Life History of Oriental Beetle and Other Scarabs, and Occurrence of *Tiphia vernalis* in Ohio Nurseries[1]

Michael Reding[2] and Michael Klein[3]

USDA-ARS, Application Technology Research Unit, Horticultural Insects Group, 1680 Madison Avenue, Wooster, Ohio, 44691 USA

J. Entomol. Sci. 42(3): 329-340 (July 2007)

Abstract The oriental beetle, *Anomala orientalis* Waterhouse, is a serious pest of nursery crops in northern Ohio and a number of other states because the larvae damage plant roots. In 3 ornamental tree nurseries (field production) in Ohio, the composition of scarab larvae, their life histories, and parasitism rates were examined. Four exotic scarabs, Asiatic garden beetle (*Maladera castanea* Arrow), European chafer (*Rhizotrogus majalis* Razoumowsky), Japanese beetle (*Popillia japonica* Newman), and oriental beetle, were found in this study. The oriental beetle and European chafer were the most common species found. Up to 60% of the oriental beetle population required 2 yrs to complete development, which is much higher than the commonly reported 15% or less in northeastern states. *Tiphia vernalis* Rohwer, an external parasite of oriental beetle and Japanese beetle larvae, was found in all nurseries surveyed. As much as 31% and 60% of the sampled oriental beetle and Japanese beetle populations, respectively, were parasitized, depending on date and nursery.

Key Words white grubs, parasitoids, ornamental nurseries, Coleoptera, Scarabaeidae

The oriental beetle, *Anomala* (=*Exomala*) *orientalis* (Waterhouse) (Coleoptera: Scarabaeidae), is an exotic scarab native to Japan or the Philippine Islands (Vittum et al. 1999, Choo et al. 2002), which was first collected in the United States in New Haven, CT, in 1920 (Hallock 1930). It currently occurs in Delaware, Hawaii, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Rhode Island, and Virginia (Alm et al. 1999). The oriental beetle has become a major pest of turf and ornamental nursery crops in many of these states (Polavarapu et al. 2002). The damaging stage is the larva, which feeds on the roots of turf and nursery crops. The larval stages of scarabs are frequently referred to as white grubs. Adult oriental beetles do little feeding and do not cause damage to any crops.

In North America, the oriental beetle generally has a 1-yr life cycle where adults emerge during late spring through early summer. By October most individuals are third instars, which is the overwintering life stage, and pupation starts the following May (Vittum et al. 1999). In northeastern Ohio, the oriental beetle is part of a complex of exotic scarabs infesting turf and nursery crops. This complex includes Asiatic garden beetle (*Maladera castanea* Arrow), European chafer (*Rhizotrogus majalis*

[1]Received 17 July 2006; accepted for publication 11 October 2006.
[2]Address inquiries (email: reding.2@osu.edu).
[3]Retired.

Razoumowsky), and Japanese beetle (*Popillia japonica* Newman). All of these species have life histories similar to the oriental beetle (Potter 1998, Vittum et al. 1999).

In June 2001, we found 2^{nd}-instar oriental beetle while sampling the exotic white grub complex in an ornamental nursery in northeastern Ohio. Oriental beetle that overwinter as second instars take 2 yrs to complete development (Vittum et al. 1999). These individuals would have overwintered as second instars, which indicated that a portion of the oriental beetle population was not following the normal (1-yr life cycle) pattern of development. We were interested in determining the proportion of the population with a 2-yr life cycle in ornamental nurseries in northeastern Ohio. We also developed profiles of the life histories of the other exotic scarabs (Asiatic garden beetle, European chafer, Japanese beetle) collected in our samples.

Tiphia vernalis Rohwer (Hymenoptera: Tiphiidae) is an exotic parasitic wasp that was released into the USA during the late 1920s and early 1930s to control the Japanese beetle (Clausen et al. 1927, King 1931, King et al. 1951). It is native to China, Japan, and Korea where it is an external parasite on several *Popillia* species (King 1931). *Tiphia vernalis* attacks third instars during late spring and early summer. The female burrows into the soil, locates a grub of a host species, then stings it causing temporary paralysis. Then the parasite lays an oblong egg on the grub's ventral surface, placed in the suture between the third thoracic segment and the first abdominal segment, perpendicular to the long axis of the grub (Clausen et al. 1927). Placement of the egg on the host is characteristic for species of *Tiphia* (Clausen et al. 1927). The parasite larva remains attached to the site where the egg was laid and feeds by sucking fluids from the grub. It passes through 5 instars with the last instar consuming all the soft portions of the grub, leaving only the head capsule and mandibles. When development of the parasite larva is complete, it spins a brown oblong silken cocoon. Development to the adult stage is completed by fall, and the winter is spent as an adult inside the cocoon (Clausen et al. 1927).

