Parasitoid Complex of the Mealybug *Oracella acuta* (Lobdell) (Hemiptera: Pseudococcidae), in Georgia, USA[1]

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Abstract The parasitoid complex of the mealybug *Oracella acuta* (Lobdell) was examined in two field populations in Georgia in 1995-96. *Allotropa* n. sp. and *Zarhopalus debarri* Sun were the primary endoparasitoids emerging from *O. acuta*. Adult abundance varied seasonally, with *Allotropa* n. sp. numbers peaking in June and *Z. debarri* in September. Parasitism rates of female *O. acuta* exceeded 60% at one site and ranged from 24 to 29% at the other site. The adult female was the preferred host stage for parasitism (76%), though *Allotropa* n. sp. and the endoparasitoid *Acerophagus coccois* E. Smith occasionally utilized second and third instar females as hosts. These two species exhibited gregarious parasitism, with up to 5 *Allotropa* n. sp. or 4 *A. coccois* emerging from a single host. Adult longevity of female and male *Z. debarri* averaged 6.4 and 5.3 days, respectively, and access to a food source usually increased adult lifespan. Female *Z. debarri* contained an average of 119 eggs, compared to 74 eggs per female for *Allotropa* n. sp.

Key Words *Oracella acuta*, parasitoids, biological control, gregarious parasitism

The pine-infesting mealybug, *Oracella acuta* (Lobdell), was accidentally introduced into Guangdong Province, China in 1988 from pine cuttings taken from the United States (Sun et al. 1996). It has since spread at an exponential rate, apparently due to the lack of natural enemies (Zhou et al. 1994). By June 1995 the infestation covered 212,540 ha of slash pine, *Pinus elliottii* Englm., in southeastern China (Sun et al. 1996). Over 352,400 ha of slash pine are now affected, and the infestation is nearing stands of loblolly pine, *P. taeda* L. (Ren et al. 2000). Symptoms of infestation include the presence of the characteristic white "resin cells" covering the body of females and heavy accumulations of black sooty mold (Clarke et al. 1990). Tree growth and resin production may be severely affected, but mortality has been rare (Ren et al. 2000).

Control efforts in China, including attempts to find native natural enemies, have been ineffective in containing the rapid spread and damage of the mealybug (Yang 1991, Pan et al. 1994, Pang and Tang 1994, Zhou et al. 1994). In the absence of natural enemies, populations increased 1.26 times each generation (Tang et al.

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1996). Thus, a new approach, the importation and release of exotic biological control agents (classical biological control), was considered as a potential strategy against this introduced pest.

In the southeastern United States, *O. acuta* attacks loblolly pine, slash pine, longleaf pine (*P. palustris* Mill.), Virginia pine (*P. virginiana* Mill.) and shortleaf pine (*P. echinata* Mill.) (Johnson and Lyon 1988, Clarke et al. 1992). *Oracella acuta* has four and sometimes five generations per year in southern Georgia (Clarke et al. 1990). Three major hymenopteran parasitoids have been reported: a platygastrid, *Allotropa* n. sp.; an encyrtid,. *Acerophagus coccois* E. Smith; and a signiphorid, *Chartocerus* sp. (Clarke et al. 1990, 1992). A new species of encyrtid wasp, *Zarhopalus debarri* Sun, is also a primary parasitoid of *O. acuta* (Sun et al. 1998, 2002). These parasitoids and other natural enemies normally maintain the population at low levels, preventing any noticeable damage (Clarke et al. 1990, Sun et al. 1996), and finding substantial numbers of both *O. acuta* and its parasitoids is difficult. Detectable populations of the mealybug usually occur in intensively-managed sites such as seed orchards and Christmas tree farms and are associated with the adverse effects of insecticide applications on the natural enemies (Nord et al. 1985, Clarke et al. 1988, 1992).

An evaluation of the relationship between the host and the natural enemies in the native environment is critical in selecting the appropriate parasitoid for classical biological control (Myers et al. 1989). Detailed, extensive field studies of the life histories of the parasitoids and their host in endemic and outbreak populations might help determine which, if any, of the parasitoids can regulate mealybug populations (Hassell 1986). To help design an effective biological control program for *O. acuta* in China, we initiated a study of the parasitoid complex in the southeastern United States. The objective was to examine the species composition, host stage preference, seasonality, longevity, and development of the predominant parasitoids.

