PREDATORS OF *DIAPREPES ABBREVIATUS* (COLEOPTERA: CURCULIONIDAE) LARVAE

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Abstract

Larvae of *Diaprepes abbreviatus* (L.) in petri dishes were susceptible to predation on the soil surface in a citrus grove. An average of 47% were removed by predators in the first 20 minutes in a 1979 study to determine rates of predation. Predators (2,613 recorded events) were exclusively ants in the grove studied, with the exceptions of 2 predation events by the spider *Corythalia canosa* Walckenaer (Salticidae) and 3 by *Labidura* sp. earwig juveniles. Of the 9 observed ant predator species, *Tetramorium simillimum* Roger, *Paratrechina bourbonica* (Forel), *Pheidole floridana* Emery, and *Pheidole dentata* Mayr were considered important because of their consistency in rates and presence in predation on *Diaprepes* larvae. Two other species, *Solenopsis invicta* Buren and *Pheidole morrisi* Forel, were found commonly. Predation rates by the various species differed over the course of the summer and with the time of day.

Resumen

Las larvas de *Diaprepes abbreviatus* (L.) en cajas de Petri puestas sobre la superficie de la tierra en un naranjal fueron susceptibles a la rapacidad de predadores. Un promedio de 47% de ellas fueron removidas por predadores en los primeros 20 minutos. Los predadores (2613 casos reportados) consistieron exclusivamente de hormigas en el naranjal estudiado, con la excepcion de 2 casos de rapacidad por una araña, *Corythalia canosa* Walckenaer (Salticidae), y 3 casos por tijeretas juveniles de la especie *Labidura*. De las 9 especies de hormigas predadoras, *Tetramorium simillimum* Roger. *Paratrechina bourbonica* (Forel), *Pheidole floridana* Emery, y *Pheidole dentata* Mayr, fueron consideradas importantes debido a sus proporciones y su presencia en la rapacidad de larvas de *Diaprepes*. Dos otras especies, *Solenopsis invicta* Buren y *Pheidole morrisi* Forel, fueron descubiertas con poca frequencia. La proporción de rapacidad cometida por las diferentes especies varió segun el progreso del verano y de acuerdo con la hora del día.

The sugarcane rootstalk borer weevil, *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae) is a comparatively new arrival to Florida. It was first reported in 1964, and has proven particularly destructive to citrus (Woodruff 1968). We divide the life cycle into 7 periods based on vulnerability to differing mortality factors (Fig. 1). Biotic factors responsible for weevil mortality during the various life stages have yet to be investigated in depth, although parasitism of eggs has been investigated by Beavers and Selhime (1975). This insect oviposits on the foliage of its many host plants including citrus. Female weevils bind 2 citrus leaves together with a sticky genital secretion deposited along with their eggs. The secretion and surrounding leaves protect eggs until eclosing larvae are ready to drop to the ground. Times and conditions for dropping to the ground are not yet known.

