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Field and Laboratory Host Ranges of the Australian Weevil, *Oxyops vitiosa* (Coleoptera: Curculionidae), a Potential Biological Control Agent for the Paperbark Tree, *Melaleuca quinquenervia*

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While some woody weeds have been targets for classical biological control, only a few of these reach a size large enough to be considered trees. In 1986, a long-term project was initiated to develop biological control agents for *Melaleuca quinquenervia* (paperbark tree; melaleuca), a large tree species which has become a serious pest in southern and central Florida. The paperbark tree is native to Australia, where we studied the host range of the weevil *Oxyops vitiosa*, a potential biological control candidate for *M. quinquenervia*, in the field as well as the laboratory. During 7 years, we collected 1077 specimens of this weevil from 644 quantitative collections of *M. quinquenervia*. It was never found in 371 quantitative collections from other (mostly closely related) tree species. In 10 of 12 intensive evaluations at six sites containing numerous tree species, *O. vitiosa* was found only on *M. quinquenervia*. In the laboratory, high feeding by *O. vitiosa* larvae was observed only on *M. quinquenervia* and two other closely related *Melaleuca* species, while moderate feeding was recorded on *Psidium guajava*. Eggs were laid on six plant species in adult oviposition trials, but of the resulting larvae, only on those on *M. quinquenervia* completed their development. This weevil's potential efficacy as a biological control agent is estimated using the Goeden–Harris scoring system. We also briefly review the success of similar agents, as well as other projects against large woody weeds. As in its native range, this weevil's impact on *M. quinquenervia* in Florida would most likely be the suppression of growth and stunting of saplings. The high degree of host specificity shown by this weevil species allowed its exportation in July 1992 to quarantine facilities in Florida for further evaluation. © 1994 Academic Press, Inc.

KEY WORDS: ***Melaleuca quinquenervia; Oxyops vitiosa;* field host range; laboratory host range; feeding host range; oviposition host range; classical biological control; biological control of trees; foliage feeding; Goeden–Harris scoring system.**

INTRODUCTION

Of the more than 100 weed species which have been targets for classical biological control (Julien, 1992), relatively few are large shrubs or trees. A few of these woody weeds can become small to moderate-sized trees, especially when they are introduced into a new area free of their natural enemies. Several Australian *Acacia* spp. are considered weeds in South Africa, and have had classical biological control programs initiated against them (Dennill and Donnelly, 1991). Of these, *Acacia melanoxylon* R. Brown ex Aiton, which can reach 15 m in Australia (Stanley and Ross, 1983), appears to be the tallest. Other large biocontrol targets include: mesquite bush (*Prosopis* spp.), which can grow to 10 m in South Africa (Zimmerman, 1991); *Schinus terebinthifolius* Raddi, which reaches 7 m in Hawaii (Wagner *et al.*, 1990) but only 3–5 m in Florida (Habeck *et al.*, 1994), although heights of 10 m have been reported (Bennett *et al.*, 1990); *Mimosa pigra* L. which reaches 6 m in Australia (Lonsdale, 1992); *Hakea sericea* Schrader which reaches 5 m in South Africa (Kluge and Neser, 1991); and *Cordia curassavica* (=*macrostachya*) (Jacquin) Roemer & Schultes, which grows to 5 m (Goeden, 1978). In this paper we report on our research on a potential classical biocontrol agent for the paperbark tree, *Melaleuca quinquenervia* (Cav.) S. T. Blake (Myrtaceae), which can reach 25 m in Australia (Holliday, 1989) and has exceeded 29 m in height in Florida (Rockwood and Geary, 1991).

Melaleuca quinquenervia is native to the east coast of Australia and a few nearby South Pacific islands (see distribution map in Balciunas and Center, 1991). This tree was introduced into Florida, where it is known as melaleuca, as an ornamental at the beginning of this century (Hofstetter, 1991). For many years this tree remained innocuous and was even considered to be a worthwhile and beneficial plant (Morton, 1966). However, in the last 30 to 40 years, it has greatly expanded its range in southern Florida, and now occurs in over 400,000 acres (Thayer and

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Bodle, 1990). It is considered by some environmental groups to be ". . . Florida's most destructive land plant" (Florida Conservation Foundation, 1993). Increasing public awareness of the environmental damage caused by this pest has resulted in the project receiving considerable attention from local and national press. The Australian weevil which is the subject of this paper has even been illustrated on the front page of the Wall Street Journal (Morgenthaler, 1993).

The extensive environmental and economic costs of this pest (Balciunas and Center, 1991; Diamond *et al.*, 1991), and the difficulties of controlling it by mechanical or herbicidal means, have resulted in the initiation of a classical biological control project targeting this tree. Brief initial surveys to detect possible insect biological control agents in Australia and New Caledonia were performed in 1977 (Habeck, 1981). In 1986, the Australian Biological Control Laboratory (ABCL), now one of the overseas laboratories of the United States Department of Agriculture, Agricultural Research Service (USDA-ARS), began a long-term project to detect and evaluate potential insect biological control agents for *M. quinquenervia* [see Balciunas (1994) for a more detailed history of this project and the ABCL]. By the end of 1991, our surveys had tabulated over 400 species of herbivorous insects on *M. quinquenervia* and six closely related *Melaleuca* species (Balciunas *et al.*, 1995).