Most of the available information concerning the distribution of *T. vernalis* in the USA, species attacked, and rates of parasitization was published before 1950. There is little published information about the occurrence of *T. vernalis* in Ohio or its current range in North America (Ladd and McCabe 1966, Rogers and Potter 2004). King et al. (1951) reported that a total of 27 colonies of *T. vernalis* were released in Ohio during 1936 - 1949, but there were no postrelease assessments to determine whether establishment occurred. In June 2001, Reding and Klein (2001) found *T. vernalis* parasitizing Japanese beetle and oriental beetle grubs in an ornamental nursery in Lake Co., OH. This county was one of the original release areas with all 3 releases occurring in 1949 (King et al. 1951). Reding and Klein's (2001) report was also the first recorded incidence of *T. vernalis* attacking oriental beetle in the field.

The objectives of this study were (1) to examine the life histories of the most common exotic scarabs (oriental beetle, Japanese beetle, European chafer, and Asiatic garden beetle) infesting ornamental nurseries of northeastern Ohio, with emphasis on the oriental beetle; and (2) to survey for *T. vernalis* and determine the species of white grubs being attacked and the rates of parasitization.

Materials and Methods

Study sites. In 2002, three ornamental nurseries in Lake Co., OH, were sampled for oriental beetle grubs and *T. vernalis*. Two of these nurseries also were sampled in 2003 for oriental beetle grubs and *T. vernalis*, and in 2004 for parasitized grubs.

Nursery-1 was a large (>100 ha) field-production (balled and burlapped) nursery growing deciduous trees and shrubs. This nursery was divided into blocks of various ages (newly planted to 4-years-old). Blocks were not necessarily arranged by age with blocks of varying ages adjacent to each other. Grass was used as a ground cover between blocks and rows. The grass strips were mowed at 1- to 2-wk intervals to a height of about 10 cm. Nursery-2 was a container-production nursery (approx. 12 ha) growing primarily deciduous and evergreen shrubs, and some herbaceous perennials, with areas of grass scattered through the nursery and along the borders. The grass was mowed at approx. 2- to 3-wk intervals to a height of about 15 cm. Nursery-3 (sampled in 2002 only) was a field production nursery (approx. 8 ha), which consisted of 8 blocks of deciduous shrubs and conifers interspersed with uncultivated areas. The uncultivated areas were mixtures of grass and herbaceous broadleaf weeds, which separated blocks and bordered the entire site. These areas were mowed at approx. 2- to 3-wk intervals to a height of about 15 cm.

Sampling. Scarab populations were sampled by using a spade to dig 0.06 $m^2 \times$ 15-20 cm deep sections of sod and soil (hereafter referred to as plugs). The plugs were broken apart and the soil and sod carefully searched for grubs. At least 10 plugs were sampled per nursery on each date. Grubs from each plug were stored separately in covered plastic containers and labeled by nursery and site for transport to the laboratory. In the laboratory, the samples were kept at 7°C until the larvae were examined to determine species and stage of development. These evaluations were completed within 48 h of collection.

Nursery-1 and Nursery-2 were sampled in 2002 and 2003 for white grubs (all species in the complex), and in spring 2004 for oriental beetle and Japanese beetle grubs parasitized by *T. vernalis*. Grub samples were collected approx. weekly during May and June and about every 2 wks in July through September. At Nursery-1, two blocks were sampled each year with samples taken from the grass strips between rows and different blocks sampled in subsequent years. The sampled blocks were 2-yrs-old (in the year sampled) with blocks sampled in the same year located at least 200 m apart. The data on scarab life history were pooled between blocks within years. At Nursery-2, samples were taken from a mowed grassy area bordering several hoop-houses full of plants. This site was sampled all 3 yrs. Nursery-3 was sampled only 10 April through 18 June 2002 with samples taken at 1- to 2-wk intervals from an uncultivated grassy area bordering one of the planted blocks.

A one-time sample from the root zones of trees was taken at Nursery-1 on 7 October 2003. This block was 3 yrs old at the time of sampling and had not been sampled before. Fourteen serviceberry (*Amelanchier canadensis* L.) and 8 Sargent crabapple (*Malus sargentii* Rehder) trees were chosen at random and dug by the nursery using their mechanical digger. The resulting root balls were about 66 cm in diam on top tapering to about 45 cm at the bottom and 45 cm tall. The root balls from all trees were broken apart, then the extracted soil and roots were carefully searched for grubs. Grubs from each tree were placed in separate plastic containers with snap-on lids and labeled by tree-species for transport to the laboratory. In the laboratory, these samples were handled as above.

