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Profile

Biology, Ecology, and Management of Masked Chafer (Coleoptera: Scarabaeidae) Grubs in Turfgrass

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Abstract

Masked chafers are scarab beetles in the genus *Cyclocephala.* Their larvae (white grubs) are below-ground pests of turfgrass, corn, and other agricultural crops. In some regions, such as the Midwestern United States, they are among the most important pest of turfgrass, building up in high densities and consuming roots below the soil/thatch interface. Five species are known to be important pests of turfgrass in North America, including northern masked chafer, *Cyclocephala borealis* Arrow; southern masked chafer, *Cyclocephala lurida* Bland [formerly *Cyclocephala immaculata* (Olivier)]; *Cyclocephala pasadenae* (Casey); *Cyclocephala hirta* LeConte; and *Cyclocephala parallela* Casey. Here we discuss their life history, ecology, and management.

Key words: Turfgrass IPM, white grub, *Cyclocephala*, masked chafer

Many species of scarabs are pests of turfgrass in the larval stage (Table 1). Also known as white grubs, larvae of these species feed on grass roots and damage cultivated turfgrasses. White grubs are the most widespread and most destructive group of insect pests of turf in the northern two-third of the United States, i.e., the cool-season and transition zones with respect to turfgrass adaptation zones. There are several important introduced white grub species in the United States, the most common and widespread of which is the Japanese beetle, *Popillia japonica* Newman. However, among the important native scarab pests of turfgrasses, masked chafers, *Cyclocephala* spp. (Order: Coleoptera; Family: Scarabaeidae; Subfamily: Dynastinae; Tribe: Cyclocephalini) are probably the most widespread (Potter 1998, Vittum et al. 1999). Among these, the northern masked chafer, *Cyclocephala borealis* Arrow, and the southern masked chafer, *Cyclocephala lurida* Bland, are the most important species, with other damaging species including *Cyclocephala pasadenae* Casey, *Cyclocephala hirta* LeConte, and *Cyclocephala parallela* Casey.

Geographic Distribution

Species of *Cyclocephala* that are pests of turfgrass are reported from most states in the United States (Fig. 1). *Cyclocephala borealis* and *C. lurida* are nearctic species and are the primary masked chafer species found east of the Rocky Mountains. *Cyclocephala borealis* commonly occurs from New England and southern Ontario west to Minnesota and Illinois and south to Kentucky and Missouri (Redmond et al. 2012). *Cyclocephala lurida* is more common from the southern United States northward to Nebraska and Illinois, southern Ohio, and Maryland. The two species have overlapping distributions throughout the Midwest, particularly in the central Ohio Valley states (Ritcher 1966, Potter 1995). *Cyclocephala pasadenae* is common in the southwestern United States from Texas, western Kansas, and Oklahoma to southern California. *Cyclocephala hirta* occurs from northwestern Oklahoma and western Kansas through Arizona to most of California, but also has been found sporadically in Utah, Nevada, and Texas (Saylor 1945), as well as Hawaii and Kansas (Bauernfeind 2001, Jameson et al. 2009). *Cyclocephala parallela* is common in south-central Florida.

Description

Adults of various *Cyclocephala* spp. are similar in appearance, having a characteristic brown to black stripe or mask across their eyes and face, which distinguishes them from other similar species. Larvae of *Cyclocephala* spp. have a similar nondistinct raster pattern or arrangement of hairs, spines, and bare spaces on the ventral surface at the abdominal tip in front of the anus (Potter 1998, Vittum et al. 1999). This nondistinct raster pattern in *Cyclocephala* spp. distinguishes them from many other groups of white grubs. However, *Cyclocephala* spp. larvae are so similar morphologically that they cannot be separated. Life stage description of *C. borealis* and *C. lurida* is available in various texts (Potter 1995, Vittum et al. 1999). *Cyclocephala parallela* life stages have been described by Gordon and Anderson (1981) and Cherry (1985). Detailed life stage descriptions of *C. pasadenae* and *C. hirta* are not available.