Of the hundreds of herbivorous insect species found on *M. quinquenervia* during our surveys, one of the weevils, *Oxyops vitiosa* Pascoe (Coleoptera: Curculionidae), quickly became our highest priority candidate. Both the larvae and adults of *O. vitiosa* prefer to feed on the young foliage of *M. quinquenervia*. Eggs are usually deposited singly on the tips of young leaves, and the resulting larvae pass through four instars. The egg to adult period takes 43–53 days. A more detailed life history and distribution of *O. vitiosa* is presented elsewhere (Purcell and Balciunas, 1994). Larvae are the most voracious and damaging stage, forming a "window" scar by consuming leaf tissue from one side of a leaf through to the cuticle on the opposite side. The resultant feeding damage may persist for many months and causes stunted growth and reduced foliage production. The adults are less voracious. Their feeding causes distinctive, short, narrow scars and perforations on the leaf. This paper reports on the host range of *O. vitiosa* in our extensive field surveys and evaluations in Australia and compares it to the results of our laboratory tests to determine the feeding and oviposition host ranges of this weevil.

MATERIALS AND METHODS

Field Collections

Our sampling, conducted from 1987 through 1993, was concentrated in two regions. The first was in northern Queensland, from the village of Daintree (latitude, 16°15.1′S) south to Townsville (19°15.6′S). The second was from Coolum (26°34.8′S) in southeast Queensland to Maclean (29°26.9′S) in northern New South Wales. A few collections were also made in the Northern Territory and along the central coast of Queensland.

In order to facilitate comparisons between hosts, sites, and seasons, the majority of the field collections were made on a quantitative basis. Each quantitative collection consisted of approximately 1 kg of branches cut from trees in the field. These quantitative collections were processed in the laboratory where the plant portions (twigs, foliage, fruits, and flowers) were separated and weighed, and all insect herbivores removed and recorded. The immatures were reared, preserved for identification, or used in laboratory studies and colonies.

In order to further assess the host range of *O. vitiosa* in the field, we conducted 12 intensive field evaluations, when this weevil was particularly abundant, at two sites in Townsville and four sites near Brisbane. The peak abundance of this weevil usually accompanied the flush of new growth by *M. quinquenervia*, subsequent to the flowering period (March–July), or (in north Queensland) the production of new foliage following defoliation by the melaleuca sawfly, *Lophyrotoma zonalis* Rohwer (Hymenoptera: Pergidae). Five of these field host-range evaluations (August 1989, March, April, and August 1990, and June 1991) were performed on landscape ornamentals, ranging from 1 to 5 m in height, planted at the James Cook University Geoscience parking lot (latitude, 19°19.9′S). In each of these five evaluations, 156 to 162 trees from 31 species in nine families were searched for *O. vitiosa* eggs, larvae, and adults. The external feeding larvae and their distinctive damage were readily observed, while the feeding damage by the adults assisted in locating them and any eggs, which are usually oviposited on leaf tips of branches with feeding scars. If parts of the tree were inaccessible, a portion (e.g., $\frac{1}{4}$–$\frac{3}{4}$) of the tree was searched, and the abundance of *O. vitiosa* was then extrapolated for the entire tree. In order to verify the accuracy of the counts, during the first evaluation, several trees with *O. vitiosa* were evaluated independently by two different individuals. The counts on the same trees were identical or very similar, increasing our confidence in this technique. The sixth intensive field evaluation in north Queensland was conducted in August 1990 on 92 potted *Melaleuca* spp. trees outside of our shadehouse in Townsville.

Six additional, field host-range evaluations were conducted in southeast Queensland at four sites near Burpengary (27°9.5′S), 34 km north of Brisbane, where 20 tree species were searched. Due to frequent fires and clearing at these sites, the trees were small (0.5 to 4 m) and often had copious fresh regrowth. At the first two sites (one evaluation each in 1988) only the presence/

absence of *O. vitiosa* was recorded for each tree. At the first site, 75 trees from nine species in four families were examined, while at the second site, 59 trees from seven species in four families were examined. The field evaluations from Sites 3 and 4 (two surveys at each site) were performed in a similar manner to those at James Cook University, where the numbers of eggs, larvae, and adults of *O. vitiosa* were counted (or estimated) for each tree. Two evaluations were performed at Site 3 in 1990. In the first evaluation at this site, 173 trees, from 11 species in eight families, were searched within a plot (14.5 × 34 m). Due to a fire which later swept through that site, the second evaluation was reduced to only 89 trees, from seven species in six families. Both evaluations at Site 4 in 1991 involved searching 182 trees, from 14 species in seven families, along a 50 m × 1 m transect. All trees at the Geoscience parking lot and Burpengary Sites 3 and 4 were tagged, and herbarium specimens were taken for verification of their identity.