Materials and Methods

Field sites. Two active infestations of *O. acuta* were located in Georgia in 1995-1996. The first site was a loblolly pine seed orchard established in 1978 in Toombs Co. (hereafter labeled TC 1). The organophosphorous insecticide azinphosmethyl (Guthion®; Mobay Chemical Company, Kansas City, MO) was applied aerially every year, with applications in 1995 on 6 April, 2 July, and 21 September; in 1996 on 29 April, 1 June, 17 July, and 30 August. The application rate was 3.36 kg AI/ha. A 5-year-old loblolly pine plantation (TC 2) near the seed orchard was also sampled. No insecticides had been applied in this plantation since 1993. The second site was a 3-year old loblolly pine plantation located in Effingham Co. (EC). One section of the plantation (EC 1) had received eight insecticide applications per year of the pyrethroid insecticide, permethrin (Pounce®, FMC, Philadelphia, PA), at a rate of 110 mL/ha to control Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), in 1993 and 1994. Another section (EC 2) was treated only with herbicide or fertilizer. A third section (EC 3) had not been treated with pesticides for the previous 2 yrs.

Species composition. All locations were sampled weekly or bi-weekly from April through October in 1995 and 1996. At least 60 shoots (10 to 15 cm) with resin cells produced by *O. acuta* were randomly collected at each site. The actual number of *O. acuta* collected was dependent on the population levels at the time of the sampling. Twenty shoots per week were inserted into small glass tubes (12 × 2 cm) filled with

water and individually placed in a 19.5 × 8 cm mailing tube for rearing of parasitoids. The mailing tubes had a small hole drilled in the side in which a 6 × 1.5 cm glass vial was inserted. The rearing tubes were maintained at room temperature beneath a light source for 45 days to ensure that all parasitoids had adequate time to emerge. Parasitoids were collected from the vials daily, sorted by species and sex, and counted. Unknown parasitoid species were sent to experts on hymenopteran systematics for identification. A subset of the predominant parasitoids collected was measured to obtain size estimates.

Host stage preference. All resin cells on 50 shoots from each sample site on each collection date were dissected. The developmental stage of all parasitized female *O. acuta* was recorded. Males were not considered, as they are much smaller than females and parasitism of males has yet to be documented.

Parasitization rates. In July 1995, 198 additional infested shoots were collected to determine the parasitization rates at the field sites. All resin cells were dissected, and the numbers of total and parasitized *O. acuta* females were recorded. For parasitized females, the number of parasitoids apparently developing within each host was also recorded.

To examine gregarious parasitism, 115 parasitized *O. acuta* females (mummies) collected in August and September 1995 were placed individually in gelatin capsules and stored in a growth chamber at 30°C and 80% RH. The 98 adults were sorted by the number of parasitoids (1 to 5) apparently developing within each female. The 3 second instars and 14 third instars contained only one apparent endoparasitoid. The species and number of emerged parasitoids per mummy were recorded.

Longevity and fecundity. The longevity of *Allotropa* n. sp. was examined by pairing newly-emerged adults and placing them in cages containing potted loblolly pine seedlings infested with *O. acuta*. The caged seedlings were placed in a greenhouse at 26°C and 70% RH. The cages were checked every 2 days and the numbers of newly-emerged parasitoids counted. The adults were held in Petri dishes (15 × 100 mm) in the greenhouse until death.

Due to a lack of greenhouse space, the influence of temperature, as well as the availability of food, on the longevity of *Z. debarri* adults was monitored in the laboratory. Newly-emerged adult parasitoids were placed in Petri dishes (15 × 100 mm) and held in temperature cabinets at 70% RH and temperatures of 20, 26, or 30°C. Approximately half of the parasitoids were supplied with the artificial diet Eliminade™ (Entopath, Easton, PA), while the other half were not fed. This diet has been shown to increase the longevity and egg production of parasitoids of the southern pine beetle, *Dendroctonus frontalis* Zimmermann (Mathews and Stephen 1997). The duration (days) of adult survival, with and without a food source, was recorded.