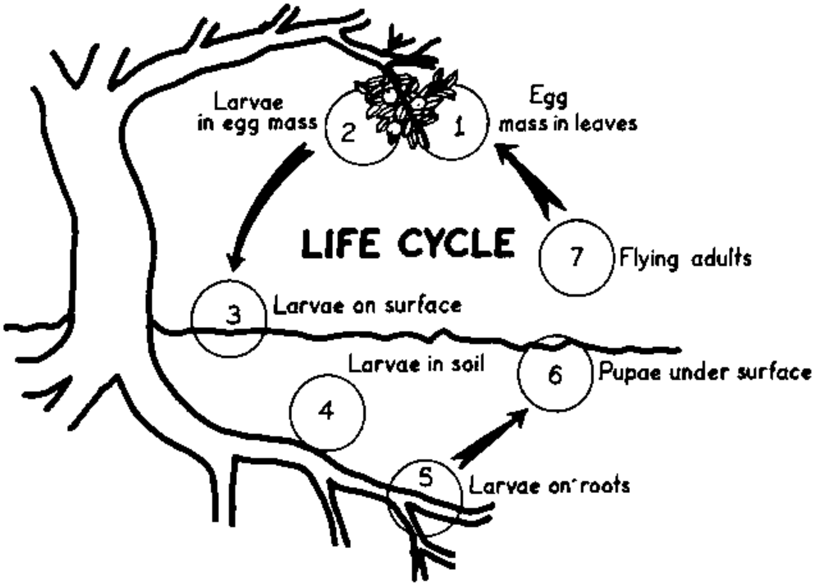

Fig. 1. Life cycle of *Diaprepes abbreviatus.*

Larvae crawl around for several minutes before penetrating the soil surface and burrowing down to the tree's roots. Whitcomb et al. (1973) showed that insects which land on the soil surface and spend a short time on the surface before burrowing into the soil are vulnerable to predation. In a preliminary investigation, Buren and Whitcomb (1977) found that this was apparently true of predation on *D. abbreviatus.* Earlier field observations by several investigators indicated that larval mortality may be extremely high before the major roots are reached. Understanding the cause of such mortality is crucial to a *Diaprepes* pest management effort. We chose to investigate predation during period 3 of the life cycle. Research on possible predators of young larvae on the soil surface was begun in the Apopka, Florida area during April, 1979. In a preliminary survey of the grove, Buren and Whitcomb (unpublished) found 30 species of ants. In other groves treated with soil insecticides within the quarantine area, soil-nesting ant populations were absent or in small numbers with no more than 3 species in each grove. Since earlier work by Buren and Whitcomb (1977) indicated ants were important natural enemies of *Diaprepes* sp., much of the present work was directed toward identifying possible ant predators and evaluating the nature of their predation on *D. abbreviatus.*

Materials and Methods

Experiments were conducted in the High Acres Orange Grove, Forest City, Florida. Recommended foliar insecticide and fungicide treatment practices were followed (scalicides, spray oils, fungicides, etc.) in this grove, which is in the *D. abbreviatus* quarantine area. Unlike all other groves in this quarantine zone, however, the soil was not treated with granular insecticides during weevil eradication efforts, and the soil fauna was not seriously disturbed (Whitcomb and Trambarulo, unpublished pitfall survey data). In particular, ants nesting in the soil approached densities and species diversity comparable to natural habitats.

Initially, 1st-instar *D. abbreviatus* larvae were placed on the soil surface and observed. Because of the debris on the surface and the particles of the soil itself, it was extremely difficult to follow the fate of individual larvae. Satisfactory observations of larvae were obtained by placing them into sterile plastic 55 mm petri dish bottoms. Dishes were screwed into the soil inside the drip line of the trees and soil pushed up to their edges.

Two types of experiments were set up. The objective of the first experiment was to determine whether predation was taking place on the soil surface, and if so, at what rate. In these experiments, 2 dishes containing 20 larvae each were placed beneath each of 6 trees in a row near the grove center at each time period. Dishes were put out at 1-min intervals. The first dish was removed 20 min after placement and the top placed over it. The remaining dishes were recovered in order of placement at 1-min intervals. Larvae remaining in dishes were counted and their numbers converted to percent predation. Any ants captured were identified to species.

In an experiment to determine which predators were feeding on the larvae and their respective rates of predation, 10 trees were chosen in a row near the grove center. On each experiment day, 1 dish was placed beneath each of these trees. At 1800 and 2400, and 0700 h on the succeeding day of each experimental session, ca. 50 1st-instar larvae were sprinkled into each dish, beginning with the first in each row, and to each successive dish at 2-min intervals. Counting of predation rates was begun in the first dish 20 min after it was filled, and counts of predation were begun in each successive dish at 2-min intervals. Counts were made for 1-min by aspirating into a vial every ant seen leaving a dish carrying a weevil larva. Ants were blown into a vial of alcohol, and more larvae were added to the dish during the second minute of each interval. The 10-dish cycle was repeated once more at each time period to complete 20 samples. Rates were averaged for each time for each dish. All ants were identified to species.