Laboratory Host-Range Studies

The laboratory host-range studies were conducted from June 1990 until October 1993 at the ABCL. The primary ABCL facility is located on the campus of James Cook University, in Townsville, northern Queensland. The ABCL also operates a substation, 1100 km to the south, at the Commonwealth Scientific and Industrial Research Organization's (CSIRO) Long Pocket Laboratories in Brisbane, southeast Queensland.

The laboratory studies consisted of two types: (1) larval no-choice feeding tests and (2) no-choice adult feeding and oviposition/immature survival trials. The larval host testing approximates a worst case scenario, where older (more destructive) larvae move off a defoliated *M. quinquenervia* to adjacent plants. The larval feeding tests were conducted on trees in the Townsville shadehouse or planted on the James Cook University campus. From the available plant species with the appropriate young leaves, we selected trees with close taxonomic affinity to *M. quinquenervia*, or, especially for the more distantly related species, those of economic importance. In each test, 10 third or fourth instar larvae, collected from the field, were enclosed in a fine-mesh gauze bag on the distal 10-cm portion of a branch of a test plant. Each group of 10 larvae represented one test, and usually four test plant species and a *M. quinquenervia* were tested on the same day. After 24 h, the larvae were removed, and the leaf area consumed was measured by outlining the feeding blotches onto tracings of leaves (or photocopies of leaves) on graph paper. As the hundreds of similar-sized larvae required to complete the test series were not available, the larvae were used sequentially on different test plants, until they reached the nonfeeding prepupal stage. To avoid starvation effects, larvae were maintained for at least 24 h on *M. quinquenervia* before being used in another feeding test. An individual larva was never exposed to the same test plant more than once.

The no-choice adult feeding and oviposition immature survival trials were conducted at ambient temperatures in a glasshouse at the Brisbane laboratory. Usually, one to four test plant species, along with a *M. quinquenervia* plant, were tested simultaneously. A mated pair of *O. vitiosa* adults from a laboratory colony was placed on each of the potted plants, which were held individually within gauze-covered cages (45 cm square by 92 cm high). After 24 h, the adults were removed, the number of eggs was counted, and the leaf area consumed was measured by placing transparent 1-mm^2 graph paper over each leaf. Adult weevils spent at least 24 h on *M. quinquenervia* before being used in another test, but were never tested twice on the same plant species. All eggs were incubated, and the resulting immatures reared, in a temperature cabinet at 25°C and a 12:12-h photoperiod. The larvae were reared in plastic containers (8 cm square by 5 cm high) lined with paper toweling and supplied with fresh tips of the test plant as necessary. During the final instar, 2 to 3 cm of dry sand was added to the bottom of each container, within which the insect pupated.

RESULTS AND DISCUSSION

Field Host Range

Between 1987 and 1993, we made 996 quantitative collections of *M. quinquenervia* and its close allies in the *M. leucadendra* complex (Blake, 1968; Barlow, 1988). Of these, 644 were of *M. quinquenervia*, 206 of *M. leucadendra*, 74 of *M. dealbata*, 30 of *M. viridiflora*, 22 of *Melaleuca* new sp. A, 9 of *M. nervosa* (Lindl.) Cheel, 7 of *M. cajuputi* Powell, 2 of *M. saligna* Schauer, 2 from undetermined *Melaleuca* spp. *Melaleuca* new sp. A is a narrow-leaved species, similar to *M. leucadendra*, that grows in sandy river beds near Australia's northeast coast. Although not formally described, this species has appeared in the literature as *M. "fluviatilis"* (Barlow, 1988). We also made an additional 19 quantitative collections from 10 other non-*Melaleuca* tree species that occur at our field sites.

From these 1015 quantitative collections, we extracted 1077 eggs, larvae, and adults of *O. vitiosa* from *M. quinquenervia*, but none of these weevils from any of the other plant species surveyed. Early in 1994, we found six *O. vitiosa* adults on natural stands of *M. nervosa* and *M. viridiflora* near James Cook University, and were able to rear to the adult stage a larva collected on *M. nervosa* at the same time. In the Northern Territory, a colleague collected some weevil larvae that may have been *O. vitiosa* on *M. viridiflora*. Unfortunately, we were unsuccessful in rearing these larvae to the adult stage to confirm

TABLE 1

Pooled Abundance of *Oxyops vitiosa* in the Geoscience Parking Lot, James Cook University, Townsville, Australia, during Five Field Evaluations between 1989 and 1991

