Permanent Control of Pest Mole Crickets (Orthoptera: Gryllotalpidae: *Scapteriscus*) in Florida

J. H. Frank and T. J. Walker

Fig. 1. An adult tawny mole cricket, one of the three pests. Photo: Lyle Buss

Mole crickets are strange insects. Their powerful forelegs let them bury themselves in sand in seconds. Like moles, they live in the ground. In spring, winged adults emerge from the ground and fly in swarms after sundown, looking for mates and new ground where they can produce offspring. Males tune their burrow entrances as loudspeakers that amplify and direct their calling songs skyward. The louder they sing, the more females (and competing males) they attract.

There are four species of mole crickets in Florida. The northern mole cricket, *Neocurtilla hexadactyla* (Perty) (subfamily Gryllotalpinae), is a native species, not a pest, and not closely related to the three South American invaders. The invaders are the shortwinged mole cricket (*Scapteriscus abbreviatus* Scudder), southern mole cricket (*S. borellii* Giglio-Tos), and tawny mole cricket (*S. vicinus* Scudder; subfamily Scapteriscinae). All are pests, but the tawny mole cricket (Fig. 1) is the worst. Its adults fly, so they disperse readily. It eats roots and leaves of grass, especially of Florida's pasture- and turfgrasses; it destroys tomato, cabbage, eggplant, and bell pepper seedlings. Like the southern mole cricket, it also kills plants by disturbing their roots so that they become desiccated. Like the tawny mole cricket, the shortwinged mole cricket is a damaging herbivore, but it cannot fly and has a restricted distribution. The southern mole cricket has spread widely, but is more of a predator than a phytophage. The specialist native wasp *Larra analis* F. and the nematode *Steinernema neocurtillae*, which attack the northern mole cricket, do no harm to the invaders. Generalist natural enemies attack the invaders, but do not inflict enough mortality to control them (Hudson et al. 1988).

When these three invaders became problems in Florida in 1899–1924, poisoned baits were used against them. Baits had to be applied year after year, and yet the mole crickets spread. In 1940, a federal emergency relief program gave 1,258 tons of arsenical bait to Florida vegetable growers in 12 counties. A low-key biological control research program was conducted for a few years in the 1940s, but was terminated when chlordane was found to control mole crickets cheaply and persistently.

In the 1970s, chlordane was banned by the U.S. EPA because of the environmental harm it caused. Florida cattle ranchers were devastated because they could not afford the more expensive chemicals that were available for use against mole crickets in turf and vegetables, and they called on the state legislature to act. The legislature's response was to earmark part of the funds provided annually to the University of Florida's Institute of Food and Agricultural Science (UF/IFAS) for mole cricket research. Earmarking was passed down as a mandate to the UF/IFAS Entomology and Nematology Department. In 1978 the UF/IFAS Mole Cricket Research Program was born, and it became the department's flagship program because a portion of its state funding was mandated to the program. Fourteen Entomology/Nematology faculty members participated: initially C. S. Barfield, D. G. Boucias, P. G. Koehler, E. L. Matheny, J. L. Nation, G. C. Smart, D. E. Short, S. J. Yu, and T. J. Walker in Gainesville; J. A. Reinert in Ft. Lauderdale; and D. J. Schuster in Bradenton; and later R. I. Sailer, J. H. Frank, and F. D. Bennett in Gainesville. Most of these faculty later retired, left Florida, or dropped out when funding ceased. T. J. Walker was coordinator between 1979 and 1985; J. H. Frank became coordinator in 1985. Postdoctoral researchers with the program were H. G. Fowler (1982–1986), W. G. Hudson (1985–1988), and J. P. Parkman (1988–1996). Many student researchers worked under the program.