Adult *C. borealis* are dull yellowish-brown with dark chocolate-brown heads that shade to a lighter-brown clypeus (Fig. 2) and are

Table 1. Major white grub pests of turfgrass in the United States

Sub family	Common name	Latin name	Origin, life cycle
Aphodinae	Black turfgrass ataenius	*Ataenius spretulus* (Haldeman)	Native, annual/biannual
Cetoniinae	Green June beetle	*Cotinis nitida* L.	Native, annual
Dynastinae	Northern masked chafer	*Cyclocephala borealis* Arrow	Native, annual
Dynastinae	Southern masked chafer	*Cyclocephala lurida* Bland	Native, annual
Melolonthinae	Asiatic garden beetle	*Maladera castanea* (Arrow)	Japan/China, annual
Melolonthinae	European chafer	*Rhizotrogus majalis* (Razoumowsky)	Europe, annual
Melolonthinae	May or June beetle	*Phyllophaga* spp.	Native, annual/multiyear
Rutelinae	Japanese beetle	*Popillia japonica* Newman	Japan, annual
Rutelinae	Oriental beetle	*Anomala orientalis* Waterhouse	Philippines/Japan, annual

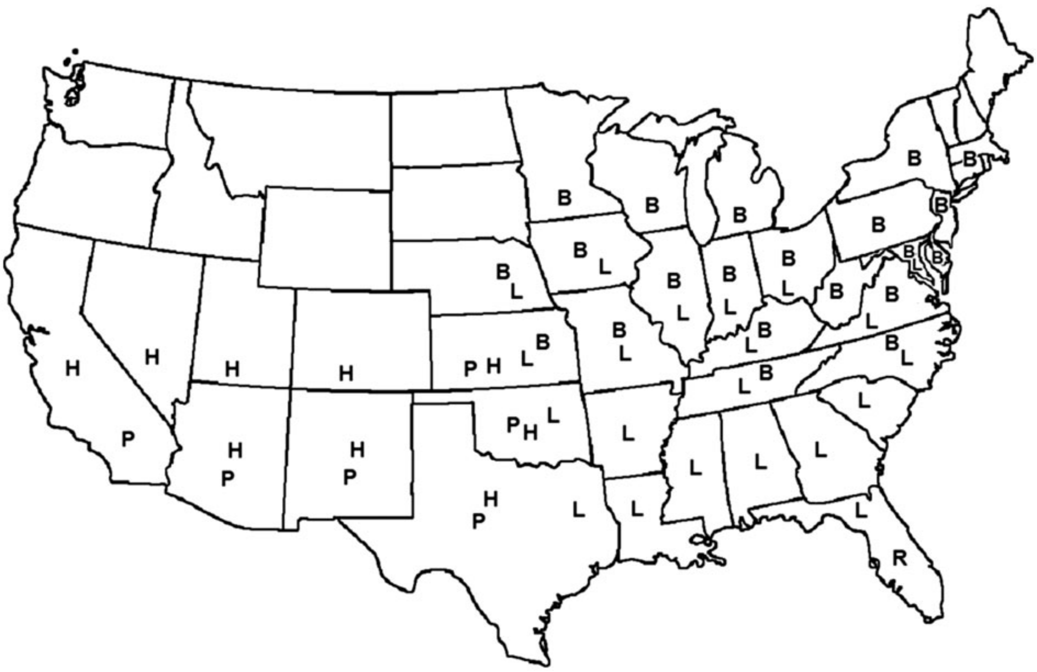

Fig. 1. Distribution of *Cyclocephala* spp. in the United States (B = *borealis*, L = *lurida*, P = *pasadenae*, H = *hirta*, R = *parallela*).

about 11–12-mm-long and 6–7-mm-wide. Adult *C. lurida* are shiny reddish-brown (Fig. 3), also have dark chocolate-brown heads that shade to a lighter-brown clypeus, and are about 10.5–12-mm-long and 6–7-mm-wide. In both species, females are slightly smaller than males, the lamellae of the antennal clubs are distinctly longer in males, and in the males, the front tarsi are heavier with wider segments and one of the two claws on each front leg is distinctly longer than the other. Male *C. borealis* have many erect hairs on the elytra, while the elytra of male *C. lurida* are bare except on the edges. Compared with male *C. lurida*, male *C. borealis* have a much longer pygidial pubescens (area covered with fine hairs on the last dorsal segment of the abdomen). Females of *C. borealis* have dense hairs on the metasternum and a row of stout bristles on the outer edge of the elytra, features that are missing in *C. lurida*.

Adult *C. pasadenae* are yellowish-brown with small hairs on the body (Fig. 4), have a characteristic "bead" along the base or posterior part of the pronotum, and are about 10.5–14.0-mm-long and 5.2–7.1-mm-wide. Adult *C. hirta* are yellowish-brown and about 12−14-mm-long and 5.1−6.7-mm-wide (Fig. 5). The head is reddish. It has comparatively less hairs on the body and lacks the basal "bead". Saylor (1945) reported to have observed variants of the adults of these species. Adult *C. parallela* are yellowish-brown beetles with a dark reddish-brown head and light yellowish-brown pronotum (Fig. 6). They are 12−15-mm-long and have a smooth body and pygidium (last dorsal segment of the abdomen).