Family	Tree species	Number of trees	Mean *Oxyops vitiosa*/tree		
			Eggs	Larvae	Adults
Anacardiaceae	*Mangifera indica* L.	1	0	0	0
Bignoniaceae	*Tabebuia* sp.	2	0	0	0
Caesalpiniaceae	*Lysiphyllum hookeri* (F. Mueller) Pedley	1	0	0	0
Fabaceae	*Pongamia pinnata* (L.) Pierre	1	0	0	0
Mimosaceae	*Acacia leptoloba* Pedley	3	0	0	0
	Acacia macradenia Bentham	1	0	0	0
	Acacia mangium Willd.	7[a]	0	0	0
	Acacia sp.	1	0	0	0
Myrtaceae	*Callistemon salignus* (Smith) DC.	4	0	0	0
	Callistemon viminalis (Sol. ex Gaertn.) G. Don ex Loudon	33	0	0.2	0
	Callistemon sp.	1	0	0	0
	Eucalyptus camaldulensis Dehnh.	1	0	0	0
	Eucalyptus citriodora Hooker	2[a]	0	0	0
	Eucalyptus papuana F. Mueller	1	0	0	0
	Eucalyptus ptychocarpa F. Mueller	2	0	0	0
	Eucalyptus robusta Smith	2[a]	0.5	3.0	0
	Eucalyptus tereticornis Smith	17	0	0	0
	Eucalyptus tessellaris F. Mueller	3	0	0	0
	Eucalyptus sp.	29	0	0	0
	Leptospermum parviflorum Valeton	2	0	0	0
	Lophostemon grandiflorus (Bentham) Wilson & Waterhouse	2	0	0	0
	Melaleuca armillaris Smith	1	0	0	0
	Melaleuca bracteata F. Mueller	6	0	0	0
	Melaleuca dealbata S. T. Blake	1	0	0	0
	Melaleuca diosmatifolia Dum. Cours.	15	0	0	0.1
	Melaleuca quinquenervia S. T. Blake (white-flower)	6	158.4	107.9	8.3
	Melaleuca quinquenervia S. T. Blake (red-flower)	4	19.0	0.7	0.8
	Melaleuca thymifolia Smith	6	0	0	0
	Melaleuca viridiflora Sol. ex Gaertner	1	0	0	0
Proteaceae	*Buckinghamia* sp.	1	0	0	0
	Grevillea banksii R. Brown	1	0	0	0
	Grevillea dryandri R. Brown	1	0	0	0
	Grevillea robusta Cunn. ex R. Brown	1	0	0	0
Rubiaceae	*Nauclea orientalis* (L.) L.	1	0	0	0
Sterculiaceae	*Brachychiton rupestris* (Mitchell ex Lindl.) K. Schum.	1	0	0	0

[a] One or more trees became too tall (or died) prior to the June 1991 evaluation.

their identity. Jones and Elliot (1986) record an unspecified *Oxyops* sp., which they refer to as the melaleuca leaf weevil, as a pest of *M. cajuputi*, *M. viridiflora*, and *M. quinquenervia* in northern Australia.

The five field evaluations at the Geoscience parking lot in Townsville (Table 1) supported the narrow host range indicated by our quantitative collections. In three of these evaluations, *O. vitiosa* was also found only on *M. quinquenervia*. Eggs, larvae, and adults of *O. vitiosa* were all more abundant on white-flowered *M. quinquenervia* than on red-flowered *M. quinquenervia*. White flowers are typical of true *M. quinquenervia*, and we believe that the red-flowered *M. quinquenervia* in the Geoscience parking lot may be hybrids with *M. viridiflora*. In the remaining two evaluations, very small numbers of *O. vitiosa* larvae were found on two other tree species, each of which was adjacent to and touching an *M. quinquenervia* tree which had been heavily attacked by *O. vitiosa*. Six larvae were found on the foliage of a *C. viminalis* tree. It is likely that these larvae had moved to this tree after defoliating the neighboring *M. quinquenervia* tree. An additional six larvae and an egg were also found on *Eucalyptus robusta*. We were able to rear one late-instar from *E. robusta* to the adult stage on leaves from that host. Since no eggs were laid on *E. robusta* by *O. vitiosa* adults in four oviposition tests (see section on laboratory host-range), we feel that this occurrence of immature *O. vitiosa* on *E. robusta* represents a rare (if not aberrant) event, perhaps precipitated by the large populations of this weevil on adjacent *M. quinquenervia*. In one of the Geoscience evaluations, a single

TABLE 2

Trees Searched for *Oxyops* Weevils in Six Field Evaluations at Four Sites at Burpengary, near Brisbane, Australia

