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POTENTIAL FOR BIOLOGICAL CONTROL OF THE LOBATE LAC SCALE, *PARATACHARDINA LOBATA LOBATA* (HEMIPTERA: KERRIIDAE)

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ABSTRACT

The lobate lac scale insect, *Paratachardina lobata lobata* (Chamberlin) (Kerriidae: Coccoidea: Hemiptera), a recent invader of southern Florida from India and Sri Lanka, now infests more than 160 economic and native plants in at least 49 plant families. It is killing wax myrtle (*Myrica cerifera* L.) and coco plum (*Chrysobalanus icaco* L.), valued native and horticultural plants in many locations. Intensive insecticide use in infested natural and residential areas is an unsuitable control approach because of the large numbers of plants infested, the high cost, and probable damage to non-target organisms. Biological control is a much needed solution for lobate lac scale. No parasitism has been detected in Florida. The lobate lac scale is native to India and Sri Lanka, occurring in localities south of 16 degrees N. latitude. The known host range includes some of the same species and families of host plants as it does in Florida, plus other plant groups on which it has yet to be detected in Florida. The natural enemies of the lobate lac scale have not been previously sought nor studied, but those of the related true lac scale of commerce are relatively well known, and some of these appear to have potential for biological control of the lobate lac scale. The most important natural enemies are predaceous Lepidoptera and *Chrysopa* species, and parasitic encyrtid and euplophid chalcidoid wasps. The chalcidoid wasps, with narrower host ranges, appear to be more suitable as potential biological control agents. Among these, *Tachardiaephagus tachardiae* Howard (Encyrtidae), seems particularly promising. It attacks the lobate lac scale, is known only from lac scale hosts, is not hyperparasitic, is one of the most important parasitoids of lac scale, has 9-12 generations per year, and occurs in the same climatic conditions as occur in southern Florida. It is recommended that this wasp and two other important parasitoids of the true lac scale, *T. somervilli* Madhihassen (Encyrtidae) and *Coccophagus tschirchii* Madhihassen (Eulophidae), be acquired and evaluated as potential biological control agents of the lobate lac scale. Explorations for unknown natural enemies of lobate lac scale in India and Sri Lanka should also be undertaken in locations with climatic similarity to that of southern Florida. Host specificity testing of species belonging to Florida's 12 native scale families (Coccoidea) and allied Hemiptera is advisable to define the potential host ranges and thus the safety of candidate biological control agents. The prospects of effective and safe biological control appear to be good. No native lac scales (Kerriidae) occur in Florida, and parasitoids are known that appear to be both narrow specialists and damaging to their host lac scales.

Key Words: New pest, native plants, fruit trees, ornamental plants, lac scales parasitoids, *Kerria lacca*, Everglades National Park, Big Cypress NWR, Florida, India

RESUMEN

La escama lobulada de la laca, *Paratachardina lobata lobata* (Chamberlin) (Kerriidae: Coccoidea: Hemiptera), un invasor reciente en el sur de la Florida y proveniente de la India y Sri Lanka, ahora infesta más de 160 plantas nativas y económicas en por lo menos 49 familias de plantas. Esta plaga esta matando árboles de arrayán, *Myrica cerifera* L., y de icaco, *Chrysobalanus icaco* L., dos plantas nativas y ornamentales valorizados en muchos lugares. El uso intensivo de insecticidas en áreas naturales y áreas residenciales infestadas es un método inapropiado de control por el gran número de plantas infestadas, el alto costo, y el daño posible a otros organismos que no son objetos de control. El control biológico es una solución muy necesitada para la escama lobulada de la laca. No se ha detectado parasitismo en la Florida. La escama lobulada de la laca es nativa de la India y Sri Lanka, ocurriendo en localidades al sur de los 16 grados de latitud norte. La variedad de hospederos conocidos incluye algunas de las mismas especies y familias de plantas hospederas que se encuentran en la Florida, más otros grupos de plantas que todavia no han sido detectados en la Florida. No se han buscados ni han estudiados los enemigos naturales de la escama lobulada de la laca, pero los de la escama verdadera de la laca de comercio, una escama relacionada, son relativamente bien conocidos, y algunos de ellos parecen tener un potencial para el control biológico de la escama lobulado de la laca. Los enemigos naturales más importantes son especies depredadores lepidópteros y *Chrysopa*, y avispas chalcidoideos parasíticos de las familias Encyrtidae y Eulophidae. Las avispas chalcidoideos, con un alcance de hospederos más estrecho, parecen ser agentes potenciales de control biológico más apropiados. Entre estos, *Ta-*

