit flies, increased effectiveness of mechanical and herbicidal control, and long-term protection of vulnerable native forest ecosystems from one of their most serious threats.

III. Alternatives

This section will explain two alternatives available to the Hawai'i Department of Agriculture (HDOA) and Hawai'i Department of Land and Natural Resources (DLNR): no action (not issuing permits), or to issue permits for release of *T. ovatus*. Although these alternatives are limited to a decision on whether to permit release of *T. ovatus* in Hawai'i, other methods available for control of strawberry guava, and presently being used by public agencies and private organizations and individuals, are also described.

A. No Action

Under the no action alternative, HDOA and DLNR would not issue permits for the field release of *T. ovatus* for the control of strawberry guava. The release of this biological control agent would not take place. The following methods are presently being used to control strawberry guava in Hawai'i and will continue under the "No Action" alternative. These methods will likely continue to some extent even if a permit is issued for release of *T. ovatus*.

1. Chemical control of strawberry guava

Herbicides currently available and effective against strawberry guava include picloram, dicamba, glyphosate, and triclopyr (Motooka et al., 2003). Cut-stump treatments can be effective, but carry the risk of resprouts from slash in wet areas (Tunison, 1991). Of the available chemicals triclopyr is recommended for use in natural areas because of low mobility, short residual activity, and well-researched application methods (Tunison, 1991). Control of strawberry guava using herbicides is prohibitively expensive except over limited areas with low density infestations (Tunison and Stone, 1992). There also may be undesirable side effects in some instances either from killing adjacent plants or chemical contamination of the soil or waterways.

2. Cultural control of strawberry guava

There are no effective cultural techniques to control strawberry guava. It is shade tolerant. No native or alien tree species are known which can grow up through it and shade it out. Controlled burning is not effective. Though aerial portions of the plant are killed by intensive fires, the plants rapidly resprout from the basal portion. In ranchlands, there are generally insufficient fuel levels to generate sufficient heat to kill the trees. In natural areas fire is unacceptable as a management tool.

3. Mechanical control of strawberry guava

Manual control efforts are extremely labor intensive and prohibitively expensive as a general management tool. Strawberry guava plants resprout readily from cut stumps and slash piles. However, plants up to 5 centimeters in diameter can be removed on a limited scale using a weed wrench (Ward, 2003). Digging up plants (grubbing) is a suitable control method for many agricultural and residential areas, however extremely dense thickets are difficult to penetrate even with large machinery. The generally undesirable ecological consequences of grubbing make it unacceptable in natural areas.

B. Permit Environmental Release of *Tectococcus ovatus*

Under this alternative, HDOA and DLNR would issue permits for the field release of *T. ovatus* for the control of strawberry guava on state lands in Hawai'i.

1. Biological control agent information

a. Taxonomy
Order: Homoptera
Suborder: Sternorrhyncha
Superfamily: Coccoidea
Family: Eriococcidae
Genus: *Tectococcus*
Species: *Tectococcus ovatus* Hempel

b. General description of *T. ovatus*
T. ovatus appears to cause substantial damage to strawberry guava in Brazil. Heavy infestations have been observed to cause defoliation and appear to reduce fruit production (Vitorino et al., 2000). It is also relatively easy to rear which facilitates careful evaluation of its specificity and increases likelihood of successful establishment in the field.

T. ovatus induces circular galls on leaves of strawberry guava. (A gall is an abnormal growth of plant tissues caused by the stimulus of another organism.) Galls up to 8 millimeters in diameter protrude from both sides of the leaf and are usually yellow to red in color. Each gall contains a single developing insect. Female galls are broadly conical, whereas male galls are smaller and narrower. Both have narrow openings at maturity for emergence of offspring or males. Females remain inside galls throughout life and are pink and ovoid with tiny legs. Adult males are pink to gold, have wings and are capable of weak flight.

T. ovatus is the only species in the genus *Tectococcus*. It is sufficiently unique that taxonomic specialists are not likely to confuse it with any other known scale insect species.

c. Geographical range of *T. ovatus* in area of origin
The insect was first collected and described from São Paulo and Ypirauga in Brazil (Hempel, 1900). Origins of the insects proposed for environmental release in Hawai'i are from three municipal districts (Piraquara, São José dos Pinhais, and Colombo) in the metropolitan area of Curitiba, Paraná, Brazil (Vitorino et al., 2000).

T. ovatus has been observed to occur naturally in Parana and Santa Catarina states at sea level with mean annual temperatures of 18-22º C, and at approximately 1,000 meters elevation with mean annual temperatures of 15-19 º C (Vitorino, 1995). There is no known evidence that *T. ovatus* has ever been exported outside its natural range previously.

d. Expected range of *T. ovatus* in Hawai'i
Populations of *T. ovatus* have been observed to persist continuously for over ten years in Curitiba, Brazil, where up to 40 mild to moderate frosts occur each winter. Because fluctuations in temperature and humidity are more extreme in subtropical Curitiba than in Hawaiian habitats where strawberry guava occurs (below 1,600 meters), climatic conditions in Hawai'i are not expected to limit the range of *T. ovatus* (Juvic and Juvic, 1998).

e. Life history of *T. ovatus*
As with other scale insects, the mobile stage of *T. ovatus* is the newly hatched nymph or crawler. Crawlers typically move to flushing leaves at the tip of a stem and there become immobile, growing as galls form around them. Each female remains enclosed in a gall throughout its life, discharging up to several hundred eggs in a thread-like matrix of wax through a narrow opening. The cottony wax is extremely light and probably serves in dispersal by wind between plants (Vitorino et al., 2000). Reproduction is presumed to be facultatively parthenogenic (females can reproduce without mating with males). Multiple overlapping generations are observed each year in Brazil. Winged males appear at least twice a year (Vitorino et al., 2000). Mating has not been observed.

Under quarantine conditions in Hawai'i, *T. ovatus* reproduces continuously, with a generation time of 6-10 weeks. In two generations, numbers build to a level that causes stunting of small potted plants.

f. Known mortality factors of *T. ovatus*
In Brazil, *T. ovatus* can be heavily attacked by parasitoids (primarily *Metaphycus flavus*, Hymenoptera: Encyrtidae; less often, *Aprostocetus sp.*, Hymenoptera: Eulophidae) and a specialist predator (*Hyperaspis delicata*, Coleoptera: Coccinellidae). Although these enemies do not appear to strongly restrict *T. ovatus* population growth or limit impact on the host plant in Brazil (Almeida and Vitorino, 1997; Vitorino et al., 2000), their introduction to Hawai'i could compromise the effectiveness of *T. ovatus* for biocontrol of strawberry guava, and they could negatively impact non-target insects related to *T. ovatus* in the superfamily Coccoidea (relatives of *T. ovatus*), including native and non-native species (Zimmerman 1948). Elimination of hitch-hiking natural enemies is a standard practice in biological control programs (Balciunas and Coombs 2004). Adherence to this practice is expected to prevent introduction of enemies of *T. ovatus* to Hawai'i and is included among the permit conditions for release of *T. ovatus* specified by the Hawai'i Department of Agriculture (Appendix 7). Exclusion of unwanted species is accomplished in quarantine by initiating colonies with only *T. ovatus* eggs and newly hatched first instars, examined under a stereomicroscope, immediately after they emerge from female galls. Two generations of screening in this manner provides a check to guarantee that enemies are excluded.

IV. Affected Environment

A. Areas affected by strawberry guava

1. Native range

Strawberry guava is native to the Atlantic Forest of southeastern Brazil, extending from Espiritu Santo state in Brazil to Uruguay (20-32º S) (Legrand and Klein, 1977; Reitz et al., 1983). It is a common component of restingas (sandy coastal plains with scrub vegetation). It also grows inland at elevations up to 1,200 meters, usually as a successional species in disturbed areas of native forest (Reitz et al., 1983). Although not planted commercially on a significant scale, strawberry guava has been cultivated for its fruit and ornamentally, and it has been distributed in Brazil beyond its natural range. It is a popular fuel wood (Hodges, 1988).