The new program investigated mole cricket origins, life cycles, behavior, physiology, ecology, sampling methods, toxicology, and pathology (Walker 1985). Earlier "basic" research on mole cricket song paid off by making it possible to produce synthetic songs that were used to bait traps to sample flying mole crickets (Walker

1982). Trapping stations were established at seven points in Florida to measure long-term population change (Fig. 2). Program members realized that permanent control was likely to be accomplished only by classical biological control, but they also investigated chemical control and relative tolerance of grass species and varieties (Walker 1985). "Basic" research on origin of the pests was beneficial in detecting the places in South America where biological control agents might be obtained and imported into Florida (Walker and Nickle 1981). Biocontrol agents were imported from southern South America in the mid- to late 1980s.

Fig. 2. A sound trap for monitoring mole cricket populations, and Tom Walker, its designer. These sound traps are in pairs (one for tawny mole crickets, one for southern mole crickets, at each location). They were operated nightly for 25 years. Photo: Lyle Buss

In the 1990s, almost all funds for mole cricket biocontrol dried up, and the program struggled to progress. Biological control agents, however, had been released and a monitoring system was in place. Under other circumstances, more might have been accomplished, but here we describe success for a part of north-central Florida, knowing that the three biological control agents discussed here are spreading success elsewhere.

Larra bicolor

Larra bicolor F. is a sphecid wasp, native to South America, which attacks only *Scapteriscus* mole crickets (Menke 1995). Unlike the familiar hornets and yellow jackets, this wasp is not social, does not build or defend nests by stinging intruders, and is not a threat to humans. Its larvae are parasitoids that feed externally on active mole crickets.

Although it was known earlier that this wasp seeks out *Scapteriscus* mole crickets as food for its progeny, that knowledge was not put to use until the late 1930s, when Puerto Rican entomologists imported it to their island. Wasps collected on the equator in Brazil were taken to Puerto Rico and released (Wolcott 1941). The idea was to establish permanent populations to control pest mole crickets at no further cost. Populations were established, but nobody measured the effect. In 1981–1983, members of the UF/IFAS program brought wasps from Puerto Rico for release at several places in Florida. These efforts were not very successful. Wasps established a population only in Ft. Lauderdale and provided little control. They did not spread far afield.

Behavioral studies on the population of *L. bicolor* at Ft. Lauderdale expanded on the Puerto Rican studies. Adult female wasps hunt in daylight for mole cricket adults and large nymphs, entering their burrows and chasing them into the open to attack (Fig. 3). With its sting, the wasp paralyzes its prey for a few minutes. It then lays an egg on the underside of the mole cricket and departs. The mole cricket revives and resumes its usual activities. The egg hatches within a week, and the wasp larva attaches to the mole cricket and begins feeding. When almost full-grown, the larva kills its host and consumes the remains. It then makes a cocoon in the ground and pupates. The pupa remains underground, insulated from extreme temperatures, for weeks or, in winter, for months (Castner 1988).

Because 1981–1983 releases had not succeeded in central or northern Florida, R. I. Sailer and F. D. Bennett speculated that the wasps might be climatically maladapted because they had come from the equator. Bennett found better adapted wasps of this same species at cooler sites in Bolivia. Bolivian wasps were imported and released in 1988/1989 in and near Gainesville. By late 1993, it was evident that the Bolivian strain had become established (Frank et al. 1995). By late 2002, it seemed to have spread 135 miles northwest and perhaps as far south; it is still spreading, only partially with assistance (Fig. 4). In time, it is likely to occupy all of Florida. A release at Tifton, GA (>31°N) in 2001 became established, but a release at Baton Rouge, LA (<31°N) in 2002 failed. Somehow, the wasp arrived in coastal Mississippi (<31°N) (Held 2005). We do not know how far north it may extend its range; but, because of the wasp's tropical origin, we doubt the range will be much north of 32°N. This would allow it to inhabit the southernmost areas of Georgia, Alabama, Mississippi, Louisiana, and southeastern Texas, all of which have severe problems with *Scapteriscus* mole crickets.

