ON RESEARCH AND ENTOMOLOGICAL EDUCATION IV: QUANTIFYING MATE SEARCH IN A PERFECT INSECT—SEEKING TRUE FACTS AND INSIGHT (COLEOPTERA: LAMPYRIDAE, *PHOTINUS*)

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ABSTRACT

Male *Photinus collustrans* LeConte fireflies fly over their grassland habitats flashing and seeking their flightless females. I followed individual males, measured, and took note of various aspects of their behavior. Then, from a sample of 255 male runs, with a total distance of 13.9 miles and 10,306 flashes, various sets of these males, those seemingly directed by other than search flight-plans, were removed to leave a sample to characterize "pure" search flight. Fireflies are good subjects for students to study foraging ecology and sexual selection, and from studies of common grassland fireflies it will be clear to students that even simple behavior by males of a single species, under seemingly uncomplicated and homogeneous conditions, can be complex, but provide opportunity for theoretical and empirical exploration. Among factors identified here as influencing male mate-seeking behavior were ambient temperature, ambient light level, and time of night. Other influencing factors, enigmas, and student explorations are indicated.

Key Words: Lampyridae, *Photinus*, mate search, sexual selection, foraging, teaching

RESUMEN

Las luciérnagas machos de la especie *Photinus collustrans* LeConte vuelan sobre los pastizales destellando su luz y buscando a las hembras que no pueden volar. Seguí a los machos, los medí y tome notas de varios aspectos de su comportamiento. Luego, de una muestra de 255 vuelos de los machos, con una distancia total de 13,9 millas y de 10.306 destellos, varios grupos de estos machos, esos dirigidos aparentemente por alguna otra razón que la de un vuelo de búsqueda, fueron removidos para formar una muestra que caracterice el vuelo de búsqueda "puro". Las luciérnagas son buenos elementos de estudio para los estudiantes de ecología del forraje y selección sexual. Del estudio de las luciérnagas comunes de los pastizales quedara claro para los estudiantes que, incluso el comportamiento simple de los machos de una sola especie, bajo condiciones aparentemente sencillas y homogéneas, puede ser complejo, pero proporciona la oportunidad para la exploración teórica y empírica. Entre los factores identificados aquí que influyen el comportamiento de búsqueda de la hembra, están la temperatura, el nivel de luz ambiental y la hora de la noche. Otros factores influyentes, enigmas y exploraciones de los estudiantes son incluidos.

In this symposium series I have passed along notes on the natural history of fireflies I have met in the field while exploring their species-level taxonomy, in the form of written lectures (Letters) to an introductory biology and natural history class. On the face of it, this Letter is an attempt to quantify the mate search of flashing males over a pasture, and apply this information toward understanding mate competition. In actuality it reveals the biological complexity of this seemingly simple behavior, and finds a num-

ber of difficulties that students can appreciate and avoid in their turn. The study was stimulated by papers in a symposium moderated by Dan Otte in the mid 1970s, which surely introduced many naturalist/systematists to a different view of insect signaling and associated behavior. The symposium was a timely event in my life with fireflies, for it offered new perspectives that fit in naturally with what I had learned from reading papers of pioneer fireflyers F. A. McDermott and H. S. Barber, and discussions with systematists T. H. Hubbell and W. L. Brown, and especially, R. D. Alexander.

A pictorial moment of firefly search flight and its variation among species is seen in the illustration orthopterist Otte created as Frontispiece for a *Photinus* behavioral-taxonomy paper (Fig. 1; note his surreptitious acridid), a graphic used not long ago as cover illustration for a mathematical (and for some naturalists an abstruse and mystical) treatise entitled "Quantitative Analysis of Movements" (Turchin 1998). This book has a number of useful considerations even for such an elementary study as reported here, and views individuals to develop models for understanding populations. In "the present study" individual fireflies were watched closely to learn something of their (adaptive) programs for mate search flight. The two views, individual and population, overlap, then merge when mate-seeking fireflies leave or enter local populations and these "migrations" influence population vigor, independence, and fate. Other relevant books and teachers that students may wish to consult are: "Foraging Theory" (Stephens and Krebs 1986), "Spatial Ecology" (Tilman and Kareiva 1997), and "The Ecological Detective" (Hilborn and Mangel 1997).

My leaves-of-grass-top project began with the naive notion that it would be easy to collect some few data on males of each of several low-flying species, and make a ready comparison of species that have different flash (signal) patterns and fly in somewhat different ecological situations. Innocent at inception, results were reminder that raw nature is not as it is often condensed for textbook generalizations, theoretical modeling, and taxonomy, a discovery students will make when they try to quantify mate-seeking behavior. It was great fun to follow individual fireflies through a twinkling of their nocturnal careers, and to see them in another dimension for the first time, and so closely that I saw individual—but nevertheless yet nameless—males quit searching and in climbing flight enter the boughs of the scattered pines in the study site. I even saw some that crashed into herbs and shrubs fall to the ground, lights burning, marking meteor-like descents. Decades ago when spinning tackle was introduced into the U.S., an expert noted that spin-fishing was a soothing, meditative experience, to be compared with making thread at a spinning wheel (though I wondered how he knew this). Chasing fireflies across a meadow while pushing a measuring wheel is also good for contemplation—and data just roll in.

It is of course obvious to almost anyone, today, that there is variation among the phenotypes of individuals even within local populations, due to a number of "innate," experiential, and of-the-moment inputs to each firefly's central processing system. After miles in pursuit of males of a near-perfect species, I was reminded that simple variables in method, equipment, and assistants can also mess-up tidy results. In the end, the chase provided previously unknown and eye-opening facts and basic statistics about firefly search behavior, and it suggested interesting, short-term studies that students can do in night-time labs (Appendix). Best of all, it incidentally dramatized an important source of selection pressure that "must" often have led to divergence of local populations, toward and, maybe, even to . . . speciation.

In summer any teacher in the range of a grassland firefly, such as the widely distributed and very common "All American Firefly" *Photinus pyralis* (L.) (Fig. 1: flash-path #8), will find that with stopwatches and foresters' measuring wheels students can acquire a new understanding of sexual reproduction in the animal kingdom, and discover that males often share a lonesome misery. They will learn to focus on details

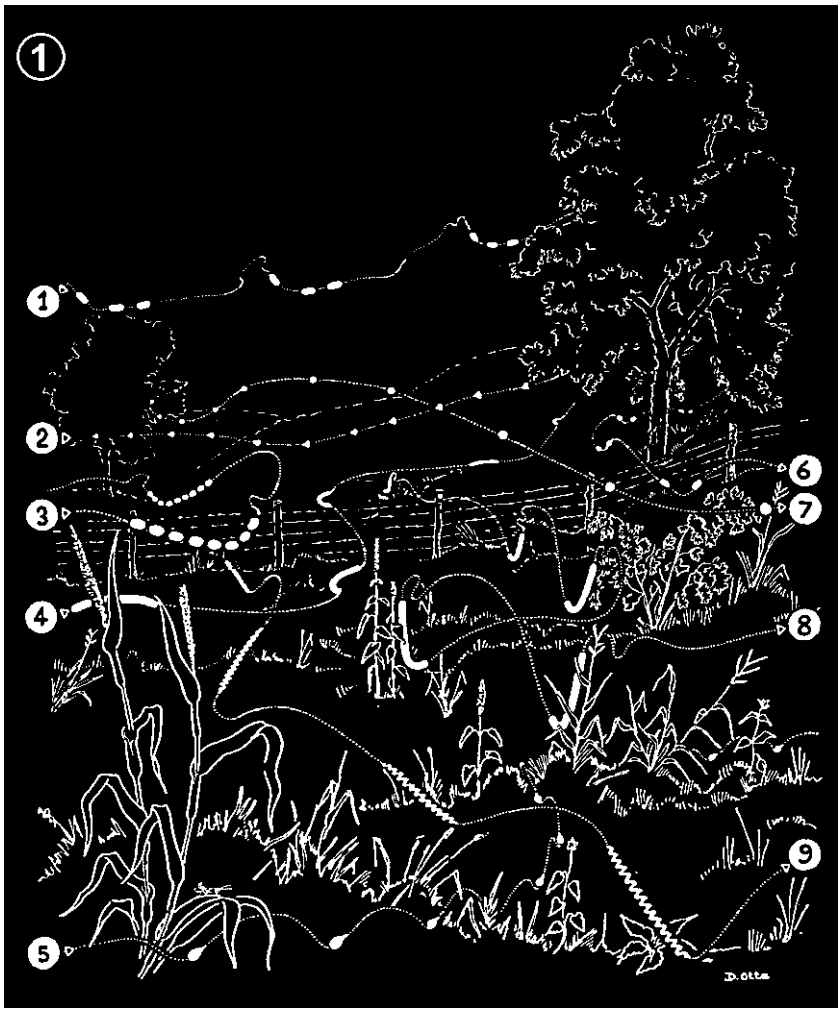

Fig. 1. Flashes and flight paths of males of several different *Photinus* species as they would appear in a time-lapse photograph. Arrowheads indicate direction of flight. The species illustrated are not all sympatric; number 4, *Photinus collustrans*, with its low arcing flight is the species of focus here. (1) *P. consimilis* complex (slow pulse sp.), (2) *P. brimleyi* Green, (3) *P. consimilis* complex (fast pulse sp.) and *P. carolinus* Green, (4) *P. collustrans*, (5) *P. marginellus* LeConte, (6) *P. consanguineus* LeConte, (7), *P. ignitus* Fall, (8) *P. pyralis* (L.), and (9) *P. granulatus* Fall.

of behavior and quantify elements against an array of variables and distractions, and discover sources of variation that they themselves introduce into their data. In my own use, this Letter serves as an introduction to a field problem for a "biology with fireflies" class—a companion guide has instructions for observing and quantifying firefly search behavior, analyzing data, dealing with ecological variables, and devel-

oping experiments for new-found questions—it provides a challenge for engineering majors to conceive of a system of aiming devices, servos, and a portable computer to quantify the 3-dimensional search paths of arboreal, crown-cruising fireflies.

The Internet (electronic) publication of this paper has additional figures as Info-Link attachments to illustrate the text. They are cited here by their number as ILR figures and their legends are included in the End Notes section. These copyrighted illustrations may be used freely with the citation: J. Lloyd, Univ. of Florida.

LETTER XXVII

In Search Of "The Pure-Seeker" Male—Following Sex-Driven Fireflies Through Pastures For the Mind (Lampyridae: *Photinus collustrans*)

"… many a requisite we see must be fulfilled in living things
ere they avail to propagate their kind …"
(Lucretius, 95-52 B.P.E.)

"You can observe a lot just by watching."
(Yogi Berra, 1925–P.E.)

Dear Fireflyers, Luminescent fireflies are good subjects for the study and quantification of mate-seeking behavior. I realized this somewhat belatedly when attending a scientific gathering on sexual selection and mate competition in insects. It came to me, with some embarrassment, that all the while I had been viewing firefly flashes exclusively from the standpoint of a biological-species-seeking taxonomist, merely as signals that were involved in mate recognition and reproductive "isolation," they were intimately connected with mate competition among conspecific males. Suddenly it was potently clear, the competitive mating context had probably been a major force of selection pressures on signaling behavior, and if I were to understand firefly signals and their evolution, and use them taxonomically, I would need to get some sense of how sexual selection might have influenced them. With information on several species, comparisons might even give clues to adaptations in signaling behavior that are tuned to specific features of the mating arena. Could there be a general theory of flash patterns, perhaps even a descriptive and predictive equation that a mathematical modeler could formulate?

Some of our commonest species in North America occur in grassland habitats where mating flights of males occur in a thin volume of air, sometimes an almost 2-dimensional space, low over the ground, and individuals can be followed and watched closely with relative ease. It was not difficult to select a prime subject that occurs in north central Florida that has characteristics that would especially lend themselves to such study. *Photinus collustrans* LeConte is a twilight firefly of fields, pastures, lawns, and savannas (Figs. 1: flash-path #4, and 2; ILR 2000, Figs. 1 and 2). The male flash pattern is a single, short, yellow flash that is emitted about each 2 seconds of flight, with flash rate varying predictably with ambient temperature (Figs. 3 and 4). Male flight paths are diagnostic, for during each flash males typically arc to the right or left (ILR 2000, Figs. 3 and 4). These arcs may enable them to see the species-typical flash-then-glow responses they have just elicited from females, and perhaps also to scan more broadly for female responses that nearby, rival males have stimulated.

Female *P. collustrans* are flightless and found on the ground or very low on grass stems near their burrow's entrance (ILR 2000, Fig. 5); their sedentary, virtually sessile "search" for passing airborne mates, and other aspects of their biology has been studied in intimate detail by Steve Wing). They respond to male flashes with a single

Fig. 2. Habitus of *Photinus tanytoxus* Lloyd, a sibling species of *P. collustrans*, differing conspicuously in external appearance only in the black rather than pale elytral sutural bead in the apical third or so of its length. Length, ca. 7 mm. Searching flight in this species will make an interesting comparison with that of *P. collustrans*, because it begins about 5 minutes after *P. collustrans* ends, at full darkness, and continues for one-half hour or more. This photo-like illustration is actually a carbon-dust drawing by Laura Line.

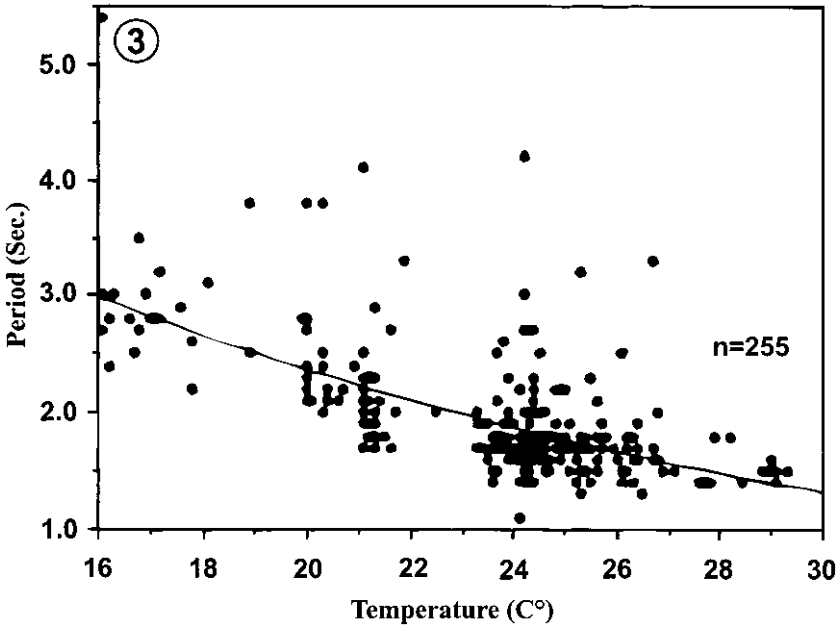

Fig. 3. Flash period duration (in sec) as a function of ambient temperature (in C°). A chart such as this can be useful for species identification in the field. However, flash rate (= 1/period) is better for comparing species because its regression is approximately a straight line, and can be plotted with fewer data points, see Figure 4.

flash that begins about a half second after the male flash, and ends in a briefly persistent, tapering glow. Males of each local, conterminous population (patch, deme) are active for about 20 crepuscle (twilight) minutes each evening, though each individual may only fly during a part of this already narrow window (note circles in Fig. 6). Such flight "compaction" in time is great for fireflyers because it makes each night's flight window a discrete and comfortably-managed sampling unit, reducing the number of environmental, behavioral, and human variables that must be considered. Also, *P. collustrans*' flight straddles one especially significant ecological event, the rapid decrease of ambient light known as twilight ("tween" light).

Is it possible to characterize, to describe the ideal, the optimum mate-seeking flight for male *P. collustrans*? That is, can we sample the behavior of males, and then describe a "pure" search flight that will have evolved because it is *the most* appropriate and efficient (competitive) for males under the ecological conditions they live with? Not likely, and the fallacy behind this notion is that there actually could be a *most* efficient or *most* appropriate search flight. Males, their genetic constitutions and the individual circumstances they experience through their lives are not identical. And, on any given day some are older and have less search time remaining before they die—males may be programmed to take more risks as they age, say, risks in where, when, and how fast they fly; also, sometimes males experience high levels of competition, with rivals always within "eyeshot"—males may be programmed, upon detection of such conditions, to employ different, more concealing flight and flash tactics, and such flight would certainly reduce their measured efficiency as "ideal searchers."

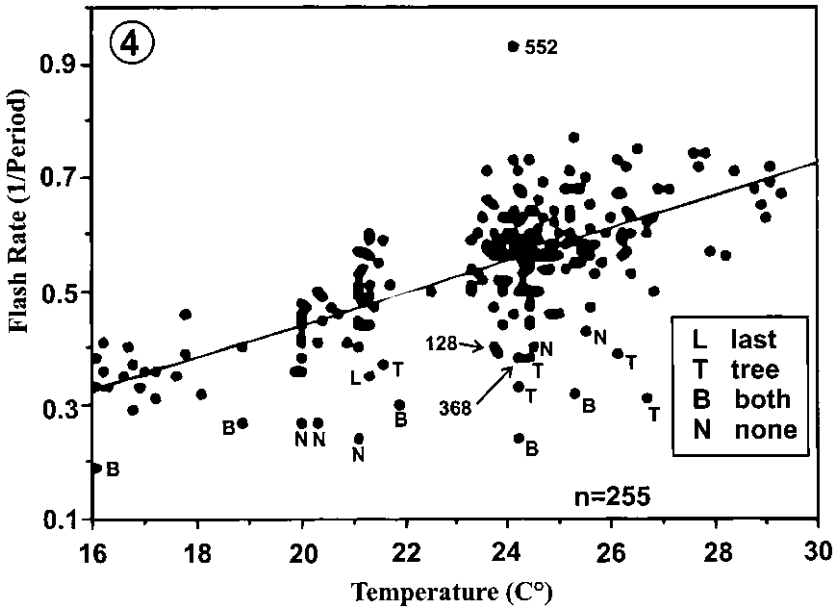

Fig. 4. Flash rate (1/period) as a function of ambient temperature (in C°); data points were converted from those in Figure 4. A "hurry up" flash period regression for field use can be approximated by converting mean flash periods from two remote temperatures to rates, drawing/extending a line through their plots, converting several points along this straight line to period, and replotting. See text for an explanation of letter and number dot tags.