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chardiaephagus tachardiae (Howard) (Encyrtidae), parece ser una especie particularmente prometedora. Ataca la escama lobulada de la laca, se conoce solamente de hospederos de escamas de la laca, no es hiperparasítico, es uno de los parasitoides más importantes de la escama de la laca, tiene 9-12 generaciones por año, y ocurre en las mismas condiciones climáticas como ocurre en el sur de la Florida. Se recomienda que se adquiera y se evalue esta avispa y los dos otros parasitoides de la escama de la laca verdadera, *T. somervilli* Madhihassen (Encyrtidae) y *Coccophagus tschirchii* Madhihassen (Eulophidae), como agentes de control biológico potenciales de la escama lobulada de la laca. Se debe llevar a cabo exploraciones para enemigos naturales desconocidos de la escama lobulada de la laca en la India y Sri Lanka en localidades con un clima similar del sur de la Florida. Se aconseje hacer pruebas de especificidad de hospederos usando especies que pertenecen a los 12 familias de escamas (Coccoidea) nativas de la Florida y hemípteros relacionados para definir el alcance de hospederos potenciales y la seguridad de los candidatos de agentes de control biológico. Las perspectivas para el control biológico efectivo y seguro aparecen ser buenas. Ninguna de las escamas de la laca (Kerriidae) nativas se han encontrado ocurre en la Florida, y se conocen parasitoides que parecen ser especialistas restringidos y dañinos a sus hospederos de escamas de la laca.

Lobate Lac Scale Introduction, Impact and Potential Harm

The lobate lac scale, *Paratachardina lobata lobata* (Chamberlin), was first detected in southern Florida in 1999 (Hamon 2001), in Davie in Broward County (Division of Plant Industry [DPI], Florida Dept. of Agricultural and Consumer Services, collection record). During the spring and summer of 2002, the insect developed alarming densities on many host plants in Broward County. In a sample of a residential yard (0.33 acre = 0.135 hectare) in Ft. Lauderdale during August 2002, the scale was found to attack 55% (37/67) of the woody plant species present in 19 of 30 (63%) of the families (Pemberton, unpublished data). Preliminary surveys of natural areas in Broward and Miami-Dade Counties indicate high levels of attack on native plants. At Secret Woods Nature Center in Broward, the scale infests more than half of the tree and shrub species, and more than half of the individual plants examined (Pemberton, 2003). Many of the most important parks and preserves in southern Florida have been invaded, including: Everglades National Park, Big Cypress National Wildlife Refuge and Loxahatchee National Wildlife Refuge. Wax myrtle (*Myrica cerifera* L.), red bay (*Persea borbonia* (L.) Spreng.), coco plum (*Chrysobalanus icaco* L.), myrsine (*Rapanea punctata* (Lam.) Lundell), important ecological dominants of mesic habitats, and wild coffee (*Psychotria nervosa* Swartz), a dominant understory shrub in tropical hardwood hammock forest, are being killed in many localities. Coco plums and wax myrtles are important landscape plants in the region. Tropical fruits including avocado, grapefruit, mango, carambola (*Averrhoa carambola* L.), atemoya (*Annona cherimoya* Mill. × *A. squamosa* L.), sugar apple (*A. squamosa*), and other less important species are known hosts of the scale. Of these, carambola is the most severely damaged. Two of the most important invasive weeds in southern Florida, melaleuca (*Melaleuca quinquenervia* S.T. Blake) and Brazilian pepper *Schinus terebinthifolius* Haddi), are hosts of the scale, and the heavily infested large stands of melalecua appear to generate large numbers of the pest which then infest other plants. Thus far, the scale has been found infesting more than 200 plant species in 55 families in south Florida (Howard et al. 2002; Pemberton, unpublished data). Its negative effects will grow as it increases in abundance and spreads to new areas. The scale has also been recorded in the Bahamas (Hamon 2001). This insect could become a threat to cultivated and native vegetation in the West Indies and Mexico as well as the subtropical regions of Texas, California, and Hawaii.