Fig. 2. Adult northern masked chafer, *Cyclocephala borealis*.

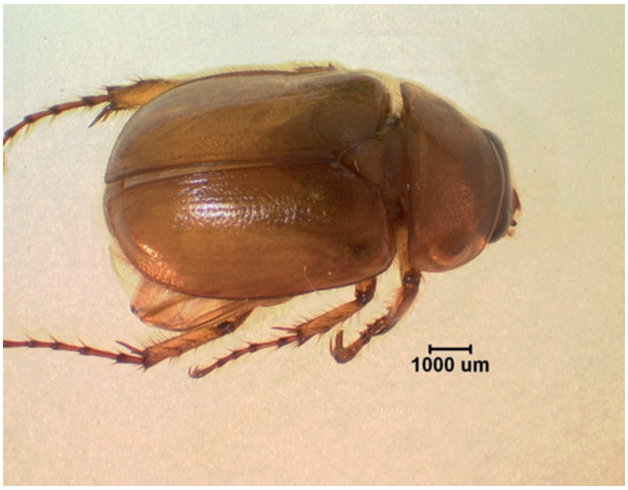

Fig. 3. Adult southern masked chafer, *Cyclocephala lurida.*

Fig. 4. *Cyclocephala pasadenae.* Photo: D.C. Lightfoot

Fig. 5. *Cyclocephala hirta.* Photo: Whitney Cranshaw, Colorado State University, Bugwood.org.

Eggs are typically found within the top 5 cm of soil (Potter 1995). Newly laid eggs are pearl white, ovoid, and approximately 1.7-mm-long and 1.3-mm-wide, and, by absorbing water from the surrounding substrate, expand to 1.7 mm in length and 1.6 mm in width before hatching (Johnson 1941; Fig. 7).

Cyclocephala larvae are typical white grubs with a creamy white, C-shaped body and six jointed legs (Fig. 8). The head capsule is chestnut brown with a darker spot on the upper side where it attaches to the thorax. *Cyclocephala* spp. have a raster pattern of approximately 25–30 coarse, long, hooked spines that become longer toward the anal slit and show no distinct arrangement (Fig. 9). The anal slit is transverse (crosswise) and arcuate (curved). There are three instars. Neonate first instars are about 3-mm-long and translucent white with a more grayish posterior region (Fig. 7). Mature third instars reach a maximum length of 23–25 mm. The head capsule widths of the first, second, and third instars average 1.6, 2.3, and 4.1 mm, respectively (Ritcher 1966).

Masked chafer pupae are about 17-mm-long, initially creamy white, but gradually change to yellowish- and then reddish-brown

Fig. 6. *Cyclocephala parallela.* Photo: Brad Barnd, Bugguide.net.

Fig. 7. *Cyclocephala lurida* eggs and first instar.

Fig. 8. *Cyclocephala* spp. third-instar grub.

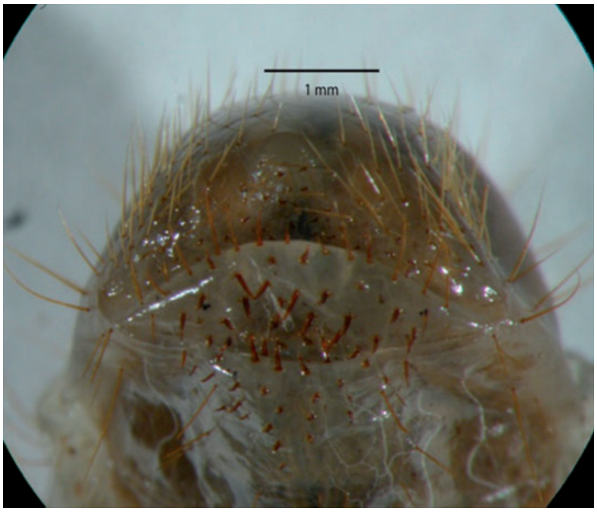

Fig. 9. *Cyclocephala* spp. larval raster pattern.