Fig. 3. Female *Larra bicolor* attacking a mole cricket. Photo: Lyle Buss

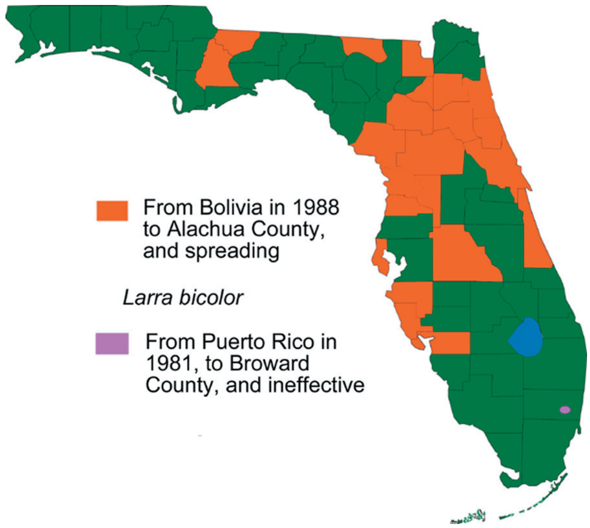

Fig. 4. Known distribution of *Larra bicolor* in Florida. Map: Howard Frank

The difficulty in calculating generational mortality inflicted on tawny mole crickets by *L. bicolor* is that this wasp has several generations each year, whereas tawny mole crickets have but one. This is not a "textbook" host–parasitoid situation where the percentage of parasitism measured in the field equates closely to generational mortality of the host. Mathematical modeler J. C. Allen (Ventura, CA) is collaborating to evaluate generational mortality of mole crickets in Florida caused by *L. bicolor*. A preliminary estimate is that under reasonable conditions (no chemical pesticides), mortality may approach 70%.

Wasp larvae need mole crickets as hosts, but adult wasps need an energy source. In northern Florida, a neotropical wildflower called *Spermacoce verticillata* L. (Rubiaceae; southern larraflower, a.k.a. shrubby false buttonweed, a.k.a. whitehead broom) was far more useful to the wasps than were other plants (Arévalo and Frank 2005) (Fig. 5). The advantages of this plant were discovered in Brazil and Puerto Rico by Wolcott (1941) and seen at Ft. Lauderdale by Castner (1988); the surprise is only that no other plant has yet proven to be more useful. Additional plants are being evaluated. It is most likely that plots of this plant can be manipulated to enhance local populations of the wasp. Details of plot size and spacing are yet to be investigated.

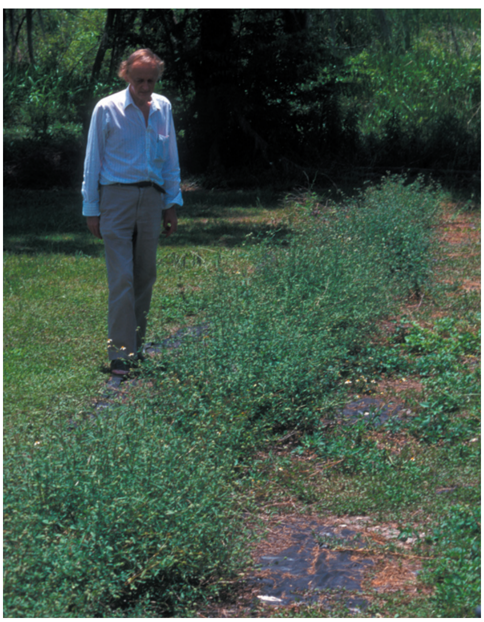

Fig. 5. Southern larraflower plot and Howard Frank. Photo: Skip Choate

Steinernema scapterisci

Steinernema scapterisci is a steinernematid nematode native to South America. It lurks in the soil and manages to enter the hemocoel of passing mole crickets, where it releases a specialized bacterium that it harbors. The bacterium soon kills the mole cricket. Feeding on the bacterium before and after the mole cricket dies, the nematode undergoes two or more generations within the host, thereby multiplying the infective form manyfold (Nguyen and Smart 1992) (Fig. 6).