Taxonomy and Identification

Specimens of a new lac scale found in southern Florida in 1999 were determined to be *Paratachardina lobata lobata* by Avas Hamon, Florida Division of Plant Industry (Hamon 2001) and confirmed by D. R. Miller, USDA-ARS-Systematic Entomology Laboratory. Many subsequent collections have been determined to be *P. lobata lobata*. This species first appeared in the literature in 1922, when E. E. Green published a detailed description and drawings of material from Sri Lanka. Green (1922) believed this insect to be conspecific with *Tachardia minuta* Morrison from the Philippines. Chamberlin (1923) recognized that the lobate scale from Sri Lanka was distinct and described it as the new species, *Tachardina lobata* (Chamberlin), based on a name used earlier by Green. The genus *Paratachardina* was separated from *Tachardina* by Balachowsky in 1950, but the new combination *Paratachardina lobata* was not published until 1976 (Varshney 1976a). The description of two subspecific taxa, *P. lobata* var. *schmidtii* (Madhihassen) and *P. lobata* var. *walczuchii* (Madhihassen) from India by Madhi-

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hassen (1946) resulted in a subspecific designation of *P. lobata lobata*. These subspecific separations were based primarily on differences in host plants from which the scales were collected, which is insufficient given the polyphagous nature of the species (R. K. Varshney, pers. comm.). Our Florida lobate lac scale appears to be similar to Green's drawings of the scale that became *P. lobata lobata*.

The lac scale family Kerridae is widely distributed in warmer parts of the New and Old World including Australia (Varshney 1976a). *Paratachardina* is in the subfamily Tachardininae with the genera *Afrotachardina* and *Tachardina*. The other subfamily in the family is the Tachardiinae, which contains *Austrotachardina*, *Kerria* (genus of the true lac scales), *Metatachardina*, *Tachardiella*, and *Austrotachardiella*. *Paratachardina* species are limited to the Old World, whereas *Austrotachardiella* and *Tachardella* (Tachardiinae) are the only New World genera in the family. Scales in the Tachardininae have horny testae, compared to testae composed of alcohol soluble resin in scales of the better known *Kerria* species and other members of the subfamily Tachardiinae**.** There are seven kerriid species in western United States, all in the genus *Tachardiella*, and a single *Austrotachardiella* species in Jamaica (Miller & Ben Dov 2002).

Native Range of the Lobate Lac Scale

The native range of the lobate lac scale, as defined in the literature, is Sri Lanka and the three southern states of India, below about 16 degrees north latitude. Recorded localities include the type localities of Peradeniya and Kandy in Sri Lanka, and Indian localities of Coimbatore in Tamil Nadu and Bangalore in Karnataka (Green 1922). Additional localities include Cuddapath in Andhra Pradesh (Ayyar 1930) and Calcutta in West Bengal (Varshney 1976a). The Calcutta locality, which is at nearly 23 degrees north latitude, is questionable because the scales from this collection were abnormal due to being parasitized which made their identification uncertain (R. K. Varshney, pers. comm.). Few specimens of the lobate lac scale exist in collections. The USNM has a single specimen, which is a paratype of Green's type material deposited at the University of California at Davis (D. R. Miller, pers. comm.). The Natural History Museum in London has no material (J. Martin, pers. comm.) and the scale is unlikely to be represented in Indian collections (Varshney, pers. comm.). I saw no material at the Indian Lac Scale Institute in Ranchi, Jarkhand during a September 2002 visit. A native distribution limited to southern India and Sri Lanka below 16 degrees north latitude is surprising given the scale's ability to thrive in southern Florida at about 26 degrees north latitude. Why it doesn't occur farther north in India is unclear. Perhaps the limited collection records do not adequately define the native distribution.