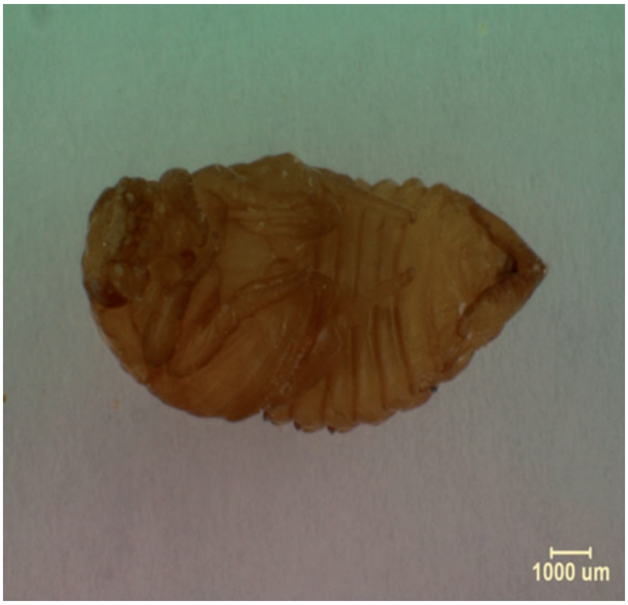

Fig. 10. *Cyclocephala* spp. pupa.

as they mature (Fig. 10). They are found in earthen cells in the soil (Potter 1995).

Life Cycle and Biology

The biology and life cycles of *C. borealis* and *C. lurida* have been described by Ritcher (1940) and Johnson (1941), respectively. Masked chafers have a 1-year life cycle and spend about 14–21 d as eggs, 10–11 mo as larvae, 4–5 d as prepupae, 11–16 d as pupae, and 5–25 d as adults. However, a life cycle of two generations per year has been reported in Florida for *C. lurida* and *C. parallela* (Buss 2009). Adults do not feed and are present in June and July. In Kentucky, *C. borealis* flights start in early to mid-June, peak in late June, and end by early August, while *C. lurida* flights start at least 1 wk later, peak 1–2 wk later, but also end in early August. Flight activity is greater after heavy rain. During the day, adults rest in the soil under turfgrass. *Cyclocephala lurida* adults emerge around dusk and are active until about 11:00 p.m., while *C. borealis* adults are active mostly after midnight (Potter 1980). Males of both species fly back and forth over turf in search of females. Virgin females remain on the ground or climb grass blades and release a sex pheromone to attract males (Potter 1980). After mating, the female burrows into soil under the turf to lay eggs.

Eggs are deposited mostly within the top 5 cm of soil singly or in small clusters (Potter 1995). *Cyclocephala borealis* females oviposit an average of 11–12 eggs as early as 2 d after emergence from the soil, and the eggs hatch in 14–21 d, depending on temperature (Johnson 1941). Female *C. lurida* lay an average of 29 eggs that take 12–15 d and 18–22 d to hatch at 28 and 23°C, respectively (Ritcher 1940). Most eggs will have hatched by early August.

First instars of *C. borealis* feed on grass roots and organic matter immediately after hatching and molt to second instar in about 3 wk with adequate soil moisture. By mid-September, most larvae will have molted to the third instar (Johnson 1941). The larvae move up and down in the soil in response to changes in soil temperature as they grow (Johnson 1941). They overwinter as third instars in earthen cells at a depth of 10–25 cm in the soil. They move back to the root zone in early spring to resume feeding and are fully mature by mid- to late May. They then move to a depth of 7.5–10 cm and form pupation cells within which they go through the prepupal and pupal stages and emerge as adults starting in early June in Kentucky.

No detailed study on the biology of the other common *Cyclocephala* spp. has been conducted, but they are believed to have a similar biology as *C. borealis* and *C. lurida* throughout all stages.

Effect of Soil Moisture and Temperature on Larval Survival

Soil moisture and temperature are very crucial for the development and survival of eggs. Female beetles prefer to lay eggs in moist, well-drained soil high in organic matter (Potter 1995). Potter (1983) reported that soil moisture levels below the wilting point cause desiccation, leading to death of eggs. High soil temperature combined with low soil moisture negatively affects the survival of eggs. Potter and Gordon (1984) observed that no eggs survived a soil temperature of 40°C and <8% soil moisture.

Fig. 11. Turfgrass damage caused by white grubs and vertebrate predators searching for masked chafer grubs in Blacksburg Country Club (Blacksburg, VA) in 2009.

Damage

Masked chafer adults do not feed and thus are not considered pests. Larvae consume grass roots, which can result in severe damage to turfgrass, especially in late summer and fall when they reach the second and third instars. In spring, masked chafer grubs typically cause less damage, as the usually cooler and moister conditions make the grass more tolerant of their feeding activity (Crutchfield and Potter 1995). Damaged turf can be pulled up easily in large pieces. Problems are exacerbated when vertebrate predators dig up the turf in search of grubs, often at larval densities that, by themselves, would not necessarily cause turf damage (Fig. 11). Masked chafer grubs also feed on organic matter in addition to grass roots (Vittum et al. 1999).