To estimate fecundity, newly emerged adults of both species were paired for mating in Petri dishes (15 × 100 mm). Two days after mating, females of both species were crushed between two microscope slides and numbers of eggs counted using a microscope.

Statistical analysis. Where appropriate, data were subjected to analysis of variance (ANOVA) (SAS Institute 1997). Means were separated using Tukey's Studentized Range (HSD) Test ($P < 0.05$).

Results

In 1995, *Allotropa* n. sp. accounted for 54.1% of the total of parasitoids reared from the tubes (Fig. 1). *Zarhopalus debarri* comprised 24.6% of the total. Other parasitoids

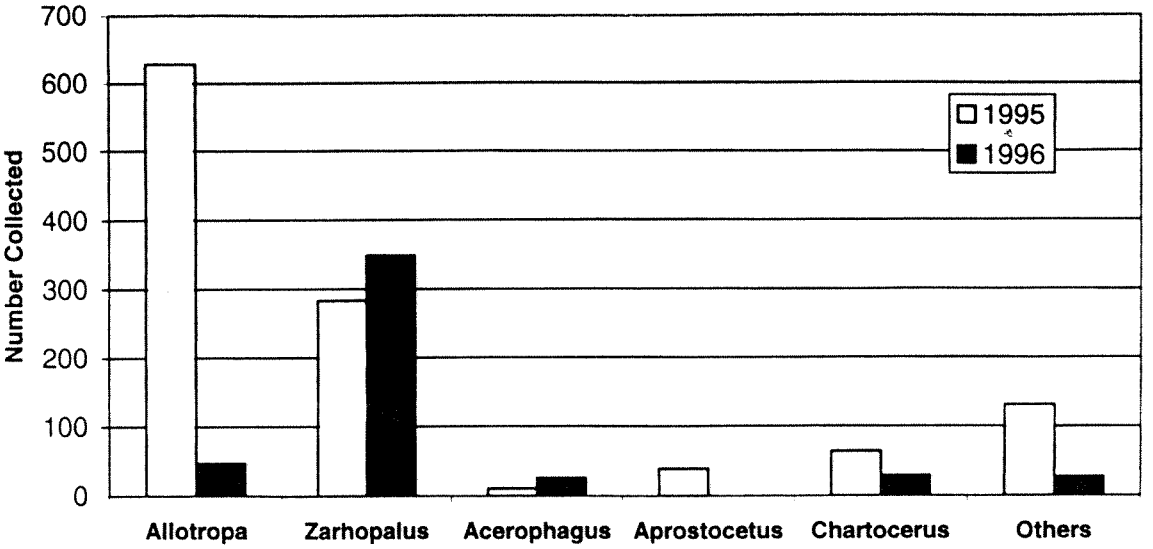

Fig. 1. Numbers of *Allotropa* n. sp., *Zarhopalus debarri, Acerophagus coccois, Aprostocetus* sp., *Chartocerus* sp., and other parasitoids of the mealybug *Oracella acuta* collected from two field sites in Georgia, 1995-1996.

collected and identified were *Acerophagus coccois, Chartocerus* sp., *Aprostocetus* sp. (Eulophidae), *Prochiloneurus* sp. (Encyrtidae), and *Aenasius* sp. (Encyrtidae). *Chartocerus* spp. and *Prochiloneurus* spp. are suspected to be hyperparasitoids, as they have been listed as hyperparasitoids in other mealybug-parasitoid systems (Neuenschwander and Hammond 1988, Pitan et al. 2000).

The number of *Allotropa* n. sp. collected declined precipitously in 1996, while numbers of *Z. debarri* increased to 73.1% of the total parasitoids collected (Fig. 1). Seasonal variation was evident in collections of the two predominant parasitoids. *Allotropa* n. sp. emergence peaked in June in both years, while *Z. debarri* adults were most abundant in September (Fig. 2).