Determination of species and life stages. Scarab larvae were identified to species and life stage in the laboratory. A stereoscopic microscope with an ocular micrometer was used to assist in identification of grubs to species and to measure head-capsule widths to determine instar. Grubs and prepupae were identified to species by the raster pattern on the caudal segment and the shape of the anal slit

(Potter 1998). The pupal stages of European chafer and Asiatic garden beetle were distinguished from other species by general size and shape. However, oriental beetle and Japanese beetle pupal stages are similar in shape and were distinguished from each other by size (overall length and width across the widest point, 10 × 5 mm and 14 × 7 mm for oriental beetle and Japanese beetle, respectively) (Vittum et al. 1999). These pupae were then reared to the adult stage to confirm identification. All identifications made by measurement were confirmed. The proportions of each species in the various developmental stages were determined for all samples.

Tiphia vernalis. Grubs from the life history samples were examined for the presence of *T. vernalis.* The position of the parasite egg or larva on the grub was used to identify the species as *T. vernalis*. The location on the grubs where the parasites attached is considered characteristic in *Tiphia* spp. (Clausen et al. 1927). Eggs of *T. vernalis* are placed in the suture between the third thoracic segment and the first abdominal segment (Clausen et al. 1927). In Nursery-1, parasitization rates were pooled between blocks. The presence of adult *T. vernalis* in nurseries was determined by spraying a 10% solution of sugar water on the foliage of trees. Adults were identified visually by shape and size, and the fact that they were attracted to the sugar water (Rogers and Potter 2004). Adult *T. vernalis* were not counted. The species of grub attacked, the time period of the season when parasitization occurred, and the rates of parasitization were determined. Rates of parasitization were based on the total number of oriental beetle or Japanese beetle found (all stages: second and third instars, prepupae, pupae, and adults were included in the calculations) on each date. A Chi-square test of association (Statistix 1998) was conducted on the number of 3^{rd}-instar oriental beetle or all stages of oriental beetle and occurrence of at least one parasitized grub. Following a significant test across all levels (1, 2, 3, and ≥4 oriental beetle grubs), Chi-square was used to compare the various levels with each other (for example 1 versus 2 oriental beetle grubs, 2 versus 3, etc., with $P < 0.05$ being significant). Samples without at least one third instar oriental beetle were excluded from this analysis because only third instars are attacked (Clausen et al. 1927).

Results

In general, oriental beetle and European chafer were the most common species found each year (Table 1). Oriental beetle, Asiatic garden beetle, and European chafer were found in all nurseries. Japanese beetle was found in all nurseries during spring except for Nursery-2 in 2003. However, except for in Nursery-3 the numbers of Japanese beetle were generally low (≤6% of the grubs found). In Nursery-1, oriental beetle and European chafer were the most common species found during spring and fall of 2002 and 2003 (Table 1). In Nursery-2, oriental beetle and Asiatic garden beetle were the most common species during spring each year, but in the fall oriental beetle and European chafer were the most common. In Nursery-3, Japanese beetle and European chafer were the most common species. Rose chafer (*Macrodactylus subspinosus* (F.)) was found in Nursery-2 and Nursery-3 (Table 1) and was relatively common during April and May each year (10-71% of the grubs found on various sample dates). Other species of grubs (*Phyllophaga* sp. and *Cyclocephala borealis* Arrow) were found, but occurred in low numbers (<1% of all grubs found) (Table 1). In this study, the measurements of mean head capsule width for Asiatic garden beetle, Japanese beetle, and oriental beetle were generally similar to those reported previously (Vittum et al. 1999) (Table 2). However, the head capsules of the 3^{rd}-instar

Table 1. Composition of scarab species found in various nurseries of Lake County, OH, USA

Year	Nursery	Season^	Total grubs	Proportion of all grubs found#					
				OB	AGB	EC	JB	RC	Other
2002	Nursery-1	spring	1320	0.506	0.117	0.332	0.045	0.000	0.000
		fall	837	0.189	0.078	0.730	0.004	0.000	0.000
	Nursery-2	spring	555	0.551	0.245	0.103	0.013	0.088	0.000
		fall	156	0.449	0.071	0.385	0.000	0.096	0.000
	Nusery-3	spring	313	0.073	0.182	0.323	0.406	0.006	0.010
2003	Nusery-1	spring	766	0.439	0.091	0.406	0.064	0.000	0.000
		fall	182	0.214	0.005	0.780	0.000	0.000	0.000
	Nursery-2	spring	664	0.684	0.116	0.081	0.000	0.105	0.014
		fall	251	0.586	0.088	0.120	0.000	0.199	0.008

^ In 2002, samples collected through 9 July were included in spring, except in nursery Nursery-3 when sampling was concluded 18 June. In 2003, spring samples were collected through 22 July. Samples through these dates represent the overwintered generation.