Host Plants of Lobate Lac Scale in its Native Range

The lobate scale was described from material collected from *Flacourtia* (Flacourtiacae) and *Fluggea* (Fabaceae) (Green 1922). The scale is known to be polyphagous and Varshney (1992) lists species in 42 genera of woody plants, in 25 families, as hosts, including: ***Annona***, *Aralia*, ***Acalypha***, ***Averrhoa***, ***Bauhinia***, *Cryptostegia*, ***Casuarina***, *Coffea*, *Celastrus*, ***Citrus***, ***Cestrum***, ***Dodonaea***, *Erythroxylum*, ***Ficus***, *Graptophyllum*, *Guazuma*, *Gymnosporia*, ***Hibiscus***, ***Hamelia***, *Kigelia*, *Loranthus*, ***Lagerstroemia***, ***Mangifera***, *Mallotus*, ***Michelia***, *Malpighia*, ***Pongamia***, *Pyrus*, *Punica*, *Phyllanthus*, *Semecarpus*, *Spondias*, *Stererospermum*, *Spathodea*, *Securinega*, *Sesbania*, *Santalum*, *Sterculia*, ***Terminalia***, and *Thespesia*. The genera in bold have been recorded as host species in southern Florida (Howard et al. 2002; Pemberton, unpublished data).

Need for Biological Control

Biological control offers a much needed solution to the lobate lac scale problem. No parasitism has been detected in the lobate lac scale populations in Florida. To attempt to detect parasitism, 3,000 mature female scales, collected on the twigs of 15 host plants (10 native plants and 5 non-native plants) in 7 localities (urban developed areas and nature preserves), were examined with a dissecting microscope for parasitoid emergence holes (Table 1). Three scales had possible parasitoid emergence holes. Dissections of these three scales found no evidence of parasitism (larval head capsules). During the process of examining and counting the 3,000 scales, large numbers of uncounted scales of various ages and sizes were scanned because the scales were in dense aggregations on the collected twigs. No emergence holes were noted in the uncounted scales.

Intensive use of insecticides to control this scale is problematic because of the cost to treat the large residential and natural areas infested, and the potential for environmental damage. Many scale insects have been successfully controlled by biological control, including the Florida red scale, *Chrysomphalus aonidum* (L.), formerly a pest in Florida (Kennett et al. 1999).

Recorded Predators of Lac scale, *Kerria lacca* (Kerr) in India

Little is known about the predators of lobate lac scale. By contrast, the predators and other natural enemies of commercial lac scale, *Kerria lacca* (Kerr) in India are better known, and the

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TABLE 1. EXAMINATION OF LOBATE LAC SCALES FOR PARASITISM-PARASITOID EMERGENCE HOLES

Collection Locality	Host plant N = Florida native	Date collected	No. examined	Holes?
Tree Island Weston, Broward Co. (preserve)	*Persea borbonia* (L.) Spreng. N	10 Oct. 2002	200	none
	Rapanea punctata (Lam.) Lundell N	10 Oct. 2002	200	none
Ft. Lauderdale, Broward Co. (residential area)	*Myrica cerifera* L. N	10 Oct. 2002	200	none
	Quercus laurifolia Michx. N	10 Oct. 2002	200	none
	Psychotria nervosa Swartz N	11 Oct. 2002	100	none
	Chrysobalanus icaco L. N	11 Oct. 2002	100	none
Secret Woods, Broward Co. (preserve)	*Ficus aurea* Nutt. N	21 Oct. 2002	100	none
	Baccharis glomeruliflora Pers. N	21 Oct. 2002	100	none
	Persea borbonia N	21 Oct. 2002	100	none
	Chrysobalanus icaco N	21 Oct. 2002	100	none
	Rapanea punctata N	21 Oct. 2002	100	none
	Eugenia axyridis (Swartz) Willd. N	21 Oct. 2002	100	none
Plantation, Broward Co. (business park)	*Quercus laurifolia* N	22 Oct. 2002	100	3?[1]
	Calophyllum antillanum Britt.	22 Oct. 2002	100	none
	Bursera simaruba (L.) Sarg. N	22 Oct. 2002	100	none
Heritage Park, Broward Co. (city park)	*Mangifera indica* L. N	22 Oct. 2002	100	none
	Ficus elastica Hornem.	22 Oct. 2002	100	none
	Bucida buceras L.	22 Oct. 2002	100	none
	Eugenia luschnathiana O. Berg.	22 Oct. 2002	100	none
Everglades NP, Dade Co. (preserve)	*Persea borbonia* N	27 Oct. 2002	100	none
	Chrysobalanus icaco N	27 Oct. 2002	100	none
	Rapanea punctata N	27 Oct. 2002	100	none
Big Cypress NWR, Collier Co. (preserve)	*Salix caroliniana* Michx. N	27 Oct. 2002	100	none
	Chrysobalanus icaco N	27 Oct. 2002	100	none
	Ficus aurea N	27 Oct. 2002	100	none
	Myrica cerifera N	27 Oct. 2002	100	none
Total			3000	3?[1]