Also, we intuitively understand that what might well be the best flight program for the discovery of females in an ideal grassland could also be more dangerous when occasional tall spikes of wing-tearing thistles are present, and an unfortunate flight accident could, with some calculable level of statistical probability, reduce the total number of days a male has to search. Thus, we expect "imperfections" in search adaptation to arise from various trade-offs, and for other reasons, too. Nevertheless, we might determine the overall search-flight characteristics of "our average male" across the (mostly unspecified and little understood) range of conditions that prevail during the evenings that data are recorded. Parameters of such a search plan, when visualized as axes of XY charts will frame a cloud of "slightly-off" as well as more deviant searches clustered 'round a mean. These are the (dots of) males with different phenotypic characteristics and whose control systems are processing different inputs. Perhaps we can find clues for some of the observed differences among males, and speculative notions that can be developed into formal hypotheses for testing by carefully focused research. (How could one construct, and then place in a meadow, 100 fake thistle spikes, and quantify male responses and losses to them?)

On Firefly Trails

To collect data I followed individual *P. collustrans* males as they flew and flashed over a pasture grassland, pushing a measuring wheel through each subject's curves and turns—I trailed a few meters behind them and never saw any indication that my

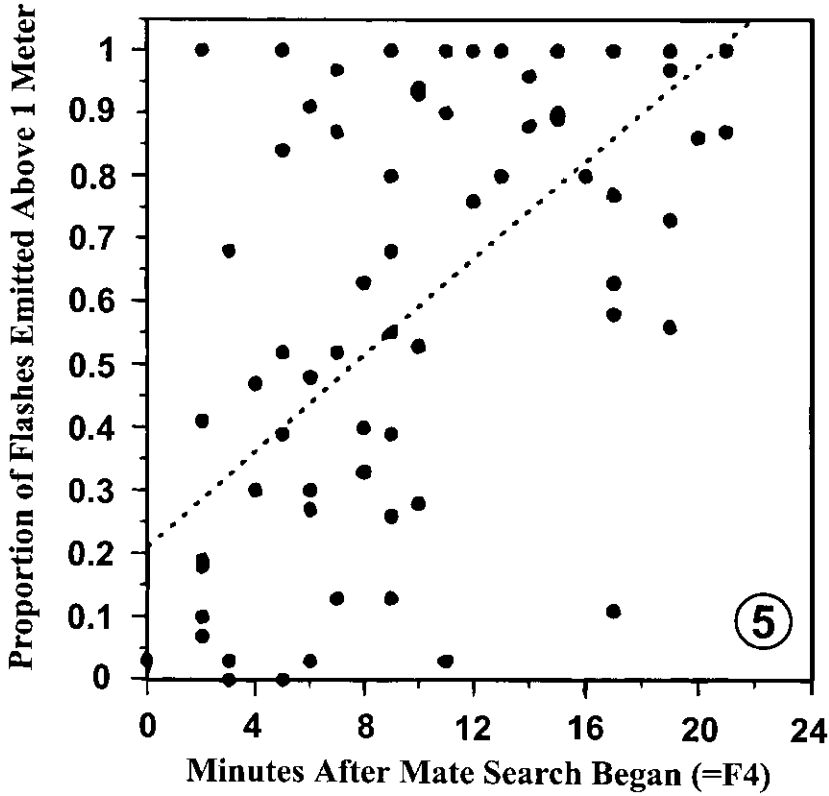

Fig. 5. Height of flight flashes of 74 male *P. collustrans*, given as the proportion of flashes (Y axis) that were emitted above one meter altitude. The ratio (above-1-meter/all altitudes) for each male is marked. The X axis shows the number of minutes after evening flight began, "marked" when four males had begun flashing flight (F4). This convention was adopted as an attempt to avoid biasing by idiosyncratic males, such as those embarking on their evening flight from especially shady places. Other conventions are possible, perhaps even better? Samples were made during 38 evenings.

delayed presence influenced their flight. A 2-channel event (blood-cell) counter mounted on the handlebar was operated by thumb and stored certain "digitized" data (ILR 2000, Fig. 6). For example, I had noticed that males fly at somewhat different altitudes over the ground, and altitude seemed to be connected with the time of evening, so in each of 74 individual followings (i.e., runs; during 38 evenings) my thumb kept track of the flashes emitted above and below 1 meter altitude. I found that during the first few minutes each evening males generally flew lower than 1 meter, but gradually through their twilight window, ever more of their flashes were emitted from above 1 meter (Figs. 5 and 6). That this change is in response to diminishing ambient light is suggested by the observation that in early evening when males fly into shady spaces beneath trees they fly conspicuously higher, and then fly lower again as they move out under open sky. The scatter seen in the plot of individual records (Fig. 5) occurs in part because males flew in or through the shade of trees.

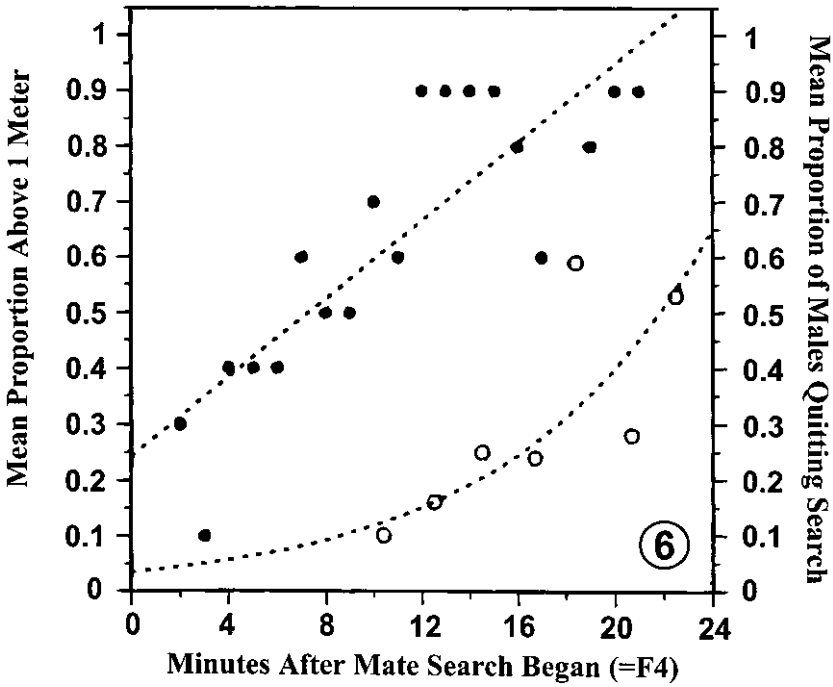

Fig. 6. Mean height ratio of males for each minute (left Y axis). With increasing darkness males tend to fly higher, possibly to avoid unseen spikes of herbs, or to see further, or to spread their light further?; can these notions be demonstrated, or be differentiated experimentally? The figure also shows (open circles, right Y axis), the proportion of followed males that quit search during consecutive brackets of time, beginning 10 minutes after evening flight began (n = 138, 24 males quitting). Lines were fitted by the graphing program, linear in dots of 5 and 6, and exponential in circles of 6.

Among the categories of data recorded for each run were: duration in seconds, from the first flash to the terminating one; number of flash periods per run, with the starting flash counted as zero and the count at the run's terminating flash giving the number of flash periods; distance flown, as read from an automatic counter clicking feet at the rim of the wheel; and time of day at the end of a run. I also made written notes of unusual flight features and the reason for ending the run; for examples, runs were terminated because males flew to a perch apparently ending their evening flight (Fig. 6, circles), because followed males intersected paths with another and I was uncertain which male I had been following, and because the run was sufficiently long (>30 flashes).

First and simpler questions to be answered by the wheel-pushing data are, what are the flash-rates and flight speeds of mate-seeking males? Next, do these parameters vary through the activity window (period)? Then, when interactions of these parameters are viewed, are there any generalizations or predictions to be made, any puzzlements or surprises? The total data set from the pasture is from 255 males, followed on 43 evenings, during the years 1976-7, for a distance of 22,356 meters (13.9 miles); this required 5.25 hours of actual following, during which time the males emitted 10,306 flashes. The longest run was 0.49 miles, and the fastest, 4.8 mph. I should

note that of all of my firefly field studies only this one seemed to demand professional, knee-length snake boots; but they were not called into their intended service.

On nine occasions males flew into vegetation and fell with lights burning to the ground, each losing a few seconds of search time (= 1 crash per 1.54 miles); males found two females and coupled with them (= 1 per 157.5 min, per 7.0 miles!). Statistically speaking, if each male should actually search 20 minutes per evening, on average, only one in eight of them would find a female? More realistically, but still statistically, if individual males average only 16 minutes of search per evening, only one in 10 will find a female! (How many males find none in their entire adult lives (7± days?), and how many find two or three—and, beyond some degree of good fortune, do exceptionally successful (super) males share an uncommon set of mate-finding features? How could you determine this, and how big a sample would it require?)

Flash rate. The period of consecutive flashes (period = time between beginning of one event to the beginning of the next such event) emitted by flying searching males decreases with increasing ambient temperature, and ranges between 3 seconds at 16° and 1.5 seconds at 29°C (Fig. 3). There is a curvilinear relationship between flash period and temperature, but between flash rate (1/period) and temperature the relation can be considered linear for our purposes (Fig. 4). Observe the slower, individually labeled runs in Figure 4. When field note (written) descriptions of these slower runs were examined it was obvious that several of these males may have been in an "activity-terminating mode" rather than a "mate-seeking mode," because they flew up into the scattered pines or down to the ground, apparently quitting flight for the evening. To characterize "pure-seeking" behavior, runs that represent alternative or mixed behavior modes, such as this set would appear to represent, must be culled from the data set. (But, note that the data set is shown in its entirety before any purging of "bad" data; Figs. 3 and 4; n = 255 runs).

Selecting pure seekers. To get statistics for presumptive "pure-seeking" flight-parameters, I culled runs when field notes suggested the males might be following mixed or other flight plan directives. Thus, I removed: all flight terminating runs (when followed males flew up into tree boughs or down into the grass and stopped flashing, "T" in Fig. 4); all last-of-the-evening runs (such males were always the last one or two that could be seen flying and flashing in the population, "L" in Fig. 4—the rationale being that they may already have been slowing down); runs during which males behaved "erratically" (flying up then down, conspicuously slowing and then speeding up); runs when the males crashed into vegetation (males can be seen glowing brightly as they fall down on the approached-side of herbs and bushes); and runs when males noticeably paused in flight, as they do occasionally over small sandy patches and pale flowers. A few very short runs were also removed, those comprising fewer than 8 flash patterns.

As examples of purged sets, note labeled run #368 (Fig. 4), in which the male paused in flight and hovered over one place for 8-9 sec; and in run 128, the male ran into a twig, fell down and lost about 2 seconds on the ground. The male of run 552 rapidly approached a 50-meter wooded sinkhole, momentarily stopped flashing at the wall of foliage at the edge, then abruptly flew back over my head. His headlong dashing flight makes me suspect that his measured parameters were not those of even an extreme "pure" search flight plan. Finally, note that there are several runs at the slow edge of the clustering marked "N", meaning that I made no relevant verbal notes at the end of the run. I must interpret these as representing the slow tail of a "normal" distribution of a pureseeker flash rate, and retain them in the hopeful set. In every case, all of the males of a given rejected category were culled, and not merely those that were conspicuous outliers on the chart. Figure 7 shows the flash-rate/temperature regression of the now much reduced, remaining sample of 123 runs. The correla-

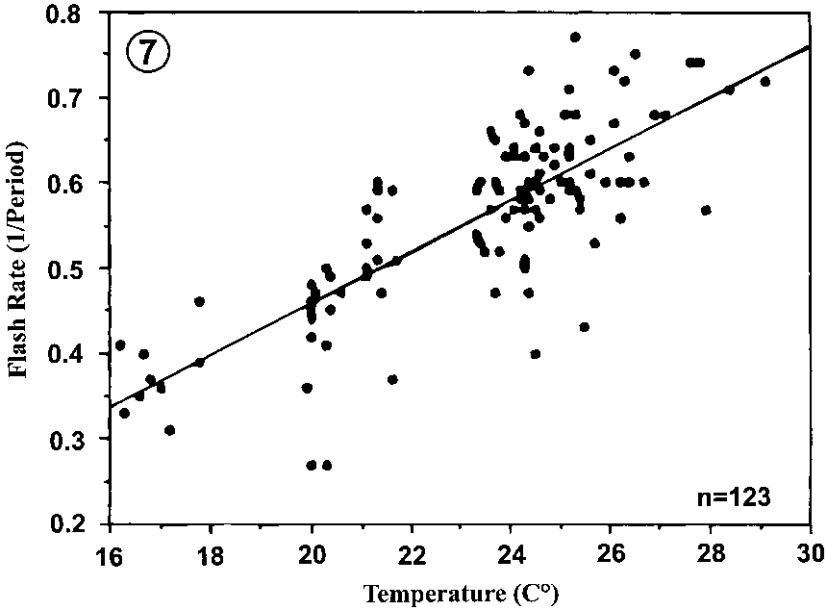

Fig. 7. "Purified" flash rate regression, with all males in categories mentioned in text removed (see outliers and key in Figure 4), as a function of ambient temperature (in C°); compare with Figure 4.

tion coefficient (r) for the complete data set in Figure 4 is 0.69, and for the selected set in Figure 7 it is 0.80, though the slope remains about the same.

Flash-rate revisited. The slope of the "purified" data in Figure 7, can be used to adjust ("correct") the flash-rates of the selected runs to what they would be at 25°C. The temperature-adjusted rates can then be plotted as a function of the time-of-night (i.e., sun-time of run midpoint) they were measured (Fig. 8). This regression slope (of flash-rate/midpoint), reveals no time-of-night effect, and nearly zero correlation (i.e., t = 1.25, slope not significantly different from flat; r = 0.12, on a scale of 0 to 1). In other words, twilight time with its ever increasing darkness, and other changes such as a (probable?) reduction in the availability of unmated females and perhaps even the number/proximity of rival males, does not appear to influence the rate of male flash pattern repetition).

Flight-speed of this "purified" set of mate-seekers increases slightly with temperature (Fig. 9; t = 2.975), significantly different from flat, though the correlation is pretty weak (r = 0.26). Then, when speed data are adjusted to 25°C and plotted as a function of the time of night, flight-speed is seen to increase through the activity period (Fig. 10: t = 5.285; r = 0.43). But, to the naked eye and common sense, the chart's dots do not really lie along a straight-line. A linear regression was imposed on the data by the graphing program, but the data points clearly increase linearly to about 1.3 creps, remain flat to about 1.5 creps, and then decline slightly.

Before addressing this, I want to whack some more outliers. Note the several faster runs especially after 1.6 creps (Fig. 10); might they indicate the presence of yet another search tactic or influence? Field notes reveal that the data for four of them were taken by a young family member (unpaid assistant) who had used a measuring

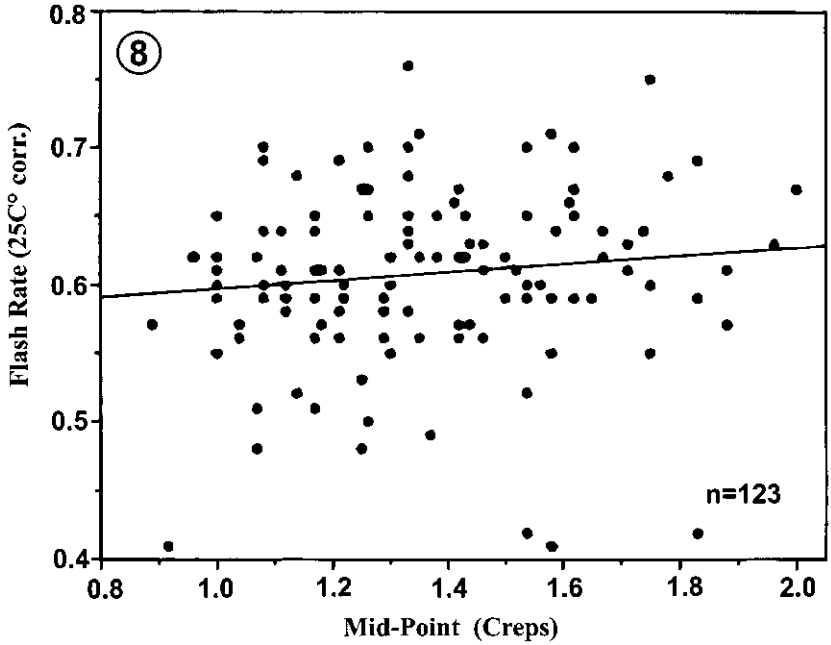

Fig. 8. Flash rate, adjusted to 25°C, as a function of time of night (in crep units, where 0 is sunset; a crep unit, which varies with date and locality, is the duration of Civil Twilight).

wheel with a smaller diameter (ILR 2000, Fig. 6—one that would probably roll more tightly over the surfaces of smaller humps and bumps, going further per linear distance and unit time. These data points thus suffered from two additional variables; consequently, all data collected by this apprentice fireflyer were purged. One outlier was a last run that escaped notice during the first culling, and another was a penultimate run that ended three minutes before the end of evening activity. These two were also removed from the data set, though purging the last mentioned point was not legitimate, not statistically proper—unless I were to remove all penultimate runs (and replot, beginning with Figure 3). The data set is now reduced another 7 percent (n = 114, down 55 percent from the original 255!). This refinement hopefully, theoretically in a loose sense of the word, should reveal the best glimpse of search behavior yet achieved, and show speed adjustments made by males through their twilight window about as well as I can now sketch them (Fig. 11). A verbal summary of what the graph suggests would be: flight speed increases at first, while twilight darkness deepens rapidly (causation?), and then after 1.5 creps there appears to be a slight downturn, indicating that males that remain active fly (flew) a bit more slowly.