OB = oriental beetle, AGB = Asiatic garden beetle, EC = European chafer, JB = Japanese beetle, RC = rose chafer, and Other includes *Cyclocephala borealis* and *Phyllophaga* (not identified to species).

Table 2. Mean ± standard deviation head capsule widths (mm) of larvae of various exotic scarabs collected in Lake Co., OH, USA

Instar	OB (n)*	AGB (n)	EC (n)	JB (n)
First	1.2 ± 0.08 (11)	na	1.4 ± 0.08 (20)	na
Second	1.8 ± 0.12 (108)	1.5 ± 0.15 (13)	2.2 ± 0.10 (30)	na
Third	2.8 ± 0.15 (259)	2.4 ± 0.11 (90)	3.4 ± 0.12 (185)	3.0 ± 0.16 (46)

* (n) is the number of individuals measured.

European chafer we collected tended to be slightly larger than previously reported (third instar mean head capsule widths 3.4 mm in Ohio versus 3.1 mm reported for other locations in Vittum et al. [1999]).

Oriental beetle. We followed the life history of the oriental beetle at Nurseries-1 and -2 because oriental beetles were relatively common at those sites. Overwintering second instars were found at both nurseries in 2002 and 2003. At Nursery-1 in spring 2002 (2 April through 25 June), about 60% of the samples had oriental beetles with about 5% second instars; and in spring 2003 (16 April through 26 June), about 48% of the samples had oriental beetles with about 10% second instars. At Nursery-2 in spring 2002 (10 April through 25 June), about 72% of the samples had oriental beetles with about 35% second instars; and in spring 2003 (6 May through 26 June), about 84% of the samples had oriental beetles with about 60% second instars. Based on the low numbers of later developmental stages (prepupae, pupae, adults), the third instars collected 9 July through 27 August 2002 and 15 July through 2 September 2003, probably developed from overwintered second instars.

The first oriental beetle prepupae were found as early as 7 May and pupae as early as 11 June (Fig. 1). The last date pupal stages were detected was 22 July. Adults were collected from plug samples only (no trapping was done). In 2002, adults were first detected 25 June in Nursery-1 and 9 July in Nursery-2. Adults occurred in plug samples through 9 July in Nursery-1 and 30 July in Nursery-2. In 2003, adults were first detected 10 and 15 July in Nursery-1 and Nursery-2, respectively. Adults occurred in plug samples through 22 July in both nurseries. First instars of the new generation were first detected 30 July (Nursery-1) and 5 August (Nursery-2) in 2002 and 2003, respectively. On 1 October 2002, 50% of the grubs were second instars (Nursery-1). In 2002, first instars were present until at least 18 September (Nursery-1). In 2003, about 29% of the grubs were first instars on 9 September in both nurseries.

The trees sampled on 7 October 2003 had an average of 22 and 19 scarab larvae per tree in the serviceberry and crabapples, respectively. In the serviceberry, about