		Number of trees searched					
		Site 1	Site 2	Site 3		Site 4	
Family	Tree species	June 1988	July 1988	June 1990	Sept. 1990	Sept. 1991	Nov. 1991
Asteraceae	*Baccharis halimifolia* L.			4	1		
Casuarinaceae	*Allocasuarina littoralis* Salisb.					19	19
	Allocasuarina ?littoralis Salisb.	3					
Fabaceae	*Jacksonia scorparia* R. Brown					2	2
	Jacksonia ?scorparia R. Brown	1		2			
Mimosaceae	*Acacia concurrens* Pedley	1	20	19	6	21	21
	Acacia sp.	25					
Myrtaceae	*Baeckea virgata* (J.R. & G. Forster) Andr.			1		28	28
	Callistemon comboynensis Cheel	2					
	Callistemon sp.	2					
	Eucalyptus seeana Maiden			1		1	1
	Eucalyptus signata F. Mueller					1	1
	Eucalyptus tereticornis Smith		1			5	5
	Eucalyptus ?tereticornis Smith		9				
	Eucalyptus sp.	20	5	1		15	15
	Leptospermum flavescens Smith (sens. lat.)	4					
	Leptospermum petersonii F. M. Bailey	2					
	Lophostemon confertus (R. Brown) Wilson & Waterhouse	4	4	12	5	5	5
	Melaleuca nodosa (Gaertner) Smith					1	1
	Melaleuca ?nodosa (Gaertner) Smith		1				
	Melaleuca quinquenervia S. T. Blake	11	7	31	7	71	71
Pinaceae	*Pinus elliottii* Engelmann		10	69	59	2	2
Proteaceae	*Banksia integrifolia* L.f.					2	2
	Persoonia cornifolia Cunn. ex R. Brown			2	1	6	6
Rhamnaceae	*Alphitonia excelsa* (Cunn. ex. Fenzl.) Reisseck ex Bentham		2	30	8	3	3
Verbenaceae	*Lantana camara* L.			1			

Note. Oxyops vitiosa was found only on *Melaleuca quinquenervia*.

adult was also found on *M. diosmatifolia*. However, since *O. vitiosa* larvae did not feed on *M. diosmatifolia* in our larval no-choice tests, we believe that this adult was simply resting on this shrub.

In the evaluation at the Townsville shadehouse, we thoroughly searched 92 trees and saplings (73 *M. quinquenervia*, 9 *M. dealbata*, 6 *M. leucadendra*, 2 *M. viridiflora*, and 2 *M.* n. sp. A) for *O. vitiosa* eggs, larvae, and adults. Once again, *O. vitiosa* was only found on *M. quinquenervia*, with 141 eggs found on 20 trees and 46 larvae found on 9 trees.

In the presence/absence evaluations at Sites 1 and 2 at Burpengary (Table 2), *O. vitiosa* was present only on *M. quinquenervia*. In the four quantitative evaluations at Sites 3 and 4 (Table 2), a total of 1543 eggs, 799 larvae, and 28 adults of *O. vitiosa* were collected from the foliage of *M. quinquenervia*, but none were collected from any other plant species examined. Thus, both our quantitative field collections and our 12 intensive field evaluations indicate that, in the field, *O. vitiosa* is highly specific to *M. quinquenervia*.

Laboratory Host Range

In the laboratory no-choice feeding tests, *O. vitiosa* larvae fed on 10 Myrtaceae species in addition to *M. quinquenervia* (Table 3). For larval feeding, we classified damage over 500 mm^2 as high, 100 to 499 mm^2 as moderate, 10 to 99 mm^2 as low, and any feeding less than 10 mm^2 as negligible. Of the species closely related to *M. quinquenervia* in the *M. leucadendra* complex, larval feeding was high on *M. dealbata* and *M. viridiflora* and moderate on *M. leucadendra*. As yet, none of these weevils have been collected from these other three *Melaleuca* species in the field or at our shadehouse. Larval feeding was negligible on *M. armillaris*, which is not a member of the *M. leucadendra* complex. Among the economic Myrtaceae, larval feeding was moderate on *Psidium guajava* (yellow guava), low on *Eugenia uniflora* (Brazilian cherry) and *Syzygium tierneyanum* (water cherry), and negligible on *Myciaria cauliflora* (jaboticaba). *Psidium* spp., *Eugenia* spp., and *Syzygium* spp. are among the plants for which further testing is planned in quar-

TABLE 3

No-Choice Feeding Test Results by *Oxyops vitiosa* Larvae on Branch Tips of 25 Plant Species