Daily or frequent rainfall in the experimental area during July and August prevented completion of a regular series of experiments, as ants were not active during or immediately after rainfalls. Experiments were completed at all 3 time periods (1800, 2400, and 0700) on only 19 July, 14 August, 11, 18 and 30 September and 4, 9 and 16 October. Data from days in which experiments were not completed in all 3 time periods was used to make hour/rate of predation comparisons, but not season or date/rate comparisons. Nightly temperature fluctuations were not great in summer, but increased in fall from late September onward. Humidity varied from 40-100% RH in summer and from 75-100% RH in fall; the dew point occurred between 2230-2300 in summer and around 2100 in October.

Results

Results of both experiments indicate significant predation on 1st-instar *D. abbreviatus* larvae on the soil surface. An average of 47% of the larvae were missing from dishes in the 20-min periods sampled from 1800 to 0700 (44% at 1800, 49% at 2400, and 62% at 0700) in the 1st experiment. None

(0%) were missing in noon or 1500 samples in preliminary studies. Time/rate comparisons and this approach to determine overall predation rates were discontinued in July when we discovered that at 0700 some of the larvae were escaping from the 1-cm-deep dishes by climbing the sides. This had not been previously observed, and was unexpected in these legless weevil larvae. Subsequent control studies indicated the rate of escape reached 10% around 0700 and was zero at 1800 and 2400. It is felt this rate was high enough to question the validity of a comparison of rates at different times of day, but not high enough to invalidate the entire experiment.

In the experiment to determine which predator species fed on the larvae and their respective rates of predation, 2,613 ant predation events were recorded for the 8 complete experimental days. We observed 2 predations by the small salticid spider *Corythalia canosa* (Walcknaer) [=aurata (Hentz)] and 3 by the immatures of *Labidura* sp. earwigs.

Nine species of ants were collected while preying on larvae in the 2 experiments. The proportion of larvae taken by each of the recorded species is presented in Table 1. Of these 9 species, *Tetramorium simillimum* Roger, *Paratrechina bourbonica* (Forel), *Pheidole floridana* Emery and *Pheidole dentata* Mayr were considered prominent predators because of consistency of appearance in dishes and high rates of predation. Each of these species was present beneath most trees in the grove and their rates of predation were high when they located larvae.

Two other species deserve mention. *Solenopsis invicta* Buren occurred only rarely, in about 1 of every 25 dishes, but had the highest rates of predation observed in this study (169 larvae per minute were taken in one observation). *Pheidole morrisi* Forel was also sparsely distributed in the grove, but also achieved very high rates of predation. These species probably would be very important predators had their densities been higher.

Predation rates and relative contributions to total predation for the 4 dominant species differed over the course of summer and between time periods (Figs. 2, 3). Predation by *T. simillimum* averaged higher at midnight over the entire experimental period (Fig. 3). Peak predatory activity of *T. simillimum* occurred in early evening and early morning in summer (Fig. 4a), and gradually moved to midnight in fall. Contribution of this

TABLE 1. PERCENT OF TOTAL (2,613) FIRST-INSTAR *Diaprepes abbreviatus* (L.) LARVAE TAKEN BY EACH ANT SPECIES, HIGH ACRES (FOREST CITY) GROVE, 19 JULY-16 OCTOBER 1979.

Species	Percent
Pheidole dentata Mayr	31.1
Pheidole floridana Emery	24.0
Tetramorium simillimum Roger	20.8
Paratrechina bourbonica (Forel)	6.4
Pheidole morrisi Forel	6.3
Solenopsis invicta Buren	4.9
Conomyrma flavopecta (M. R. Smith)	3.8
Pheidole moerens Wheeler	1.9
Paratrechina vividula (Nylander)	0.9