S. scapterisci was found in *Scapteriscus* mole crickets collected by Aquiles Silveira-Guido, a retired entomologist who was hired by the UF/IFAS Mole Cricket Research Program to search Uruguay for parasites of pest mole crickets. Once brought to Florida, the nematode was investigated and eventually described as a new species (Nguyen and Smart 1990). At first, it could be reared only in pest mole crickets. With only a few available, releases were organized in small plots in Alachua County pastures, where it established populations and killed pest mole crickets. Monitoring these pastures ceased after five years, but the nematode was beginning to spread. It showed up miles away in Gainesville (Parkman et al. 1993b) and became well established at both Alachua County monitoring stations.

Fig. 6. *Steinernema scapterisci* emerged from a dead mole cricket. Photo: Khuong Nguyen

G. C. Smart filed for a patent for the use of the nematode. Stock was provided to a commercial producer of beneficial nematodes, which developed an artificial diet for it, allowing it to be reared by the tens of billions.

With large numbers thus available, projects were begun to evaluate the effects of releases of billions of nematodes in selected pastures in six counties (Parkman et al. 1993a), on three golf courses in northern Florida and three in southern Florida

(Parkman et al. 1994). Soon thereafter, when such large numbers again became unavailable, smaller numbers were reared in the laboratory, and millions were released by another method on 29 golf courses from end to end of Florida (Parkman and Frank 1993). Establishment was achieved at sites in 12 counties (Fig. 7). The earlier releases of billions of nematodes had more success. When the pasture release sites were revisited seven years later, all had populations of the nematode (Frank et al. 1999). When two golf courses were revisited 12–13 years later, we found populations of the nematode at both (Frank et al. 2002).

A start-up company in Tampa bought rights from the University of Florida to market nematodes reared by an offshore company. It sold and applied this nematode in several counties beginning in 1990, but did not release information about the locations. After a few years, the offshore company went out of the nematode business. The Florida company foundered and failed.

In 1996, ranchers in southwestern Florida reported devastating mole cricket populations. But the nematode was no longer available, and no other biological control agent could be brought to action without further research. Norman Leppla, UF/IFAS IPM Coordinator, brokered a licensing agreement between MicroBio (a beneficial nematode producer) and the University of Florida Office of Technology Licensing to produce and sell the nematode again. MicroBio is now owned by Becker Underwood of Ames, IA, and the nematode is marketed as Nematac S. From 2001, applications of the nematode have been made in several additional counties by the "Mole Cricket Task Force," but establishment has not been completely evaluated.

The effect of *S. scapterisci* on mole cricket mortality is easier to establish than that of *L. bicolor* because infected adults often fly to sound-baited traps. Indeed, on average, when populations were still high, >30% of mole crickets trapped in April and May at the Alachua County monitoring stations were infected. The reproductive cycle of *S. scapterisci* takes no more than 10 d at 24 °C (Nguyen and Smart 1992). This suggests that the cumulative mole cricket mortality during those 60 d could have been as high as 88% [0.7^6]. This may be the only one of the three biological control agents suitable for use in the Carolinas. We do not know whether it can overwinter there. At least it should survive during the warmer months and could be applied annually in spring.

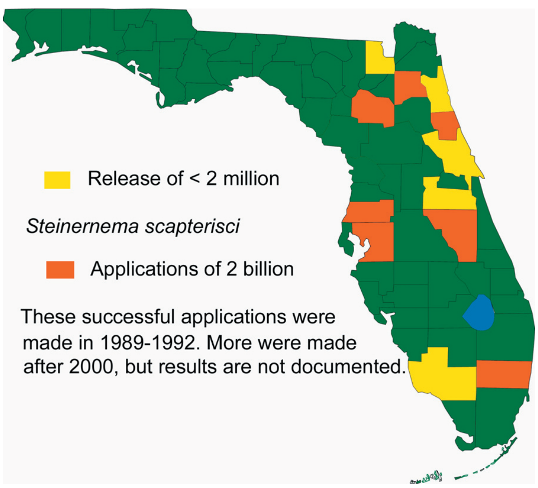

Fig. 7. Known distribution of *Steinernema scapterisci* in Florida. Map: Howard Frank

Ormia depleta

Ormia depleta (Wiedemann) is a tachinid fly native to South America (Fig. 8). It had already been described when Puerto Rican entomologists detected it on the equator in Brazil in the late 1930s. They found that it attacks pest mole crickets (Wolcott 1940) and later tried without success to import it onto their island.