The sex ratio (♀:♂) of the emerging parasitoids was 1.3:1 for *Allotropa* n. sp, 1.5:1 for *Z. debarri,* 0.9:1 for *A. coccois,* and 2.6:1 for Chartocerus sp. The sex ratio was not calculated for the other species. Adult *Allotropa* n. sp. had a mean (±SE) length of 0.48 ± 0.07 mm and a mean width of 0.28 ± 0.02 mm. Adult *Z. debarri* were much larger than *Allotropa* n. sp., and size differences between the sexes were evident. Females averaged 1.36 ± 0.26 mm in length and 0.68 ± 0.05 mm in width (pronotum), while males were smaller, averaging 0.96 ± 0.21 mm and 0.32 ± 0.06 mm in length and width, respectively.

The parasitization rates of female *O. acuta* at the Effingham Co. plantation ranged from 58 to 63%, while lower rates (24 to 29%) were observed at the Toombs Co. site (Table 1). Though mean numbers of females per shoot (F = 1.67; df = 4, 194; P = 0.158) and developing parasitoids per host (F = 1.59; df = 4, 194; P = 0.179) did not differ significantly by site, mealybug density (resin cells/shoot) within a site was numerically higher in the section of the plantation or orchard that had received the most recent insecticide treatments (EC1 and TC1). These two sections also had lower numbers of developing parasitoids per host.

Primary parasitoids emerged from only 39 of 98 parasitized females (Table 2).