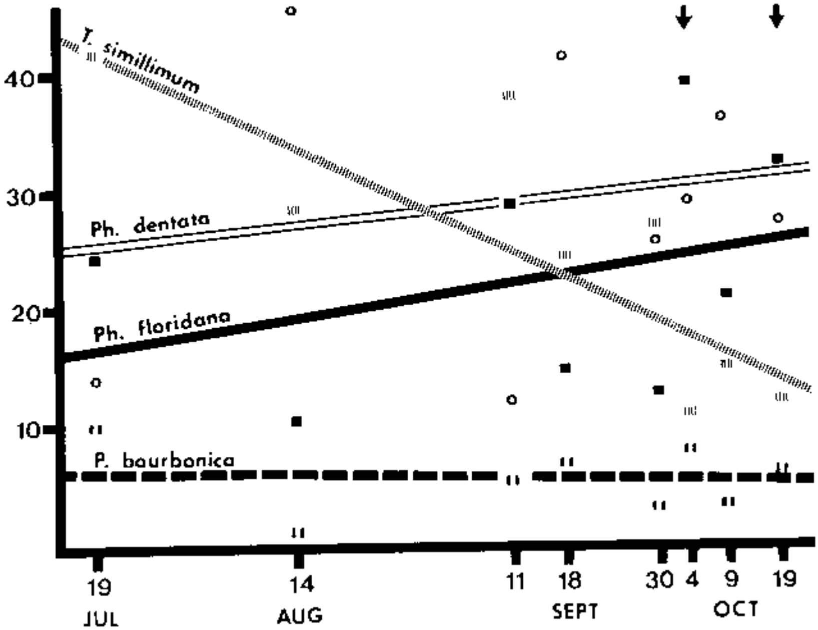

Fig. 2. Regressions of percent of total larvae numbers taken by each species of important ant by date; High Acres Grove, 19 July-16 October 1979. Arrows indicate rain in afternoon before experiments.

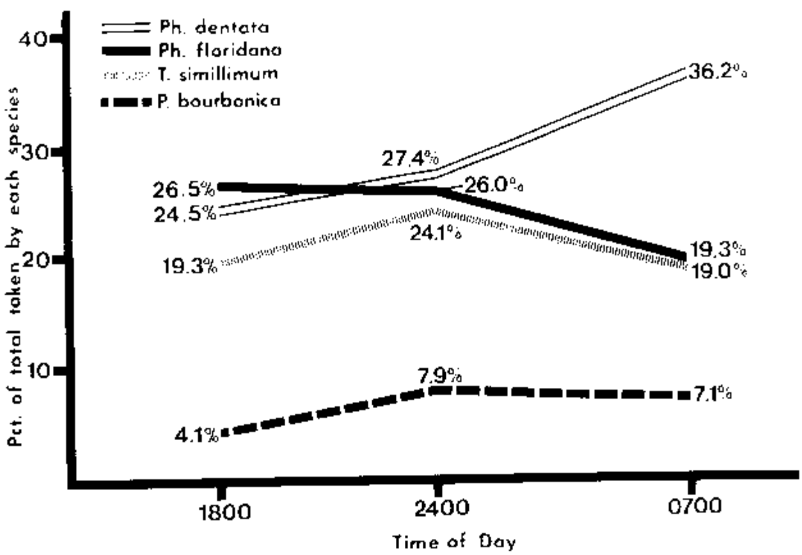

Fig. 3. Mean percentage of total taken by each species of important an in each experiment time period, 19 July-16 October 1979.