Fig. 8. Adult female of *Ormia depleta.* Photo: Lyle Buss

The electronic mole cricket song synthesizer, developed by the UF/IFAS Mole Cricket Research Program, was put to use in South America. Not only mole crickets were attracted to the song, but also gravid females of *Ormia depleta* (Fowler and Kochalka 1985). Like little guided missiles, the flies home in after dark on singing mole crickets. At target, they deposit larvae on and near the singer. The larvae burrow into the singer and nearby mole crickets that they contact. Their feeding kills the host in about a week, and the fully grown fly larvae pupate in the ground. After 11 to 12 days, adult flies emerge from the pupae to mate and begin the process again. For the flies to larviposit requires that these little mobile larvae hatch from eggs inside their mother. To harvest the larvae means giving caesarean sections to the mother flies.

A research agreement between UF/IFAS and Universidade de São Paulo made it possible to hire Brazilian technicians in Piracicaba to trap adult flies and rear their offspring on collected mole crickets. Several times in the late 1980s, *O. depleta* pupae were brought from Brazil to quarantine in Gainesville. Attempts to rear them were at first unsuccessful. After a method had been developed to rear native *Ormia* flies, the method was adapted to *O. depleta* (Wineriter and Walker 1990).

Although expensive, the ability to rear *O. depleta* allowed releases in the field in 1988—first a few hundred in Gainesville and then in Bradenton. Next, 29 golf course members of the Florida Turfgrass Association sponsored a project to rear and release >10,000 flies, mainly on those courses, scattered from end to end of Florida. Populations spread. By 1994, the fly occupied 38 counties of peninsular Florida

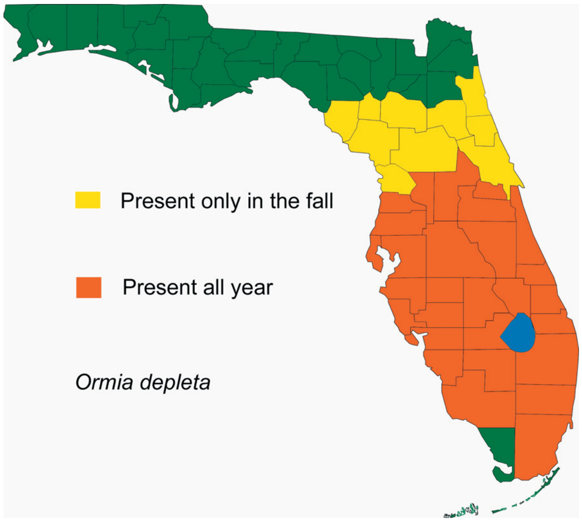

Fig. 9. Known distribution of *Ormia depleta* in Florida. Map: Howard Frank

(Frank et al. 1996) (Fig. 9). Disappointingly, the northern limits of the fly population proved to be just about where the first release was made—in Gainesville. Monitoring of the fly populations shows that they are abundant in the Bradenton area, but now are seldom caught near Gainesville. Their effective population may not extend north of 29°N (Walker et al. 1996).

As the fly population spread in the early 1990s, a survey conducted with help from the Florida Turfgrass Association showed significantly less damage by mole crickets on golf courses in counties that the fly had reached, compared with golf courses in counties the fly had not reached (Parkman et al. 1996). As with *L. bicolor* and *S. scapterisci*, it is difficult to evaluate the generational effect of the fly on pest mole cricket populations.