Distance-flown per flash-period (flash rate melded with flight speed), decreases with temperature (Fig. 12; $t = 6.630$, $r = 0.52$). This is to say, the cooler it is, the greater the distance along the flight track, out in front of the male, the flash is "expected/required(?)" to cover ("to stimulate?" Tom asked, illuminatingly). Though flight speed appears to decrease slightly as temperature decreases (Fig. 9), flash rate decreases considerably (i.e., period lengthens, Fig. 7), and this results in a longer distance flown between flashes. This

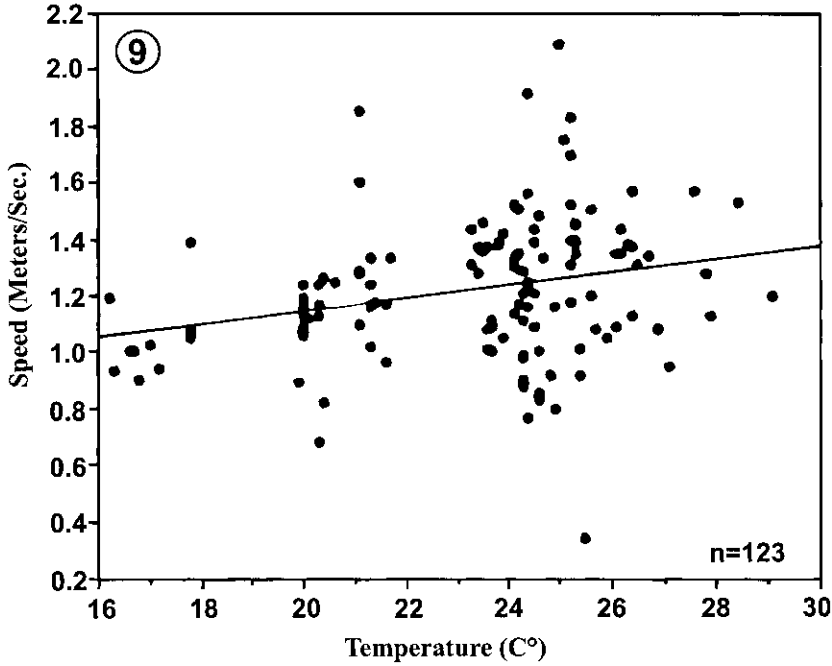

Fig. 9. Flight speed (in meters/sec) as a function of ambient temperature (in C°).

would seem to indicate that with decreasing temperature, flashes "are required to" stimulate progressively larger areas. There are too many unknowns to interpret this: we do not know and cannot easily determine whether the intensity (photons emitted) of flashes remains constant at lower temperatures, or, whether the angular spread of the light leaving the lantern remains constant—some luminescent click beetles apparently control the spread of the light beams emitted by their ventral lanterns!

Predator Pressure and Deme Divergence. Females of many, seemingly most Nearctic species of the genus *Photuris* prey upon mate seeking males of other species. They perch in the activity spaces of their prey and mimic the flash responses of the males' own females, attract and eat them. No such deceivers were seen at the pasture site, and this makes for a very interesting contrast with data from another site. The latter was a narrow, roadside, pine savanna with a nearby mesic hammock and marshy catch-basin and drainage ditch. These habitats produce the predators *Photuris versicolor* (Florida form) and *Photuris bethaniensis* (Florida form). Females of these two species occurred in the *P. collustrans* site and flashed responses to *P. collustrans* males I was following. Thirteen such predators were observed to answer them, and though some males landed and lost search time, none were caught by these femmes fatales. What makes these statistics especially noteworthy, was that the savanna sample of measured runs was a great deal smaller than that from the pasture—40 males were followed for a total of only 3,550 meters (2.2 miles). The score card: pasture, 2 mates and no predators; savanna, no mates and 13 predators! Converting this to a numerical comparison: if, during the next instant such a predator had been found at the pasture (I need one predator to avoid the unworkable zero), mimicking the re-

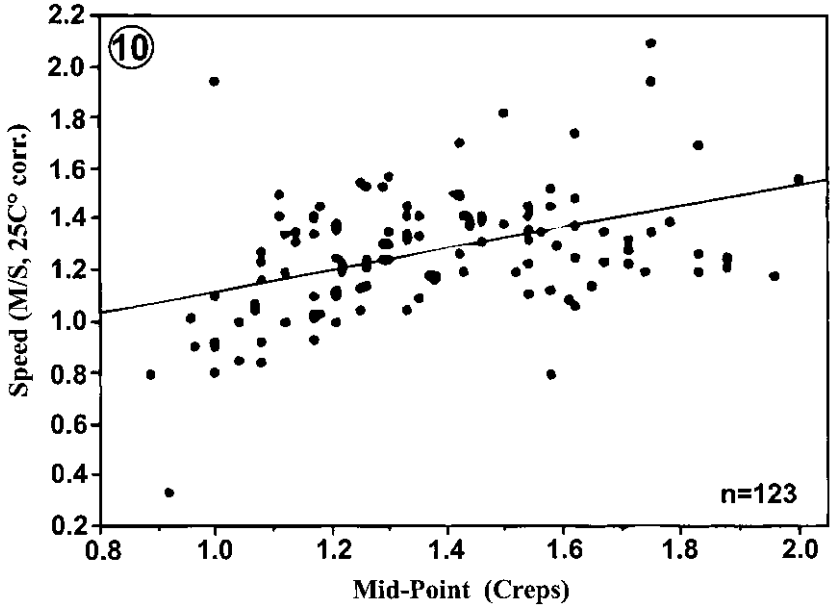

Fig. 10. Flight speed (in meters/sec, adjusted to 25°C), as a function of time of night (in crep units), with a forced linear regression line that even to the eye is not a good fit; note the rise then fall of data points.

sponses of *P. collustrans* females, the hunter-exposure rate in the savanna would have been nearly 69 times that of the pasture site (3.10 vs. 0.045 predators/kilometer). In other words, in this predator connection, this savanna was "immeasurably", virtually "infinitely" more dangerous than the pasture for male *P. collustrans*. This really brings home the fact that local populations (demes) can be under grossly different selective pressures, pressures that must be expected to have a significant influence upon mate seeking and code-recognition behavior of males—and this is a phenomenon that can be measured and compared!

Other Conclusions and Explanations. At the outset of this study, it seemed that for a number of reasons mentioned in the introduction, it might be fairly simple to describe the mate-seeking flight of *P. collustrans*, and identify characteristics that made it well-tuned, "optimal" for finding mates in a competitive environment. Each of the sets of male runs that was distinguished and then removed at some point in the analysis, including quitting, crashing, and last-of-the-night runs, and runs whose measurements may have had technical inconsistencies, not only produced a tidier sample, but more importantly identified sources of influence and variation for future reference. Some of the culled sets revealed something about *P. collustrans'* biology, whether tentative explanations were correct or not. But, it now is clear that to characterize the simple search flight of *P. collustrans* for comparison with that of other species will require a great deal more intraspecific comparative study. Studies must first be comparable at the technical and deme levels, and find and identify the influences of: (1) the mechanical aspects of sampling techniques, including different wheel sizes, different wheel operators, and different bump and hummock sizes (with consideration given to

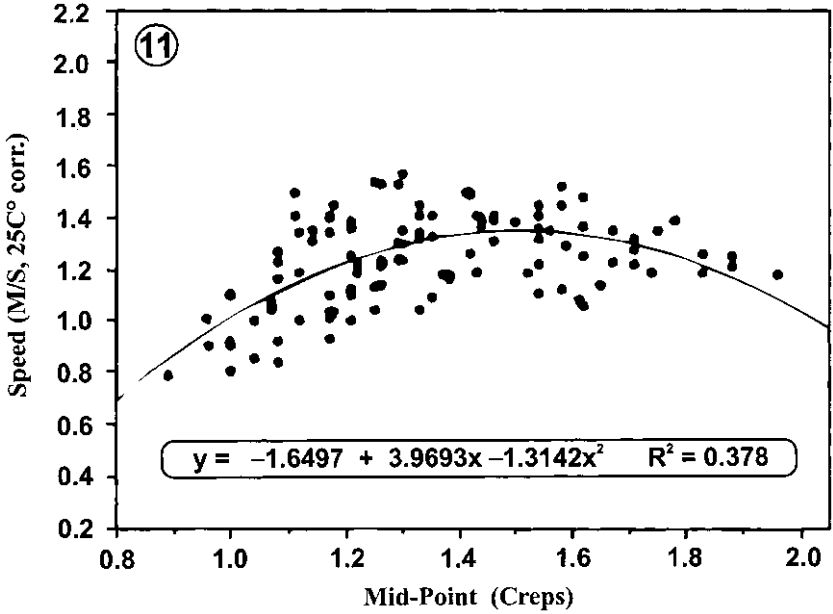

Fig. 11. Flight speed (in meters/sec, adjusted to 25°C), as a function of time of night (in crep units), with a regression line and equation for a second-order polynomial plotted and calculated by the graphing program.

varying flight speed) on over-the-ground measuring accuracy and precision; (2) different ecological conditions, including vegetation, predator and rival-density, ambient light, and season; and (3) (presumptive) population genetic differences—for example, by comparing contiguous pairs of demes, pairs of more remote demes such as those in different drainage systems, and pairs of demes from extreme ends of the species' geographic range. The fact that females of this species are flightless and burrowing means that any gene flow that occurs must be either through male flight, female or larval dislocation/dispersion through flood waters, or flight by as yet unknown macropterous females, which I have unsuccessfully sought for many years. The fact that sex determination in fireflies does not involve a Y (male) chromosome may mean that we do not have a simple male versus female genetic marker to use to differentiate the mechanics of gene flow among local populations.

The proper study and characterization of but one aspect of the biology of but one presumptively simple, ground level firefly species could take a person a lifetime; or the efforts of an insect behavioral ecology course for generations of students. It is fortunate that wheel pushing is a rewarding and a relaxing thing to do in itself, especially in high-stress times.

ENDNOTES

I thank Cindy Weldon Lasley, for making the hundreds of data sortings and manipulations that were necessary for this analysis, and Steven Lasley, Department computer specialist, who gave us considerable instruction and wrote essential analy-

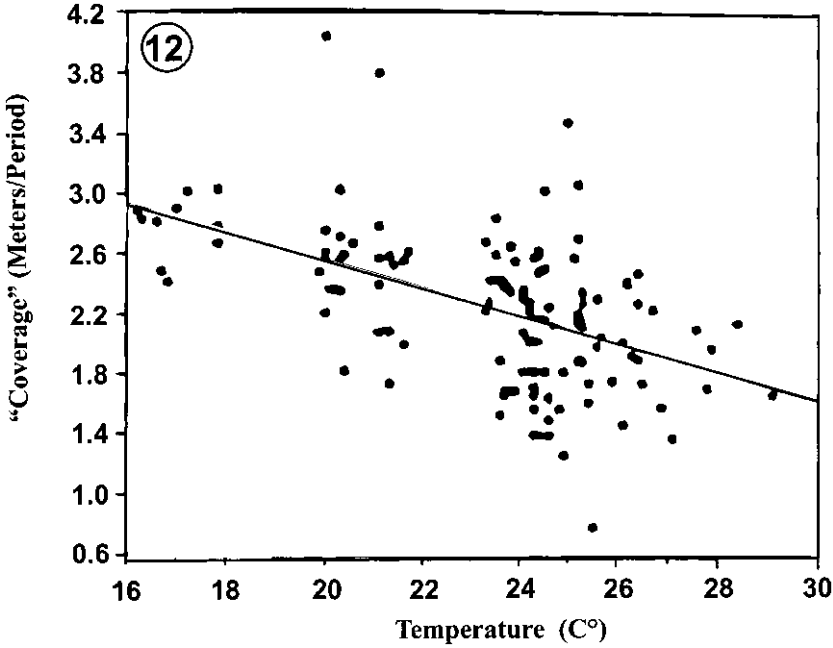

Fig. 12. Meters flown per flash period as a function of ambient temperature (in C°). But what of actual area illuminated in front of the male by each flash? See text.

sis programs. The late Harry A. Lloyd made modifications on the wheel to make it more suitable for the special application required for this study; Robert S. Lloyd followed and measured some males. I also thank Tim Forrest, John Sivinsky, Steve Wing, M. I. Montenegro, and Jade Williams for comments on the manuscript at various stages of its development. Flora MacColl and the late Barbara Hollien provided considerable technical expertise and assistance. Jenny Gavilanez-Sloan for translating the abstract. Florida Agric. Exp. Station Journal Series No. R-07406.

Measuring wheels were Rolatape® Models; Model 623 was the larger and used for all but the few exceptional runs mentioned in the text. The event counter was a Clay Adams 2channel. For analysis, the midpoint time of each run was calculated by halving run duration and subtracting this quotient from the day-time of the run's end. This time, expressed in minutes after sunset, was then converted to Crep Units by dividing by the duration of Civil Twilight for that date and place (Nielsen 1961). Sunset times and C.T. durations were determined from a computer program, "Sunset", written by J. P. Oliver with modifications by T. Forrest. Early and partial summaries of certain data have previously been reported (Lloyd 1979).

The following enumerated statements are figure legends for color illustrations (photographic slides) that appear as InfoLink attachments to this article in the electronic publication of this issue of the Florida Entomologist, and are cited in text here as ILR 2000, Fig.#: 1. Copulating pair of *Photinus tanytoxus* Lloyd, a sibling species of *P. collustrans*, which except for the dark coloration of the elytral bead is morphologically indistinguishable. The female was perched just off the ground near her burrow. 2. A copulating pair of *P. tanytoxus* on the ground, with attentions from a second (top)

male. Wing (1984) made several interesting discoveries concerning this situation, and the competitive and defensive tactics of males. 3. Twilight on the lawn of a lakeside house near Gainesville, Florida, with several *P. collustrans* males searching for females. Note their arcing, slowing flight while flashing, and the thin slice of space they use over the ground. 4. A firefly student observing the flashing flight of a single male *P. collustrans*, along the grassy roadside on the west side of Newnans Lake, Gainesville. 5. A female *P. collustrans,* showing her short elytra and large and thinly cuticled abdomen, with her burrow's entrance at the tip of her abdomen. 6. Large and small measuring wheels. The wheel at the right has the "event counter" mounted on the handle bar; the smaller one was used by an assistant and seems to have been responsible for somewhat different values. Another wheel model has a solid rather than spoked wheel and would work better in brushy areas.

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APPENDIX

Field studies for consideration.

1. How long should a sample run be (number of flashes) to adequately sample the behavior of an individual male?

2. How much agreement is there between consecutive samples (e.g., 30 flashes) of an individual's search behavior—i.e., between a 30-flash sample and the next consecutive 30-flash sample?

3. Do older males take more risks in their flight? Do they fly longer each evening, earlier or later, or faster and lower? Is it possible to sample an individual's search behavior when he is young and then again when he is elderly?

4. Is flight altitude smoothly proportional to ambient light level, and what (physiological) mechanism of altitude determination is involved?

5. From what distance are males able to competitively approach female flashes given in response to a rival male's flashes? (see Otte and Smiley 1975?)

6. Is the direction of the arcing flash-trajectory of males influenced by the presence of nearby males or other aspects of the natural environment, such as large or dark herbs, shrubs, or the brighter (western) horizon?

7. Are local activity patches (deme sites) as delineated by observing the flights of males, constant in space occupied, or do "hot spots" change from moment to moment, night to night, or with the number of males active in the site?

8. Can patch-entering and -leaving males be detected by their flashes, or do they fly flashless, and can be found only with flight-interception traps (e.g., window-pane traps)?

9. Do crashing males always light up, or do the data reported here need to be adjusted (calibrated)?

10. Do run-terminating males as observed in this study here actually end flight for the evening or do they return to aerial search?

11. When males fly into a space just previously searched by another male in their presumptive vision-space do they adjust their direction of flight?

12. What is the adaptive significance (function) of the higher flight altitude observed in later-flying males? That is, when it is darker will they see and broadcast further? Or, is it that they cannot see to avoid tall plants and higher flight is safer? Which of these, either or both, is the actual explanation, and can these two be tested and separated simultaneously?

13. What is the adaptive significance of the (apparently) smaller area coverage of flashes at higher temperatures? For example, at higher temperatures might neighboring males react to female response flashes and interlope faster, so (the apparent) smaller flash coverage is a defensive tactic?

DUNG BEETLES (COLEOPTERA: SCARABAEIDAE), MONKEYS, AND CONSERVATION IN AMAZONIA

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ABSTRACT

Dung beetles are important in several ecological processes, including nutrient recycling, soil aeration, the transport of other organisms, and the burial of vertebrate dispersed and defecated seeds. Dung beetle species vary widely in their abilities as seed dispersers. The biomass of beetle species that bury no seeds, bury small seeds only, or bury small and large seeds, is significantly different among sites along the Amazon River. The abundance of monkeys that act as high quality seed dispersers also varies at different sites. Implications of these differences in seed dispersal dynamics are discussed. Recent clearing and disturbance of primary forest is having an effect on the populations of primary and secondary seed dispersers, and suggestions for conservation of these critical faunas are presented.

Key Words: dung beetles, Scarabaeidae, monkeys, primates, seed dispersal, Amazon, Brazil

RESUMO

Os coleópteros coprófagos são importantes em vários processos ecológicos, incluindo reciclagem de nutrientes, aeração do solo, transporte de outros organismos e enterramento de sementes dispersadas e defecadas por vertebrados. As espécias de besouros coprófagos variam imensamente quanto a sua habilidade em dispersar sementes. A biomassa das espécies de besouros que não enterram sementes, a biomassa daqueles que enterram somente sementes pequenas, e a biomassa daqueles que enterram tanto sementes grandes como pequenas é significativamente diferente entre varios locais ao longo do Rio Amazonas. A abundância de primatas que agem como bons dispersores de sementes também varia grandemente entre diferentes locais. As implicações dessas difereças na dinâmica de dispersãa de sementes são discutidas neste trabalho. As recentes derrubadas de ávores e as perturbações de dispersores primário e secundário, e sugestões para a conservação da fauna são apresentadas.