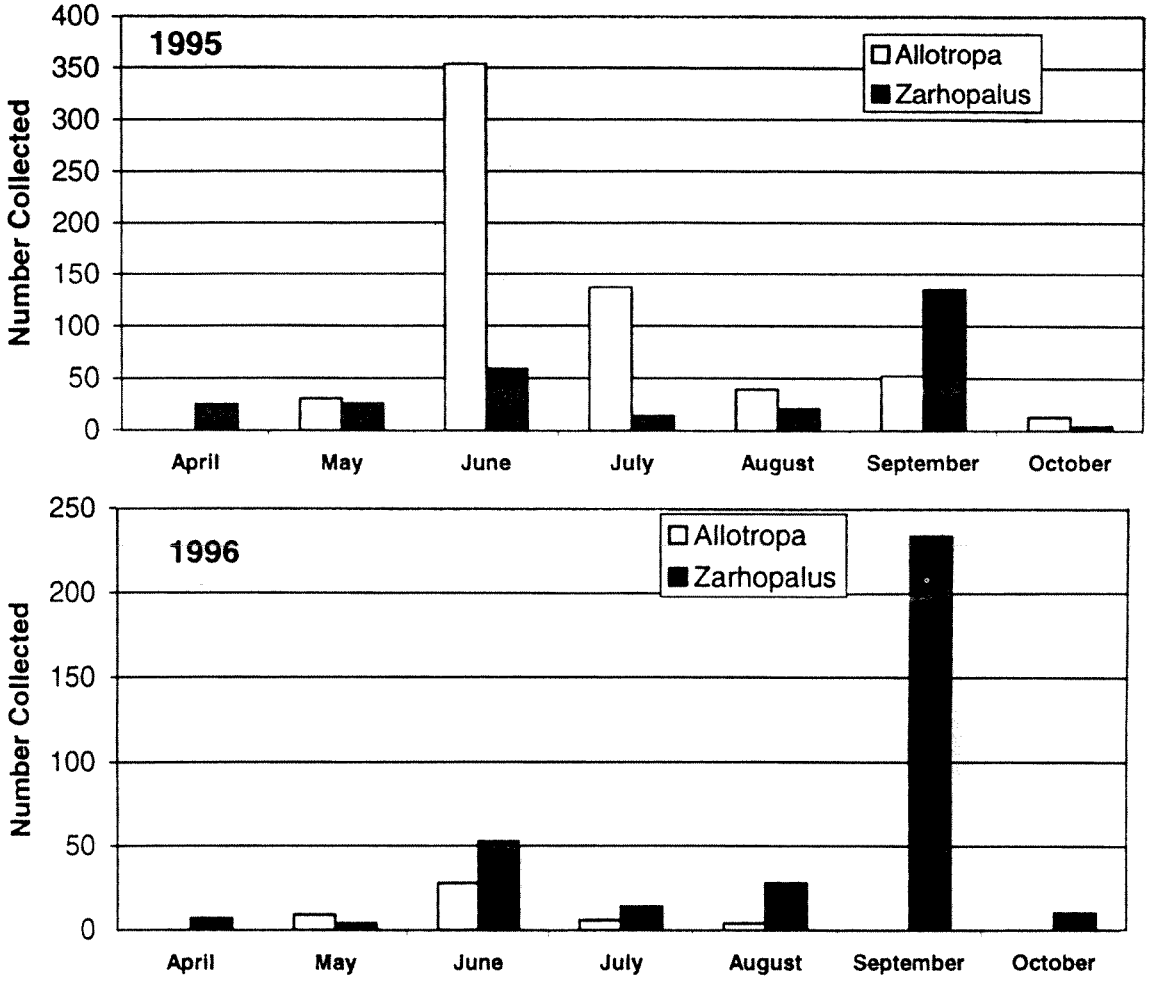

Fig. 2. Collections of *Allotropa* n. sp. and *Zarhopalus debarri*, parasitoids of *Oracella acuta*, by month from two field sites in Georgia; April-October, 1995-1996.

Emergence rates of developing parasitoids were lower when more than one parasitoid was within the host. However, parasitoid production from gregarious parasitism (30 parasitoids from 50 hosts) was slightly higher than from solitary parasitism (23 parasitoids from 48 hosts). *Zarhopalus debarri* only emerged from hosts with one developing parasitoid, while *Allotropa* n. sp. and *Acerophagus coccois* exhibited both solitary and gregarious parasitism. Six *Prochiloneurus* sp. emerged, five from solitary parasitized hosts. One emerged from a gregariously parasitized host, but no primary parasitoids emerged from this mummy.

Examination of 3,268 parasitized female *O. acuta* found that 76% of the hosts were adults. Second and third instars accounted for 7% and 17% of the total parasitized hosts, respectively. One *Allotropa* n. sp. emerged from the 3 parasitized second-instar mealybugs placed in gelatin capsules, and 2 *Allotropa* n. sp. and 2 *Z. debarri* emerged from the 14 third-instar hosts.

Longevity of *Z. debarri* adults ranged from 2 to 11 days and varied with temperature and availability of food. In general, adult longevity increased with decreasing temperature (Table 3). In all but one instance (females at 20°C), access to a food source also significantly increased adult longevity. Overall, adult females lived a

Table 1. Parasitism of *Oracella acuta* in resin cells on infested loblolly pine shoots collected at Effingham and Toombs Counties, GA July 1995

Site	Number of shoots examined	Number of female *O. acuta*	Mean (±SEM) female *O. acuta* per shoot	Number of parasitized *O. acuta*	Parasitization rate (%)	Total developing parasitoids	Mean (±SEM) parasitoid progeny per parasitized host
EC 1	46	247	5.30 ± 1.44	156	63.2	195	1.25 ± 0.46
EC 2	69	164	2.38 ± 0.78	96	58.5	212	2.21 ± 0.29
EC 3	20	52	2.60 ± 0.83	30	57.7	59	1.97 ± 0.90
TC 1	43	150	3.49 ± 1.25	44	29.3	64	1.45 ± 0.57
TC 2	20	21	1.05 ± 0.08	5	23.8	15	3.00 ± 0.43

Table 2. Parasitoid emergence from *Oracella acuta* females parasitized by *Allotropa* n. sp., *Acerophagus coccois*, or *Zarhopalus debarri*