[1]Dissection of the three scales with holes found no evidence of parasitism such as larval head capsules.

most important species are relatively well studied. The most important invertebrate predators of the commercial *K. lacca* are predatory Lepidoptera (primarily *Eublema amabilis* Moore (Noctuidae) and *Pseudohypatopa* (= *Holcocera*) *pulvera* Meyr; (Blastobasidae), followed by lacewings (*Chrysopa* spp., Chrysopidae: Neuroptera) (Narayanan 1962). The predators causing the greatest mortality of *K. lacca* are *E. amabilis* and *P. pulvera*, which can destroy 35-40% of a lac crop (Malhotra & Katiyar 1975 cited by Sharma & Jaiswal 2002). Their larvae feed on the scales from silken tubes and consume between 40 and 60 scales during their development. The *Chrysopa* spp. are sporadic pests that sometimes cause significant morality (Sharma & Jaiswal 2002). The important predators of *K. lacca* are thought not to be limited to lac scales in their range of prey (Sharma & Bhattacharya, pers. comm.). Less important predators include many moths and lacewings (Narayanan 1962), a cucujid, a tenebrionid, a mycetophagid, several blattellids (Bhattacharya 2002), as well as an assortment of coccinellids and other insects (Sharma et al., unpublished data). Coccinellids may be worth investigating because many species are scale specialists (Hodek 1973). The earliest and perhaps best known example of insect biological control involved the vedalia beetle, *Rodolia cardinalis* (Mulsant) on the cottony cushion scale (*Icerya purchasi* Maskell) in California during the late 1800s (DeBach 1974). A scale-feeding coccinellid (*Cryptognatha nodiceps* Marshall) successfully controlled the coconut scale (*Aspidiotus destructor* Signoret) in Fiji (Sweetman 1936), but coccinellids can have difficulty in successfully controlling some scales with hard coverings, such as many Diaspididae (Clausen 1940). This suggests that coccinellids might have difficulty controlling the lobate lac scale which has a very hard testa.

Recorded Parasitoids of Lac Scales (Kerriidae)

Varshney (1976b) lists and discusses 28 parasitoids recorded from lac scale species worldwide. The four braconid wasps listed are erroneously recorded as lac scale parasitoids and are actually parasitoids of some of the many predacious Lepidoptera that attack lac scales (Editor V. K. Gupta's note in Varshney 1976b). The remaining 24 species are all chalcidoid wasps (Aphelinidae, Encyrtidae, Eulophidae, Eupelmidae and Pteromalidae). Most

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(16) of these have been recorded from the commercial lac scale in India. The nine parasitoids which regularly attack the commercial lac scale (Narayanan 1962) are listed in Table 2.

The parasitoids of lobate lac scale have not been sought nor studied, but three species, *Tachardiaephagus tachardiae* Howard (Encyrtidae), *Tetrastichus purpureus* Cameron (Eulophidae), and *Marietta leopardina* Nietner (Aphelinidae), are reported to attack it (Varshney 1976b). *Tetrastichus purpureus* is a primary parasitoid of lac scales and a hyperparasitoid of chalicidoid primary parasitoids of lac scales. *Marietta leopardina* also is probably a hyperparasitoid of chalcidoids attacking lac scale, as is another parasitoid, *Marietta javensis* Howard, commonly reared from commercial lac (Narayanan 1962). Riek (1970) observed that *Marietta* species are hyperparasitoids. *Tachardiaephagus tachardiae* and two other parasitoids commonly associated with the commercial lac scale, *Tachardiaephagus somervilli* Madhihassen (Encyrtidae) and *Coccophagus tschirchii* Madhihassen (Eulophidae), are not known to be hyperparasitoids nor have alternative hosts (Narayanan 1962). The latter two species also may have the ability to parasitize the lobate lac scale.