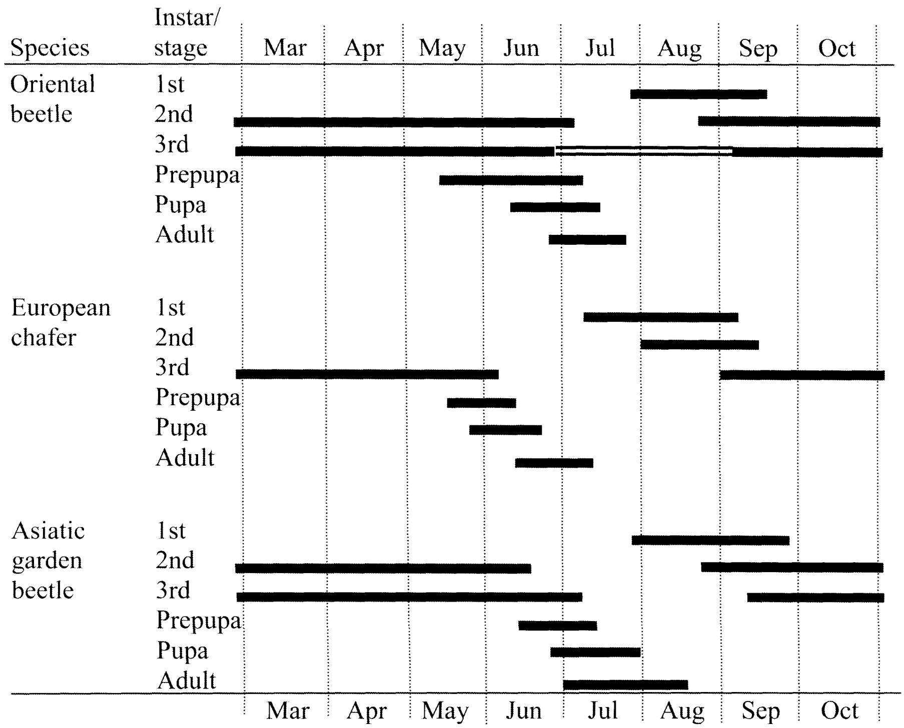

Fig. 1. Life history profiles of the most common exotic scarabs found in commercial nurseries in northeastern Ohio during 2002 and 2003. The split line () in *A. orientalis* third represents third instars that probably overwintered as second instars.

90% of the grubs were oriental beetles with European chafer, Asiatic garden beetles, and rose chafer also found. In the crabapples, about 92% of the grubs were oriental beetles with Asiatic garden beetle the only other species found. Only 2^{nd}- and 3^{rd}-instar oriental beetle were found with 44% and 22% second instars in the serviceberrys (*A. canadensis*) and crabapples (*M. sargentii*), respectively.

Other scarabs. European chafer overwintered as third instars only (Fig. 1). Pupation began midMay with prepupae detected as early as 14 May (2003) and pupae detected as early as 23 May (2002). Adults were detected in plug samples from midJune through early July. First-instar larvae occurred from early-July through early-September. Second instars occurred from the end of July through midSeptember and third instars from late-August through the following spring (Fig. 1).

Asiatic garden beetle overwintered as second and third instars with the second instars present until about midJune (Fig. 1). Apparently, the individuals overwintering as second instars pupated during the same summer as overwintered third instars. Second instars were generally absent by late May or early June and, in most cases, no grubs were detected from early July through early August. If there was a 2-yr life cycle, third-instar grubs should have occurred during late July and early August, but we did not find any.

Japanese beetle overwintered as third instars only. The timing of pupation was similar to oriental beetle. However, too few Japanese beetles were collected each year to develop an accurate profile of its life history. We found Japanese beetles on only one occasion during late summer-early fall (27 August 2002 at Nursery-1). Japanese beetles were uncommon at Nursery-2 each year, being collected on only 3 occasions (all in early summer 2002).

Tiphia vernalis. In 2002, adult *T. vernalis* were found in all 3 nurseries. Parasitized grubs were found in Nursery-1 and Nursery-3 (oriental beetle and Japanese beetle, and Japanese beetle, respectively). In 2003, parasitized grubs (oriental beetle and Japanese beetle) were found in Nursery-1 and adult *T. vernalis* were found in Nursery-1 and Nursery-2 (only nurseries sampled). In 2004, only parasitized oriental beetle grubs were found, and they were found in Nursery-1 and Nursery-2. Rates of parasitization varied between species of grubs, nurseries, years, and sample dates (Table 3). The highest rates of parasitization of oriental beetles detected in Nursery-1 were 13%, 31%, and 29% in 2002, 2003, and 2004, respectively. Only one parasitized grub (oriental beetle) was found in Nursery-2 in 2004, and it was in a sample of 67 specimens. There was a significant association between the number of oriental beetles found in a section of sod and the occurrence of at least one parasitized grub (Table 4). A parasitized oriental beetle grub was more likely to occur in a plug of grass and soil (0.06 $m^2 \times 15$ - 20 cm deep) with at least two third-instar oriental beetles or 3 total oriental beetles than when fewer were present ($\chi^2 = 10.1$, df = 3, $P = 0.02$, and chi-square = 16.0, df = 3, $P = 0.001$, respectively). We found *T. vernalis* cocoons at Nursery-1 in 2002 and 2003. We began finding cocoons 9 and 10 July in 2002 and 2003, respectively.

Parasitized Japanese beetle grubs were found in Nursery-1 in 2002 and 2003, and in Nursery-3 in 2002. Rates of parasitization in samples ranged from 13-100% (1 of 1 Japanese beetle) on various dates in Nursery-1, but the numbers of Japanese beetle (all stages) found in these samples were low (1-13 individuals) (Table 3). During the time parasitized Japanese beetles were detected in 2002, we found higher numbers of Japanese beetle grubs in Nursery-3 than in Nursery-1 (61 versus 29). In

Table 3. Rates of parasitization of OB and JB grubs by *T. vernalis* in nurseries of northeast Ohio, USA