Association	Host family	Tree species	Common name	No. of tests[a]	Mean (max.) mm² consumed by *O. vitiosa* larvae
Primary host	Myrtaceae	*Melaleuca quinquenervia* S. T. Blake		6	1386 (2022)
Same complex as primary host	Myrtaceae	*Melaleuca dealbata* S. T. Blake		2	842 (1213)
		Melaleuca leucadendra (L.) L.		1	278
		Melaleuca viridiflora Sol. ex Gaertner		1	659
Same genus as primary host	Myrtaceae	*Melaleuca armillaris* Smith		1	5
		Melaleuca bracteata F. Mueller		1	0
		Melaleuca diosmatifolia Dum. Cours.		1	0
		Melaleuca thymifolia Smith		1	0
Non-*Melaleuca* Myrtaceae	Myrtaceae	*Callistemon salignus* (Smith) DC.		1	0
		Callistemon viminalis (Sol. ex Gaertner) G. Don ex Loudon		1	0
		Eucalyptus robusta Smith		1	0
		Lophostemon grandiflorus (Bentham) Wilson & Waterhouse		1	57
		Xanthostemon chrysanthus (F. Mueller) Bentham		1	84
Economic Myrtaceae	Myrtaceae	*Eugenia uniflora* L.	Brazilian cherry	1	69
		Feijoa sellowiana O. Berg.	Pineapple guava	1	0
		Myciaria cauliflora (DC.) O. Berg.	Jaboticaba	1	6
		Psidium guajava L.	Yellow guava	2	275 (318)
		Syzygium jambos (L.) Alston	Rose apple	1	0
		Syzygium tierneyanum (F. Mueller) T. Hartley & Perry	Water cherry	1	90
Economic non-Myrtaceae	Anacardiaceae	*Mangifera indica* L.	Mango	1	0
	Araliaceae	*Schefflera actinophylla* (Endl.) Harms	Ornamental	1	0
	Lauraceae	*Persea gratissima* Gaertner	Avocado	1	0
	Mimosaceae	*Acacia mangium* Willd.	Ornamental	1	0
	Proteaceae	*Macadamia tetraphylla* L. A. S. Johnson	Macadamia nut	1	0
	Rutaceae	*Citrus sinensis* (L.) Osbeck	Valencia orange	1	0

[a] 10 larvae/test.

antine (G. Buckingham and B. Dawicke, USDA-ARS, Gainesville, FL, personal communication). The larvae fed, at low levels, on only two of the noneconomic, non-*Melaleuca* Myrtaceae (*Lophostemon grandiflorus* and *Xanthostemon chrysanthus*) and failed to feed on the remaining 14 plant species tested.

Herbivorous larvae will frequently feed briefly (especially under no-choice conditions) on plants which will not support their development (Harley and Forno, 1992). The results from the *O. vitiosa* no-choice adult feeding and oviposition/immature survival trials (Table 4) confirmed this. It should be noted that adult feeding was minimal compared to that of the late-instar larvae, with the mean daily consumption by an adult weevil being only 7% of the latter. Feeding by adults was nearly as high on four Myrtaceae (*Callistemon pachyphyllus*, *C. viminalis*, *M. argentea*, and *Syzygium leuhmannii*) as on *M. quinquenervia*. Lower feeding was also recorded on 10 other Myrtaceae species. No feeding was observed on 15 of the 30 test plant species, including three *Melaleuca* species. A total of 199 eggs were laid in 29 of the 38 *M. quinquenervia* tests. Of these 199 eggs, 49 were reared to the adult stage. Oviposition was recorded on only five plant species other than *M. quinquenervia*, all of which had also been fed upon by the adults, but none of the immatures on these five species completed development to the adult stage. All three eggs laid on *S. tierneyanum*, as well as the three on *M. argentea*, failed to hatch. Larvae emerged from both of the two eggs on *M. viridiflora*, but both died after 21 days. Larvae also emerged from each of the four eggs oviposited on *Lophostemon confertus*, but all died within 6 days (as first instars). Of the 24 eggs oviposited in four of the nine tests upon *C. viminalis*, four of the resulting larvae survived to the fourth and final instar (up to 32 days), but all failed to pupate. Since none of the immatures from eggs laid on non-*M. quinquenervia* hosts completed development to adult stage, we feel that this confirms our field results. This weevil is essentially specific to *M. quinquenervia* and only rarely attacks other members of the *M. leucadendra* complex.

Implications for Biological Control

Safety is the primary concern about any organism being considered for introduction into a new country as

TABLE 4

Feeding and Oviposition by Mated Pairs of Adult *Oxyops vitiosa* Weevils and the Subsequent Survival of Immatures in Tests Conducted between June 1990 and October 1993