Parasitoid Biology, Abundance, and Impact on Commercial Lac Scale in India

Lac scale parasitoids are well adapted to their hard-bodied hosts. The wasps lay one or more eggs through the anal tubercular opening on top of the testa, and either oviposit on or in the body of the scale, depending on the parasitoid species (Narayanan 1962). Superparasitism can occur but typically one parasitoid larva occurs in a single scale (Narayanan 1962). The parasitoids have life cycles of about one month in length, compared to 4-9 months, depending on the scale strain and season, for *K. lacca* (Narayanan 1962). The parasitoids can therefore have many generations within a particular scale colony, attacking older stages as the scale colony matures.

Of the regularly occurring parasitoids, *Tachardiaephagus tachardiae* and *Tetrastichus purpureus* are the most abundant (Bhattacharya 2002). *Tachardiaephagus tachardiae*, *Tetrastichus purpureus*, and *C. tschirchii* have 10-12 generations on commercial lac each year, compared to 9 generations for *Paraechthrodryinus clavicornis* Cameron, an encyrtid that can be either a primary or secondary parasitoid (Narayanan 1962). The level of parasitism, measured for the regularly occurring parasitoid complex for seven years from 1928 to 1935, was only 4.8%, but in certain localities and seasons the parasitism level could be as high as 50% (Narayanan 1962). Chauhan (1984 cited in Sharma & Jaiswal 2002) reinterpreted these data and reported that parasitism of the relatively more important females was between 20-37%. Parasitized scales are consumed in large numbers by predatory Lepidoptera larvae, primarily *E. amabilis* and *H. pulvera*, which are the major pests of lac scale culture. After cultural methods were developed to reduce the abundance of these lac scale predators, the average parasitism level jumped to about 30% (Bhatta-

TABLE 2. MOST IMPORTANT PARASITOIDS OF LAC SCALE, *KERRIA LACCA* IN INDIA (NARAYANAN 1962 AND VARSHNEY 1976B). SPECIES IN BOLD ARE KNOWN TO PARASITIZE THE LOBATE LAC SCALE.

Parasitoid families and species	Alternate hosts	Hyperparasitoid?	Comments
Eulophidae			
Coccophagus tschirchii Madhihassen	*Kerria*	no	
Marietta javensis Howard	*Aspidiotus* (Diaspididae)	yes, of chalcidoids of *K. lacca*	chiefly on males
Marietta leopardina Nietner		probably	
Tetrastichus purpureus Cameron	*Aspidiotus* (Diaspididae) *Chionaspis* (Diaspididae)	yes, of *C. tschirchii* and *T. tachardiae*	primary and secondary parasitoid
Encyrtidae			
Erencyrtus dewitzi Madhihassen	*Kerria*, *Metatachardia conchiferata* (Green)	no	chiefly on 4th instar females
Eupelmus tachardiae Howard	*Machaerota* (Machaerotidae)	yes, of *Microbracon* and *Apanteles*	primary and secondary parasitoid
Parechthrodryinus clavicornis Cameron	*Kerria*	yes, of chalcidoids of *K. lacca*	
Tachardiaephagus tachardiae Howard	*Kerria*	no	
Tachardiaephagus somervilli Madhihassen	*Kerria*	no	

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charya, pers. comm.). This level occurs despite the abundant and persistent hyperparasitoids which presumably kill many primary parasitoids.

Recorded Pathogens of Commercial Lac Scale in India

Sharma & Jaiswal (2002) reviewed the literature on diseases of lac scale. Most of the organisms involved are fungi and these are primarily black molds, such as species of *Capnodium*, *Fumago*, and other species that grow on the honeydew secreted by the scales. These fungi can cause losses in lac yield because their growth inhibits the respiration, mating, larval emergence, and efficient use of the plant by the scale. A *Pythium* sp. is reported to cause heavy mortality of the larvae, which fail to complete development (Misra 1928 cited in Sharma & Jaiswal 2002).