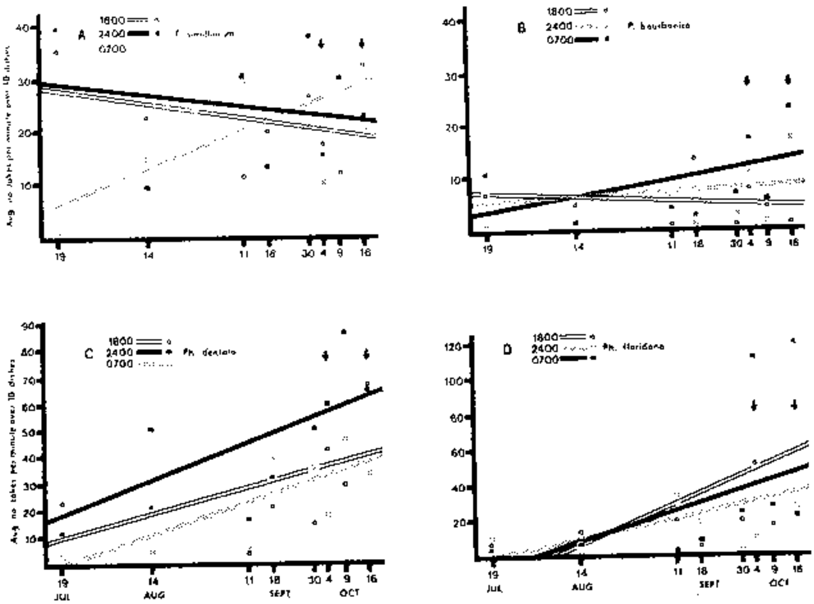

Fig. 4. Regressions of mean number of predations per minute (of 2 runs over 10 dishes) at 3 times of night, by date; 19 July-16 October 1979. Arrows indicate rainfall in afternoons before experiments. *A. Tetramorium simillimum;* B, *Paratrechina bourbonica;* C, *Pheidole dentata;* D, *Pheidole floridana.*

species to total predation was much greater in summer. The rates were more than 30% of the total. Daily RH fluctuations are greater in the summer (40-100%), and this species seemed to prefer the lower RH levels for peak predatory activity. As RH fluctuations decreased and settled at higher levels in fall (75-100% RH), this species' activity and contributions to total predation on *Diaprepes* decreased greatly. Predation activity ceased after rains and in high RH conditions.

Paratrechina bourbonica contributed to total predation at a relatively constant level during the experimental period (Fig. 2). This species was more active during the cooler midnight to morning hours over the entire summer (Fig. 3), and especially near morning and after rainfall in autumn (Fig. 4b). *Paratrechina bourbonica* is rapid-moving, very successful in prey location, and was more frequently the first species to find larvae in dishes. It usually established trail-following behavior quickly, and frequently removed all larvae from dishes before the 20-min post-placement period passed. This ant was tolerant of and was tolerated by other ant species in the same dishes.

Relative contributions to total predation by *Pheidole dentata* and *P. floridana* increased over the entire experimental period (Fig. 2), remained almost constant during the hot days of July, August, and early September, and increased greatly with the onset of cooler temperatures in late September. Differences between the 2 species became obvious when their predation rates at different times of night were compared (Fig. 3). Their contributions were approximately the same during early evening (ca. 25% of the total each), and diverged slightly around midnight. However, *P. dentata* became much more active after midnight, while activity of *P. floridana* decreased. Over the entire summer, *P. dentata* was more active in early morning, and especially after rains (Fig. 4c: 4 and 16 October). *Pheidole floridana* appeared to be crepuscular (Fig. 3), increasing dusk activity as the summer passed, and decreasing nocturnal activity (Fig. 4d). These species each had high predation rates on *Diaprepes* larvae when alone, but the smaller *P. floridana* (and *T. simillimum*) was excluded from dishes in the presence of *P. dentata*.

Discussion

Interpreting broadly from this study, the data seem to support the a priori hypothesis that predation on *D. abbreviatus* larval 1st-instars can be high, and that ants, if present, are significant contributors to total predation. A rate of 47% predation in 20-min by ants on the soil surface would seem to indicate that weevil larvae, after dropping to the soil surface from foliage, must burrow into soil rather quickly to escape this rapid predation. If soil conditions are not optimum for rapid tunneling, and if a normal mix of surface-foraging predators are present, then it seems reasonable to suggest that many larvae will not survive this critical stage in their life history. On the other hand, if application of soil insecticides has reduced the surface foraging predator populations to very low levels, then time until entry into the soil may not be as critical to survival of the larvae, and survival of 1st-instar larvae would increase even when conditions for entering the soil are less than ideal.

The purposeful increase of *Formica* ant populations for biological control of forest pests has been underway in Europe for many years (Pavan 1961, Gosswald et al. 1968). The increase of other ant species, especially through habitat manipulation, has been investigated only recently.

In Ghana, Leston (1972, 1973), Majer (1972), and Room (1971) showed that a mosaic of ant species frequently exists in tree crops, with each dominant species exerting significant control on specific pests of any area. These kinds of mosaic patterns in ant distribution have not previously been found in Florida, but if present, they may be used to enhance the effectiveness and usefulness of ants as biological control agents. Those species determined to be the best predators could be favored with cultural practices favorable to growth of their populations, while other competitive species, undesirable as control agents, might be discouraged by cultural practices disadvantageous to them.