In Brazil, strawberry guava is a small tree, 1 to 5 meters tall, rarely growing to 15 meters. Trees growing within forests have slender, twisted stems and small crowns, whereas open-grown trees have dense, spreading crowns (Hodges, 1988). Strawberry guava usually occurs as scattered individual trees and rarely in small clumps (Hodges, 1988). Flowering occurs mainly in November-December, and fruit mature during February-April (Reitz et al., 1983). Yellow and red-fruited varieties occur, but the former is much more common. The red-fruited variety may be distributed primarily above 700-800 meters (Hodges, 1988; Vitorino et al., 2000). At upper elevations in its southern range in Brazil, strawberry guava persists in subtropical conditions, experiencing repeated winter frosts.

2. Distribution in Hawai'i

Strawberry guava is common on all the major Hawaiian Islands between sea level and approximately 4,000 feet in elevation, particularly in areas of moderate to high rainfall (Wagner et al., 1990). Its highest recorded elevations so far are at 4,800 feet near Kulani Prison on Hawai'i (Keali'i Bio personal communication) and 5,300 feet at Manawainui on Maui (Art Medeiros personal communication). Strawberry guava continues to expand into relatively pristine native forest areas, although it has spread so widely in Hawai'i that its future impacts are expected to consist largely of filling-in areas where it has reached already (Jacobi and Warshauer, 1992). Growth rates of strawberry guava in native forests are very high: at 3000 feet on Hawai'i island, average annual increases of over 12% in stem density and 9% in total basal area have been measured (Julie Denslow, unpublished data). Based on habitat characteristics of sites of existing infestations, strawberry guava has the potential to invade and degrade an estimated 47% of the land area of Hawai'i island (Keali'i Bio personal communication).

3. Beneficial uses of strawberry guava

The fruit can be eaten or made into juice and other products (Morton, 1987). However, commercially produced "strawberry guava" juice typically is not made from strawberry guava but rather a mixture of strawberry puree and guava (*P. guajava*) puree. Strawberry guava stems sometimes are used as firewood for smoking meat. The plant is sometimes featured in gardens for its smooth multicolored bark contrasting with shiny, dark green leaves and toleration of pruning and shaping. Potted plants and seed are sold by some horticulturalists in Hawai'i.

B. Plants related to strawberry guava and their distribution in Hawai'i

Guava (*Psidium guajava* L.) and strawberry guava were cultivated widely in Hawai'i following their introduction in the early 1800's (Wagner et al., 1990). Today only guava is commonly cultivated as a significant agricultural commodity (National Agricultural Statistics Service, 2004) although strawberry guava is occasionally grown as an ornamental. Within their genus, these two species appear to be distant relatives.

The genus *Psidium* is a member of the family Myrtaceae (subfamily Myrtoideae) and includes 50-100 neotropical species (McVaugh, 1968). Although there are no native members of the genus *Psidium* in Hawai'i, the family Myrtaceae is represented by 49 species in 9 genera. These include 7 naturalized, 1 indigenous, and 2 endemic species in the subfamily Myrtoideae and 35 naturalized species and 5 endemic species in the subfamily Leptospermoideae (Wagner et al., 1990). The native species in the same subfamily as strawberry guava (Myrtoideae) are the endangered endemic *Eugenia koolauensis* Degener, the indigenous *E. reinwardtiana* (Blume) DC, and the endemic *Syzygium sandwicensis* (A. Gray) Nied. The dominant tree of native Hawaiian forests, *Metrosideros polymorpha* Gaud., and numerous introduced timber species, including *Eucalyptus* spp., are in the subfamily Leptospermoideae.

The Myrtaceae are within the order Myrtales, which also includes the families Sonneratiaceae, Lythraceae, Rhynchocalycaceae, Alzateaceae, Penaeaceae, Crypteroniaceae, Thymelaeaceae, Trapaceae, Punicaceae, Onagraceae, Oliniaceae, Melastomataceae, and Combretaceae (Cronquist, 1981). Only the Lythraceae and Thymelaeaceae include native Hawaiian species: *Lythrum maritimum* Kunth (Lythraceae) is an indigenous shrub, and there are up to 12 endemic species of *Wikstroemia* (Thymelaeaceae) (Wagner et al., 1990). Other families in the Myrtales with representatives naturalized in Hawai'i are the Combretaceae (3 species in 2 genera), Onagraceae (10 species in 4 genera), and Melastomataceae (15 species in 12 genera).

V. Environmental Consequences

This section will discuss the consequences of two alternatives available to the Hawai'i Department of Agriculture (HDOA) and Hawai'i Department of Land and Natural Resources (DLNR): no action (not issuing permits), or to issue permits for release of *T. ovatus*.

A. No Action

1. Impact from strawberry guava on native plants and animals

The effect of strawberry guava on native Hawaiian plant populations is extensive and is expected to worsen dramatically in coming decades in the absence of biological control or other measures. Because of clonal growth and abundant seed production, strawberry guava can quickly crowd out native vegetation (Huenneke and Vitousek 1990). Many low and middle elevation forest areas are now devoid of native species displaced by strawberry guava (Smith 1985). The weed continues to spread and increase in density in less disturbed, high elevation rainforests that are still rich in native species. There is no direct evidence of its causing the extinction of any species, but its potential domination of the habitat of many endangered plants is a matter of considerable concern. Strawberry guava has been noted as a particular threat in critical habitat areas for 74 endangered plant species and 3 threatened plant species on the islands of Kauai, Oahu, Maui, Molokai and Lanai (Appendix 1; USFWS 2003a-d). On the island of Hawai'i at least 10 federally listed endangered plant species, including five island endemics, are restricted to habitats entirely within the potential distribution of strawberry guava (Appendix 2; wet and mesic forests below 1600m, Jonathan Price pers. comm.).

As strawberry guava forms large single-species stands in native forests, it can break up natural areas and disrupt native animal communities. Along with its relative *P. guajava*, strawberry guava is considered one of the greatest threats to endangered forest birds on all the major Hawaiian Islands (USFWS 2003e). Native birds and insects are closely adapted to using native tree species, and most cannot utilize stands of strawberry guava. Use of fruits by invasive animals, particularly pigs, facilitates spread of seeds and helps sustain non-native animal populations that damage native ecosystems extensively in a variety of ways (Diong 1982). Beyond Hawai'i, strawberry guava is recognized as a major threat in native rainforest ecosystems in Mauritius, Reunion, the Seychelles, the Society, Fiji, Norfolk, Palau and Lord Howe Islands (Baijnath et al. 1982, Smith 1985, MacDonald et al. 1991, Cronk and Fuller 1995, Mueller-Dombois and Fosberg 1998).

2. Impact from strawberry guava on economy

Strawberry guava has little positive economic value. The fruit may be collected and eaten or made into juice and other products (Morton 1987), and stems are used by some for firewood for smoking meat. The plant is sometimes featured in gardens for its smooth multicolored bark contrasting with shiny, dark green leaves and toleration of pruning and shaping. However, the fruits are messy and attract insects, so planting next to sidewalks and driveways is discouraged. Potted plants and seed are sold by some horticulturalists in Hawai'i, although this market is probably limited by the ubiquity of wild plants.

Economic costs associated with strawberry guava infestations in Hawai'i are not well quantified, but appear to be substantial. Strawberry guava in Hawai'i serves as a critical wild host of economically important fruit flies, including oriental fruit fly (*Bactrocera dorsalis*) and Mediterranean fruit fly (medfly, *Ceratitis capitata*) (Vargas et al. 1983a&b, Vargas and Nishida 1989, Vargas et al. 1990, Harris et al 1993). Pest populations developing in fruit from wild hosts, especially strawberry guava and *P. guajava*, overflow into dozens of fruit and vegetable crops. In some cases fruit flies cause direct yield loss, but they also limit possibilities for export of Hawaiian produce to major markets such as California and Japan. Concern over accidental introduction of Hawai'i's fruit flies into the U.S. mainland costs millions of dollars annually in quarantine and eradication efforts (Kaplan 2004). A USDA-ARS areawide pest management program has recently undertaken the task of integrating a variety of control tactics over large areas in Hawai'i (Kaplan 2004). However, attempts at management of fruit fly pests are severely constrained by the abundance of fruiting strawberry guava (Vargas and Nishida 1989, Vargas et al. 1990, Vargas et al. 1995). In the absence of biological control of strawberry guava, the weed can be expected to increase in density in many agricultural areas and the magnitude of problems with pest fruit flies will increase.