Association	Host family	Tree species	Number of tests	Mean (range) mm² consumed/ test	Mean (max.) number eggs/test	% of eggs reared to adult
Primary host	Myrtaceae	*Melaleuca quinquenervia* S. T. Blake	38	18.5 (1–37)[a]	5.2 (15)	24.6
Same complex as primary host	Myrtaceae	*Melaleuca argentea* W. V. Fitzg.	3	14.7 (6–26)	1.0 (2)	0
		Melaleuca leucadendra (L.) L.	5	0	0	—
		Melaleuca viridiflora Sol. ex Gaertner	3	4.0 (0–12)	0.7 (2)	0
Same genus as primary host	Myrtaceae	*Melaleuca armillaris* Smith	3	1.7 (0–5)	0	—
		Melaleuca bracteata F. Mueller	3	0	0	—
		Melaleuca linariifolia Smith	3	0	0	—
Non-*Melaleuca* Myrtaceae	Myrtaceae	*Callistemon pachyphyllus* Cheel	1	17.0 (17)	0	—
		Callistemon viminalis (Sol. ex Gaertner) G. Don ex Loudon	9	16.3 (8–29)[b]	2.7 (10)	0
		Eucalyptus citriodora Hooker	3	6.7 (3–9)	0	—
		Eucalyptus gummifera (Sol. ex Gaertner) Hochr.	2	— (0)[c]	0	—
		Eucalyptus ptychocarpa F. Mueller	6	— (0)[c]	0	—
		Eucalyptus robusta Smith	4	5.5 (0–19)	0	—
		Eucalyptus tereticornis Smith	3	2.0 (0–6)	0	—
		Leptospermum polygalifolium Salisb.	1	0	0	—
		Leptospermum sp.	2	0	0	—
		Lophostemon confertus (R. Br.) Wilson & Waterhouse	6	1.8 (0–4)	0.7 (1)	0
Economic Myrtaceae	Myrtaceae	*Eugenia brasiliensis* Lam.	3	1.3 (0–4)	0	—
		Feijoa sellowiana O. Berg.	4	0	0	—
		Psidium littorale Raddi	3	0	0	—
		Syzygium jambos (L.) Alston	3	0	0	—
		Syzygium luehmannii (F. Mueller) L. A. S. Johnson	3	13.0 (3–27)	0	—
		Syzygium tierneyanum (F. Mueller) T. Hartley & Perry	3	7.3 (1–14)	1.0 (2)	0
Economic non-Myrtaceae	Araliaceae	*Schefflera actinophylla* (Endl.) Harms	3	0	0	—
	Lauraceae	*Persea americana* Mill.	3	0	0	—
	Mimosaceae	*Acacia harpophylla* Bentham	3	0	0	—
		Acacia oncinocarpa Bentham	5	0	0	—
	Rutaceae	*Citrus limon* (L.) N. L. Burm.	2	0	0	—
		Citrus reticulata Blanco	2	0	0	—
		Citrus sinensis (L.) Osbeck	1	0	0	—

[a] Amount of feeding not measured in 10 tests.
[b] Amount of feeding not measured in 2 tests.
[c] No feeding, except in 1 test where the amount was not recorded.

a potential biological control agent for a weed. Possible harm to economic and other nontarget plants must be carefully assessed. Few field observations of the host range in the country of origin of a potential biological control agent have been published. However, most practitioners in the field of biological control feel that laboratory tests will frequently indicate a broader host range than the "true" or "realized" host range in the field (Wapshere, 1989; Cullen, 1990; Harley and Forno, 1992). For this weevil, this does not appear to be the case. Our extensive field collections and laboratory tests both clearly indicate that the target, *M. quinquenervia*, is the highly preferred host for *O. vitiosa*. In the laboratory, *O. vitiosa* larvae could not complete their life cycle on any other plants tested. In the field, *O. vitiosa* are only found on *M. quinquenervia*, or, more rarely, on two of its close relatives in the *M. leucadendra* complex.

The Australian bottlebrush, *Callistemon viminalis*, widely used as an ornamental in southern Florida, is perhaps at some slight risk from *O. vitiosa*. A few larvae of this weevil were, on one occasion, found on *C. viminalis* after they defoliated an adjacent *M. quinquenervia*. In our laboratory tests on *C. viminalis*, *O. vitiosa* oviposited a total of 24 eggs, but none of the resulting larvae survived to pupate. *C. viminalis* is closely related to *Melaleuca*, and some authors (Byrnes, 1984) have even placed this species in that genus. *O. vitiosa* might attack *C. viminalis* bushes which are adjacent to heavily infested or damaged *M. quinquenervia* trees. The high degree of host specificity of *O. vitiosa* to *M. quinquenervia* in the field in Australia suggests that this would be a rare event, and they would be unlikely to persist for more than one generation on *C. viminalis*.

Thus, we are confident that *O. vitiosa* would pose little risk to Florida vegetation. However, we have fielded concerns about whether this weevil (or other potential *Melaleuca* biocontrol agents), despite the evidence regarding its host specificity, might, after having been released, evolve to accept another host. As Lawton (1985) points out, "Worries about biological control agents switching to non-target plants are persistent, but unjustified." He calculates that the odds against a host shift occurring for a given biological control agent as being of the order of 1×10^{-8} to 1×10^{-7}/year. We concur with him that while a host shift cannot ever be ruled out, the possibilities of it occurring are minute, and concerns about it should not hinder the development of a biological control agent.