Dung beetles, an omnipresent component of tropical biotas, perform important ecosystem functions. Several characteristics make this group of beetles ecologically significant (Hanski & Cambefort 1991; Halffter & Matthews 1966). They are particularly vulnerable to deforestation and other changes in habitat and fauna, and this sensitivity makes them useful as indicators of ecosystem health (Halffter et al. 1992; Klein 1989). As they are primarily associated with mammals, they are also indicators of mammalian abundance and possibly diversity. Nevertheless, dung beetles' functions in ecological systems go far beyond the status of an indicator. They contribute services including, recycling of nutrients, aerating the soil, serving as transport for predatory mites, and

burying of seeds in dung (Hanski & Cambefort 1991; Halffter & Matthews 1966; Estrada et al. 1991). Because of these roles, the decline in dung beetle abundance and diversity may have cascading effects on the environment. In this paper, I discuss the results of some of my studies of deforestation, rainforest disturbance, and dung beetle abundance and diversity. I also present my research on the seed burying characteristics of different species of dung beetles, and how these differences may effect seed dispersal in tropical rainforests. Finally, I will discuss rainforest survival associated with seed dispersal and some suggestions for accelerating recovery from disturbed habitat.

Dung beetles are generally grouped into dwellers, which live and nest within a dung pat, burrowers, and rollers (Hanski & Cambefort 1991; Halffter & Edmonds 1982; Halffter & Matthews 1966). Dung beetles of the burrower guild dig nests under dung pats, and those of the roller guild roll the dung away from the site of deposition to be buried later. Members of both of these guilds pack these nests with dung, usually formed into balls, and lay eggs in the balls. The larvae develop and pupate within the brood balls, and emerge as adults (Halffter & Edmonds 1982; Halffter & Matthews 1966). Additionally, most species of rollers and burrowers also make feeding balls that are buried, may be abandoned uneaten, or if eaten, contaminants (from the beetles point of view), such as seeds, are often moved underground (Vulinec, 1999). These behaviors hasten the decomposition of waste, aid in nutrient recycling, and contribute to aeration of the soil (Halffter & Matthews 1966). They also reduce pests in dung, such as dung breeding flies (Bornemissza 1970; Fincher 1981).

Additionally, dung beetles have an important role in seed dispersal. Seeds swallowed by frugivorous mammals are often defecated intact and viable (Garber 1986; de Figueiredo 1993). Nevertheless, as much as 90% of seeds defecated onto the surface of the soil may be destroyed by rodents or other seed predators unless buried; this burial is accomplished almost entirely by dung beetles (Estrada & Coates-Estrada 1991).

However, dung beetles are especially susceptible to ecosystem change (Morón 1987; Klein 1989; Halffter et al. 1992; Estrada et al. 1998). Disturbance of tropical rainforest may affect dung beetles directly by altering temperature, humidity, or soil characteristics, or indirectly by reduction in mammal faunas. Disturbance may have a number of different outcomes. Intensive land use in tropical areas, such as bulldozing, may result in degradation that will never be reversed (Buschbacher et al. 1992). On the other hand, less disturbed areas may have the potential to reforest. This rebound may be very important in developing management practices for revolving agriculture in tropical forests (Fearnside 1993). Studies done in Brazil and Costa Rica suggest that the most important factor in reforesting land is getting the seeds to the sites (Young et al. 1987; Pannell 1989; Nepstead et al. 1991; Holl 1999). Primary seed dispersers such as birds, bats, and monkeys are instrumental in this process (Chapman & Chapman 1995. As rodent density can be very high in secondary growth (Chapman & Chapman 1999), secondary dispersal and burial by dung beetles may also be an essential element in reforestation. Habitat characteristics that encourage use by these dispersers will improve an area's chance of regenerating natural rainforest.

To determine the effect of land disturbance on populations of dung beetles in rainforests, I investigated beetle abundance and diversity in three habitats at three sites in the states of Rondônia, Amazonas, and Pará, Brazil; more specifically, I censused beetle populations at the three sites, and in three habitats, primary terra firma forest, secondary growth, and clear-cuts. I also examined the most common beetles in these habitats for seed burial capabilities. I asked: What beetles are best at seed burial? Are there limits to the type of seeds that are buried by different species of beetles? What communities of beetles occur at each site? Are there differences in the communities of monkeys? What are the implications of community differences for forest regeneration? Finally, what effect will development of the Brazilian rainforest have on seed dispersal dynamics?

Materials and Methods

Sites

I examined dung beetle and monkey communities in three widely separated sites on tributaries of the Amazon River in Brazil. The land near Caucalandia in the state of Rondônia, Brazil, is mostly cattle ranches, secondary growth, and some patches of primary rainforest. Mean annual rainfall is 2300 mm, and mean annual temperature is 27°C (Landowner, pers. comm.). The state of Rondonia was undeveloped until the late 1960s, when the government brought in people from the overcrowded cities in the northeast (Page 1995). This area currently has one of the highest rates of deforestation in the world. With clearing, erosion has increased, and soil quality has decreased; laterization of the soil is common. By 1991, over 37,000 km^2 were cleared, more than 16% of the total state; a good quarter of the state is probably cleared by now (Stone et al. 1991).

My research site here was a small section, 250 ha of primary forest, bordered by overgrown banana and cacau plantations, and some areas of capoiera, natural regrowth. Hunting is discouraged on the private land; however, poachers were encountered in the primary forest area. Even so, peccaries, agoutis, jaguarundi, deer, and sloths, were often seen. Additionally, monkeys were easily observed. The work at this site was done between October 1996 and March 1997.

The city of Manaus is located in the state of Amazonas at the confluence of the Rio Negro and Rio Solimões (Amazon). Rainfall in the area averages 2200 mm per year, and average temperature is 27°C (Salati 1985). The biological station Reserva Adolfo Ducke (10,000 ha) is 25 km northeast of the city, and is surrounded by land that is rapidly being developed. Poaching is common, and most of the large mammals have been extirpated. Agoutis, which are seed predators, and coati were common, but no tapir or peccaries have been seen for possibly more than 15 years. Monkeys are the most common large mammal, but are also hunted regularly within the reserve by people in the surrounding communities. As these communities often have a higher standard of living than many parts of the Amazon, this hunting pressure is particularly unfortunate. Two dead howlers that had been shot and escaped to die later were found during my time at this site. I worked at Reserva Ducke between November 1997 and December 1998.

In Caxiuanã, Pará, is a recently created biological station (established 1990), the Ferreira Penna Scientific Research Station. It is located off the Rio Pará at the southwest side of the Ilha do Marajó. This station includes 33,000 ha, 80% of which is terra firma forest, and 20% is blackwater floodplain forest (Lisboa 1997). Annual rainfall is around 3000 mm (Lisboa 1997), however, October is the driest month, the month of my collection, and the year of my work, 1998, El Niño increased dryness and fire potential all over the Amazon. Surrounding communities of the reserve are sparsely populated, and hunting pressure is low. Monkeys, especially howlers and the silvery marmosets, have been habituated to humans by previous research. The upland area at this site is surrounded by swampy seasonally flooded habitat.

Seed Burial Experiments

The number of dung beetle species was high at some sites (> 50); I tested the most common species that are large enough to bury at least 5 cc of dung. Beetles not tested in burial experiments were assigned the same categories as similar sized congeners.

To determine what proportion of seeds imbedded in dung particular species of dung beetles bury, I used natural seeds or plastic beads that were small (<5 mm) or large (>10 mm). I placed beetles in mesh-covered buckets (40 cm diameter × 36 cm depth) filled with 150 mm sandy soil, and placed 50 cc of fresh cow dung with embed-

ded seeds in the center of each bucket. Buckets were left up for 72 hrs. The number of individuals of each species varied depending on the size of the beetles, such that biomass of beetles remained approximately equal (Vulinec 1999). Sample sizes varied depending on the number of beetles captured alive.

For smaller species (e.g., *Sybalocanthon* sp.), I placed beetles in 1-liter containers with 100 mm sandy soil, and10 cc fresh cow dung containing only small seeds. After 72 hrs., I excavated the burrows, 10 mm at a time. I recorded seeds buried and depth of burial.

Surveys

Beetles

Using baited pitfall traps set along the same route as the monkey transect, I censused beetle community composition and species abundance in three habitat types at each site: primary rain forest, secondary growth (edges of primary forest, old plantations, and previously cleared areas), and clear-cuts. Beetle traps were 1-liter plastic cups buried to the rim in soil, and topped with a 3 cm aperture funnel. A 50 ml cup baited with human dung was suspended by wire above the trap (Howden & Nealis 1975; Gill 1991). The volume of dung in the traps attracted even the largest beetles (Peck & Howden 1984). I set a total of 27 traps each census, which were left up for 24 hrs, then collected. Three traps were set at 20 m intervals at 9 different trapping stations (3 sites in primary forest, 3 in secondary growth, and 3 in clear-cut). This trapping regime yielded 1242 trap-days (sensu Klein 1989) for the three locations. Each site was surveyed for nearly the same number of trap-days.

Beetle biomass was measured as dry weight; the beetles were dried at room temperature for 1 week prior to weighing. Ten individuals of selected species, those most common, were weighed on an Ohaus balance at the USDA-ARS laboratory in Gainesville, Florida to determine mean biomass. For beetle species that were not weighed, biomass was assumed to be similar to beetles of the same size. Extrapolation was necessary only with small, less common beetles.

Beetle biomass at all sites was summed over time, and the differences between primary, secondary, and clear-cut habitats were tested with a one-way ANOVA. I used Scheffés test for multiple comparisons, and Students t-test to compare primary and secondary growth at Caxiuanã (beetle biomass in the clear-cut at this site totaled only 0.006 grams, and was excluded from the analysis).

Beetles were categorized as those that buried almost no seeds, those that buried at least 20% of small seeds, and those that buried at least 20% of both large and small seeds. These groups were then compared for their proportion of total dung beetle biomass at each site using one-way ANOVA.

Monkeys

To categorize primate primary seed dispersers, I censused monkey populations at the three sites: 36 times in Rondônia and Ducke, and 27 times in Caxiuanã. Monkey transects were stratified by the proportion of secondary and primary growth at each site. Transects were walked by 2 people, and transect pace was about 1 km/hr. Monkey species and number of individuals were recorded.

I used methods described in Chapman et al. (2000) to calculate monkey density, using a 50% cut-off rule to select the sighting distance. Observer to animal distance, as opposed to perpendicular distance was used, as quantitative comparisons suggest

perpendicular distance underestimates transect width for forest primates (Chapman et al. 1988). Densities of groups were then calculated as the number of groups sighted within the truncated sighting distance divided by the area sampled, that is, the length of the transect times the truncated distance (Chapman et al. 2000). Densities were calculated for groups per square kilometer and number of individuals per square kilometer.

The proportion of monkeys that are seed predators as opposed to seed dispersers was evaluated using a Chi-square contingency table test for differences among the three sites.

Results

Seed Burial

Some beetles, for example all species of *Euysternus*, bury almost no seeds. The quality of other species as seed buriers depends on several factors, including seed burier size. Larger beetles bury more seeds than smaller beetles simply because they bury more dung. Additionally, large species are capable of burying larger seeds (Table 1). Burrower guild beetles bury small seeds fairly well, while rollers are less capable. Seeds over 10 mm are only buried by the largest burrowers (Figs. 1 and 2).

Biomass of Seed-Burying Beetles In Different Sites

Beetle biomass differed among sites (ANOVA, $F = 7.58$, $P < 0.03$); Rondônia had nearly four times higher biomass than Reserva Ducke. The mean biomass in primary forest was significantly higher than secondary forest at Rondônia and Caxiuanã, but not at Reserva Ducke (Table 2). Biomass at all sites was highly significant between both primary and secondary forest and clear-cuts (only two beetles were collected in the clear-cut at Caxiuanã).

Biomass was significantly different among the three seed burial categories at Reserva Ducke (ANOVA, $F = 4.97$, $P < 0.02$), and Rondônia (ANOVA, $F = 5.79$, $P < 0.005$), but was not significant at Caxiuanã. Biomass of small seed buriers was low at Reserva Ducke, while beetles that buried large and small seeds dominated the biomass (Fig. 3). At Caxiuana, beetles of all size categories were somewhat equal in biomass, and at Rondônia, beetles that buried large and small seeds comprised the largest amount of biomass, but other categories were also abundant.

Proportion of Seed Predating Monkeys at Each Site

Monkey densities varied significantly among the three sites (ANOVA, $F = 4.5$, $P < 0.01$). Total densities for all species at each site were 38.55 individuals per square kilometer for Caxiuanã, 8.94 for Reserva Ducke, and 28.42 for Rondônia. Differences in the proportions of seed predators versus seed dispersers in monkey abundance were significant among the sites (χ^2: Caxiuanã vs. Ducke = 44.7, $p < 0.001$; Caxiuanã vs. Rondônia = 10.4, $P < 0.005$; Ducke vs. Rondônia = 101.0, $P < 0.001$; Fig. 4).

Discussion

In rainforests, seedlings have a higher survival rate when not directly under the parent tree (Howe et al. 1985; DeSteven and Putz 1984; Augspurger 1983). This survival is thought to occur because the seedling escapes from predators and pathogens

TABLE 1. SOME OF THE BEETLE SPECIES TESTED FOR SEED BURIAL CATEGORY, THE ABBREVIATIONS USED IN THE FIGURES, SOME BEHAVIORAL CHARACTERISTICS, AND MEAN BIOMASS. ABB = ABBREVIATION; GMS = GRAMS.

Species	Abb.	Type of dung manipulation	Activity period	Mean biomass gms (SE)
Canthon aequinoctialis Har.	Ca	Roller	Nocturnal	0.130 (0.045)
Canthon triangularis (Drury)	Ct	Roller	Diurnal	0.038 (0.010)
Coprophanaeus lancifer (L.)	Cl	Burrower	Crepuscular	3.260 (1.021)
Dichotomius nr. *batesi*	Dbat	Burrower	Diurnal	0.073 (0.007)
Dichotomius boreus (Oliv.)	Dbor	Burrower	Nocturnal	0.452 (0.161)
Dichotomius lucasi (Har.)	Dluc	Burrower	Nocturnal	0.099 (0.020)
Dichotomius podalirius (Fels.)	Dpod	Burrower	Nocturnal	0.452 (0.161)
Eurysternus caribaeus Herbst	Ec	Neither	Nocturnal	0.102 (0.028)
Oxysternon conspicillatum (Web.)	Oc	Burrower	Diurnal	0.798 (0.244)
Phanaeus cambeforti Arnaud	Pcam	Burrower	Diurnal	0.136 (0.042)
Phanaeus chalcomelas (Perty)	Pch	Burrower	Diurnal	0.146 (0.042)
Scybalocanthon nr. *pygidialis*	Sp	Roller	Diurnal	0.027 (0.005)

of the parent (Howe & Smallwood 1982; Connell 1971; Janzen 1970), and because dispersal reduces competition for resources (Stiles 1989).

Trees have evolved strategies to disperse their offspring to other locations. Fruit and the seeds within generally travel away from their parent inside animal guts. Monkeys are considered by many authors to be high quality seed dispersers (Castro 1991; Estrada et al. 1991; Rowell & Mitchell 1991; Chapman 1989; Howe 1989; Garber 1986). However, some monkeys are better seed dispersers than others, for example, some eat leaves or nectar in addition to fruit, some travel more, some defecate seeds out singly, or may defecate them in a mass (Veracini 1996; Zhang & Wang 1995; Castro 1991; Chapman 1989; Garber 1986). Most importantly, some monkeys, primarily the sakis, are generally seed predators (Norconk 1998; Peres 1993; Van Roosemalen et al. 1988). The proportion of seed predators in monkey communities varies greatly at each locality. These findings may reflect a very different potential in different areas for forest regeneration.

Secondary seed dispersal and burial by dung beetles may also have an impact on rainforest regeneration (Feer 1999; Andresen 1998; Estrada et al. 1991). The highly significant difference between beetle biomass at Rondônia and the other two sites might have a number of causes. It could reflect the shorter history of disturbance, the abundance of mammals, climatic factors, or vicariance. Nevertheless, the overall bio-

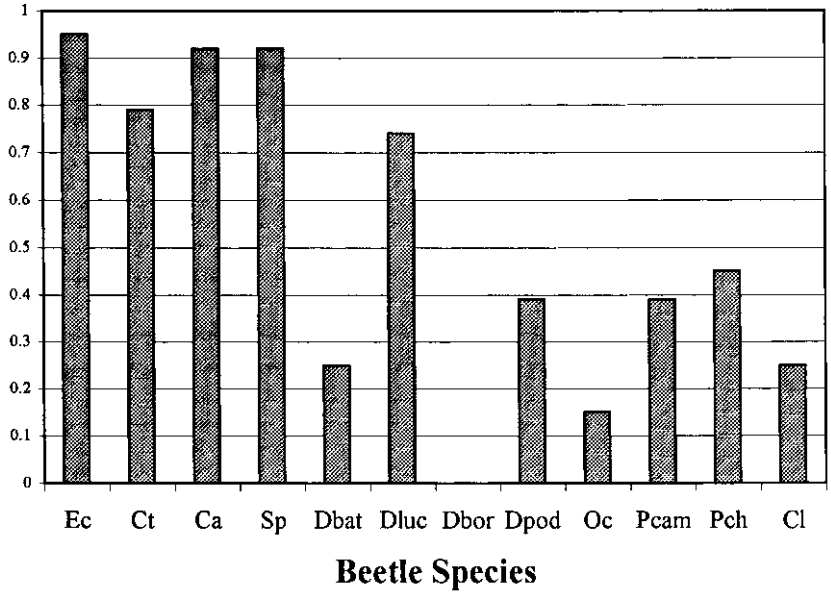

Fig. 1. The total proportion of small seeds (< 5 mm) left on the soil surface by some beetle species. See Table 1 for species abbreviations and characteristics.