Current costs of strawberry guava control using herbicidal and mechanical methods are also not well quantified. Control occurs in natural areas, on roadsides, under power lines, and on private property cleared for agriculture or residences. The plant's ability to resprout from cut or downed stems makes repeated control efforts necessary. Strawberry guava also appears to have costs in lost economic opportunities: it has been recognized as an impediment to sustainable koa harvests because many areas disturbed by logging are colonized by strawberry guava more quickly than by koa (Dobbyn, 2003).

3. Impact from use of other control methods

The continued use of chemical herbicides and mechanical controls would be a result if the "no action" alternative is chosen. Existing chemical and mechanical control methods, because of their expense, are not likely to be used at such a scale to cause extensive damage to nontarget organisms. However, because they are difficult to administer with perfect selectivity, chemical and mechanical techniques will cause death of some nontarget native plants in areas where they are used. Strawberry guava's ability to regenerate after these control efforts means that chemical and mechanical control are only temporarily effective and must be repeated, with possible long term cumulative impacts on nontarget species. These environmental consequences may occur even with the implementation of the biological control alternative, depending on the efficacy of *T. ovatus* for reducing strawberry guava populations in Hawai'i.

B. Permit environmental release of *Tectococcus ovatus*

1. Impact of *T. ovatus* on strawberry guava

T. ovatus is expected to directly affect only the target weed strawberry guava in Hawai'i. Impacts on the target are expected to include reduced growth rate and reduced seed production. High levels of infestation have been observed to cause leaf drop to the point of complete defoliation of strawberry guava in Brazil (Vitorino et al., 2000). This level of damage is relatively rare however, and may require combined stress from other factors such as drought. Both dispersal by seeds and vegetative propagation by clonal sprouts should decline over a period of years where *T. ovatus* becomes established. Environmental impacts of *T. ovatus* release are expected to occur gradually over a period of decades. Its impacts are expected to be highly beneficial to nontarget species, in helping protect large areas of native forest from being invaded and dominated by strawberry guava, and contributing to large scale control of pest fruit flies.

Since strawberry guava is occasionally planted as an ornamental, infestation by *T. ovatus* may be perceived as damaging to their aesthetic value. In these cases infestation could be controlled by application of appropriate insecticides. For example, *T. ovatus* is susceptible to insecticidal oil sprays, which are relatively innocuous to the environment and are compatible with production of fruit for consumption (Cranshaw and Day 1994). Substituting other plants, such as native Hawaiian trees, for ornamental plantings of strawberry guava is an alternative option.

Some cultural uses of strawberry guava may be affected as a consequence of release of the biological control agent. In particular, availability of fruit from wild strawberry guava trees is expected to decline over time as trees become infested by *T. ovatus* and their fruit production is reduced. However, long term protection of native forests, including many native rainforest species of importance in Hawaiian culture, from degradation by strawberry guava is expected to provide cultural benefits that far outweigh the value of strawberry guava as a resource in itself.

2. Impact of *T. ovatus* on nontarget plants

a. Laboratory tests and field observations

All laboratory tests and field observations indicate that *T. ovatus* is highly specialized to utilize only strawberry guava and closely related species within the genus *Psidium*. These data all suggest a tight evolutionary and ecological link between *T. ovatus* and strawberry guava. Laboratory tests of *T. ovatus* host specificity in Brazil demonstrated that it could not develop on guava, *Campomanesia xanthocarpa*, *Eucalyptus dunii*, *Eugenia uniflora*, or *Metrosideros polymorpha* (Vitorino et al., 2000). Quarantine tests of a broad spectrum of Hawaiian plant species (Appendix 3), including all ecologically prominent Myrtaceae and some uncommon native members of this family, indicate that no species in Hawai'i other than strawberry guava are suitable hosts for this insect (Appendices 4 and 5). Host specificity tests conducted in Florida support these results also (Wessels et al., 2007; Appendix 6). Evidence that *T. ovatus* cannot develop even on *P. guajava* also includes over 10 years of observations of *T. ovatus* populations developing on strawberry guava in close proximity to *P. guajava* at field sites in Brazil. Within Brazilian literature on pests of common guava, *P. guajava*, there is no mention of *T. ovatus* or any gall-forming homopterans.

b. Literature

There are very few records pertaining to *T. ovatus* and its biology in the literature. In his description of *T. ovatus*, Hempel (1900) noted that it formed galls on leaves of a plant in the Myrtaceae, and was not common. Ferris (1957) illustrated *T. ovatus* from specimens collected from *Psidium*. References to this insect in catalogs of coccoid scales in Brazil also recorded its host as Myrtaceae (Costa Lima, 1927; Lepage, 1938). With one exception that appears to be an error, existing literature are consistent with an extremely narrow host range for *T. ovatus*, restricted to *P. cattleianum* and sibling species. One catalog recorded *T. ovatus* on *Daphnopsis racemosa* Griseb. (in the family Thymelaeaceae) (Hoy, 1963); however this reference is not well supported in other literature. In fact in a previous report Hoy (1962) makes the contradictory statement: "The Myrtaceae are the exclusive hosts for the genera *Apiococcus*, *Apiomorpha*, *Ascelis*, *Carpochloroides*, *Macracanthopyga* and *Tectococcus*." The record in Hoy (1963) appears to refer to a catalog by Costa Lima (1936) in which *T. ovatus* was recorded from "aracazeiro" and "embira." The former is a well-known common name for *P. cattleianum* in southeastern Brazil. "Embira" is more ambiguous. It may refer to *Daphnopsis racemosa* or species of *Anona* or *Rollinia* (in the family Annonaceae). The latter possibility suggests that Costa Lima's reference may be due to confusion between *T. ovatus* and its relative *Pseudotectococcus anonae*. Recent laboratory tests of *T. ovatus* specificity included species of Thymelaeaceae and Annonaceae; results indicated that these are not suitable host plants (Appendices 4-6).

c. Other evidence

T. ovatus has few close relatives, which suggests limited potential for evolution to use new host plants. There have been very few studies of this group of insects, none of them recent. There is only the single species, *T. ovatus*, in the genus *Tectococcus* (Hempel, 1900; Hoy, 1963). Hempel (1935) considered its closest relative to be *Pseudotectococcus anonae*, also the only species in its genus, which he described from galls on leaves of a cultivated species of *Anona* (Annonaceae, the custard-apple family) in Vicosa, Minas Gerais, Brazil. Another genus containing only one species described by Hempel (1937), *Neotectococcus lenticularis*, was considered by Ferris (1957) to be possibly in the same genus as *Tectococcus*. This species also formed galls on the leaves of its host plant, which was identified only as a "wild shrub" in Itatinga, Brazil (Hempel, 1937). Although these related insect species use host plants in at least two entirely different families, their genetic relationships have never been studied, which prevents assessment of the genetic distance between them and the possible direction of future evolution.

3. Impact of *T. ovatus* on other nontarget species

T. ovatus is expected to directly affect only the target weed strawberry guava in Hawai'i. Impacts associated with control of strawberry guava are expected to be highly beneficial to native nontarget species, in helping protect large areas of native forest from being invaded and dominated by strawberry guava. There are 317 species of plants and animals in the Hawaiian Islands that are federally listed as endangered or threatened. Those species occurring in mesic and wet forests are most affected by strawberry guava and are most likely to benefit from control of this weed (Appendices 1 and 2).

Indirect impacts on nontarget species have been documented in a few cases of weed biocontrol, but unfortunately the ability to predict such effects remains poor (Coombs et al., 2004). Herbivory of strawberry guava plants is currently negligible; therefore *T. ovatus* is not likely to compete directly with any herbivores already in Hawai'i. Its major effect on other species is likely to be through reduced fruit production. A variety of non-native species utilize strawberry guava fruit seasonally, and all of these species can be expected to be impacted negatively to varying degrees. Pigs, which feed heavily on strawberry guava fruit when it is in season (Diong, 1982), may be forced to find other food sources in the short term and may experience reduced population growth in the long term. Rats, mice, and non-native birds all probably benefit somewhat from current levels of fruit production, although their use of strawberry guava is not well quantified. Alien fruit flies, including major pests such as the oriental fruit fly and Mediterranean fruit fly, can be expected to experience local population declines as a result of biocontrol of strawberry guava.