Biological Control Approaches for the Lobate Lac Scale

Several biological control approaches to acquire natural enemies appear feasible. Because the natural enemies of lobate lac scale have been neither sought nor studied, explorations for its natural enemies should be made in its native range. The Biological Control Institute in Bangalore has expressed a willingness to provide assistance in such a research project (J. Rabindra, pers. comm.). Bangalore is a locality where the lobate lac scale has been collected so would be a good base to conduct surveys. It is not known how common the lobate lac scale is within its native range. Green (1922) indicated that he had known the species for more than 20 years, suggesting that it might be common at least in parts of Sri Lanka. For this reason, surveys should be made in Sri Lanka as well as in southern India. Baiting for parasitoids and other natural enemies, with scale cultures of a range of age-size classes, in lobate lac scale's native range could be informative and profitable, especially if the lobate lac scale is uncommon or has a patchy distribution.

Another approach would be to examine the potential of using parasitoids of commercial lac scale for the control of lobate lac scale. Some, including *Tachardiaephagus tachardiae*, are known to attack lobate lac scale and others may have the potential to use the scale. In September 2002, I visited the Indian Lac Institute in Ranchi, Jarkhand, India, and R. K. Varshney in Aligarh, Uttar Pradesh, India, to investigate the possibilities of using the parasitoids of the commercial lac scale for the biological control of lobate lac scale. The Indian Lac Institute was established in 1926 to conduct research on lac scale cultivation and lac scale products which include resin, waxes, dyes and other chemicals. Lac cultivation is an ancient agricultural activity and cottage industry in India, that was mentioned in the Hindu Vedas more than 2,000 years ago (Mukhopadhay & Muthana 1962). Income from lac is an important subsidiary income for farmers and forest-dwelling peoples in Bihar, Jarkhand, Orrissa and other areas of India (Mukhopadhay & Muthana 1962).

Scientists at the Indian Lac Institute are intimately familiar with lac scale cultivation and maintain lac scale cultures for research purposes, including research on the pests of lac scale. They have the capability to collect desired parasitoids that emerge from their cultures and ship them to a Florida quarantine laboratory. Adults of lac scale parasitoids are apparently short-lived (A. Bhattacharya, pers. comm.) but, if fed with honey, they might live long enough to be successfully shipped to Florida. The Lac Institute also has the capability to provide lac scale parasitized with desired parasitoid species. To do this, they could rear parasitoids of interest from their lac scale cultures, and induce these to parasitize clean (unexposed) even-aged cultures of the lac scale. The parasitized lac scale could be protected from additional parasitism by unwanted species and maintained for several weeks to allow for parasitoid development, and then shipped to Florida quarantine prior to adult parasitoid emergence. Because the temporal life cycles of lac scale strains are well known, it would be possible to induce parasitism in cultures of large recently mated female scales that are months away from producing crawlers. After parasitoid emergence and transfer to lobate lac scale cultures in the Florida quarantine laboratory, the lac scale hosts could be destroyed prior to crawler emergence. Advantages of obtaining parasitoids from lac scale cultures at the Lac Institute would include the following: (a.) known, desired parasitoid species could be obtained in sufficient numbers; (b.) these should have few if any hyperparasitoids; and (c.) the potential risk related to large numbers of small crawlers associated with the commercial lac hosts could be avoided. Because the lac scale is quite polyphagous (Varshney 1992), its regularly occurring parasitoids probably have the ability to locate the scale on very diverse host plants. This behavioral trait should give these parasitoids the ability to locate lobate lac scale on its diverse plant hosts in Florida. *Tachardiaephagus tachardiae* is the parasitoid of most interest because it is known to be able to attack the lobate lac scale. Two other parasitoids, *Tachardiaephagus somervilli* and *C. tschirchii*, should be tested as well. They are not recorded to parasitize lobate lac scale, but the absence of recorded parasitism may reflect the lack of parasitoid rearing on the lobate lac scale. Most of the research on lac scale predators and parasitoids has been done north of the apparent native range of the lobate lac scale in India. The commonness of these parasitoids, despite the presence of predators and hyperparasitoids, suggests the capacity to develop large populations when freed of these enemies. This could make them valuable in

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lobate lac scale control in Florida. These parasitoids should also be able to establish and thrive in the climatic conditions of southern Florida because the climates of Ranchi, Jarkhand and southern Florida are similar. Ranchi is located at 24 degrees N. latitude and 600 meters above sea level, compared to Miami at 26 degrees N. near sea level. Both areas have cool dry winters, hot rainy summers, and infrequent frosts.