An economic threshold level of 6–10 larvae per 0.1 m^2 (1 ft^2) has been generally used for masked chafer grubs (Potter 1982, Merchant and Crocker 1996). However, there is a high disparity between the typically used economic threshold levels and what field studies have shown regarding damage thresholds for *Cyclocephala* spp. Grasses have been observed to tolerate higher numbers of *Cyclocephala* spp. larvae in well-managed turf. Potter (1982) suggested a damage threshold of 13–16 masked chafer larvae per 0.1 m^2 (1 ft^2) on Kentucky bluegrass. Crutchfield and Potter (1995) found that 15–20 larvae per 0.1 m^2 (1 ft^2) were required to cause damage. Crutchfield and Potter (1995) also found that tall fescue and perennial ryegrass tolerated even higher densities of larvae in cool and moist growing seasons. However, turf that is stressed owing to heat, drought, or other factors has a significantly lower tolerance level. Redmond et al. (2012) summarize that vigorous turf may support more than 20 larvae per 0.1 m^2, whereas stressed turf may only tolerate 8-10 larvae per 0.1 m^2. Damage will also vary with grass species; for example, on adequately watered and fertilized turfgrass fields, tall fescue was regularly found to tolerate 30 larvae per 0.1 m^2 without visible damage, whereas perennial ryegrass started to show damage at densities of 10–15 larvae per 0.1 m^2 (A.M.K., unpublished data).

Effect of Turfgrass Species on Larval Feeding

Both cool-season and warm-season turfgrass are suitable hosts for masked chafer larvae (Potter et al. 1992, Merchant and Crocker 1996). However, warm-season grasses are less susceptible to larval feeding. Among cool-season grasses, *C. lurida* larvae develop and survive better on tall fescue, *Festuca arundinacea* Schreber; hard fescue, *Festuca avina* L. var. *duriuscula*; and perennial ryegrass, *Lolium perenne* L., than on creeping bentgrass, *Agrostis palustris* (Hudson), and Kentucky bluegrass, *Poa pratensis* L. (Potter et al. 1992). Moreover, Crutchfield and Potter (1995) found that *C. lurida* larvae feed significantly less on creeping bentgrass roots compared with roots of other cool-season grasses. However, in another study, *C. lurida* larvae did not discriminate among grass species (Crutchfield and Potter 1994).

IPM of *Cyclocephala* spp.

Sampling/Monitoring

Degree-day (DD) models have been developed to predict first adult emergence and peak adult flight for *C. pasadenae* (Blanco and Hernandez 2006), *C. borealis*, and *C. lurida* (Potter 1981). For first emergence, *C. borealis* required DD accumulations (base 10°C) of about 500 and 540 DD measured in air and soil, respectively. *Cyclocephala lurida*, however, required slightly higher DD accumulations of about 585 and 660 DD, respectively, to first emerge as an adult (Potter 1981). Female *C. lurida* produce a volatile sex pheromone that is attractive to males of both *C. lurida* and *C. borealis* (Potter 1980). Potter and Hayes (1993) used sticky traps baited with *C. lurida* female crude extract to test the female pheromone in the field and found that although male *C. lurida* were attracted to the trap, there was no correlation between numbers of males caught and ensuing larval populations in turfgrass.

Monitoring of white grubs can be done by taking sod/soil samples to a depth of 7.5–10 cm (3–4 inches) and examining the roots and soil for larvae (Potter 1998, Vittum et al. 1999). This can be done with a flat-blade spade by cutting three sides of a turf square and peeling back the flap. Alternatively, cores can be taken with a standard golf cup cutter (10.8 cm diameter) and examined on a tray. Owing to the patchy distribution of white grubs, samples need to be taken in a grid pattern, with samples taken every 2–6 m, depending on the size of the sampled area, or on golf course fairways, samples are taken 9–14-m-apart in parallel lines or zig-zag patterns, as done on golf course fairways (Potter 1998, Niemczyk and Shetlar 2000). Experienced samplers can process 20 cores per hour.

Cultural Control

Deep-rooted and vigorous turfgrass can tolerate higher grub densities and more feeding than weak and stressed plants. Cultural practices including irrigation, fertilization, mowing, and thatch management may be used to promote grass health and root recuperation from damage. For example, nitrogen fertilization of damaged areas in fall can help the grass recover from grub damage (Crutchfield et al. 1995). Appropriate irrigation in the late summer and fall, particularly when late instars feed voraciously, improves grass tolerance to feeding by alleviating root loss and promoting root regrowth (Potter 1982). However, irrigation should be minimized during the oviposition period to reduce attraction of egg-laying females and survival of eggs and young larvae (Potter et al. 1996). Also, mowing height is directly related to turf root depth and ability to regrow damaged roots (Christians 1998), and increasing cutting height may increase turf tolerance to grub feeding and reduce grub densities, possibly because taller grass harbors more natural enemies, providing better grub suppression (Potter et al. 1996). Computer simulations suggest that turf aeration may kill as many as 40% of grubs with appropriate hole patterns (Blanco-Montero and Hernandez 1995). Cranshaw and Zimmerman (1989) reported up to 56% mortality of white grubs in turfgrass when about 155 holes/ 0.1 m^2 were made by spiked sandals, which indicates that use of such techniques has potential for white grub control in turf.