T. ovatus is not expected to be heavily attacked by natural enemies in Hawai'i because it lies protected inside a gall for most of its life, and there are few related insects in Hawai'i that appear likely to share its natural enemies. One parasitoid known to attack *T. ovatus* in Brazil, *Metaphycus flavus* (Vitorino et al., 2000), also is recorded from Hawai'i (Nishida, 2002), but it is unknown whether the Hawai'i biotype of this parasitoid is able to utilize *T. ovatus*. If this or other natural enemies are able to attack *T. ovatus*, it is possible that populations might build up on *T. ovatus* to a point that they have significant spill-over effects on other insect hosts or prey species. Impacts mediated through a natural enemy shared with *T. ovatus* would most likely be a risk to insects in the superfamily Coccoidea, which includes native and non-native species (Zimmerman, 1948).

If strawberry guava were removed suddenly and extensively from steep, wet areas without being replaced by other species, catastrophic erosion could ensue. However, the impact of weed biocontrol agents on their target is unlikely to be severe and rapid enough to promote such a sequence of events (Schooler et al., 2004). In the case of strawberry guava this scenario is particularly unlikely because *T. ovatus* has never been observed to kill even small potted plants under extremely high infestation. Even if they were killed, the process would likely be so gradual that strawberry guava roots would continue to hold soil long enough to allow replacement by other plants.

Because the impact of *T. ovatus* on strawberry guava populations is expected to be gradual, reducing recruitment and plant vigor over a period of many years, chances for replacement with native species is expected to be higher than if strawberry guava were removed suddenly, for example by mechanical and/or herbicidal treatment. This advantage to gradual control has been demonstrated experimentally with *Morella faya* in Hawaiian rainforests (Loh and Daehler, 2007). In this case, gradually killing the invasive trees by girdling or partial girdling led to higher recruitment of native species and lower recruitment of weedy species compared with complete removal of the invasive trees. In some areas invaded by strawberry guava, particularly at higher elevation, there are relatively few other alien weeds present, so decline of growth and spread of strawberry guava is likely to benefit native species primarily. Thus, patches that would have been colonized and dominated by strawberry guava will probably be filled by native species. In some areas, strawberry guava may tend to be replaced by other invasive species over time. Himalayan raspberry (*Rubus ellipticus*), fayatree (*Morella faya*), and kahili ginger (*Hedychium gardnerianum*) are examples of weeds that, like strawberry guava, can invade intact forests and form dense patches excluding native plants.

Other invasive species may benefit from increased light availability within declining patches of strawberry guava. For example, palm grass (*Setaria palmifolia*) and other invasive grasses (*Andropogon virginicus*, *Paspalum conjugatum*) that flourish in high-light forest gaps may increase within stands of strawberry guava that may be partially defoliated by *T. ovatus*. Although fires are very uncommon in the wet forests where strawberry guava is mainly distributed, increases in grass density could lead to increased risk of wildfires during occasional dry periods. Wildfires are recognized as highly detrimental to Hawaiian ecosystems, because they eliminate native species and perpetuate systems dominated by fire-adapted alien grasses (Smith and Tunison, 1992).

Impacts of *T. ovatus* on nontarget species will be monitored primarily at release sites in native forest plots where density of selected native species will be measured over several years. Releases in experimental plantings of strawberry guava bordered by *P. guajava* will provide demonstrations of specificity of *T. ovatus*. Semiannual reports provided to the Hawai'i Department of Agriculture Plant Quarantine Branch will record all findings regarding nontarget species.

4. Uncertainties regarding the environmental release of *T. ovatus*

Once a biological control agent such as *T. ovatus* is released into the environment and becomes established, there is a slight possibility that it could move from the target plant (strawberry guava) to attack nontarget plants. Native species that are closely related to the target species are the most likely to be attacked, which forms the scientific basis of host specificity testing of proposed biological control agents (Louda et al., 2003). All tests conducted with a broad range of related plants indicate that *T. ovatus* is host-specific on strawberry guava (Appendices 4-6). Historically, host shifts by introduced weed biological control agents to unrelated plants are extremely rare (Pemberton, 2000). If other plant species were to be attacked by *T. ovatus*, the resulting effects could be environmental impacts that may not be easily reversed.

The extremely close interaction of *T. ovatus* and its host *P. cattleianum*, typical of other gall-forming insects, appears to constrain the insect from transferring to feed on other plant species. A shift to a new host plant would require evolution of new traits, a process that might occur over time. The timescale expected for *T. ovatus* to evolve the ability to use a new host plant is difficult to evaluate based on ecological genetics of closely related insect species because its relatives are so few and poorly known. Past experience with agents for biocontrol of weeds indicates that use of non-target species has been almost entirely predictable and that evolution of ability to use host plants in new, unpredictable ways does not occur very rapidly (over times as long as several decades) (Pemberton 2000). Evolutionary science suggests that, given sufficient time, such as thousands of years or more, novel traits are likely to appear naturally among insects introduced to Hawai'i (Gillespie and Roderick 2002), biocontrol agents included. Environmental consequences of such evolution would be largely unpredictable and may not be easily reversed. Past patterns of insect evolution in Hawai'i suggest that, while evolution may result in new species and new associations over a large time scale, it is not a major threat to maintenance of a highly diverse and unique biota.

Movement of *T. ovatus* following release in the environment is difficult to predict. Populations of the insect are expected to disperse gradually from release sites, mainly carried by wind. In addition to purposeful releases on strawberry guava, unintentional dispersal of *T. ovatus* may occur by transport of the tiny insects by humans, most likely on infested strawberry guava plants. The ease of transporting *T. ovatus* on infested foliage makes unapproved distribution of the insect within the Hawaiian Islands a significant risk that may not be adequately controlled under existing quarantine procedures. Therefore, release of this biological control agent at even one site in Hawai'i should be considered equivalent to release over the entire area of the state in which strawberry guava occurs and in which the climate is suitable for reproduction and survival of the insect. Unauthorized or accidental transport of the insect to the US mainland or elsewhere also could occur, but appears less likely under existing quarantine procedures.

There is uncertainty associated with the eventual impact of *T. ovatus* on strawberry guava. Although observations in Brazil and laboratory tests indicate that this agent can significantly impact individual strawberry guava plants, it may not reduce strawberry guava populations to desired levels or in all areas of Hawai'i. Worldwide, biological weed control programs have had an overall success rate of 33 percent; success rates have been considerably higher for programs in individual countries (Culliney, 2005). Actual impacts on strawberry guava by *T. ovatus* will not be known until after release occurs and post-release monitoring has been conducted.

5. Cumulative impacts

"Cumulative impacts are defined as the impact on the environment which results from the incremental impact of the action when added to other past, present and reasonably foreseeable future actions regardless of what agencies or person undertakes such other actions" (40 CFR 1508.7).

Past and present actions in Hawai'i to control strawberry guava include mechanical and chemical controls applied by a variety of state and federal agencies as well as private organizations and individuals. The Hawai'i Division of Forestry and Wildlife conducts control activities of strawberry guava along trails using mechanical and chemical methods. The Hawai'i Department of Transportation and utility companies conduct control measures of strawberry guava along roads and utility right-of-ways. The National Park Service and The Nature Conservancy Hawai'i have programs to control strawberry guava in natural areas. At Hawai'i Volcanoes National Park (HVNP), strawberry guava has been targeted for control since 1985 in Special Ecological Areas, selected for intactness of native vegetation, high species diversity, rare flora and manageability (Tunison and Stone, 1992). Dramatic reductions in density of strawberry guava and other weeds have been achieved within these limited areas, and the labor to maintain low weed density declines after the initial large investment. However, as densities of strawberry guava increase outside the boundaries of Special Ecological Areas, their vulnerability to invasion and the cost of maintaining them can be expected to increase (Tunison and Stone, 1992).