				Number of grubs		Proportion of population with		
Species	Year	Nursery	Date	Collected	Parasitized*	*T.v.* egg	*T.v.* larva	Total *T.v*
Oriental beetle	2002	Nursery-1	4 June	67	5	0.075	0	0.075
			11 June	83	8	0.096	0	0.096
			18 June	80	10	0.038	0.088	0.125
			25 June	39	2	0	0.051	0.051
	2003	Nursery-1	13 June	23	3	0.130	0	0.130
			20 June	59	16	0.203	0.068	0.271
			26 June	36	11	0.028	0.278	0.306
	2004	Nursery-1	19 May	54	3	0.056	0	0.056
			26 May	27	3	0.111	0	0.111
			3 June	17	5	0.059	0.235	0.294
			8 June	19	5	0	0.263	0.263
		Nursery-2	15 June	67	1	0	0.015	0.015
Japanese beetle	2002	Nursery-1	11 June	8	3	0.250	0.125	0.375
			18 June	13	2	0	0.154	0.154
			25 June	8	1	0	0.125	0.125
		Nursery-3	6 June	25	15	0.520	0.080	0.600
			11 June	27	11	0.222	0.185	0.407
			18 June	9	2	0	0.222	0.222
	2003	Nursery-1	13 June	6	1	0.167	0	0.167
			20 June	1	1	1.000	0	1.000
			26 June	1	1	0	1.000	1.000

* No parasitized JB were found in Nursery-1 in 2004; no parasitized grubs of either species were found in Nursery-2 in 2002 or 2003; and Nursery-3 was sampled in 2002 only and no parasitized oriental beetles were found.

Nursery-3, we found 60% (15 of 25) and 41% (11 of 27) of the grubs parasitized on 6 and 11 June, respectively (Table 3).

Discussion

Four species of exotic scarabs (Asiatic garden beetle, European chafer, Japanese beetle, oriental beetle) were found in our samples. Of these, Japanese beetle was the least common species found in the nurseries we sampled and, in general, was uncommon. Smitley (1996) reported similar results from nursery fields sampled in Michi-

Table 4. Association between numbers of OB and occurrence of parasitized OB

OB life stage	Number of OB*	Number of sod sections	Number of sections with parasitized OB	Percentage with parasitized OB^
3rd instars	1	74	15	20.3a
only counted	2	47	18	38.3b
	3	22	11	50.0b
	≥4	23	10	45.5b
	χ^2	10.1		
	df	3		
	P	0.018		
All stages	1	38	7	18.4a
counted	2	42	7	16.7a
	3	31	15	48.4b
	≥4	55	25	45.5b
	χ^2	16.0		
	df	3		
	P	0.001		

* Plugs of sod and soil without 3rd instar OB were excluded from all analyses.

^ Following a significant χ^2 ($P < 0.05$) of all levels (1, 2, 3, and ≥4 OB), χ^2 was used to make comparisons between levels (1 OB versus 2, 2 versus 3, etc.). Percentages within columns and groups followed by the same letter are not significantly different from each other.

gan and Lake Co., OH. European chafer and oriental beetle appear to be the most likely species to infest the roots of woody ornamentals in northeast Ohio. We have sampled 5 species of field-grown ornamental trees (rhododendron, hemlock, crabapple, serviceberry, and kousa dogwood) in 3 different nurseries (5 samples total) and twice found only European chafer (Reding et al. 2004), twice ≥90% oriental beetle (see results), and once 84% oriental beetle (MER, unpub.) with no Japanese beetle in any of these samples. In Nursery-1 fall 2003, oriental beetle represented a larger percentage of all the grubs found in the root zones of the trees sampled than in the grass samples (90+% versus 21.4%, respectively). This grower uses a drip system for irrigation, and thus supplemental water is supplied only to the tree rows. Grass between the rows receives water only from precipitation. Because moisture is necessary for egg development, the irrigation system used in this nursery may have made the tree row a more favorable oviposition site than the grass. Alternatively, oriental beetle may favor woody plants over grass for oviposition, but this was not examined in our study.