Safety Considerations of Lobate Lac Scale Biological Control

The adoption of nontarget native insects by introduced biological control insects has been increasingly documented in recent times (Louda et al. 2003). The potential host range of candidate biological control insects should be predicted prior to their release to lessen the risk to native insects and introduced insects of value (Strong & Pemberton 2000). This can be accomplished by an evaluation of the well-known taxonomically limited prey specialization of some natural enemy taxa, and host-specificity testing research. Host-specificity testing of parasitoids has been shown to be a good predictor of field host range (Barratt et al. 2000) and is recommended for candidate biological control agents of the lobate lac scale. Risk to nontarget insects depends on how closely related the potentially exposed, valued insect fauna is to the lobate lac scale, and the degree of specificity of the natural enemies employed against the lobate lac scale. There are no native species of the lac scale family (Kerriidae) in Florida and, as mentioned above, only seven kerriids occur in the United States and these are confined to the arid Southwest which would probably preclude both exposure and adoption by parasitoids introduced to Florida. Neither the genus *Paratachardina* nor the subfamily to which it belongs (the Tachardininae) occur in the New World (Varshney 1976a), so there are no closely related scales in the region. The closest family members are *Tachardiella* species in Texas and Mexico and a single *Austrotachardiella* species in Jamaica (Miller & Ben Dov 2002). Testing of some species in these genera should be considered, although obtaining and/or culturing them could be difficult. Representative species of the 13 native scale families (superfamily Coccoidea) in Florida also should be tested. These families are the Aclerdidae, Asterolecaniidae, Cerococcidae, Coccidae, Conchaspidae, Dactylopidae, Diaspididae, Eriococcidae, Kermesidae, Lecanodiaspididae, Margarodidae, Ortheziidae, and Pseudococcidae (derived from Miller and Ben Dov in 2002 by F. W. Howard). The inadvertent reduction of native scale populations by introduced natural enemies might have consequences far beyond the scales affected. *Dactylopius* scales illustrate the point. *Dactylopius* species have been successfully used in many parts of the world to control exotic weedy prickly pear cacti (*Opuntia* species) (Julien & Griffiths 1998). This suggests that *Dactylopius* species play a role in regulating their host *Opuntia* in their native areas, such as in Florida. Reduction of *Dactylopius* scales could reduce or eliminate their regulatory effects, which could allow some host *Opuntia* species to become unnaturally abundant. One Florida species, *Opuntia stricta* (Haworth) Haworth, has been a severe weed in many parts of the world (Julien & Griffiths 1998), where it has been introduced and without its natural enemies. Representatives of other hemipteran families, particularly those that have species with sessile or sedentary nymphs, should be tested. This includes: the recently introduced psyllid *Boreioglycaspis melaluecae* Moore, a promising biological control agent of *Melaleuca quinquenervia* (Cav.) S.T. Blake; *Calophya* spp. (Psyllidae) Similarly Hemiptera being evaluated as potential biological control agents of Brazilian pepper and strawberry guava (*Psidium cattleianum* Sabine) in Florida should be tested. These include and *Tectoccocus ovatus* Hempel (Eriococcidae) respectively (J. P. Cuda, pers. comm.). Although it is desirable to avoid nontarget use of native insects, the potential adoption of some native insects as hosts should not in my opinion automatically exclude the introduction of a promising natural enemy. The potential risk to native and valued insects needs to be evaluated in relation to the potential benefit gained by control of lobate lac scale, which is a great threat to native and economic vegetation in Florida and elsewhere where it is likely to spread. It should be possible, however, to find and employ natural enemies with narrow enough host ranges to minimize the risk to nontarget species. Parasitoids will probably be safer agents than predators.

A cooperative biological control effort against the lobate lac has been developed. Participants at this point include this author, R. W. Pemberton (USDA-ARS), R. Nguyen (Division of Plant Industry, Bureau of Methods and Biological Control, Gainesville, Florida), F. W. Howard (University of Florida, IFAS, Davie), Florida, and Indian cooperators at the Indian Lac Institute and Biological Control Institute in Bangalore.

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