Impact of release of *T. ovatus* on the target weed is expected to advance gradually in time and area, providing long-term method control of strawberry guava, allowing natural substitution of strawberry guava by other plant species, and preventing spread of strawberry guava into areas at risk from invasion. Acceleration of this process may be possible over selected areas by combining mechanical or herbicidal control with suppression by *T. ovatus*. Effective biological control of strawberry guava is expected to complement and benefit other weed management programs, for example, increasing the efficacy of mechanical removal of strawberry guava by slowing the weed's ability to resprout from surviving stems. To the extent that *T. ovatus* enhances conventional control of strawberry guava, it may promote use of chemical or mechanical methods against this weed over larger areas of land. In these cases it may be appropriate to plan for active restoration of controlled areas, such as by introducing native species. The positive and negative impacts of greater use of chemical or mechanical methods against strawberry guava would depend on the care taken to avoid damage and promote restoration of native ecosystems.

6. Endangered Species Act

Section 7 of the Endangered Species Act (ESA) and ESA's implementing regulations require Federal agencies to ensure that their actions are not likely to jeopardize the continued existence of federally listed threatened endangered species or result in the destruction or adverse modification of critical habitat.

One endangered plant in the family Myrtaceae occurs in Hawai'i, *Eugenia koolauensis* (nioi). USDA APHIS has determined that based on the host specificity of *T. ovatus,* there will be no effect on *Eugenia koolauensis.* Several *Eugenia* species, *Eugenia reinwardtiana* (Blume) DC, *E. uniflora* L., *E. axillaris* (Sw.) Willd., *E. foetida* Pers., *E. confusa* DC, and *E. rhombea* Krug & Urban were tested in host specificity tests in Hawai'i and Florida, but no galls formed on these plants or on any other plant tested besides some closely-related *Psidium* species.

VI. Other Issues

1. Federal Executive Orders

Consistent with Executive Order (EO) 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-income Populations," USDA APHIS considered the potential for disproportionately high and adverse human health or environmental effects on any minority populations and low-income populations. There are no adverse environmental or human health effects expected from the field release of *T. ovatus*, and it will not have disproportionate adverse effects on any minority or low-income populations.

Consistent with EO 13045, "Protection of Children from Environmental Health Risks and Safety Risks," USDA APHIS considered the potential for disproportionately high and adverse environmental health and safety risks to children. No disproportionate effects on children are anticipated as a consequence of the field release of *T. ovatus*, and no circumstances that would trigger the need for special environmental reviews are involved in implementing the preferred alternative for field release of *T. ovatus*.

2. Hawai‘i Administrative Rules

In relation to the following criteria identified in the Hawai‘i Administrative Rules § 11-200-12, the proposed environmental release of *T. ovatus* is expected to receive a Finding of No Significant Impact:

1) Involves an irrevocable commitment to loss or destruction of any natural or cultural resource.
The proposed action is intended to result in a permanent reduction of wild fruits of strawberry guava, which are considered a cultural resource by some Hawai'i residents who have occasionally collected fruits for consumption. However, the loss of this resource is expected to have great benefits for the natural environment by protecting existing native forest, watershed and habitat for native plants and animals from invasion by one of Hawai'i's most destructive environmental weeds. These benefits to the natural environment will also accrue significant cultural benefits in that many native species of importance in Hawaiian culture will be protected from the deleterious effects of strawberry guava.

2) Curtails the range of beneficial uses of the environment.
The proposed action will not curtail beneficial uses of the environment. Instead, the release of *T. ovatus* is expected to substantially increase long-term beneficial uses of the environment by protecting native forests against degradation by invading strawberry guava and protecting agricultural activities from a major environmental source of non-native pest fruit flies.

3) Conflicts with the state's long-term environmental policies or goals and guidelines as expressed in Chapter 344, HRS, and any revisions thereof and amendments thereto, court decisions, or executive orders.
The proposed action is consistent with the environmental policies and guidelines established in Chapter 344, Hawaiʻi Revised Statutes (HRS) and contributes to the conservation of threatened and endangered species, as covered by Chapter 195D, HRS. It is also consistent with Section 8 of the County of Hawaiʻi General Plan (2005), which sets goals and policies for maintaining natural resources. Release of *T. ovatus* for biological control of strawberry guava is consistent with priorities identified in the Hawai'i Comprehensive Wildlife Conservation Strategy (2005), the Recovery Plan for the Big Island Plant Cluster (1996), the Draft Revised Recovery Plan for Hawaiian Forest Birds (2003), and the Three Mountain Alliance Final Management Plan (2007).

4) Substantially affects the economic or social welfare of the community or state.
The proposed action will not adversely affect the economic or social welfare of the community or state. Instead, it is expected to contribute positively to the economic and social well-being of local communities and the state through long-term improvement in the health of native forests and reduced impacts of pest fruit flies on Hawaiian agriculture.

5) Substantially affects public health.
The proposed action is not anticipated to substantially affect public health. The proposed action may have a positive impact on public health by protecting native forests and watersheds.

6) Involves substantial secondary impacts, such as population changes or effects on public facilities.
Impacts on agriculture, via reduced populations of pest fruit flies, are expected to be highly beneficial. Impacts on public utility rights-of way are expected to be positive, in that slower growth of strawberry guava is expected to result in lower costs required for weed control under utility lines. Other benefits to public facilities can be expected in the long term, since strawberry guava is expected to lessen in importance as an invasive weed as a result of biocontrol. Other effects of biocontrol of strawberry guava are expected to remain in forest areas, largely out of public awareness, and without substantial secondary impacts on human populations or public facilities.

7) Involves a substantial degradation of environmental quality.

The proposed action does not involve a substantial degradation of environmental quality. Instead, the proposed action is expected to contribute to long-term protection of environmental quality associated with healthy native forests.

8) Is individually limited but cumulatively has considerable effect upon environment or involves a commitment for larger actions.
The proposed release of *T. ovatus* is expected to have direct effects limited to reduced growth and reproduction of strawberry guava. Indirect effects are expected to be substantial and positive, by reducing degradation of native forests and impacts of pest fruit flies on Hawaiian agriculture. The proposed action does not involve commitment to larger actions because the impacts of the biocontrol agent are expected to be very targeted and gradual.

9) Substantially affects a rare, threatened or endangered species, or its habitat.
Release of *T. ovatus* is expected to affect habitats of rare, threatened and endangered species positively, rather than negatively, by limiting further degradation of native forest areas where these species occur. If no action is taken, decline in endangered plant populations are probable and extinctions are possible as a result of continuing invasions by strawberry guava.

10) Detrimentally affects air or water quality or ambient noise levels.
The proposed action will have no detrimental effects on air quality, water quality, or noise levels. Long term benefits to air and water quality are expected as a result of protecting forest health.

11) Affects or is likely to suffer damage by being located in an environmentally sensitive area such as a flood plain, tsunami zone, beach, erosion-prone area, geologically hazardous land, estuary, fresh water, or coastal waters.
The proposed action is not expected to adversely affect any environmentally sensitive areas, since impacts are expected to be gradual and should improve the stability of forest environments by allowing persistence of native species which strawberry guava currently competes against. The biocontrol agent and affected strawberry guava are not likely to suffer damage associated with environmentally sensitive areas because the affected forest areas are relatively stable inland environments.

12) Substantially affects scenic vistas and view planes identified in county or state plans or studies.
The proposed action is not anticipated to affect any vistas or view planes identified in county or state plans or studies. The insect and its effects on strawberry guava are not expected to be noticeable to tourists and the general public.

13) Requires substantial energy consumption.
The proposed action does not require substantial energy consumption. The biocontrol agent will persist and spread gradually without any human assistance.