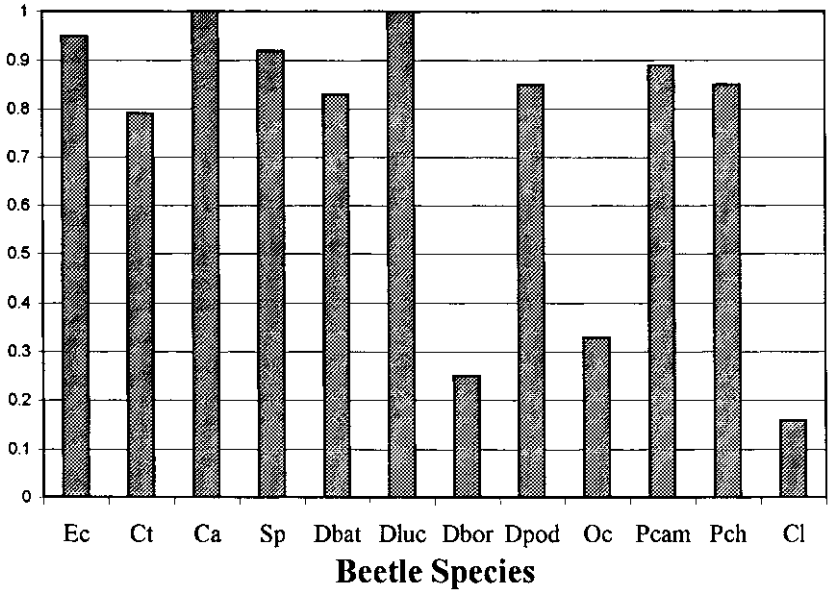

Fig. 2. The total proportion of large seeds (> 10 mm) left on the soil surface by some beetle species. See Table 1 for species abbreviations and characteristics.

TABLE 2. MEAN BEETLE BIOMASS (SE) IN EACH OF THREE HABITAT TYPES AT EACH SITE. MEANS SHARING LETTER IN EACH ROW ARE NOT SIGNIFICANTLY DIFFERENT. CAXIUANÃ (STUDENT'S T-TEST, $P < 0.001$), * = ONLY THREE BEETLES CAUGHT; DUCKE (SCHEFFES' MULTIPLE COMPARISONS, $P \leq 0.003$) AND RONDÔNIA (SCHEFFES' MULTIPLE COMPARISONS, $P \leq 0.002$).

Site	Primary forest	Secondary growth	Clear-cut
Caxiuanã	5.07 (2.65)[a]	2.49 (1.66)[b]	*
Ducke	9.85 (1.71)[a]	7.03 (1.15)[a]	0.41 (0.11)[b]
Rondônia	36.55 (4.16)[a]	19.78 (3.10)[b]	0.58 (1.10)[c]

mass of beetles and the proportion of those that bury seeds may be highly important to the local ecology. Reserva Ducke is dominated by beetles that bury both large and small seeds. The proportion of the biomass that buries only small seeds is very low. Because beetles that bury large seeds are mostly nocturnal (Vulinec 1999), the partitioning of beetle biomass may have an effect on seeds that are deposited during the day. Seeds deposited by monkeys in transit may not be buried immediately, and could be left on the ground until discovered by rodents, ants, or weevils. It would be expected that at this site, seeds may suffer higher mortality from seed predation, first by saki monkeys, and then by seed predators on the forest floor.

In regeneration of secondary growth areas, dung beetles may prove even more important than in primary forest. Primary seed dispersers, such as birds and monkeys will enter secondary growth, especially if there are trees such as bananas and *Cecropia* spp. (Holl 1999). Therefore, seeds from primary forest can get to these areas (Duncan & Chapman 1999). However, rodents are often more prevelant in secondary

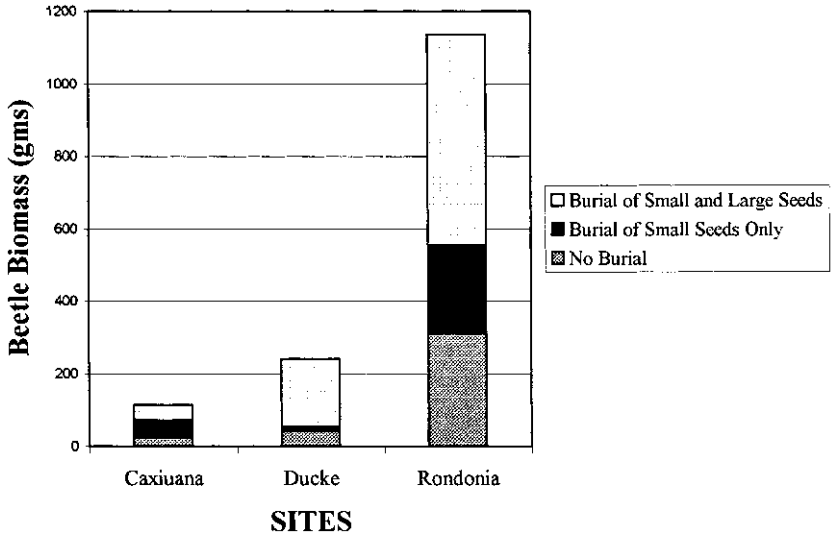

Fig. 3. Total beetle biomass at each site stratified by three categories of seed burial behavior.

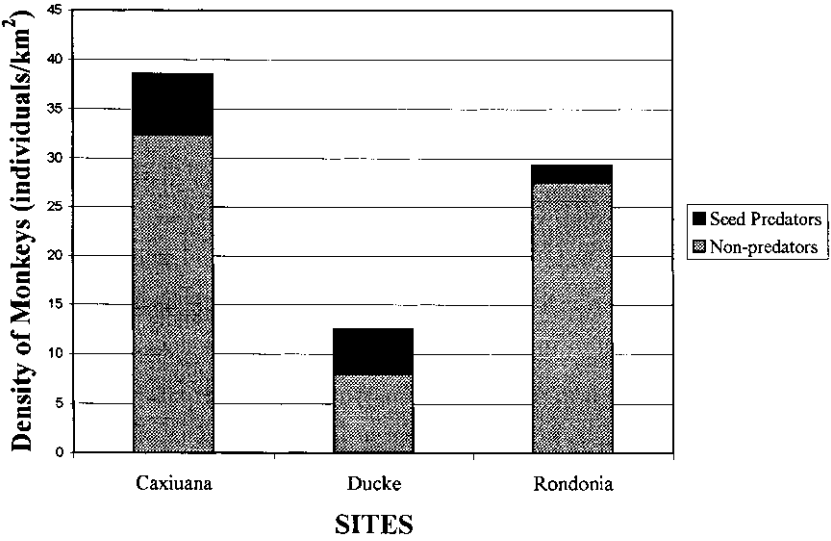

Fig. 4. Density of monkeys at each site and proportion of seed predators versus seed dispersers.

growth, so predation may also be greater (Asquith 1997). It would be advantageous to a seed to be buried quickly in these areas. Dung beetles are far more abundant in secondary growth than clear-cuts (Vulinec 1999; Estrada et al. 1998). Additionally, secondary growth has more similar microclimates and soil characteristics to primary forest than pastureland, where soil compaction and low humidity may keep many dung beetles out. Secondary growth has the potential to reforest relatively quickly given the primary and secondary dispersers that enter it. Clear-cuts have much less chance of rapid reforestation, and in some cases, no chance.

Beetles that roll dung, rather than burying it directly under the dung pat, dominate clear-cuts (Vulinec 1999; Halffter et al. 1992). Rollers, despite relocating seeds from the source, often do not bury brood balls deeply enough to protect the seeds within from rodent predation. Additionally, the generally smaller size of these beetles would make them less effective as processors of larger seeds, or a quantity of seeds. This factor suggests that savanna adapted species would probably not contribute significantly to forest regeneration in secondary growth (Vulinec 1999).

Beetles that frequent secondary forest are, like those in primary forest, more likely to be good seed "planters", due to beetle size, depth of burrowing activity, and abundance (Vulinec 1999). Nevertheless, in two of the three sites, beetle biomass was significantly greater in primary growth than secondary growth. Many beetle species are very sensitive to changes in habitat, while other species, such as *Dichotomius*, are more flexible in habitat preferences (Vulinec 1999). The factors that encourage high-quality seed buriers to enter secondary forest should be investigated. Manipulation of these factors could increase regeneration of primary forest from secondary growth areas. For example, beetles may respond to humidity when foraging or mate seeking. Planting broad leafed trees (such as *Cercropia)* in abandoned cut areas may increase ground level humidity and recruit more large dung beetles (and monkeys) from primary forest to these areas, resulting in quicker primary forest regeneration.

Amazon rainforest is disappearing at a distressing rate; in the Brazilian Amazon 2,554,000 ha of forest are cleared yearly, a number that does not include clearing due to selective logging or destruction by fires (FAO 1999). Deforestation in the Neotropics has profound effects on carbon cycling, the hydrological cycle, and soil and water quality (Salati 1985). For example, 50-75% of precipitation in the Amazon is returned to the atmosphere in the form of water vapor through evaporation of the water retained by leaves, and through transpiration of the plants (Salati 1985). Cutting the forest can radically change the water cycle.

The majority of the clear-cutting in the Amazon is for cattle ranching, and the greatest clearing is by large agribusiness corporations. According to Fearnside (1993), beef productivity on Amazon soils is low, and is unsustainable. Available phosphorous limits grass yields on oxisols and ultisols. Inedible weeds that are more adapted to the poor soils quickly invade pastureland. Massive government programs that subsidize pasture have claimed that pasture improves the soil, and is indefinitely sustainable. However, further studies have shown that maintained pasture productivity is not possible without the addition of phosphorous fertilizer. But adding fertilizer will still not solve the problem of pasture degradation. Soils become compacted through the exposure to sun and the trampling of cattle. My own measurements of soil density in forest and clear-cuts showed a 2 to 4 fold increase in relative density in clear-cuts, even without cattle (Vulinec, unpub.).

In a recent study, Holl (1999) suggests that although regeneration of forest in pastures is limited by colonization, establishment, growth, and survival, the major limiting factor in seedling establishment is lack of seed availability. She suggests pasture restoration to forest by planting native tree seedlings to increase canopy architecture, installing bird perching structures, and planting rapidly growing shrubs that quickly produce fruit and attract seed dispersers. I also suggest that there must be a nearby refuge of protected species to provide the necessary colonizers, including plants, pollinators, and dispersers, and secondary dispersers such as dung beetles.

Logging is another large-scale use of tropical forests. Currently, decisions about logging in the Amazon have no central planning or coordination. Without this planning, logging industries could easily log all of the forest in the state of Pará (Veríssimo et al. 1998). Veríssimo et al. (1998) conclude that logging could be a sustainable industry that would preserve diversity and indigenous rights and suggest several ways to do this. Logging would have to be highly monitored, however. Nepsted et al. (1998b) maintain that even selective logging diminishes forest cover, allows the drying of understory vegetation, and sets the stage for devastating fires as were seen in 1998. Even one fire in an area significantly increases the chances of future fires. The more fires in an area, the more brushy secondary growth and open canopies invite more fires in a positive feedback loop (Nepstad et al. 1998a).

Perhaps most importantly, loss of tropical rainforest leads to loss of biodiversity. There may be as many as 5-30 million species of plants and animals still undescribed, and unknown, the vast majority in tropical forests (Erwin 1982). We have yet to understand the interrelationships among the flora and fauna living in these critical areas. What we don't understand may do more than just prevent us from finding a cure for cancer. The loss of pollinators and dispersers will affect uncounted species of plants, many of potential economic and ecological importance. My research shows how even seemingly insignificant organisms may have important roles in ecosystem function. If dung beetles were gone, the buildup of feces, the increase in dung breeding pathogens, the loss of some soil turnover, would become rapidly apparent (Vulinec 1999; Klein 1989). Predatory mites that hitch rides on dung beetles would disappear. Potential antifungal and antibacterial chemicals may never be discovered. And very importantly, seeds deposited in dung would remain on the surface vulnerable to ro-

dents, fungi, and granivorous insects. Conversely, if vertebrate seed dispersers disappeared, the 60% of tree species, and almost 100% of understory plants that depend on vertebrate seed dispersal would also decline. Dung beetles would vanish with them.

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BIOLOGY OF *BRUCHIDIUS VILLOSUS* (COLEOPTERA:BRUCHIDAE) ON SCOTCH BROOM IN NORTH CAROLINA

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ABSTRACT

Scotch broom, *Cytisus scoparius* (L.), a weed in the Pacific Northwest, is rapidly invading open areas and ecologically sensitive dunes along the coast. Scotch broom populations also exist in the eastern United States, but are apparently stable and not expanding. The eastern Scotch broom populations may be kept in check by the broom weevil, *Bruchidius villosus* (F.), a bruchid found in eastern populations of broom but absent from those in the Northwest (Bottimer 1968). We studied the natural history and biology of the broom weevil in North Carolina. Our purpose was to relate the bruchid's life history to the phenology of the host plant and to quantify oviposition and seed destruction by the bruchids. Adult weevils were active around the plant from the first flowering in early spring until dehiscence of the seedpods in summer. The sex ratio of the beetles was nearly 1:1 throughout the adult activity season. The number of weevil eggs laid on the pods was correlated to the length of the pod and to the number of seeds in the pod. The larvae develop in and destroy the seeds of the broom plant. Seed destruction at two sites in North Carolina was more than 80%; a field experiment showed that seed destruction was dependent on the density of beetles in cages on the plants. Because of its impact on seed production, the broom weevil may be a viable candidate for biological control of broom in the Northwest.

Key Words: broom weevil, oviposition, seed destruction, Scotch broom, *Cytisus scoparius*

RESUMEN

La escoba escocesa, *Cytisus scoparius* (L.), una maleza del Noroeste Pacifico, esta invadiendo rápidamente áreas abiertas y dunas ecológicamente delicadas a lo largo de la costa. Poblaciones de escobas existen también en el este de los Estados Unidos, pero aparentemente son estables y no se están expandiendo. Es posible que las poblaciones orientales de escobas estén bajo control gracias al gorgojo de escoba, *Bruchidius villosus* (F.), que se encuentra en poblaciones orientales de escoba pero esta ausente en el noroeste. Estudiamos la historia natural y la biología del gorgojo de escoba en Carolina del norte. Nuestro propósito fue relacionar el historial de vida del gorgojo a la fenología de la planta huésped y cuantificar oviposición y destrucción de las semillas por los gorgojos. Los gorgojos adultos eran activos alrededor de la planta desde la fluoración primera al comienzo de la primavera hasta la dehiscencia de las cápsulas de semillas en el verano. La proporción sexual de los escarabajos fue casi 1:1 durante la temporada de actividad adulta. El numero de huevos de gorgojo colocados en las cápsulas fue correlacionado al lo largo de la cápsula y al numero de semillas en la cápsula. La larva se desarrolla y destruye las semillas de la planta escoba. La destrucción de semillas en dos lugares en Carolina del Norte fue mas de 80%; un experimento de campo demostró que la destrucción de semillas dependía en la densidad de

las jaulas de escarabajos en las plantas. Debido a su impacto en la producción de semillas, el gorgojo de escoba puede ser un candidato viable para el control biológico de la escoba en el noroeste.

Scotch broom, *Cytisus scoparius* (Fabaceae: Leguminosae), was introduced from western Europe into the Pacific Northwest as an ornamental and as a soil and coastal dune stabilizer. This woody shrub is well adapted to dry, disturbed habitats. Since its introduction, *C. scoparius* has become a pest by spreading and displacing valued forage and native plants (Andres & Coombs 1995). In addition, Scotch broom has made reforestation difficult in many areas in British Columbia, California, Oregon and Washington (Balneaves 1992). Historically, *C. scoparius* has been difficult to control because of its large and long-lasting seed bank (Bossard & Rejmanek 1994).

In western North Carolina the distribution of feral *C. scoparius* is restricted to isolated patches and its populations do not seem to be expanding (Syrett et al. 1999). One possible factor contributing to the limited spread of Scotch broom in this area is the weevil, *Bruchidius villosus*. Adult weevils lay eggs on the broom seedpods and the larvae feed on the seeds within the pod. Parnell (1966) studied the life history of *Bruchidius* on broom in England. However, little is known about the life history and biology of this potentially beneficial bruchid in North America. Because the broom populations in North Carolina are stable, the ecological agent that limits population growth in North Carolina could potentially be introduced into the Northwest to control this problem plant.

Bruchidius villosus shows potential as a biological control agent for *C. scoparius* due to its direct effect on the host's seed production. This study's purpose was to improve our understanding of *B. villosus'* biology as it relates to its host plant in western North Carolina. We compared the biology of the bruchid in North America with that in England to see how consistent the behavior and ecology of this species are in widely separated populations. Our studies focused on the overwintering of the weevils, on the relationship between beetle activity and host plant phenology, and on measurement of oviposition and destruction of seeds. An understanding of these basic aspects of this insect's biology is useful if this beetle is to be introduced as a biological control agent for Scotch broom in the Pacific Northwest.

Materials and Methods

Site Descriptions

Site 1. The larger of the two stands of *Cytisus scoparius* used for this study was located on a hillside approximately 11 km east of downtown Asheville, North Carolina. The 69 × 24 m area has a northeastern exposure and contains 36 shrubs. The majority of the shrubs are 1-2.5 m in height. In addition to *C. scoparius,* the hillside is densely covered with two species of *Solidago, Lespedeza cuneata, Lathyrus latifolius,* and *Eupatorium hyssopifolium*. Several small *Robinia pseudo-acacia* and *Acer rubrum* also grow at the site. The *C. scoparius* shrubs at this site are exposed to full sun throughout the day.

Site 2. The second study site was located in a residential area on the edge of the Bent Creek Research and Recreational area approximately 16 km southwest of Asheville, North Carolina. The broom plants are old ornamentals that are no longer

being maintained. The area is approximately 19 × 12 m and it contains 12 shrubs that are 1-2 m in height. The site has a dense ground cover of *Hedera helix*. Also growing on the site are *Lespedeza* sp., *Solidago* sp., *Clematis terniflora, Aster pilosus, Lonicera japonica, Celastrus orbiculatus, Quercus alba, Tsuga canadensis,* and *Prunus serotina*. The centrally located shrubs at this site receive little sun most of the day, whereas the shrubs at the edges of the site receive sun for about half of the day.

At each site, continuous temperature readings were made using a StoAway® TidbiT® temperature logger. The loggers were placed at the base of mature *C. scoparius* shrubs with the temperature probes in the leaf litter. The temperature data were downloaded each week and transferred to computer.