Biological Control

A wide range of microbial agents and natural enemies infect or attack white grubs, including *Cyclocephala* spp. (Figs. 12–15). Many of these natural enemies have been studied for biological control of white grubs. These include entomopathogenic bacteria, fungi, and nematodes, as well as insect predators and parasitoids.

Entomopathogenic Bacteria

Paenibacillus popilliae (Dutky) (formerly *Bacillus popilliae*) and *Paenibacillus lentimorbus* (Dutky) are the causal agents of milky disease in many scarabaeid larvae in the United States (Klein 1992, Garczynski and Siegel 2007, Jurat-Fuentes and Jackson 2012). These bacterial species have many strains that are species-specific,

Fig. 12. *Cyclocephala* spp. larva infected by *Heterorhabditis bacteriophora*.

Fig. 13. *Cyclocephala* spp. larva infected by *Metarhizium brunneum*.

Fig. 14. *Cyclocephala* spp. larva infected by *Beauveria bassiana* (left: healthy grub; right: infected grub).

Fig. 15. *Cyclocephala* spp. pupa infected by *Metarhizium brunneum* (left: healthy pupa; middle: early infection; right: sporulation).

with little to no cross-infectivity among species. Only the strain infecting *P. japonica* larvae has been commercialized (White 1947, Harris 1959). Warren and Potter (1982) reported that the *Cyclocephala* strain of *P. popilliae* could be very virulent against *C. lurida*.

Among many insecticidal *Bacillus thuringiensis* (Bt) strains, Bt subsp. *japonensis* var. *buibui* has been reported to have insecticidal properties against white grubs (Obha et al. 1992). Bixby et al. (2007) found that rates as low as 100 g of δ-endotoxin/ha provided control of oriental beetle, *Anomala orientalis* Waterhouse, and Japanese beetle. However, *C. borealis* has been found to be less susceptible to this bacterial toxin (Mashtoly et al. 2009). In addition, this strain is not commercially available. *Bacillus thuringiensis* subsp. *galleriae* SDS-502 strain appears to be effective against *C. lurida* (Baxendale et al. 2005, Stamm et al. 2009). To be effective, both Bt strains have to be applied against early instars.

An insecticide based on the bacterium, *Chromobacterium subtsugae* Martin et al., and its fermentation products has also been shown to be effective against *C. lurida* (Stamm et al. 2012, 2013). More research on the efficacy of this commercially available insecticide against white grubs is needed.

Entomopathogenic Nematodes

Members of the families Steinernematidae and Heterorhabditidae are the most widely studied groups of nematodes that infect white grubs, including masked chafers (Grewal et al. 2005, Georgis et al. 2006). However, their efficacy differs among grub species (Grewal et al. 2002, Koppenhöfer et al. 2004). *Cyclocephala borealis, C. lurida,* and, especially, *C. pasadenae* are less susceptible to common entomopathogenic nematodes such as *Heterorhabditis bacteriophora* Poinar and *Steinernema glaseri* (Steiner) under laboratory and greenhouse conditions (Koppenhöfer et al. 2004, 2006). In field studies, good control of *C. borealis* has been observed with *Heterorhabditis zealandica* Poinar X1 strain (72–96%), *Steinernema scarabaei* Stock and Koppenhöfer (84%), and *H. bacteriophora* GPS11 strain (47–83%; Grewal et al. 2004, Koppenhöfer and Fuzy 2003), but not with *H. bacteriophora* TF strain (Koppenhöfer and Fuzy 2003), *S. glaseri* MB strain (0%), or *Steinernema kraussei* (Steiner) (50%; Grewal et al. 2004). Baxendale et al. (2003) found *H. zealandica* effective (80–90%) against *C. lurida*. Against *C. hirta*, *H. bacteriophora* NC1 strain (13–48%), *S. glaseri* NC strain (9%), and *Steinernema kushidai* Mamiya (33%) were not effective. And against *C. pasadenae*, *H. bacteriophora* NC1 strain (8%; Koppenhöfer et al. 1999) and *H. bacteriophora* (10%; Dreistadt et al. 2004) were ineffective.