VII. Agencies, Organizations and Individuals Consulted

Arthur Medeiros – USGS, Pacific Island Ecosystems Research Center
Charles Wikler – Universidade Estadual Centro-Oeste, Irati, Brazil
Clifford Smith – University of Hawai'i at Manoa, Botany Department (retired)
Frank Wessels – University of Florida, Entomology & Nematology Department
J.B. Friday – University of Hawai'i at Manoa, College of Tropical Agriculture and Human Resources
James Cuda – University of Florida, Entomology & Nematology Department
Jonathan Price - Smithsonian Institution, National Museum of Natural History, Department of Botany
Jose Henrique Pedrosa Macedo – Universidade Federal de Parana, Curitiba, Brazil
Julie Denslow - USDA Forest Service, Institute of Pacific Islands Forestry
Keali'i Bio – USGS, Pacific Island Ecosystems Research Center
Kenneth Teramoto – Hawai'i Department of Agriculture, Plant Pest Control Branch
Marcelo Vitorino – Universidade Regional de Blumenau, Brazil
Roger Vargas – USDA Agricultural Research Service, Pacific Basin Agricultural Research Center

Hawai'i Department of Agriculture Advisory Subcommittee on Entomology:
Arnold Hara – University of Hawai'i at Manoa, College of Tropical Agriculture and Human Resources
Francis Howarth – Bishop Museum
Lorna Arita-Tsutsumi – University of Hawai'i at Hilo, College of Ariculture
Peter Follett – USDA Agricultural Research Service, Pacific Basin Agricultural Research Center
Ronald Mau – University of Hawai'i at Manoa, College of Tropical Agriculture and Human Resources

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Appendix 1. Federally listed endangered (E) and threatened (T) plant species for which strawberry guava (*Psidium cattleianum*) has been noted by USFWS as a threat in critical habitat areas on the islands of Kauai, Oahu, Maui, Molokai and Lanai (USFWS 2003a-d).

Species	Common name	Island(s) with critical habitat affected by *P. cattleianum*	Status
Abutilon sandwicense	-	Oahu	E
Adenophorus periens	Pendant kihi fern	Kauai, Molokai	E
Alectryon macrococcus	Mahoe	Kauai, Maui, Molokai, Oahu	E
Alsinidendron obovatum	-	Oahu	E
Bonamia menziesii	-	Oahu	E
Brighamia insignis	Olulu	Kauai	E
Cenchrus agrimonioides	Kamanomano	Oahu	E
Chamaesyce halemanui	-	Kauai	E
Chamaesyce herbstii	`Akoko	Oahu	E
Chamaesyce rockii	`Akoko	Oahu	E
Colubrina oppositifolia	Kauila	Oahu	E
Ctenitis squamigera	Pauoa	Kauai, Lanai, Maui, Oahu	E
Cyanea (=Rollandia) crispa	-	Oahu	E
Cyanea grimesiana ssp. *grimesiana*	Haha	Oahu	E
Cyanea grimesiana ssp. *obatae*	Haha	Oahu	E
Cyanea humboldtiana	Haha	Oahu	E
Cyanea koolauensis	Haha	Oahu	E
Cyanea longiflora	Haha	Oahu	E
Cyanea pinnatifida	Haha	Oahu	E
Cyanea remyi	Haha	Kauai	E
Cyanea superba	Haha	Oahu	E
Cyanea truncata	Haha	Oahu	E
Cyanea undulata	Haha	Kauai	E
Cyrtandra dentata	Ha`iwale	Oahu	E
Cyrtandra limahuliensis	Ha`iwale	Kauai	T
Cyrtandra munroi	Ha`iwale	Lanai, Maui	E
Cyrtandra viridiflora	Ha`iwale	Oahu	E
Delissea subcordata	Oha	Oahu	E
Diellia erecta	Asplenium-leaved diellia	Molokai, Oahu	E
Diellia falcata	-	Oahu	E
Diellia unisora	-	Oahu	E
Dubautia latifolia	Na`ena`e	Kauai	E
Dubautia pauciflorula	Na`ena`e	Kauai	E
Eragrostis fosbergii	Fosberg's love grass	Oahu	E
Eugenia koolauensis	Nioi	Oahu	E
Euphorbia haeleeleana	`Akoko	Oahu	E
Flueggea neowawraea	Mehamehame	Oahu	E
Gardenia mannii	Nanu	Oahu	E
Gouania meyenii	-	Kauai, Oahu	E
Gouania vitifolia	-	Oahu	E
Hedyotis degeneri	-	Oahu	E
Hedyotis mannii	Pilo	Lanai	E
Hedyotis schlechtendahliana var. *remyi*	Kopa	Lanai	E

Appendix 1 (continued). Federally listed plant species threatened by strawberry guava.

Species	Common name	Island(s) with critical habitat affected by *P. cattleianum*	Status
Hesperomannia arborescens	-	Oahu	E
Hesperomannia arbuscula	-	Oahu	E
Hibiscus clayi	Clay's Hibiscus	Kauai	E
Isodendrion laurifolium	Aupaka	Oahu	E
Isodendrion longifolium	Aupaka	Oahu	T
Labordia cyrtandrae	Kamakahala	Oahu	E
Lipochaeta tenuifolia	Nehe	Oahu	E
Lycopodium (=Phlegmariurus) nutans	Wawae`iole	Kauai, Oahu	E
Melicope balloui	Alani	Maui	E
Melicope munroi	Alani	Lanai	E
Melicope ovalis	Alani	Maui	E
Melicope pallida	Alani	Oahu	E
Melicope saint-johnii	Alani	Oahu	E
Myrsine juddii	Kolea	Oahu	E
Myrsine linearifolia	Kolea	Kauai	T
Neraudia angulata	-	Oahu	E
Nototrichium humile	Kulu`i	Oahu	E
Phyllostegia hirsuta	-	Oahu	E
Phyllostegia kaalaensis	-	Oahu	E
Phyllostegia mollis	-	Oahu	E
Phyllostegia parviflora	-	Oahu	E
Pritchardia viscosa	Lo`ulu	Kauai	E
Pteralyxia kauaiensis	Kaulu	Kauai	E
Pteris lidgatei	-	Oahu	E
Schiedea hookeri	-	Oahu	E
Schiedea kaalae	-	Oahu	E
Schiedea membranacea	-	Kauai	E
Schiedea nuttallii	-	Oahu	E
Solanum sandwicense	`Aiakeakua, popolo	Kauai, Oahu	E
Stenogyne kanehoana	-	Oahu	E
Tetraplasandra gymnocarpa	`Ohe`ohe	Oahu	E
Urera kaalae	Opuhe	Oahu	E
Viola helenae	-	Kauai	E
Viola oahuensis	-	Oahu	E

Appendix 2. Federally listed endangered plant species on the island of Hawai'i restricted to habitats entirely within the potential distribution of strawberry guava (wet and mesic forests below 1600m, Jonathan Price pers. comm.).

Species	Common name
Endemic to the island of Hawai'i	
Cyanea platyphylla	\`Aku\`aku
Cyrtandra tintinnabula	-
Ochrosia kilaueaensis	Holei
Phyllostegia warshaueri	-
Pritchardia schattaueri	Lo\`ulu
Found on Hawai'i and other islands	
Adenophorus periens	Pendant kihi fern
Flueggea neowawraea	Mehamehame
Gardenia brighamii	Nanu
Phyllostegia parviflora	-
Phyllostegia stachyoides	-

Appendix 3. List of plant species tested against *Tectococcus ovatus* at Hawai'i Volcanoes National Park Quarantine.