Overwintering

Field Sampling. To determine if the bruchids overwinter near the broom plant, the soil and leaf litter around the plants at each site were sampled by two separate methods. In January, three soil samples (100 cm^2 × 2.5 cm deep) were collected at 30, 60 and 90 cm from the base of a mature broom plant at each site. Soil samples were placed in Berlese funnels over jars of alcohol. After the soil dried for two weeks, the alcohol and dried soil were examined for bruchids.

Litter samples were taken weekly from 26 Jan to 20 Apr 1998. Each litter sample was approximately 100 cm^2 × 1 cm deep. From each site a sample was taken at 30, 60 and 90 cm from the base of a mature plant. Each of the six weekly samples were emptied into a large tub and examined thoroughly with a hand lens for *B. villosus*.

Laboratory Observations. To observe activity of adult weevils during the winter, we set up eight 10 × 10 × 8 cm^3 clear plastic observation cages. Each cage was filled with soil to a depth of about 5 cm and contained 8 to 10 weevils. Four of the containers were kept indoors at room temperature and four were kept outdoors under natural temperature conditions. Because the group kept indoors was near a window, both groups of beetles received the same natural photoperiod. Moisture was applied weekly to each container. If the bruchids were active during warm winter days, individuals kept indoors could be observed on the lid and walls of their cages more than individuals in the cages kept under natural temperatures. We checked the cages each week (13 Feb through 30 Mar) and recorded the number of bruchids located on the lid or side of the cage or on the soil. The number of beetles not visible was also recorded. We used a sign test for paired-sample data to test for differences between the activity of bruchids kept indoors and those kept outdoors.

Seasonal Abundance and Host Phenology

Weekly beat and sweep samples were made at each site to quantify seasonal changes in the adult bruchid population. Samples were standardized throughout. Beat samples consisted of beating a branch of a broom plant over a white tray (0.5 × 0.4 m). Beetles falling into the tray were counted and collected using an aspirator. Three plants at each site were sampled by beating branches at the top, middle and bottom of each plant. Sweep samples consisted of 10 uniform sweeps of the vegetation surrounding the broom plants. The contents of the sweep nets were emptied into a white tray and beetles were collected using an aspirator and counted. Each week, the bruchids collected at the two sites were examined individually under a dissecting microscope and sexed (see Parnell 1964). In addition to sampling for beetles, the phenological stage of the broom plants was quantified. We paid particular attention to the stage of leaf, flower, and seedpod development.

Oviposition and Seed Destruction

We dissected females collected on three dates (N = 7, 4 May—before pod set; N = 10, 19 May—just after pod set; N = 9, 1 Jun—when pods begin turning brown) and determined the development of their oocytes and checked for sperm in their spermathecae. Once oviposition was occurring in the field, we collected three to five seedpods from different heights and directions on four bushes at each of the sites. Using a dissecting microscope, we determined the number of bruchid eggs on each of the pods. We also measured the length of each pod (calyx to tip) and counted the number of seeds in each pod. We tested for a significant correlation between the number of bruchid eggs laid per pod and the number of seeds per pod. We also correlated the number of eggs with the number of infested seeds.

We also conducted a field-cage experiment to determine the effect of bruchid density on the seed destruction. The cages were (1 mm) mesh bags about 30 cm in diameter. We used four densities of female bruchids: 0 (control), 1, 4 and 8 female bruchids per bag. We tied and taped each bag around the end of a broom branch with 8 to 18 young (green) seedpods. Because the seedpods had been exposed to natural oviposition, we removed bruchid eggs from the seedpod exterior by hand prior to introducing female bruchids into the cages. To control for the effect of plant and location, each of the four densities were placed on branches of a single broom plant and the density treatments were randomly assigned to each cage. Four blocks (different broom plants) of the four treatment densities were left in the field. At the end of four weeks (24 May to 22 Jun 1998), the cages and branches were collected and examined in the laboratory to determine the number and size of the seedpods, the number of seeds, and the infestation rates. We used an ANOVA to test for differences in seed destruction among the treatment densities. Because the number of pods and seeds in each cage varied, we also used a regression analysis to determine the relationship between the density of weevils per seed and seed destruction.

Parasitism

Once the seedpods had started to dehisce (late June through August) and the weevils were maturing, we collected five to ten pods from different heights and directions from four bushes at each site. The length and number of seeds were recorded for each pod. The pods were opened and we recorded the number of live and parasitized bruchids.

Results

Overwintering

No *B. villosus* were found in any of the soil or litter samples from either of the sites during January and February. Except those insects that were in pods in the leaf litter sample, all beetles found in the litter samples were dead. Some pods from the previous year were collected in the litter samples and these contained a few live beetles (N = 7).

The adults kept in indoor cages were significantly more likely to be active (on cage lid and walls) compared with those in cages kept outdoors (P = 0.04). In only two of twelve observations were a greater number of active weevils found in outdoor cages. Both of these were later observations (30 Mar and 6 Apr) when the beetles were becoming active in the field. Based on our sampling and cage experiment, it seems likely that the beetles overwinter away from the plants and may become active during the winter when temperatures are warm.

Seasonal Abundance and Host Phenology

Adult weevils can be found on the plants from early April to the end of August (Figs. 1 and 2). Arrival of the weevils is closely correlated with the first bloom of the plant. We found beetles at each site during the weekly sample where flowers first appeared. At both sites we found a peak in the population during the flowering stage of the plant (beat samples Figs. 1 and 2). Another peak in the population from late June to August was observed in beat samples of the broom and in sweep samples of surrounding vegetation. The second peak corresponds to the darkening and dehiscence of the seedpods and probably represents the emergence of the new generation of weevils. Adults were active over a wide range of temperatures (Figs. 1 and 2). The overall sex ratio sampled was slightly male biased 542m:500f. The sex ratio of weekly samples fluctuated around 1m:1f throughout the adult activity (10 weeks with slight male biases and 9 weeks with slight female biases).

Oviposition and Seed Destruction

None of the females collected 4 May, prior to pod formation on the plants, had mature oocytes although some (2 of 7) had mated. These females noticeably lacked fat deposits. Once pods were set, all females (N = 19, 19 May and 1 Jun) had some large mature oocytes and most (13 of 19) were mated. The mature oocytes were large compared with the size of the females and typically filled the abdominal cavity. The average number of mature oocytes found in gravid females was 10 (range 4 to 14).

For field collected seedpods (N = 100), the overall seed destruction was 82% (492/600). Eighty-six percent of the seedpods sampled had more than 60% of their seeds destroyed by weevils (Fig. 3). Seed destruction was similar at both sites [site 1: 85% (225/266); site 2: 80% (267/334)]. Not surprisingly, the number of seeds per pod increased significantly with the length of the seedpod (Fig. 4: N = 100; $P < 0.001$; $r^2 = 0.53$). There was a significant relationship between the number of bruchid eggs laid on the seedpod and the length of the pod (Fig. 5: N = 59; $P < 0.001$; $r^2 = 0.23$), with more eggs being laid on longer pods. Beetles also laid more eggs on pods with more seeds (Fig. 6: N = 59; $P < 0.001$; $r^2 = 0.18$), although the number of seeds was a less reliable indicator of the number eggs than was the size of the seedpod.

In the field cage experiment, there was a significant difference among the treatments with respect to the proportions of seeds infested with larvae (Fig. 7: ANOVA; $F_{3,12} = 5.67$; $P < 0.02$). There was also a significant relationship between the number of beetles per seed in the cage and the proportion of seeds damaged ($P < 0.02$; $r^2 = 0.35$).

Parasitism

Parasitization occurred at relatively low rates at both sites, 14% (14/100) at site 1 and about 6% (6/102) at site 2. The parasites have tentatively been identified as *Dinarmus* sp. (Pteromalidae), known parasites of bruchids.

Discussion

Overwintering

The weevils apparently overwinter away from the plant. We did not find any live *B. villosus* in the soil, litter or sweep samples during January and February, although a few live weevils were found in seedpods in litter samples and in seedpods still on the

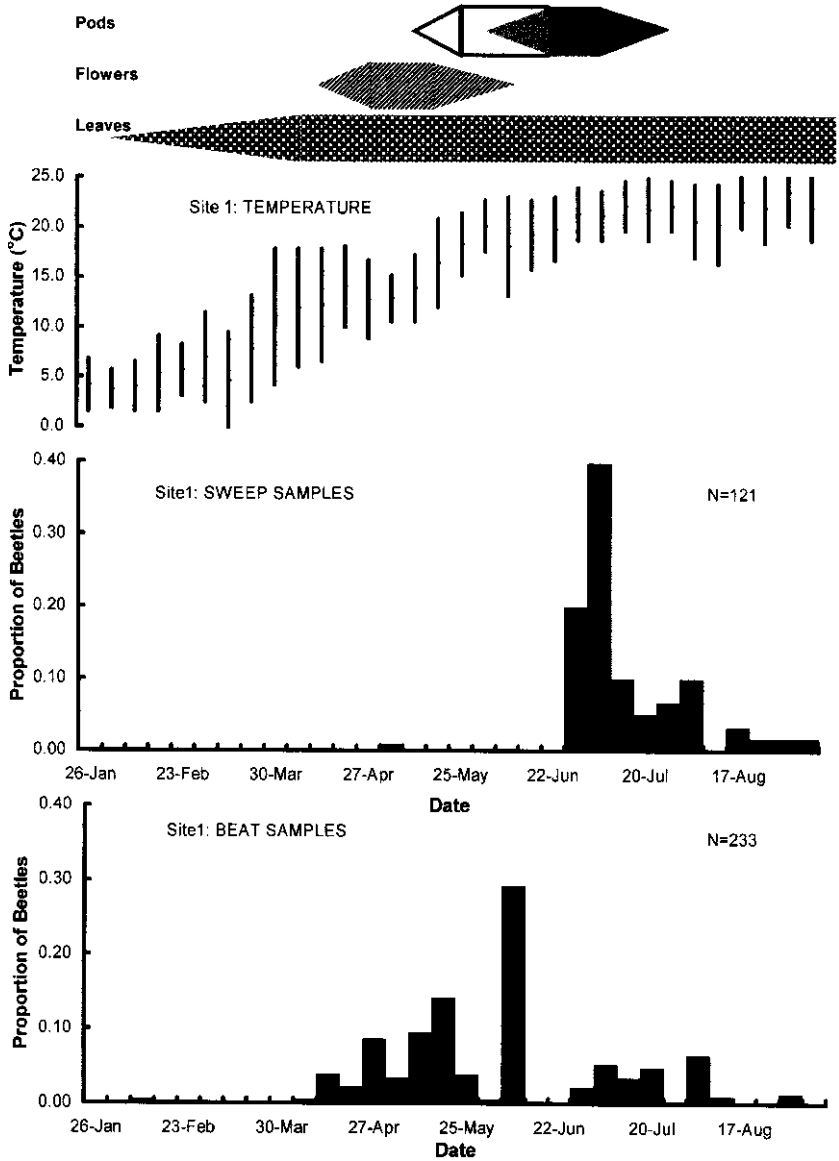

Fig. 1. Field sampling and temperature data for site 1, Asheville, NC. Bar graphs show the proportion of beetles in weekly beat samples (lower bar graph, N = 233 weevils) and sweep samples (upper bar graph, N = 121 weevils). Maximum and minimum temperatures (°C) for each week are also shown. Shaded horizontal bars at the top of the plot show the phenology of the broom plant at the site. Upper bar shows the development of seedpods, with the darker portion showing the dried dark pods. The middle hatched bar represents the presence of flowers. Lower dotted bar shows development of leaves.

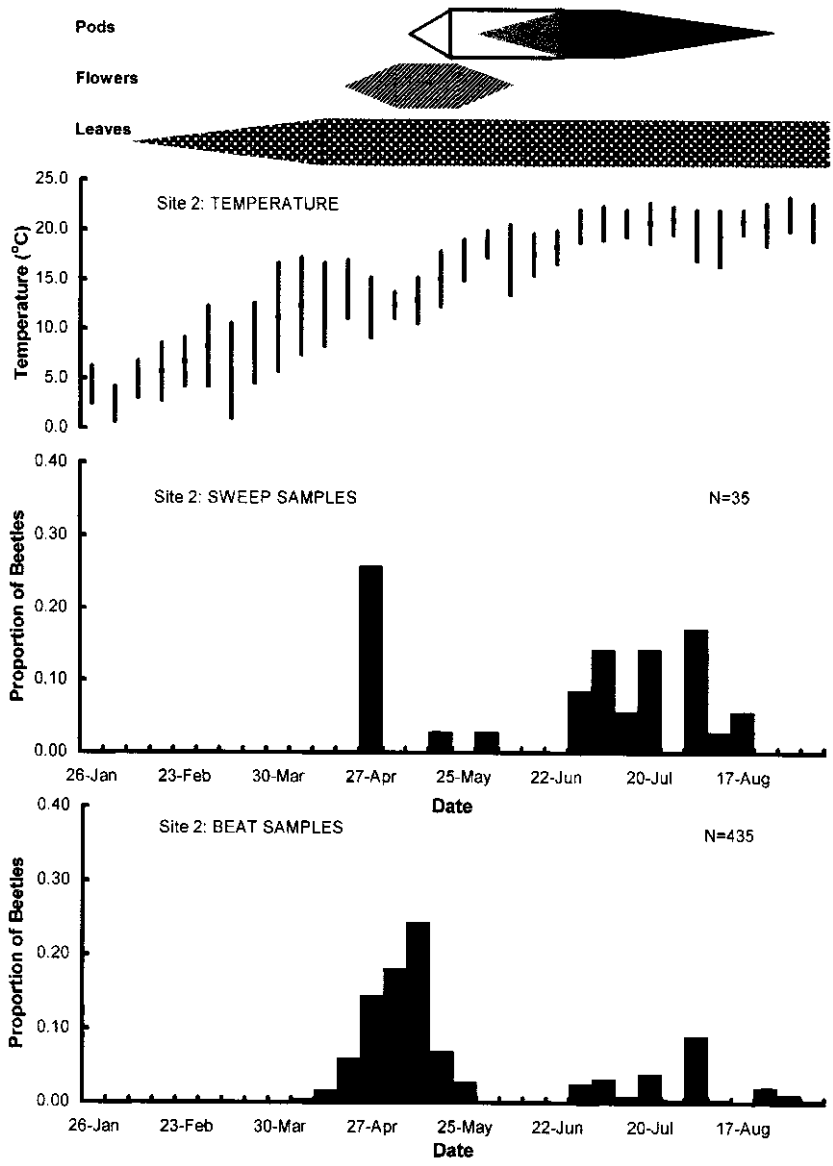

Fig. 2. Field sampling and temperature data for site 2, Asheville, NC. Bar graphs show the proportion of beetles in weekly beat samples (lower bar graph, N = 435 weevils) and sweep samples (upper bar graph, N = 35 weevils). Maximum and minimum temperatures (°C) for each week are shown. Shaded horizontal bars at the top of the plot show the phenology of the broom plant at the site. Upper bar shows the development of seedpods, with the darker portion showing the dried dark pods. The middle hatched bar represents the presence of flowers. Lower dotted bar shows development of leaves.

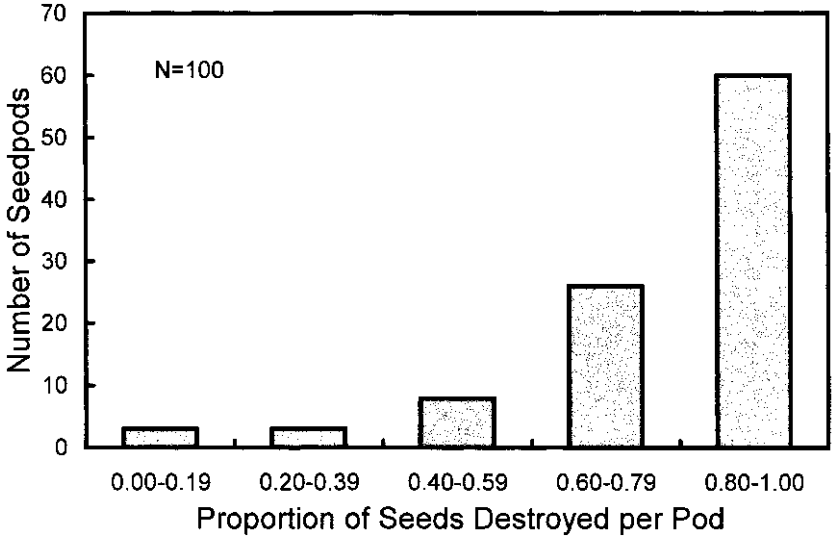

Fig. 3. Frequency distribution of seed destruction in broom seedpods by *Bruchidius villosus* in North Carolina. Each bar shows the number of seedpods found with proportions of their seeds infested with bruchid larvae or pupae. Of the seedpods examined, 86% had more than 60% of their seeds destroyed by weevils.

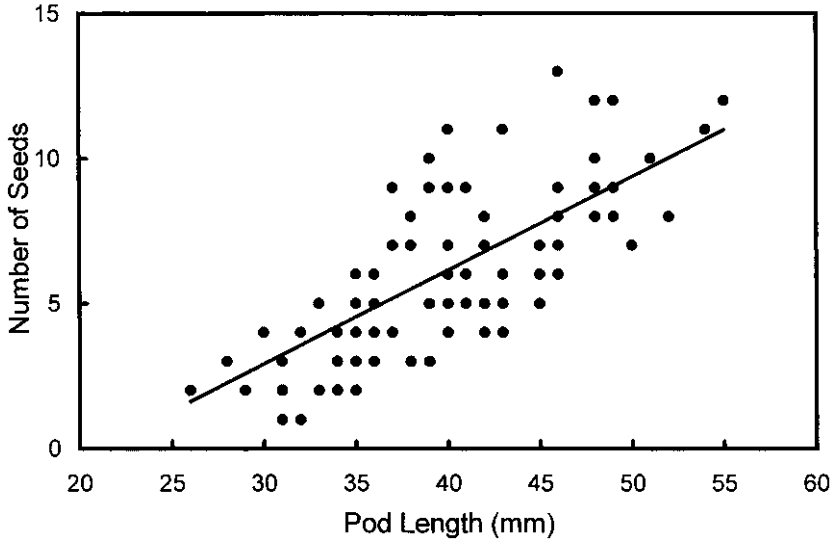

Fig. 4. Correlation between the length of the seedpod and the number of seeds within the pod for Scotch Broom. Pods ranged in length from 26 to 56 mm and larger pods tend to have more seeds ($P < 0.0001$; $r^2 = 0.53$). Trend line through the points is the least-squares linear fit to the data ($Y = 0.32X - 6.79$).