After safety, the next greatest concern is for effectiveness. Will the proposed biocontrol agent prove to be useful in controlling the target weed? Unfortunately, potential efficacy is difficult to demonstrate conclusively. As part of our request to the Technical Advisory Group on Biological Control of Weeds (TAG) (Coulson, 1992) to allow importation of *O. vitiosa* into quarantine in the United States, it was necessary for us to estimate the biocontrol potential of this weevil using Goeden's (1983) revision of Harris' (1973) scoring system. There are many criticisms of this scoring system. For example, Wapshere (1985) critiques each step of Harris's scoring system as well as Goeden's revision of it. Wapshere's (1974, 1985, 1989) alternative evaluation systems may assist in selecting the best agent out of an array of herbivores attacking a particular target weed. However, they, along with other proposed systems for selecting biocontrol agents (e.g., Winder and van Emden, 1981; Müller, 1990) do not provide a numeric score allowing the rating of potential agents, not only on a particular weed, but also across a variety of weeds—something which the TAG committee apparently finds desirable and perhaps even useful. We have our own reservations about the Goeden–Harris scoring system. We are unsure of its practical value (outside of the TAG request) and found the wording for the scoring criteria to be sometimes subjective. Two of the authors of this paper, while independently scoring the *O. vitiosa* weevil using the Goeden–Harris criteria, initially arrived at scores differing by seven points. However, we do not feel that our own misgivings about this scoring system, or the shortcomings cited by other scientists, necessarily reduce the potential value of the Goeden–Harris scoring system. In fact, a review of the success of high- (and low-) scoring agents after release might allow for a further refinement of this system. Unfortunately, although scores are required for weed biocontrol agents approved by the TAG committee for release in the United States, few of these scores are reported in refereed journals. We therefore feel that it may be useful to provide the score for this agent. Using the Goeden–Harris system, *O. vitiosa* scored 51 points. This score would drop to 39 points if the bottlebrush, *C. viminalis*, widely used as an ornamental tree in Florida, is considered a "critical test plant" [question II (4)]. According to Goeden, any candidate scoring between 20 and 50 points should be partially effective as a biological control agent. *O. vitiosa* is at the upper range of this estimate, indicating that it should be an effective biocontrol agent, but that (not unexpectedly) additional insect species are likely to be needed to control *M. quinquenervia*.

This numeric score does provide us with a yardstick for comparisons with other classical biological control projects, and indicates the potential for this foliage-feeding weevil. Reviewing the results of other projects directly does not provide a clear prognosis for this weevil. While weevils are among the most commonly used biological control agents, the majority have been targeted at flowers and seeds (Julien, 1992). However, some foliage-feeding weevils have provided control for certain exotic weeds. Among the most notable have been several species of Bagoini weevils, which have controlled (at a variety of locations) giant water fern, *Salvinia molesta* D. S. Mitchell (Room *et al.*, 1981, 1990; Room and Thomas, 1985), water lettuce, *Pistia stratiotes* L. (Dray *et al.*, 1990; Harley *et al.*, 1990), and water hyacinth, *Eichhornia crassipes* (Wright, 1981; Center *et al.*, 1990). As mentioned in the introduction to this paper, large shrubs/trees have not been frequent targets for classical biological control, and therefore the results provide little guidance. A weevil that attacks vegetative growth and reduces seedling regeneration, was released against *Hakea sericea* in South Africa, and although it established at some sites, its impact on the host plant has been minimal (Kluge and Neser, 1991). The weevils released against *Acacia* spp. in South Africa are seed feeders (Denill and Donnelly, 1991) as are the bruchids released there against *Prosopis* spp. (Zimmerman, 1991). Several insects that feed on vegetative growth have recently been released against *Mimosa pigra* in Australia, but their impact has not yet been demonstrated (Farrell *et al.*, 1992; Forno, 1992). The leaf-feeding chrysomelid beetle, *Metrogaleruca obscura* DeGeer (=*Schematiza cordiae* Barber) was released against *Cordia curassavica* in Mauritius in 1948, Malaysia in 1977, and Sri Lanka in 1978 (Julien, 1992). This beetle had defoliated large stands of *C. curassavica* within 2 years of its release in Mauritius (Williams, 1952), resulting in the death of the trees or their replacement by other plant competitors (Goeden, 1978). Although *M. quinquenervia* can grow considerably larger than any of the above plant species, we have already demonstrated the rapid, negative impact on the growth rate of *M. quinquenervia* saplings by herbivores, especially those attacking vegetative growth (Balciunas and Burrows, 1993).

Permission to ship *O. vitiosa* to quarantine in Florida was received in June 1992, and the first shipment was hand-carried to the Florida Biological Control Laboratory's quarantine facility at Gainesville the following month. It is presently being evaluated there, primarily on Florida plant species which were unavailable in Australia. If *O. vitiosa* is released, *M. quinquenervia* will be, to the best of our knowledge, the largest tree species targeted by a classical biological control agent.

Since *O. vitiosa* primarily damages new foliage, we do not anticipate widespread mortality of mature *M. quinquenervia* trees in Florida. However, the growth of *M. quinquenervia* trees, especially saplings, is likely to be retarded. Balciunas (1990) has speculated that *O. vitiosa* may reduce this weed's notorious fire tolerance in Florida. While *M. quinquenervia* easily survives (even thrives) on the regular brush fires in Florida (Myers, 1983; Hofstetter, 1991), it is considered to be a fire-intolerant species in Australia (Tweddell, 1982; Hall *et al.*, 1990). This weevil may play a role in reducing the rate at which new sites in Florida are infested. However, adequate control of *M. quinquenervia* will likely require the establishment of numerous other biocontrol agents.

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