Class Subclass Order	Family (Subfamily)	Species	Common names	Native range	Status in Hawai'i	Earliest record in Hawai'i
Magnoliopsida Rosidae Myrtales	Myrtaceae (Myrtoideae)	*Psidium cattleianum* Sabine	strawberry guava, waiawi	SE Brazil	invasive	1825
		Psidium guajava L., variety:	common guava	Neotropics	naturalized,	1840
		Puerto Rico #2			cultivated	
		Waiakea				
		Allahabad Safeda				
		Fan Retief				
		Ka hua kula				
		Beaumont				
		Thai maroon				
		Eugenia reinwardtiana (Blume) DC	nioi	Hawai'i	endemic	
		Eugenia uniflora L.	pitanga, Surinam cherry	Brazil	cultivated	1871
		Myrciaria cauliflora (DC.) O. Berg	jaboticaba	S. Brazil	cultivated	
		Syzygium cumini (L.) Skeels	Java plum, jambolan plum	India, Ceylon, Malesia	naturalized	1871
		Syzygium jambos (L.) Alston	rose apple	Malesia, SE Asia	naturalized	1825
		Syzygium malaccense (L.) Merr. & Perry	mountain apple	Malesia, SE Asia	naturalized, Polynesian introduction	
		Rhodomyrtus tomentosa (Aiton) Hassk.	downy myrtle, rose myrtle	India, SE Asia, Phillipines	naturalized	1920
	Myrtaceae (Leptospermoideae)	*Callistemon citrinus* (Curtis) Stapf	crimson bottlebrush	Australia	horticultural	
		Eucalyptus citriodora Hook.	lemon-scented gum	Australia	naturalized, widespread plantings	1921
		Eucalyptus globulus Labill.	blue gum	Australia	naturalized, extensive plantations	1871

Appendix 3 (continued). List of plant species tested against *Tectococcus ovatus* at Hawai'i Volcanoes National Park Quarantine Facility.

Class Subclass Order	Family (Subfamily)	Species	Common names	Native range	Status in Hawai'i	Earliest record in Hawai'i
	Myrtaceae (Leptospermoideae)	*Lophostemon confertus* (R. Br.) Peter G. Wilson & Waterhouse	vinegar tree	Australia	forest plantings, recently naturalized	1929
		Melaleuca quinquenervia (Cav.) S.T. Blake	paperbark	Australia, New Guinea	naturalized, extensive forest plots	1920
		Metrosideros macropus Hook. & Arnott	ohia lehua	Hawai'i	endemic	
		Metrosideros polymorpha Gaud.	ohia lehua	Hawai'i	indigenous	
		Metrosideros rugosa A. Gray	lehua papa	Hawai'i	endemic	
		Metrosideros tremuloides (A. Heller) P. Knuth	lehua ahihi	Hawai'i	endemic	
	Lythraceae	*Cuphea hyssopifolia* Kunth	false heather	Mexico-Honduras	naturalized in disturbed sites, streambeds	1909
		Cuphea ignea A. DC	cigar flower	Mexico	horticultural, naturalized	1871
		Lythrum maritimum Kunth	pukamole	Peru, Hawai'i	indigenous	
	Thymelaeaceae	*Wikstroemia sandwicensis* Meisn.	akia	Hawai'i	endemic	
		Wikstroemia uva-ursi A. Gray	akia	Hawai'i	endemic	
Fabales	Fabaceae	*Acacia koa* A. Gray	koa	Hawai'i	endemic	
		Sophora chrysophylla (Salisb.) Seem.	mamane	Hawai'i	endemic	
Sapindales	Anacardiaceae	*Rhus sandwicensis* A. Gray	neleau	Hawai'i	endemic	
	Sapindaceae	*Dimocarpus longan* Lour	longan	India	cultivated	
		Dodonaea viscosa Jacq.	a'ali'i	Pantropical	indigenous	
		Nephelium lappaceum L.	rambutan	Malaysia	cultivated	
Lamiales	Myoporaceae	*Myoporum sandwicense* A. Gray	naio	Cook Islands, Hawai'i	indigenous	
Rubiales	Rubiaceae	*Coprosma rhynchocarpa* A. Gray	pilo	Hawai'i	endemic	
Filicopsida Polypodiales	Dicksoniaceae	*Cibotium glaucum* (Sm.) Hook. & Arnott	hapu'u pulu	Hawai'i	endemic	

Appendix 4. Host specificity of *Tectococcus ovatus* in no-choice (starvation) tests at Hawai'i Volcanoes National Park Quarantine Facility, 2002-2005.

Family (Subfamily)	Test plant species	Common names	No. of replicates	Total no. galls initiated	% Survival of nymphs[a]
Myrtaceae (Myrtoideae)	*Psidium cattleianum*	strawberry guava	25	275	44±12
	Psidium guajava L. variety:	common guava			
	Puerto Rico #2		2	0	0
	Waiakea		4	0	0
	Allahabad Safeda		2	0	0
	Fan Retief		2	0	0
	Ka hua kula		4	0	0
	Beaumont		2	0	0
	Thai maroon		3	0	0
	Eugenia reinwardtiana	nioi	3	0	0
	Eugenia uniflora	pitanga, Surinam cherry	5	0	0
	Myrciaria cauliflora	jaboticaba	5	0	0
	Syzygium cumini	Java or jambolan plum	5	0	0
	Syzygium jambos	rose apple	6	0	0
	Syzygium malaccense	mountain apple	5	0	0
	Rhodomyrtus tomentosa	downy or rose myrtle	6	0	0
Myrtaceae (Leptospermoideae)	*Callistemon citrinus*	crimson bottlebrush	5	0	0
	Eucalyptus citriodora	lemon-scented gum	2	0	0
	Eucalyptus globulus	blue gum	5	0	0
	Melaleuca quinquenervia	paperbark	5	0	0
	Metrosideros macropus	ohia lehua	5	0	0
	Metrosideros polymorpha	ohia lehua	6	0	0
	Metrosideros rugosa	lehua papa	2	0	0
	Metrosideros tremuloides	lehua ahihi	2	0	0
Lythraceae	*Cuphea ignea*	cigar flower	1	0	0
	Lythrum maritimum	pukamole	2	0	0
Thymelaeaceae	*Wikstroemia sandwicensis*	akia	5	0	0
	Wikstroemia uva-ursi	akia	2	0	0
Fabaceae	*Acacia koa*	koa	3	0	0
	Sophora chrysophylla	mamane	4	0	0
Sapindaceae	*Dodonaea viscosa*	a'ali'i	4	0	0
Myoporaceae	*Myoporum sandwicense*	naio	4	0	0
Dicksoniaceae	*Cibotium glaucum*	hapu'u pulu	4	0	0

[a]Mean ± standard deviation.

Appendix 5. Host specificity of *Tectococcus ovatus* in choice tests (insects could choose between test plants and *P. cattleianum*) at Hawai'i Volcanoes National Park Quarantine Facility, 1999-2001.

Family (Subfamily)	Test plant species	Common names	No. of replicates	No. galls initiated on test plants	No. galls initiated on *P. cattleianum*
Myrtaceae (Myrtoideae)	*Psidium guajava* L.	common guava			
	Variety: Waiakea		3	0	20,17,27
	Ka hua kula		3	0	20,17,18
	Beaumont		5	0	20,18,6,55,32
	Syzygium jambos	rose apple	2	0	5,21
	Syzygium malaccense	mountain apple	2	0	10,9
Myrtaceae (Leptospermoideae)	*Eucalyptus citriodora*	lemon-scented gum	2	0	6,8
	Eucalyptus globulus	blue gum	2	0	9,9
	Lophostemon confertus	vinegar tree	2	0	10,90
	Melaleuca quinquenervia	paperbark	2	0	10,5
	Metrosideros macropus	ohia lehua	2	0	39,20
	Metrosideros polymorpha	ohia lehua	4	0	50,100,16,86
Lythraceae	*Cuphea hyssopifolia*	false heather	2	0	34,14
	Cuphea ignea	cigar flower	3	0	7,33,27
	Lythrum maritimum	pukamole	2	0	7,9
Thymelaeaceae	*Wikstroemia sandwicensis*	akia	2	0	9,16
Fabaceae	*Acacia koa*	koa	3	0	100,6,47
	Sophora chrysophylla	mamane	3	0	100,10,23
Anacardiaceae	*Rhus sandwicensis*	neleau	1	0	5
Sapindaceae	*Dimocarpus longan*	longan	3	0	7,8,30
	Dodonaea viscosa	a'ali'i	2	0	8,83
	Nephelium lappaceum	rambutan	3	0	7,8,30
Myoporaceae	*Myoporum sandwicense*	naio	2	0	85,11
Rubiaceae	*Coprosma rhynchocarpa*	pilo	2	0	20,44
Dicksoniaceae	*Cibotium glaucum*	hapu'u pulu	2	0	34,12

Appendix 6. Results of *Tectococcus ovatus* host specificity testing at the University of Florida, 2003-2005. "+" indicates feeding damage and gall development; "-" indicates a lack of feeding damage and gall development (Wessels et al. 2007).