One possible management practice is suggested by the strong increase in predation by 3 ant species on nights after afternoon rains. Using sprinkler systems in groves for 1 or 2 h each afternoon could increase predation by these species during nights in the *Diaprepes* season. Recently, researchers at the U.S. Department of Agriculture Laboratories in Plymouth and Orlando have developed a new spray oil formulation for scales which causes minimal harm to ant populations, and also breaks the genital secretion holding leaves together around *Diaprepes* egg masses. Observers at trials of the new spray oil formulation in Puerto Rico have reported the opening of leaves protecting egg masses on trees, and large number of ants, principally *Monomorium* sp., attacking the exposed *Diaprepes* egg masses. Other possible management practices not influenced by weevil life history and not detrimental to ant populations could be suggested but await availability of further information on the potential of the various ant species involved. Thompson and Buren (unpublished research) have found significant levels of predation by the strictly subterranean predator ants, *Solenopsis* (*Diplorhoptrum*) spp. present in this and other area groves, supporting our hypotheses of predation occurring on *Diaprepes* in Stage 4 of the life cycle (Fig. 1).

In the research at Forest City, 5 different species appeared to be potentially useful. A mosaic of dominance by peak activity at different times or days, or constant low-level activity, appears to be established among the competing ant species in this grove. The possibility of increasing populations of the following species could be considered when discussing possible management practices in this grove:

1. *Tetramorium simillimum*, a very small species with several small colonies (50-150 ants) beneath every tree, is a tropicopolitan species widely distributed by commerce and well established in peninsular Florida. This species had very high predation activity near dusk in summer. It was chiefly diurnal or crepuscular in summer, became more nocturnal in fall (Fig. 4a), and preferred lower RH levels for peak activity. It ceased activity in early morning or after rains. This species is thought to be an excellent candidate for manipulation studies to control *Diaprepes* larvae in groves because its peak activity periods may parallel preferred conditions for weevil larvae dropping to the ground from egg masses. Recent research by USDA workers has found the highest rates of dropping to the ground by weevil larvae to be in the late afternoon (Jones and Schroeder, in press).
2. *Paratrechina bourbonica*, a medium-sized species occurring in 0-2 medium-sized colonies beneath each tree, is also a tropicopolitan, commerce-distributed species well established in peninsular Florida. It was active at low levels throughout the night in summer, but more active in mornings in fall, especially after rains (Fig. 4b) occurring the day before. When *P. bourbonica* found larvae, trails were set up quickly and predation rates were very high, making this species potentially very useful in a program of augmentation or other manipulative cultural practices.
3. *Pheidole floridana,* a small native species with 1-4 large colonies (to 1000 ants) beneath each tree, also increased its predation rates with approach of fall (Fig. 4d). Its predation rates peaked sharply on nights after daily rains, and it was most active between dusk and midnight. It could be suitable for use in habitat management studies because of frequency of occurrence and large colony size.
4. *Pheidole dentata*, a small species with 1-2 small to large colonies beneath each tree (50-400 ants), also increased its predation rates with approach of fall. It was most active in early mornings especially after rains during the night or the preceding day (Fig. 4c).
5. *Solenopsis invicta* occurred in a few large colonies in this grove, and predated heavily when it found *Diaprepes* larvae. Presence of this species in numbers in a grove could prove to be a very effective deterrent to establishment of *Diaprepes* sp. It is not considered a potential management tool for *Diaprepes* because of its purported history

of interfering with weed management in groves by stinging equipment operators. Its potential as a biological control agent should be investigated, however, because of its very high predation on *Diaprepes* in this study (only 2 colonies in the grove provided 5% of the total predation in this study).

In conclusion, more knowledge, especially about the reproductive biology of the weevil and ant ecology is required before ants can be adequately used in management of this pest. More concise information is needed on when and why larvae drop to the ground, amount of time spent crawling about on the soil surface, factors affecting this time, and factors governing the species makeup, abundance, and activity of the ant members of the grove community.

Florida Agricultural Experiment Station Journal Series No. 3079. This study was partially supported by PL-89-108, Sect. 406 Grant TAD 124914329, entitled "Control of *Diaprepes* and other root weevils."

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