Entomopathogenic Fungi

Metarhizium and *Beauveria*, two genera of entomopathogenic fungi, cause green and white muscardine diseases, respectively, in insects. They are well-known for their ability to infect white grubs in natural habitats. *Beauveria bassiana* (Bals.) Vuill is registered for white grub control in the United States, but its efficacy against white grubs under field conditions is highly variable (Morales-Rodriguez and Peck 2009, Bélair et al. 2010). Mortality of third-instar *C. lurida* by *Metarhizium brunneum* Petch F52 strain [formerly *M. anisopliae* (Metchnikoff) Sorokin F52] and *B. bassiana* GHA strain was very low under laboratory, greenhouse, and field conditions (Wu 2013, Wu et al. 2014).

Predators and Parasitoids

In addition to entomopathogens, natural enemies including invertebrate and vertebrate predators and parasitoids may be also manipulated to provide natural suppression of white grub populations. A native parasitoid, *Tiphia pygidialis* Allen (Hymenoptera: Tiphiidae), is an important natural enemy of *Cyclocephala* spp. larvae. Rogers and Potter (2004) reported 33% parasitism by *T. pygidialis* of *Cyclocephala* larvae collected in Kentucky.

Many predatory ground beetles, rove beetles, and ants prey on eggs and young grubs as food (Koppenhöfer 2007, and references therein). Particularly, ants play an important role in natural control by feeding on their eggs (Zenger and Gibb 2001). In an experiment to investigate the role of ant predation, Zenger and Gibb (2001) found that the ant, *Solenopsis molesta* (Say), can carry away as much as 83% of eggs in field.

These natural enemies can be conserved by modifying cultural practices, i.e., raising mowing height to provide habitat refuge, and planting wildflower beds to supplement food for predators and parasitoids (Rothwell and Smitley 1999, Frank and Shrewsbury 2004). In addition, avoiding unnecessary insecticide sprays (i.e., spot treatment instead of broadcast applications), proper timing of applications, and reducing the use of broad-spectrum insecticides, such as carbamates, organophosphates, and pyrethroids, would reduce the risk of direct kill of natural enemies or depleting them of food resources (Koppenhöfer, 2007, and references therein).

Chemical Control

Currently, insecticides are the primary method for control of white grubs, including masked chafers (Table 2). In most cases, they offer the only practical method to control white grub densities that have already reached damaging levels (Baxendale and Grant 1995). Based on the timing of an application relative to presence of different white grub developmental stages, applications can be roughly grouped as either curative or preventive (Potter and Potter 2013). Each approach has its own advantages and disadvantages. With curative control, insecticides are typically applied in late summer, after the eggs have hatched and larvae are actively feeding, either after damage to turf has occurred (typically when third instars are present) or after sampling has detected densities above the action threshold (typically before the third instars occur). Insecticides used for curative control typically have a relatively short residual activity (usually 2 to 3 wk or less), and also tend to be more effective if applied to target younger larvae. Curative applications are usually intended to

Table 2. Insecticides currently registered for control of white grub/masked chafer grubs in turfgrass in the United States

Active ingredient	Insecticide class	Application timing[a]	Trade names
Bacillus thuringiensis subsp. galleriae strain SDS-502	Microbial (bacterium)	Curative	grubGONE
Beauveria bassiana	Microbial (fungus)	Curative	BotaniGard
Carbaryl	Carbamate	Curative	Sevin
Chlorantraniliprole	Diamide	Preventive	Acelepryn, Scotts Grub-Ex
Clothianidin	Neonicotinoid	Preventive, curative	Arena
Clothianidin + bifenthrin	Neonicotinoid + pyrethroid	Preventive, curative	Aloft
Dinotefuran	Neonicotinoid	Preventive	Zylam
Heterorhabditis bacteriophora	Microbial (nematodes)	Curative	e.g., Nemasys G, Heteromask, Terranem, nema-green
Halofenozide	Diacylhydrazine	Preventive	Natural Guard Grub Control
Imidacloprid	Neonicotinoid	Preventive	Merit, Bayer Advanced Lawn Season-long Grub Control
Imidacloprid + bifenthrin	Neonicotinoid + pyrethroid	Preventive	Allectus
Imidacloprid + cyfluthrin	Neonicotinoid + pyrethroid	Preventive	Bayer Advanced Complete Insect Killer
Thiamethoxam	Neonicotinoid	Preventive	Meridian
Trichlorfon	Organophosphate	Curative	Dylox, Bayer Advanced 24-hour Grub Control