Test Plant	Family	Gall development	Replications
Psidium cattleianum var. *lucidum* Sabine	Myrtaceae	+	50
Psidium cattleianum var. *cattleianum* Sabine	Myrtaceae	+	3
Psidium friedrichsthalianum O. Berg	Myrtaceae	-[a]	3
Psidium guineense Sw.	Myrtaceae	+[b]	3
Psidium guajava L.	Myrtaceae	-	3
Acca sellowiana (O. Berg) Burret	Myrtaceae	-	3
Eugenia axillaris (Sw.) Willd.	Myrtaceae	-	3
Eugenia foetida Pers.	Myrtaceae	-	3
Eugenia uniflora L.	Myrtaceae	-	3
Myrciaria cauliflora (C. Martius) O. Berg	Myrtaceae	-	3
Pimenta dioica (L.) Merr.	Myrtaceae	-	3
Pimenta racemosa (P. Mill.) J.W. Moore	Myrtaceae	-	3
Syzygium malaccense (L.) Merr. & Perry	Myrtaceae	-	3
Syzygium paniculatum Gaertner	Myrtaceae	-	3
Callistemon citrinus (Curtis) Staph	Myrtaceae	-	3
Callistemon viminale (Gaertn.) G.Don ex Loudon	Myrtaceae	-	3
Eucalyptus camaldulensis Dehnhardt	Myrtaceae	-	3
Leptospermum scoparium J.R. & G. Forst.	Myrtaceae	-	3
Melaleuca quinquenervia (Cav.) Blake	Myrtaceae	-	3
Calyptranthes pallens Griseb.	Myrtaceae	-	3
Calyptranthes zuzygium (L.) Sw.	Myrtaceae	-	3
Eugenia confusa DC.	Myrtaceae	-	3
Eugenia rhombea Krug & Urban	Myrtaceae	-	3
Mosiera longipes (Berg) McVaugh	Myrtaceae	-	3
Myrcianthes fragrans (Sw.) McVaugh	Myrtaceae	-	3
Ammannia coccinea Rottb.	Lythraceae	-	3
Cuphea hyssopifolia Kunth	Lythraceae	-	3
Cuphea micropetala Humb., Bonpl. & Kunth	Lythraceae	-	3
Decodon verticillatus (L.) Ell.	Lythraceae	-	3
Lagerstroemia indica L.	Lythraceae	-	3
Lythrum alatum Pursh	Lythraceae	-	3
Rhexia lutea Walt.	Melastomataceae	-	2
Rhexia mariana L.	Melastomataceae	-	3

Appendix 6 (continued). Results of *Tectococcus ovatus* host specificity testing at the University of Florida, 2003-2005.

Test Plant	Family	Results	Replications
Rhexia nashii Small	Melastomataceae	-	3
Tetrazygia bicolor (P. Mill.) Cogn.	Melastomataceae	-	3
Rollinia mucosa (Jacq.) Baill.	Annonaceae	-	3
Punica granatum L.	Punicaceae	-	2
Conocarpus erectus L.	Combretaceae	-	3
Chrysobalanus icaco L.	Chrysobalanaceae	-	3
Nyssa sylvatica var. *biflora* Walt.	Nyssaceae	-	3
Daphnopsis americana (P. Mill.) J.R.	Thymelaeaceae	-	3
Ilex cassine L.	Aquifoliaceae	-	3
Ilex x *attenuata* Ashe	Aquifoliaceae	-	3
Delonix regia (Bojer ex Hook) Raf.	Fabaceae	-	3
Quercus hemisphaerica Bartr. ex Willd.	Fagaceae	-	3
Persea americana P. Mill.	Lauraceae	-	3
Ficus aurea Nutt.	Moraceae	-	3
Myrica cerifera (L.) Small	Myricaceae	-	3
Saccharum officinarum L.	Poaceae	-	3
Eriobotrya japonica (Thunb.) Lindl.	Rosaceae	-	3
Prunus angustifolia Marsh.	Rosaceae	-	3
Prunus persica (L.) Batsch	Rosaceae	-	3
Pyrus x *lecontei* ‘Hood’	Rosaceae	-	3
Citrus limon (K.) Burm. F.	Rutaceae	-	3
Citrus x *paradisi* Macfad.	Rutaceae	-	3
Citrus sinensis (L.) Osbeck	Rutaceae	-	3
Taxodium distichum (L.) L.C.	Cupressaceae	-	3
Pinus elliottii Engelm.	Pinaceae	-	3
Podocarpus macrophyllus (Thunb.) Sweet	Podocarpaceae	-	3

[a] *T. ovatus* survived longer than the 2 week test period; test was extended to 4 weeks, but no damage or gall formation was observed.

[b] *T. ovatus* survived longer than the 2 week test period; test was extended to 4 weeks, weak leaf gall formation was observed.

Appendix 7. Import Permit Conditions for *Tectococcus ovatus* established by the Hawai'i Department of Agriculture Plant Quarantine Branch in 2007.

1. The restricted article(s), *Tectococcus ovatus*, shall be used for field release as authorized by the Plant Quarantine Branch (PQB).

2. The permittee(s), Dr. M. Tracy Johnson, shall be responsible and accountable for all restricted article(s) imported, from the time of their arrival to their disposition.

3. The restricted article(s) shall be safeguarded at the Permittee(s)' facility located at the Quarantine Facility, Hawai'i Volcanoes National Park, which has been inspected and approved by the PQB prior to importation.

4. The permittee(s) shall submit samples of the restricted article prior to importation to the PQB, which will be placed in the Hawai'i Department of Agriculture Insect Quarantine Facility of the Hawai'i Volcanoes National Park Quarantine Facility for screening for other species, predators, parasites, parasitoids or hyperparasitoids for a minimum of two generations. A report shall be submitted to PQB of any organisms found other than the restricted article(s).

5. All parcels containing the restricted article(s) that are imported into the State shall be clearly marked: "May be opened and delayed for agricultural inspection in Hawai'i".

6. An invoice, bill of lading, or other document shall accompany each shipment listing the scientific name and quantity of each restricted article(s) imported.

7. All parcels containing the restricted article(s) shall be subject to inspection by the PQB prior to entering the State and shall be imported through an approved port-of-entry as designated by the Board of Agriculture.

8. The imported restricted article(s) and the permittee(s)' facility shall be made available for inspection by the PQB or other designated Hawai'i Department of Agriculture employee(s).

9. The permittee(s) shall submit a report to the PQB on results of post-release monitoring programs on a semi-annual basis.

10. The permittee(s) shall immediately report any theft, accidental release, or disease outbreaks involving the restricted article(s) to the PQB at (808) 832-0566.

11. The permit is subject to revocation and all restricted article(s) and materials that came into contact with the organism may be subject to confiscation should any of the restricted article(s) or infected materials be removed from the approved facilities without authorization from the PQB prior to removal.

12. The permit is subject to cancellation for violation of permit conditions upon written notification from the PQB. A canceled permit is invalid and all article(s) listed on the permit shall not be imported.

13. The permittee(s) shall agree in advance to defend and indemnify the State of Hawai'i, its officers, agents and employees for any and all claims against the State of Hawai'i, its officers, agents, or employees that may arise from or be attributable to any of the restricted article(s) that are introduced under this permit. This permit condition shall not apply to a permittee that is a federal or State of Hawai'i entity or employee, provided that the State or federal employee is a permittee in the employee's official capacity.

14. This permit or conditions of this permit are subject to cancellation or amendment at any time due to changes in administrative rules restricting or disallowing import of the restricted article(s) or due to Board of Agriculture action disallowing a previously permitted use of the restricted article(s).

Appendix 8. Proposed site for initial release of *Tectococcus ovatus* is in the Ola'a Forest Reserve on the island of Hawai'i (TMK 3-1-9-001-004), however the eventual impact of this agent is expected to extend statewide. Redistribution of the agent to additional sites on Hawai'i and other islands will be conducted by state and federal agencies with responsibilities for managing strawberry guava.