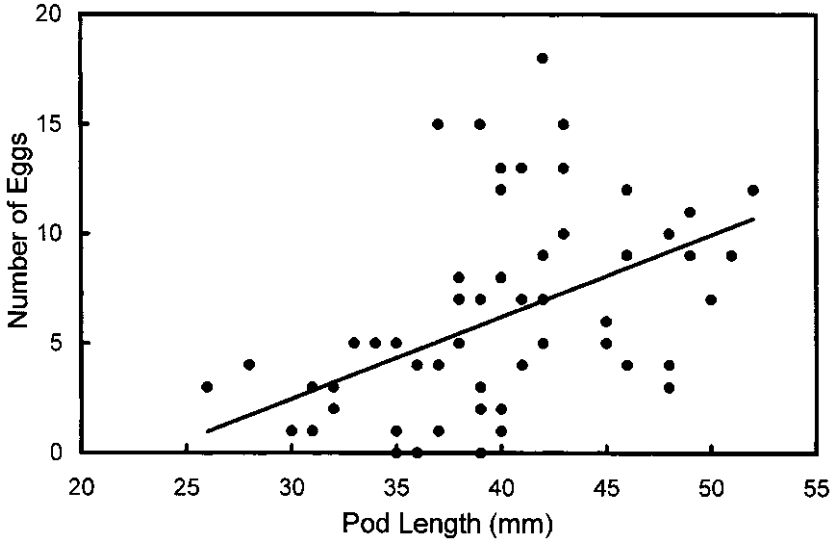

Fig. 5. Correlation between the numbers of *Bruchidius villosus* eggs laid on the exterior of seedpods and the length of the pod. Beetles laid significantly more eggs on longer seedpods ($P < 0.0001$; $r^2 = 0.23$). The least-squares linear fit to the data is plotted ($Y = 0.37X - 8.72$).

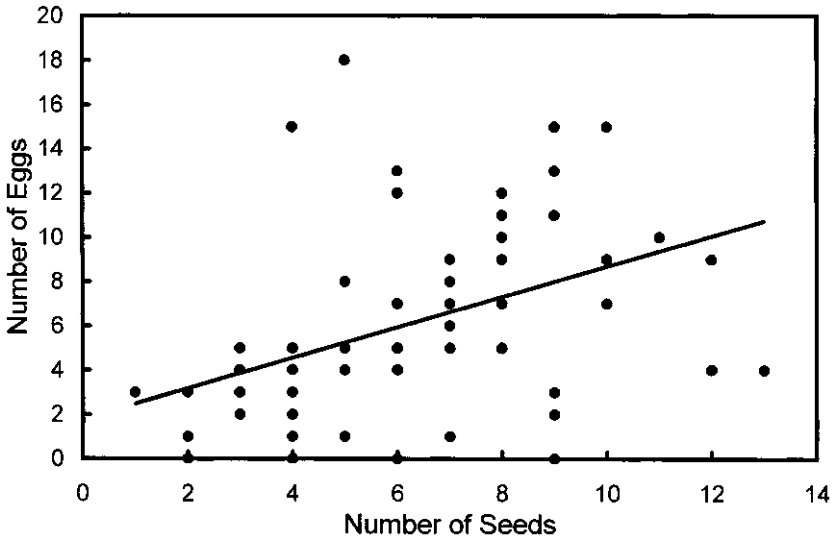

Fig. 6. Correlation between the numbers of *Bruchidius villosus* eggs on seedpods and the number of seeds within the pod. Beetles laid significantly more eggs on pods having more seeds ($P < 0.0001$; $r^2 = 0.18$). The trend line ($Y = 0.69X + 1.82$) is the least-squares fit to the data.

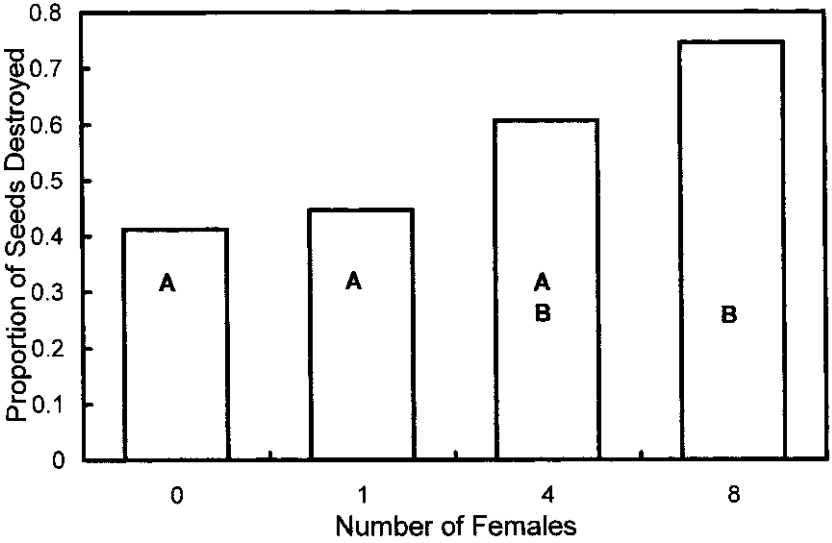

Fig. 7. Bars are the average proportions of seeds destroyed by *Bruchidius villosus* larvae when different densities of females were placed in field cages. There is a significant effect of female density on the proportion of seeds infested with bruchid larvae (ANOVA; $F_{3,12} = 5.67$; $P < 0.02$). Bars with different letters represent means that are significantly different (*post hoc* Tukey's studentized range test).

broom bushes in November and December the previous year. In a two-year study of *Bruchidius* in England (Parnell 1966), no beetles were discovered in large leaf litter samples. In our cage experiments more beetles were found on lids and sides of the cages under warm conditions (inside) compared with cages kept at colder temperatures (outside), suggesting that bruchids spend cold temperatures in the soil and become active if the temperature warms. Parnell (1966) found some beetles on flowering gorse early in the spring prior to the flowering of broom. The only time we collected weevils away from broom plants was later in the season. Although site 1 was densely covered in other legumes, *B. villosus* was not found in any beat samples of the vegetation surrounding the broom plants prior to or during the bloom of the broom plants. There was an increase in the numbers collected in sweep samples from vegetation around the broom plants in late June, July and August (Fig. 1). The beetles in these samples were probably newly emerged adults. Large numbers of bruchids apparently leave the host plant in late summer once they emerge from the seedpods. We still do not know where they go and how the bruchids overwinter.

Seasonal Abundance and Host Phenology

The phenology of the broom in North Carolina is nearly identical to that described for broom in England (Parnell 1966). Leaves bud in late January or early February. The first flowers appear in late March or early April with the first pods forming a few weeks later. The green pods begin to blacken in mid-May, and most of the pods have split and fallen from the broom plants by the end of August (Figs. 1 and 2). The weevils arrive simultaneously with the first flowering of the plant. Females have no visi-

ble fat deposits at this time and probably have used all their reserves during the overwintering period. Both sexes can be collected in flowers where they feed on pollen and nectar (see Parnell 1964). It seems likely that pollen would be used as a nitrogen (protein) source for egg yolk deposition. However, when we dissected females and examined their digestive tract, the tract was simple with no distended crop and we did not find pollen. Individual plants at our sites differed in flower set by a week or two. As the more advanced plants lose their flowers (begin to set pods), the beetles move to plants with newly opened flowers. When the seedpods are green, females deposit eggs on the outer surface.

Oviposition and Seed Destruction

In North Carolina, egg development within females occurs soon after females arrive at the plant. Prior to the set of pods in mid-May, ovaries were not developed and did not contain mature oocytes. Once the first pods appeared (19 May), nearly all the females collected had mature oocytes and were mated. Parnell (1966) found that all females were mature and had mated by the end of May. The number of mature oocytes we found in dissected females agreed with Parnell's (1966) description of 14 ovarioles in the ovaries. We never found more than 14 mature eggs in the abdomen of females (mean = 10), and all the mature eggs seemed to be in the same stage of development.

We found a significant relationship between the number of eggs laid on a pod and the size of the pod (length or seed number). Typically one larva requires a single seed to develop, and Parnell (1966) found that late-arriving larvae died. The first larva to reach the seed apparently prevents others from reaching and feeding on the cotyledons. Females probably can detect oviposition by other females, and the number of eggs laid is adjusted to minimize the loss of offspring due to competition within the pods. The larva hatches from the bottom of the egg where it is attached to the pod and excavates a small tunnel into the pod. Some of the tunnels can be 1 cm long before the tunnel enters the seed cavity. The destruction of the seeds by the weevils is high, over 80% at both sites. In California broom populations where *Bruchidius* does not occur, seed damage by another beetle (*Apion*) is variable and rises from 5 to 10% early in the season to 22 to 80% late in the season (Bossard & Rejmanek 1994). It seems likely that *B. villosus* could have a significant impact on seed production. However, seed destruction is dependent on the density of weevils. In cages without females, the average seed destruction was about 40% (Fig. 7), indicating that a number of eggs had hatched in some of the pods prior to our removing them for the experiment. The average increased to about 70% when there were 8 females in the cages. When we normalized the data and correlated females per seed with seed destruction, our data indicated that 1 female for every 1 to 2 seeds would be required to reach about 60 to 70% seed damage.

Parasitism

We do not know what stage of the bruchid is parasitized by the *Dinarmus* we found. However, the parasites apparently do not affect the bruchid until later larval stages because most of the parasitized bruchids had already consumed much of the seeds they occupied. Thus, the damage to the seeds by the bruchid will not be influenced by the activity of this parasite.

Our work shows that the biology of the North Carolina population is synchronized to the phenology of the plant and is similar to that found in Europe. Because *B. villosus* typically reduces the seed production by about 80%, this beetle is likely to have a

significant impact on broom populations. The number of eggs laid on seedpods is correlated with the size of the pods and number of seeds in the pods. Females probably distribute their eggs in an ideal manner (Fretwell 1972) to reduce competition between their larvae and those of other females. Based on cage experiments, the density of females must be fairly high to have 80% seed destruction seen in North Carolina broom stands. However, once populations of *B. villosus* reach sufficient densities they should make an important contribution to the biological control efforts directed at Scotch broom in the Pacific Northwest.

Acknowledgments

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SELECTIVE TOXICITY OF SOME PESTICIDES TO *HIBANA VELOX* (ARANEAE: ANYPHAENIDAE), A PREDATOR OF CITRUS LEAFMINER

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ABSTRACT

The toxicity of fourteen different pesticides used in 'Tahiti' lime, *Citrus aurantifolia* (Christman) Swingle, to the spider, *Hibana velox* (Becker) was tested under laboratory conditions. Among the nine pesticides tested using a coated glass vial method, the five broad-spectrum insecticides (azinphos-methyl, chlorpyrifos, ethion, carbaryl, dicofol) were all highly toxic to *H. velox*, causing 100% mortality even at the lowest concentration. Avermectin and Provado® (a.i., imidacloprid) applied as sprays had moderate toxicity; whereas, Admire® (a.i., imidacloprid) applied as a drench and Tri-Basic® (copper fungicide) caused the lowest percent mortality (10-30%) even at the highest concentration. With a leaf-dip method, petroleum oil exhibited a low toxicity to *H. velox*. However, when combining petroleum oil with avermectin, a synergistic effect elevated the toxicity to moderate. Azadirachtin, *Bacillus thuringiensis*, and diflubenzuron showed low impact on *H. velox*. Less than 20% mortality was recorded at the highest concentrations for all of these products.

Key Words: toxicity test, *Hibana velox*, *Phyllocnistis citrella*, predatory spider, citrus leafminer

RESUMEN

El efecto tóxico de catorce pesticidas comúnmente usados en limón 'Tahiti', *Citrus aurantifolia* (Christman) Swingle, se evaluó en la araña, *Hibana velox* (Becker) bajo condiciones de laboratorio. Entre los pesticidas evaluados usando un método de frasco de cristal cubierto, los cinco pesticidas de amplio espectro ([azinphos-methyl, chlorpyrifos, ethion, carbaryl, dicofol]) fueron altamente tóxicos hacia *H. velox*, causando 100% de mortalidad aun a la concentración más baja. Los insecticidas, Avermectina y Provado® [(i.a., imidacloprid)] aplicados en forma atomizada demostraron tener baja toxicidad; mientras que aplicaciones hasta empape de Admire® [(i.a., imidacloprid)] y Tri-Basic® (funguicida de cobre) causaron el porcentaje de mortalidad mas bajo (10-30%) hasta en las concentraciones mas altas. Al usar el método de sumergir las hojas del limón en la solución con insecticida, el aceite de petróleo mostró baja toxicidad hacia *H. velox*. Sin embargo, al combinar el aceite de petróleo con Avermectina, el efecto de sinergismo elevó la toxicidad de baja a moderada. Las concentraciones mas altas de Azadirachtina, *Bacillus Thuringiensis*, y diflurobenzuron mostraron bajo impacto, al causar una mortalidad menor del 20% de los especimenes de *H. velox*.

The citrus leafminer (CLM), *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae), is a widely distributed and major pest of *Citrus* spp. as well as other species in the family Rutaceae (Heppner 1993). Insecticides provide a rapid means of suppressing CLM populations, especially during heavy infestations. However, chemical control of CLM is difficult to achieve due to the development of resistance by CLM (Tan & Huang 1996), harmful effects on natural enemies (Huang & Li 1989) and due to CLM adults' prolonged and overlapping emergence which may require multiple sprays (Peña & Duncan 1993). Nevertheless, chemical control is still considered an adjunct to nonchemical control (cultural and biological control), particularly for the protection of the main leaf flushes that are important in tree growth and fruit production.

Several species of spiders are found commonly inhabiting lime, *Citrus aurantifolia* (Christman) Swingle, orchards in south Florida. A preliminary survey revealed that three species of hunting spiders, *Chiracanthium inclusum* Hentz, *Hibana velox* (Becker), and *Trachelas volutus* (Gertsch) and one species of jumping spider, *Hentzia palmarum* (Hentz), fed on the larvae and prepupae of CLM (Amalin et al. 1996). In addition to insecticides used for CLM control (Beattie et al. 1995, Heppner 1993), citrus trees, particularly in nurseries, are regularly treated with pesticides to protect them from other arthropod pests and diseases (Villanueva-Jimenez & Hoy 1997, Knapp 1996). These materials could threaten survival and sustainability of native and introduced natural enemies (Browning 1994, Peña & Duncan 1993, Villanueva-Jimenez 1998).

The use of selective pesticides is a major consideration in developing an integrated control program. Utilizing pesticides that are relatively harmless to spiders and other predatory arthropods could increase the effectiveness of natural predation and thereby reduce the overall population of injurious insects in lime orchards.

In this laboratory study, we tested the susceptibility of the hunting spider, *Hibana velox* (Araneae: Anyphaenidae), to some pesticides commonly used in lime orchards.

Materials and Methods

Toxicity tests of 14 pesticides recommended for citrus (Knapp 1996) were conducted in the laboratory on spiderlings of *H. velox*. Table 1 shows the target insect pests and diseases of the selected 14 pesticides. Test organisms were obtained by collecting egg sacs of *H. velox* in the field. The egg sacs were transported to the laboratory for spiderling emergence. After emergence, the spiders were then reared in the laboratory using artificial diet (Amalin et al. 1999). Two-week-old spiderlings were utilized in the tests. Two methods were developed for the bioassay: coated glass vial and leaf-dip methods. The selective efficiency of these two methods in assessing pesticide effect on *H. velox* was compared.

Coated glass vial Method

Surface coating (Fig. 1) was done by exposing the spiders to surface coated glass vials (15 mm diameter × 60 mm long) with pesticide solution. Each vial was coated with pesticides by dispensing 80 ul of the pesticide solution. The vials were rolled manually until the whole surface was coated with the solution and air-dried at room temperature for an hour or until they were completely dry. The spiders were placed individually in the surface coated vials. A cotton swab saturated with artificial diet was inserted in each vial and sealed with cotton. The artificial diet consisted of a mixture of 230 ml soybean beverage, 230 ml homogenized whole milk, 2 fresh chicken egg yolks, and 5 ml honey (Amalin et al. 1999).

TABLE 1. PESTICIDES TESTED FOR THE LABORATORY BIOASSAY AND THE PESTS THEY ARE RECOMMENDED TO CONTROL (KNAPP 1996).