[a]Preventive = until larvae start to appear in soil, targeting first and early second instars; curative = targeting late second and third instars.

quickly suppress grub feeding activity and prevent further damage on turf. Insecticides that provide control of larger larvae include the carbamate carbaryl, the neonicotinoid clothianidin, and, especially, the organophosphate trichlorfon. Regardless of the product, rainfall or post-treatment irrigation should be applied to leach the insecticide residues into the root zone (Potter 1998). Advantages of a curative control approach include: 1) treatments are applied only if damaging grub populations are known to be present, which reduces unnecessary insecticide use; and 2) because white grub infestations are usually localized, only certain portions of the turf or “hot spots” will need to be treated (Potter 1998). Disadvantages of the curative approach include: 1) proper timing of treatments; insecticides applied too early may degrade before most eggs have hatched, but if applied too late, the grubs will be harder to kill and turf damage may have already occurred (Potter 1998); and 2) because managed turfgrass often implies a proximity to people, pets, homes, and businesses, pesticide applications during the summer months of peak activity may pose greater risks of human exposure than other times of the year.

Preventive insecticide applications are intended to prevent damage from grubs. They are typically applied before grubs or damage is detected by monitoring, usually before or during adult egg-laying activity. Preventive control requires the use of insecticides with relatively long residual activity in soil. Many of the newer insecticides persist long enough to allow applications well before peak egg-laying activity. However, earlier applications are often chosen because of rainfall (necessary to move products into soil if no irrigation is available) patterns being more reliable earlier in the season, or because it may be easier to coordinate them with other management activities.

Advantages of the preventive strategy include: 1) a greater flexibility in application timing; 2) applications made when there is greater chance for rainfall to water the insecticide into the root zone; and 3) opportunity to use insecticides that have more selective activity on target insects and pose relatively less hazard to humans, pets, birds, fish, or the environment. Disadvantages of the preventive approach include: 1) preventive insecticides typically are only effective against young grubs and, thus, will not control older or overwintered (third-instar) grubs; and 2) the decision to treat is made before knowing if and where damaging grub problems will occur; thus, preventive control often results in a greater amount of area being treated unnecessarily.

Neonicotinoid insecticides, especially imidacloprid, have become the primary insecticides used for white grub control in a preventative method. The neonicotinoids imidacloprid, clothianidin, and thiamethoxam all provide effective preventive and early curative control of masked chafer grubs (Heller and Walker 2002a, b, c, e; Heller et al. 2006a, b, c, 2008a, b; Shetlar and Andon 2013; Gyawaly et al. 2015). However, early application of these insecticides can negatively affect hymenopteran parasitoids of the grubs (Rogers and Potter 2003). In addition, commercial mixtures of these insecticides with pyrethroids such as imidacloprid + bifenthrin and clothianidin + bifenthrin also provide effective preventive and early curative control (Eickhoff et al. 2006; Heller et al. 2006a, 2008a, c; Ramm et al. 2010). It should be noted that the pyrethroid component of these mixtures probably is not contributing much to the grub control, as pyrethroids typically do not move very well into the soil. Moreover, these combination products have an extremely broad activity spectrum and will obviously have even more nontarget effects than the neonicotinoids by themselves. On the other hand, combination products are convenient, especially for the landscape industry, as their activity against both soil-dwelling insect pests and surface-active insect pests would allow for fewer applications. However, because of the short residual activity of bifenthrin, these combinations are most effectively used when surface insect pests are active.

Recently, the increased concerns over nontarget effects of neonicotinoids on pollinators have resulted in the U.S. Environmental Protection Agency mandating products containing imidacloprid, thiamethoxam, dinotefuran, or clothianidin include a bee protection box on the pesticide label. This label prohibits the use of these insecticides on blooming plants that may be visited by pollinators. The potential harmful effects of neonicotinoids on bee pollinators were highlighted recently in a field study by Larson et al. (2013), who found that treating lawns with the recommended rate of clothianidin when white clover was blooming significantly affected weight gain and queen production of bumble bees.

More IPM-friendly insecticide options include chlorantraniliprole, a diamide insecticide that has demonstrated excellent control of masked chafer grubs (Buss et al. 2006; Heller et al. 2006c, 2008d, e, f, g; 2009; Royer et al. 2009; Toda et al. 2006; Shetlar and Andon

2013; Gyawaly et al. 2015), and the insect growth regulator, halofenozide, which is highly effective when applied to target small grubs (Held et al. 2000; Muegge et al. 2000; Heller and Walker 2000, 2002d; Muegge and Quigg 2002; Heng-Moss et al. 2005).

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