The life history of the oriental beetle in northeastern Ohio was similar to that reported for NY (Hallock 1930, Vittum et al. 1999). Hallock (1930) reported that about 40% of the population overwinters as second instars. Vittum et al. (1999) indicated that up to 15% of the population overwinters as second instars. We found populations at both ends of this spectrum. In one nursery (Nursery-1) we found about 5 and 10% of the population overwintering as second instars in 2002 and 2003, respectively. In another nursery (Nursery-2) we found 35 and 60% of the population overwintering as second instars in 2002 and 2003, respectively. These nurseries are only about 1.5 km apart. The differences in life histories between these nurseries may be related to the cultural practices used by the growers. The mowing regimes of these nurseries were different with Nursery-2 being mowed less often and having a higher mowing height than Nursery-1. Potter et al. (1996) found that *P. japonica* and *Cyclocephala* spp. had delayed development in relatively high-mown plots. Regardless, this study corroborates the flexibility of the oriental beetle's life cycle indicated in previous reports. Friend (1927) reported that the oriental beetle had 2 generations a year in Hawaii, and Choo et al. (2002) found only 1 generation per year in Korea with no second instars overwintering. Apparently, *A. orientalis* has a flexible life history, which should be advantageous for colonizing new locations. Most areas of the contiguous United States should have suitable climates, as far as temperature, for establishment of oriental beetles. However, one of the primary constraints to colonization is moisture. Moisture is necessary during the time eggs are developing (Friend 1927, Hallock 1933). Therefore, the arid sections of the United States would be poor habitats for oriental beetles except where sufficient irrigation is applied.

The life histories and phenology of all 4 exotic scarabs were similar. This is convenient for control efforts. One of the most common management strategies currently used is to apply preventive treatments of imidacloprid or halofenozide timed to target the egg and first instars (Potter 1998). Among the 4 exotic scarabs we encountered (Asiatic garden beetle, European chafer, Japanese beetle, oriental beetle), emergence of adults occurred within a few weeks of each other. While not synchronized, the egg laying periods of these species overlap. Therefore, in Ohio, carefully timed preventive treatments should contact the correct stages of all 4 scarabs to provide effective control. In northern Ohio, the emergence of adult European chafer and start of oviposition occurs about 2 wks earlier than the other exotic scarabs. The earliest we found 1^{st}-instar European chafer grubs was 9 July and 22 July in 2002 and 2003, respectively. According to the Ohio State University web-based Growing Degree Days (GGD) and Phenology Calendar (http://www.oardc.ohio-state.edu/gdd/), these events occurred in Lake Co., OH, at 1252 and 1299 GGD (base temperature 10°C) in 2002 and 2003, respectively. Therefore, preventive treatments targeting the egg and 1^{st}-instar stages should be timed correctly for the Asiatic garden beetle, European chafer, Japanese beetle, and oriental beetle when applied by approximately 1300 GGD (midJuly). Alternatively, pesticide applications could coincide with full bloom of *Koelreuteria paniculata* Laxm. (panicled goldenraintree 1250 GDD), first bloom of *Sorbaria sorbifolia* (L.) A. Braun (Ural falsespirea 1170 GDD), or first bloom of *Aesculus parviflora* Walter (bottlebrush buckeye 1158 GDD) (http://www.oardc.ohio-state.edu/gdd/).

We found *T. vernalis* in the 3 nurseries we surveyed for this study. Since that time, we collected (in Lindgren funnel traps) adult *T. vernalis* from two other nurseries. This parasitoid appears to be relatively widespread in Lake Co., OH. Rates of parasitization of oriental beetle by *T. vernalis* were 13-30%, in our survey. Because Japanese beetle numbers were so low it's difficult to assess the impact of *T. vernalis* on Japanese beetle. However, while parasitization rates of *T. vernalis* on oriental beetle were probably not high enough to suppress the population to nondamaging levels; *T. vernalis* may have a suppressive effect on the oriental beetle population.

Rogers and Potter (2003) found that treatments of imidacloprid were detrimental to *T. vernalis*'s ability to locate Japanese beetle grubs and reduced rates of parasitization. However, they found no effect of imidacloprid on survival of *T. vernalis* larvae. In our survey, grubs with *T. vernalis* eggs were not found later than 26 June each year. According to the Ohio State University web-based GGD and Phenology Calendar for Lake Co., OH (http://www.oardc.ohio-state.edu/gdd/), GDD for the last date *T. vernalis* eggs were found were 720 and 758 for 2002 and 2003, respectively. Treatments of imidacloprid applied as preventive treatments for control of white grubs in nurseries in Lake Co., OH, should have less adverse effect on populations of *T. vernalis* when applied later than 26 June or after 720 GGD. Alternatively, the following local plant phenology events could be used to time treatments: apply treatments after full bloom of *Weigela florida* Bunge. 'Red Prince' (727 GDD), full bloom of *Crataegus phaenopyrum* L. (Washington hawthorn 730 GDD), or first bloom of *Deutzia scabra* Thunb. (fuzzy Deutzia 727 GDD) (http://www.oardc.ohio-state.edu/gdd/). Based on our data on oriental beetle and European chafer life history, preventive treatments targeting the egg and 1st-instar larval stages of both scarabs should be effective when applied by midJuly or full bloom of *K. paniculata*. Timing these treatments between late June or full bloom of *W. florida* 'Red Prince,' *C. phaenopyrum*, or first bloom of *D. scabra* and full bloom of *K. paniculata* or first bloom of *H. syriacus* should provide acceptable control of scarab grubs while conserving populations of *T. vernalis* in nurseries of northern Ohio.