Number of parasitoids developing per host	N	Number of hosts with emerging primary parasitoids	Percent emergence per parasitized host	Primary parasitoids emerging*	Percent emergence of potential parasitoids	Ratio parasitoids/hosts**
1	48	23	47.9	6 *Allotropa* n. sp.	47.9	0.48:1
				1 *A. coccois*		
				16 *Z. debarri*		
2	22	6	27.3	1 *Allotropa* n. sp.	18.2	0.36:1
				1 *Allotropa* n. sp.		
				1 *Allotropa* n. sp.		
				1 *Allotropa* n. sp.		
				1 *Allotropa* n. sp.		
				2 *Allotropa* n. sp.		
				2 *A. coccois*		
3	16	4	25.0	1 *Allotropa* n. sp.	16.6	0.5:1
				2 *Allotropa* n. sp.		
				3 *Allotropa* n. sp.		
				2 *A. coccois*		
4	6	3	50.0	1 *Allotropa* n. sp.	25.0	1:1
				1 *Allotropa* n. sp.		
				4 *A. coccois*		
5	6	3	50.0	5 *Allotropa* n. sp.	26.7	1.3:1
				1 *Allotropa* n. sp.		
				2 *Allotropa* n. sp.		

* Each entry for gregariously parasitized hosts (2-5 parasitoids developing per host) represents emergence from one host.

** Ratio of total parasitoids emerging (column 5) to number of hosts (column 2).

Table 3. Effects of temperature and feeding on longevity (mean ± SEM) of adult *Zarhopalus debarri* held in temperature cabinets at 70% relative humidity

		Males		Females	
Temperature	Food Provided	n	Longevity (days)	n	Longevity (days)
20°C	No	18	4.4 ± 0.2c	20	8.4 ± 0.2a
20°C	Yes	27	9.4 ± 0.5a	16	7.1 ± 0.4b
26°C	No	13	4.2 ± 0.2c	15	5.3 ± 0.2c
26°C	Yes	15	5.8 ± 0.2b	19	7.4 ± 0.2b
30°C	No	8	2.8 ± 0.2d	19	4.4 ± 0.2d
30°C	Yes	14	5.2 ± 0.2b	18	5.6 ± 0.2c

Means within a column followed by the same letter do not differ significantly ($P \geq 0.05$); Tukey's HSD test.

mean (±SE) of 6.4 ± 0.3 days, while males averaged 5.3 ± 0.4 days. Egg production averaged 119 ± 4.7 eggs per female.

The mean (±SE) generation time (adult to adult) for *Allotropa* n. sp. was 28.7 ± 1.2 days in the greenhouse. Longevity of adults ranged from 3 to 11 days, with an average of 5 to 6 days at 26°C. Males generally lived one day longer than females. Females averaged just over 74 eggs.

Discussion

The three primary endoparasitoids of *O. acuta* identified to date in the southeastern U.S. vary in abundance seasonally, annually, and by site. *Allotropa* n. sp., the most abundant parasitoid in our collections, consistently has been associated with *O. acuta* infestations in the U.S. (Clarke et al. 1990, Sun et al. 2002). Low numbers of *Acerophagus coccois* were collected in this study, but this species was abundant in previous studies in Georgia (Clarke et al. 1990) and in recent collections in Mississippi (Clarke, unpubl. data). Conversely, *Z. debarri* was prevalent in our collections and during trapping by Sun et al. (2002). However, very few *Z. debarri* were collected during life history studies of the mealybug in Georgia in the 1980s (Clarke, pers. obs.).

These variations in abundance may result from differing responses to insecticides, the availability of suitable hosts, and/or the particular characteristics of each species. *Allotropa* n. sp. and *Acerophagus coccois* are gregarious parasitoids, while *Zarhopalus debarri* only emerged from solitary parasitized hosts. *Allotropa* n. sp. and *Acerophagus coccois* can utilize second and third instars, though *Allotropa* n. sp. females prefer to oviposit in adult mealybugs (Sun, unpubl. data). *Zarhopalus debarri* is larger than the other two parasitoids, and primarily attacked the adult stage of female *O. acuta*. Clancy and Pollard (1947) reported that another species of *Zarhopalus*, *Z. sheldoni* Ashmead, may require large hosts for successful development. *Allotropa* n. sp. is currently considered to be host-specific or oligophagous (L. Masner, pers. comm.). *Acerophagus coccois*, the most studied of the three species, attacks a va-

riety of mealybug hosts and is considered a generalist (Dorn et al. 2001). The host specificity of *Z. debarri* is unknown, though *Z. corvinus* attacks at least two mealybug species (Meyerdirk and Newell 1979). Hosts parasitized by *A. coccois* and *Allotropa* n. sp. continue to feed and produce eggs, indicating these species are koinobionts (Calatayud et al. 2001, Clarke pers. obs.). Host-feeding on *O. acuta* by any of the parasitoids has not been observed, and their utilization of honeydew is unknown. As *Z. debarri* lived longer when provided Eliminade, a food source should be provided in a parasitoid mass-rearing program.