We expected to find that the adult flies used plant nectar as an energy source, just like *Larra bicolor*, although at night when the flies are active. Surprisingly, the flies were found to use honeydew secreted by insects such as aphids (Welch 2000), but they also used plant nectars (Welch 2004).

Monitoring, Results, and Things Still to Do

Monitoring stations installed in 1979 near Gainesville (Walker 1982) now prove their worth. Like weather stations, they are site-specific and operate every night of the year. They catch mole crickets to detect changes in numbers from year to year. Of five stations set up elsewhere, one persists, run by D. J. Schuster at the Gulf Coast Research and Education Center.

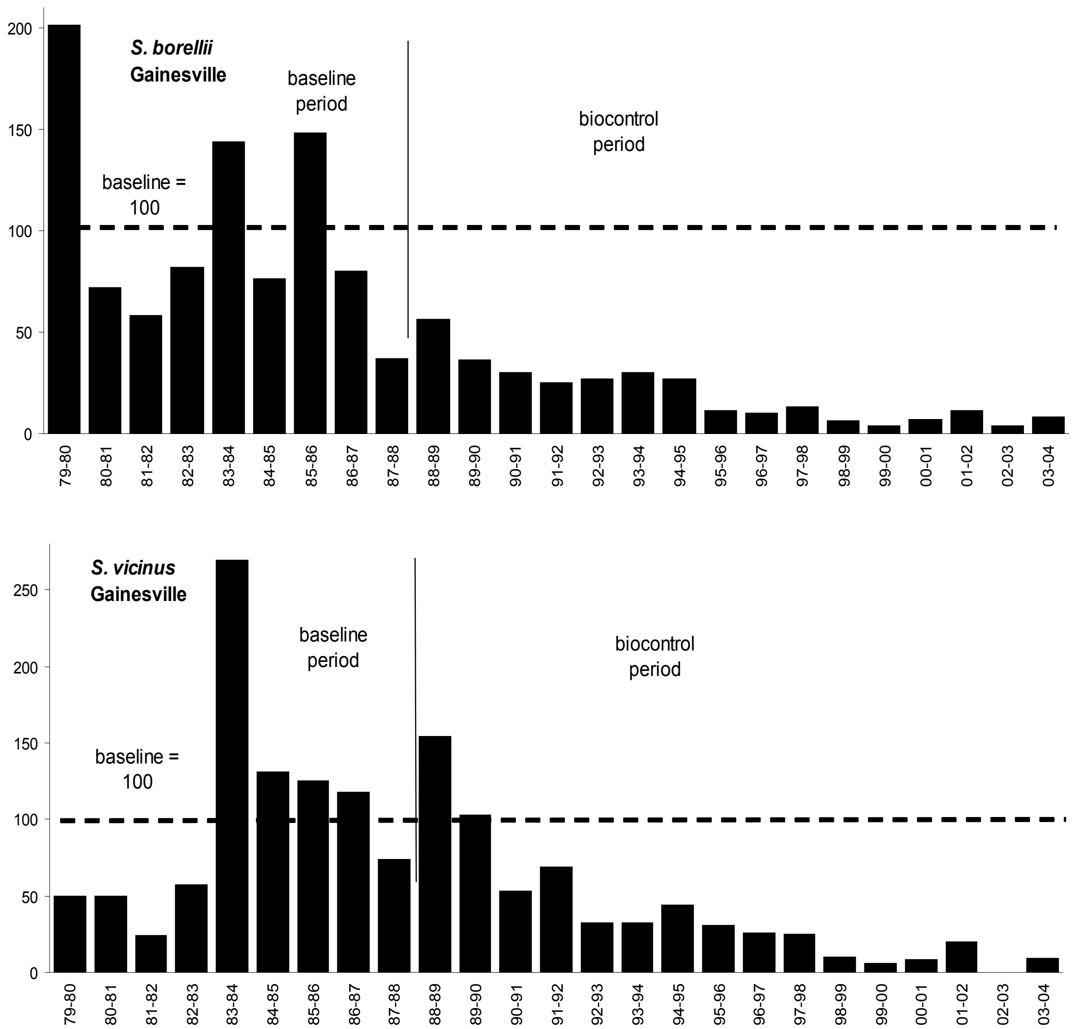

Fig. 10. Histogram of 25 years of pest mole cricket data from monitoring traps in Gainesville. The penultimate year (2002–2003) shows that zero tawny mole crickets were collected (<0.5% of the baseline number). The baseline number was calculated for the years before biocontrol agents had reached the trapping stations. The histogram suggests complete local success in the program. The task is now to spread success everywhere in Florida and augment it. Histograms: Tom Walker and Howard Frank

Data from the two Gainesville stations show that in the first nine years of operation (baseline data) numbers of mole crickets trapped fluctuated annually, but the trend was neither up nor down (Parkman et al. 1996). The baseline data provided an average for those nine years; then flies, wasps, and nematodes gradually showed up, having spread from other localities. Numbers of mole crickets trapped for the next two years were equivocal. In about 1992, numbers of mole crickets began a steady downward trend and eventually reached just 5% of the baseline number. This happened at both stations and for both winged species of pest mole crickets (Fig. 10). Linked to the evidence for the effect of the wasp and the nematode in the Gainesville area, we believe that biological control by these two organisms is working extremely well.

Although *Scapteriscus* mole crickets had been the acknowledged worst insect pests on Florida golf courses for decades, their ranking has recently slipped. White grubs (scarab larvae) have gained prominence. The Florida Turfgrass Association annually lists priority research areas, and mole crickets have not appeared on that list for a few years. Three years ago, the manager of a Gainesville pest control company admitted that the number of lawn care accounts held by his company for control of mole crickets has slipped from about 60 to 1 or 2.