Acknowledgments

The authors thank Betsy Anderson, Jim Moyseenko, Will Driscol, and Tina Berry for their technical assistance. We also thank Drs. Denny Bruck and Dan Herms for reviewing an earlier version of this manuscript.

References Cited

Alm, S. R., M. G. Villani and W. Roelofs. 1999. Oriental beetles (Coleoptera: Scarabaeidae): current distribution in the United States and optimization of monitoring traps. J. Econ. Entomol. 92: 931-935.

Choo, H. Y., D. W. Lee, J. W. Park, H. K. Kaya, D. R. Smitley, S. M. Lee and Y. M. Choo. 2002. Life history of oriental beetle (Coleoptera: Scarabaeidae) in golf courses in Korea. J. Econ. Entomol. 95: 72-80.

Clausen, C. P., J. L. King and C. Teranishi. 1927. The parasites of *Popillia japonica* in Japan and Chosen (Korea), and their introduction into the United States. U.S. Depart. Agric. Bull. No. 1429.

Friend, R. B. 1927. The Asiatic beetle (*Anomala orientalis* Waterhouse). J. Econ. Entomol. 20: 362-365.

Hallock, H. C. 1930. The Asiatic beetle, a serious pest in lawns. United States Department of Agriculture Circular No. 117.

1933. Present status of two Asiatic beetles (*Anomala orientalis* and *Autoserica castanea*) in the United States. J. Econ. Entomol. 26: 80-85.

King, J. L. 1931. The present status of established parasites of *Popillia japonica* Newman. J. Econ. Entomol. 24: 453-462.

King, J. L., L. B. Parker and H. J. Willard. 1951. Status of imported parasites of the Japanese beetle in 1950. U.S. Depart. Agric.-Agric. Res. Serv. Spec. Suppl. No. 5.

Ladd, T. L. and P. J. McCabe. 1966. The status of *Tiphia vernalis* Rohwer, a parasite of the Japanese beetle, in southern New Jersey and southeastern Pennsylvania in 1963. J. Econ. Entomol. 59: 480.

Ohio State University's Ohio Agricultural Research and Development Center. Growing Degree Days and Phenology for Ohio. www.oardc.ohio-state.edu/gdd.

Polavarapu, S., M. Wicki, K. Vogel, G. Lonergan and K. Nielsen. 2002. Disruption of sexual communication of oriental beetles (Coleoptera: Scarabaeidae) with a microencapsulated formulation of sex pheromone components in blueberries and ornamental nurseries. Environ. Entomol. 31: 1268-1275.

Potter, D. A. 1998. Destructive turfgrass insects. Biology, diagnosis, and control. Ann Arbor Press, Chelsea, MI.

Potter, D. A., A. J. Powell, P. G. Spicer and D. W. Williams. 1996. Cultural practices affect root-feeding white grubs (Coleoptera: Scarabaeidae) in turfgrass. J. Econ. Entomol. 89: 156-164.

Reding, M. E. and M. G. Klein. 2001. *Tiphia venalis* (Hymenoptera: Tiphiidae) parasitizing oriental beetle, *Anomala orientalis* (Coleoptera: Scarabaeidae) in a nursery. Great Lakes Entomol. 34: 67-68.

Reding, M. E., M. G. Klein, R. D. Brazee and C. Krause. 2004. Fall subsurface insecticide treatments control European chafer grubs damaging field-grown nursery crops. J. Environ. Hort. 22: 32-36.

Rogers, M. E. and D. A. Potter. 2003. Effects of imidacloprid application for white grub control on parasitism of Japanese beetle (Coleoptera: Scarabaeidae) by *Tiphia vernalis* (Hymenoptera: Tiphiidae). J. Econ. Entomol. 96: 1412-1419.

2004. Biology of *Tiphia pygidialis* (Hymenoptera: Tiphiidae), a parasitoid of masked chafer (Coleoptera: Scarabaeidae) grubs, with notes on seasonal occurrence of *Tiphia vernalis* in Kentucky. Environ. Entomol. 33: 520-527.

Smitley, D. R. 1996. Incidence of *Popillia japonica* (Coleoptera: Scarabaeidae) and other scarab larvae in nursery fields. J. Econ. Entomol. 89: 1262-1266.

Statistix. 1998. Statistix for Windows. Analytical Software, Tallahassee, FL.

Vittum, P. J., M. G. Villani and H. Tashiro. 1999. Turfgrass Insects of the United States and Canada. Cornell Univ. Press, Ithaca, NY.