Though the mean length for *Allotropa* n sp. is larger than the 0.8 mm length reported for *A. burrelli* Muesebeck (Clancy 1944), the number of eggs found in dissections was much smaller (74 vs 565). *Allotropa burrelli* also produced more parasitoids per host (mean 5.2, range 1-22), and the female:male ratio was higher, ranging from 2:1 to 3:1.

The increase in numbers of parasitoids produced per host in relation to reduced host density may result from differences in host searching behavior and/or host quality (e.g., size). Charnov and Skinner (1985) hypothesized that optimal clutch size may increase as search time for hosts increases. Though gregarious parasitoids often oviposit more eggs in larger hosts (Luck et al. 1982, Nechols and Kikuchi 1985), Clancy (1944) found that the number of eggs laid per host by *Allotropa burrelli* did not depend on host size. Perhaps when faced with a perceived shortage of hosts, the parasitoid may deposit more eggs per host, regardless of host size. Also, we rarely observed complete emergence from gregariously parasitized hosts.

The high maximum parasitization rates observed by Clarke et al. (1990) and in this study suggest that classical biological control of *O. acuta* in China would have excellent potential (Hawkins and Cornell 1994). However, the infestations in China differ from those observed in the U.S. Loblolly pine is the primary host in the U.S., while infestations in China occur on slash pine. A cosmopolitan parasitoid, *Anagyrus dactylopii* (Howard), has attacked *O. acuta* in some areas in China (Ren et al. 2000), and introduced parasitoids would have to compete with this species. However, the combination of *A. dactylopii* and other native natural enemies have not led to significant reductions in *O. acuta* populations to date (Pan et al. 2002).

In China, current populations are located at latitudes south of the range of *O. acuta* in the U.S. (Sun et al. 1996), and population decreases observed in the summer have been attributed to the effects of high temperature (Tang et al. 2000). Effective parasitoids must be able to adapt to the environmental conditions and the lack of available hosts in the summer. Mean July temperatures within the range of *O. acuta* in China are 26.5-28.4°C, which are within the mean temperature span reported for U.S. (Zhou et al. 1994). Longevity of adult *Allotropa* n. sp. and *Z. debarri* was similar at 26°C, and *Z. debarri* adult longevity declined slightly at 30°C. Abundance of *Allotropa* n. sp. peaked annually in June and July, as it did in previous studies in Georgia (Clarke et al. 1990). The fall peak in Georgia for *Z. debarri* matched the results of Sun et al. (2002), who also reported a spring peak in South Carolina. The lifespan of *Allotropa* n. sp. indicates the number of generations per year is equal to or greater than the number for *O. acuta*.

The selection of the species of parasitoids to import is critical. Denoth et al. (2002) recommended caution when considering multiple agents for importation against insect pests because usually only one agent was responsible for the successful host regulation. Moreover, multiple species introductions may only increase the chance that the correct agent is released (Myers 1985). The release of several species of

natural enemies may lead to the competitive exclusion of a potentially effective controller (Ehler and Hall 1982) and increases the odds that an introduced species could disrupt native communities (Hawkins and Marino 1997). However, a complex of imported parasitoids has often helped in the successful control of mealybug pests. The Comstock mealybug, *Pseudococcus comstocki* (Kuwana), was brought below economically injurious levels by three imported parasitoids plus native natural enemies (Meyerdirk et al. 1981). *Allotropa* n. sp., *Z. debarri,* and *A. coccois* may all have a significant role in a biological control program for *O. acuta* in China.

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