In the Gainesville area, anyone who is not satisfied with 95% control may buy and apply nematodes or plant plots of southern larraflower to achieve still better control. Farther south, with help of the fly, better control may be achieved; with results of ongoing research, even that may be improved. Golf courses with zero tolerance for damage by mole crickets on tees and greens may use chemicals there, and use biological control on roughs and fairways, achieving integrated pest management (Frank and Parkman 1999). The nematode is tolerant of chemical insecticides (Barbara and Buss 2005).

The wasp, nematode, and fly attack adults and large nymphs of pest mole crickets. No biocontrol agent has been released against eggs or small nymphs. There is a candidate, the beetle *Pheropsophus aequinoctialis* L. (Carabidae), which may be useful against eggs, especially on golf courses, where the desired level of control is very high (Hudson et al. 1988, Weed and Frank 2005, unpublished data). This species needs more research, as do the wasp and fly. The wasp should eventually spread throughout Florida, and there is now an effort to hasten that spread. None of the three established biocontrol agents seems likely to have nontarget effects (Frank 1998).

The UF/IFAS Mole Cricket Research Program's 1985 interim bulletin Mole Crickets in Florida (Walker 1985) is reprinted at http://buzz.ifas.ufl.edu/g341lw84.htm Its website (Frank et al. 2003). The program's website http://MoleCrickets.ifas.ufl.edu (Frank et al. 2003) is current, is accessed internationally and frequently, and includes a long bibliography.

Acknowledgments

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"What is it?" answer.

This is a laboratory-reared western tussock moth caterpillar (*Hemerocampa vetusta gulosa* (Boisduval)) (Lepidoptera: Lymantriidae) killed by a native polyhedrosis virus. The afflicted caterpillars become filled with liquid and droop from their host plant, prompting the name "Hang-down Disease". Photo by Malcolm Furniss, 1825 Orchard Ave., Moscow, ID 83843.

If you have a photograph of an insect, insect part, or entomological apparatus that you would like to submit for the What is it? feature, please e-mail a 300 dpi TIFF image and a description of the image to the editor at cdarwin@aol.com.

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