Trade names	Common name	Arthropod pests	Diseases
Agrimek (technical grade)	Abamectin	citrus rust mites, broad mites, citrus leafminer	
Agrimek + Petroleum oil	Abamectin + Petroleum oil (FC435)	citrus rust mites, broad mites, citrus leafminer	
Petroleum oil	FC435	citrus rust mites, broad mites, citrus leafminer, scale, whitefly, spider mites	greasy spot, sooty mold
Admire 2F, Provado 1.6F	Imidacloprid Imidacloprid	citrus leafminer citrus leafminer	
Copper WP	Tri Basic		phytophthora, foot rot, root rot, brown rot, greasy spot, melanose, citrus scab, alternaria brown spot
Micromite 25W	Diflubenzuron	citrus rust mites, citrus root weevil, citrus leafminer	
Dipel DF	*Bacillus thuringiensis*	orange dog	
Ethion 4EC	Ethion	citrus rust mites, citrus snow scale	
Guthion 2L	Azinphos-methyl	scales, whitefly, mealybug, adult citrus root weevil, cricket	
Kelthane 50WP	Dicofol	spider mites, citrus rust mites	
Lorsban 4EC	Chlorpyrifos	scale, mealybugs, orange dog, katydid, grasshopper, termites, fireants, aphids, crickets	
Neemix 4.5F	Azadirachtin	citrus leafminer	
Sevin 4L	Carbaryl	citrus root weevil, orange dog, katydids, grasshoppers, crickets	

Three concentrations of each pesticide (for both technical and formulated grade) were tested, i.e. simulated field rate (SFR), twice SFR, and half SFR. Simulated field rate is based on 50 gal of spray per acre, in amounts adequate to cover but not to the point of run off. The SFR for each insecticide used is shown in Table 2. The different concentrations were prepared using deionized water for all the pesticides except for the technical grade of abamectin, and Admire® for which acetone was used as a solvent. A bioassay using the coated glass vial method was conducted for nine pesticides,

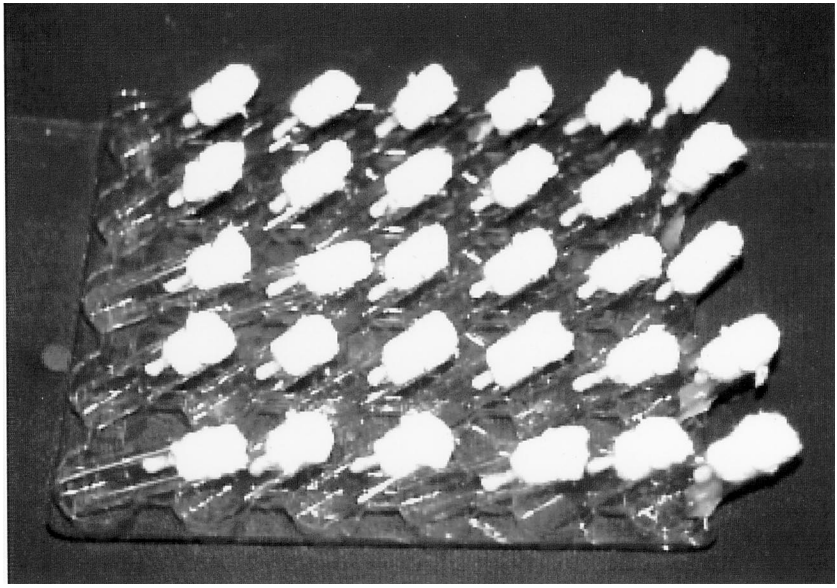

Fig. 1. Coated glass vial method.

i.e. abamectin (a compound produced by soil actinomycetes), azinphos-methyl, carbaryl, chlorpyrifos, dicofol, ethion, Admire® (a.i., imidacloprid, drench formulation), Provado® (a.i., imidacloprid, spray formulation), and Tri-Basic® (a copper fungicide).

Leaf-dip Method

Dipping was done by cutting lime leaves into 25 mm diameter circles. The leaf circles were dipped separately for approximately 30 seconds into different concentrations of five pesticides, i.e., azadirachtin (neem extracts), *Bacillus thuringiensis* (insecticidal bacterium), diflubenzuron (insect growth regulator), abamectin + petroleum oil (FC-435), and petroleum oil alone. After dipping, the leaves were air-dried for

TABLE 2. SIMULATED FIELD RATE FOR EACH INSECTICIDE USED.

Pesticides	Simulated field rate (SFR)
Abamectin	10.0 ug/ml
Azinphos-methyl	2.5 ul/ml
Carbaryl	2.5 ul/ml
Chlorpyrifos	2.5 ul/ml
Dicofol	3.0 ul/ml
Ethion	3.0 ul/ml
Imidacloprid-Provado®	0.27 ul/ml
Imidacloprid-Admire®	30.0 ug/ml
Tri-Basic®	4.5 mg/ml

approximately 2 h or until dry and placed singly on the bottom of a 30-hole (25 × 30 mm) cup tray (Fig. 2). A single spiderling was added to each arena and fed with the artificial combination diet provided on a cotton swab. The cup openings were covered with a plastic lid.

Experimental Protocol

For both methods, ten individual spiderlings were tested for each concentration. The control was deionized water for all pesticides except abamectin and Admire for which acetone was used as a control. The arenas were placed in an incubator conditioned at 27°C and 80% RH. The tests were repeated 30 times for each concentration for all the pesticides used. The spiders were held in the treated substrates for 72 h and the spider mortality was compared with the control from day 1 to day 3 after treatment. The percent spider mortality was calculated for each concentration for all pesticides. The mean percent spider mortality in treatment was adjusted for that of control using Abbott's formula (1925).

Results and Discussion

A wide range of toxicity was exhibited by the different pesticides included in the bioassay tests. Among the nine pesticides tested using the coated glass vial method, Admire®, and Tri-Basic® resulted in a low percentage of spider mortality (10-30%), producing the lowest mortality even at the highest concentration (twice of SFR) (Fig. 3). This suggests that both pesticides have low or no acute impact on *H. velox*. Abamectin and Provado® had moderate toxicity to *H. velox*. Abamectin had more than 50% spider mortality at the highest concentration, whereas Provado® had almost 40%. Both showed less than 35% spider mortality using the SFR (Fig. 3). The organophos-

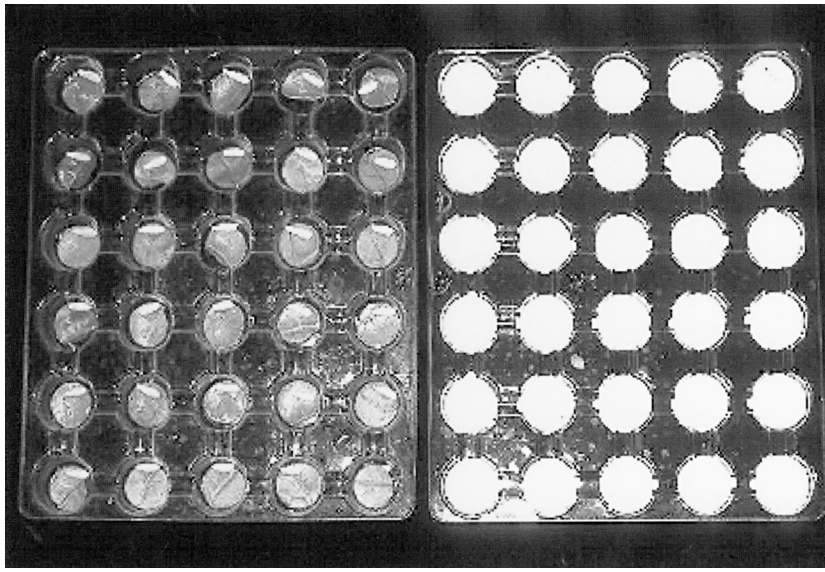

Fig. 2. Leaf-dip method.

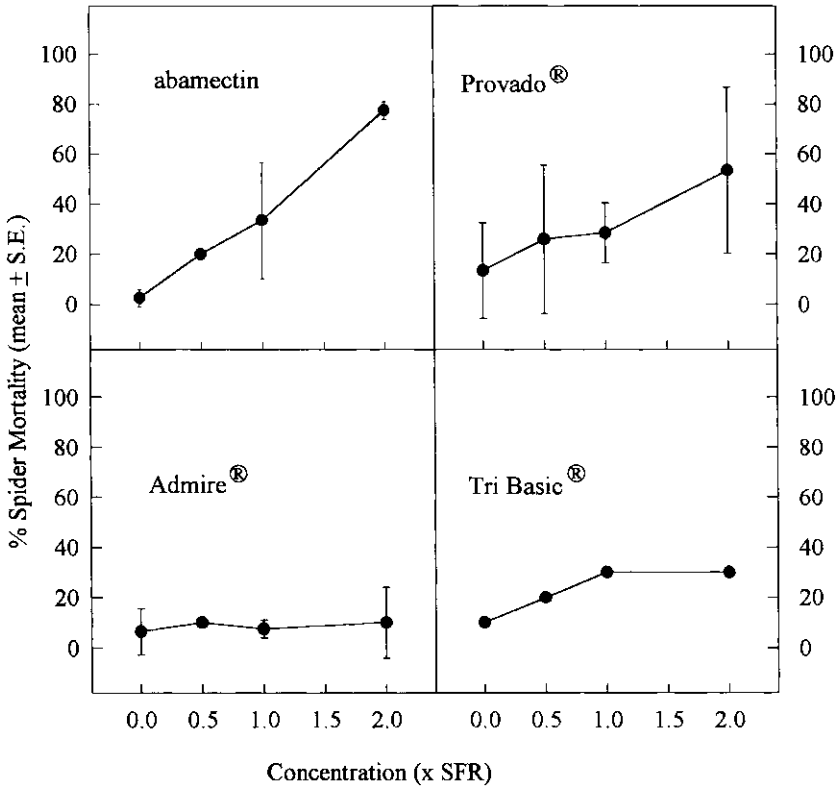

Fig. 3. Percent mortality of spiders exposed to three different concentrations of abamectin, Provado®, Admire®, and Tri-Basic® using a coated glass vial method.

phates (azinphos-methyl, chlorpyrifos, and ethion), the carbamate (carbaryl), and the organochlorine (dicofol), were all highly toxic, causing 100% spider mortality even at the lowest concentration (half of SFR). In the leaf-dip method, oil alone exhibited a low toxicity to *H. velox*. Only 15% mortality was recorded from the highest concentration, 5% from the SFR, and 0% from the lowest concentration (Fig. 4). However, petroleum oil + abamectin caused moderate toxicity. This demonstrates that abamectin has a moderate effect, which was similar using abamectin alone (Fig. 3). The naturally derived products (azadirachtin, *Bacillus thuringiensis*, and diflubenzuron) showed low toxicity to *H. velox*. Less than 20% mortality was recorded at the highest concentration for all of these products (Fig. 4).

Other laboratory studies have also shown that broad-spectrum insecticides such as organophosphates, carbamates and organochlorines have significant lethal effects on spiders in general. For instance, in Israel, laboratory residue studies using grapefruit leaves as the substrate showed that the organophosphate chlorpyrifos was highly toxic to *Chiracanthium mildei*, a hunting spider known to occur abundantly in citrus orchards, whereas natural products (i.e. *Bacillus thuringiensis* and neem extracts) were virtually non-toxic to spiders (Mansour 1987). Saxena et al. (1984) found

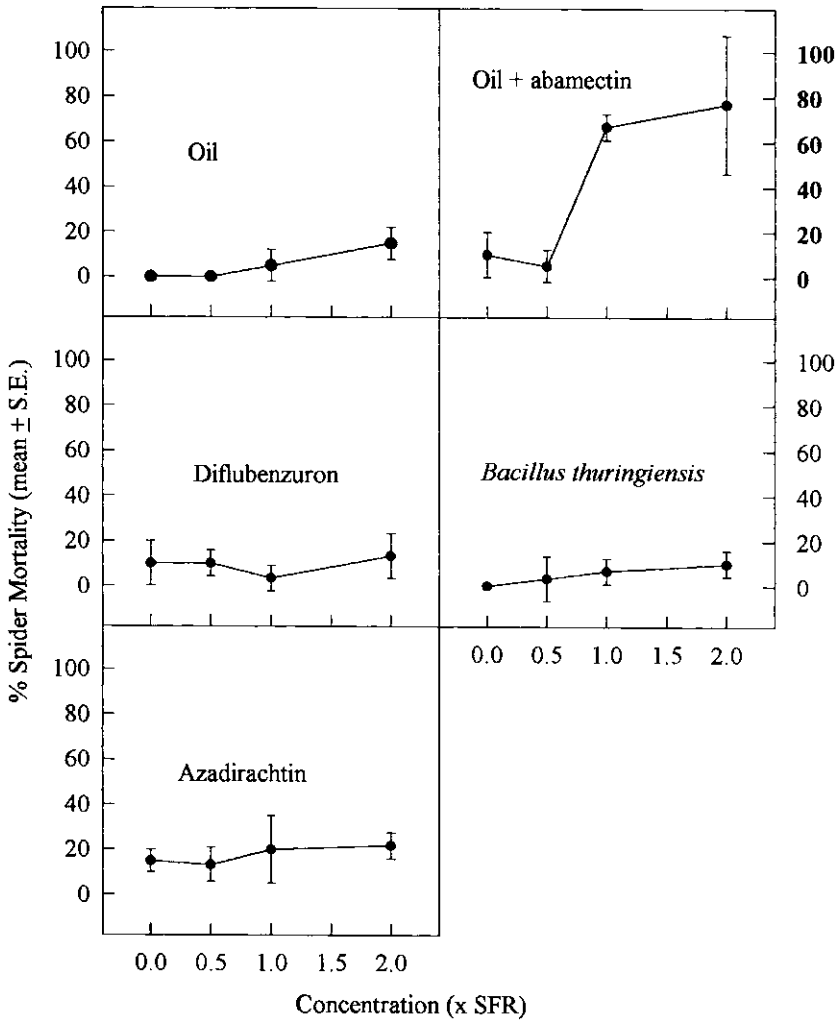

Fig. 4. Percent mortality of spiders exposed to three different concentrations of naturally derived pesticides using a leaf-dip method.

that topical application of 50 g of a neem seed kernel extract did not affect the spider, *Lycosa pseudoannulata*, a major predator of brown planthopper in Southeast Asia.

Fungicides have been shown to have little or no toxicity for spiders (Stark et al. 1995). Thus, results of our toxicity tests with these different groups of pesticides on *H. velox* are comparable to findings of previous laboratory bioassays conducted on other species of spiders.

Villanueva-Jimenez (1998) evaluated the nontarget effects of some of the pesticides used by citrus nursery growers in Florida on adults of *Ageniaspis citricola* Logvinovskaya, an introduced parasitoid of CLM. He found that naturally derived products

(neem, azadirachtin) and the insect growth regulator (diflubenzuron) were not toxic to *A. citricola*. Similarly, we found that these types of products had low toxic effect on *H. velox*. The impact of imidacloprid on *H. velox* and *A. citricola* also showed similar trends in our study to that of Villanueva-Jimenez (1998). Provado® applied to foliage was highly toxic, while Admire® used as drench was less toxic to both *A. citricola* and *H. velox.* Ethion, a broad-spectrum organophosphate, was highly toxic to both *H. velox* and *A. citricola*. Abamectin was moderately toxic to *A. citricola* and *H. velox*. Petroleum oil was the safest pesticide for spiders. It was also the safest for *A. citricola* (Villanueva-Jimenez 1998). Previous studies showed that petroleum oil has a short residual activity on natural enemies (Beattie & Smith 1993, Erkilic & Uygun 1997, Beattie et al. 1995), and is cost-effective (Beattie 1992, Beattie et al. 1995). Thus, petroleum oil may be ideal as a component for a pest management program for CLM on limes.

The similarity of our results with the results of other studies on predacious arthropods and parasitoids indicate that the impact of pesticides on the existing pest/natural enemy complex must be taken into consideration when controlling CLM. The broad-spectrum pesticides should be used cautiously. The use of naturally-derived products and petroleum oil should be recommended as an adjunct control measure with biological control to effectively manage the population of CLM.

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GENETIC RELATIONSHIP AMONG *DIABROTICA* SPECIES (COLEOPTERA: CHRYSOMELIDAE) BASED ON RDNA AND MTDNA SEQUENCES

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ABSTRACT

Corn rootworms of the genus *Diabrotica* (Coleoptera: Chrysomelidae) are the most serious pest of corn in midwestern United States. Despite their economic importance, phylogenetic relationships within the genus remain unclear. Phylogenetic analysis of five *Diabrotica* species and subspecies was undertaken using DNA sequences of the nuclear rDNA first internal transcribed spacer region (ITS1) and a portion of the mtDNA cytochrome oxidase I and II genes (COI/COII). Parsimony and maximum likelihood analysis indicated that southern corn rootworm is sister to banded cucumber beetle, whereas, northern corn rootworm forms a distinct clade with western and Mexican corn rootworm. ITS1 and COI/COII were found to be useful markers for determining phylogenetic relationships among diabroticites.

Key Words: *Diabrotica*, rootworm, phylogenetics, mitochondrial DNA, ribosomal DNA

RESUMEN

Gusanos de raíz de maíz del genero *Diabrotica* (Coleoptera: Chrysomelidae) son la plaga de mayor seriedad para el maíz en el medio oeste de los Estados Unidos. A pesar de su importancia económica, relaciones filogenéticas dentro del genero permanecen confusas. Análisis filogenético de cinco especies de *Diabrotica* y subespecies fueron llevadas a cabo usando secuencias de ADN del [rDNA] nuclear primer orden, región [spacer] (ITS1) y una porción del [mtDNA cytochrome oxidase] I y II, genes (COI/COII). Parsimonia y [cladograms] junta-vecinos indicaron que el gusano de raíz de maíz sureño es hermano del escarabajo bandeado del pepino, mientras que los gusanos de raíz de maíz norteños forman un [clade] diferente de con los gusanos de raíz de maíz occidentales y Mexicanos. ITS1 y COI/COII resultaron ser marcadores útiles para determinar las relaciones filogenéticas entre diabroticitas.

Corn rootworms are a complex of species in the genus *Diabrotica* and are the most serious pest of corn in midwestern United States (Levine and Oloumi-Sadeghi 1991). Economically important species include western corn rootworm, *Diabrotica virgifera virgifera* LeConte (WCR); Mexican corn rootworm, *D. v. zeae* Krysan & Smith (MCR); northern corn rootworm, *D. barberi* Smith and Lawrence (NCR); banded cucumber beetle, *D. balteata* LeConte (BCB); and southern corn rootworm, *D. undecimpunctata howardi* Barber (SCR). In the United States, 20 to 25 million acres of corn are treated annually with soil insecticides to protect crops from corn rootworm larval feeding damage (Fuller et al. 1997). In addition, SCR is an economically important pest of cucurbits and peanuts, and BCB is a pest of sweet potatoes in southeastern Unites States.

Despite their importance as pest species, the phylogenetic relationships within *Diabrotica* are poorly understood, primarily because of the morphological homogeneity of the genus (Wilcox 1965, Krysan 1986). A phylogenetic study based on UPGMA clustering of allozymes of 11 Diabroticites by Krysan *et al*. (1989) supported two distinct groups, virgifera and fucata. Two molecular DNA markers, the nuclear ribosomal intergenic transcribed spacer (ITS1) and a 254 bp DNA sequence of the mtDNA NADH 4 gene have proved useful for differentiating three *Diabrotica* spp. using DNA sequences and polymerase chain reaction—restriction fragment length polymorphism (PCR-RFLP) (Szalanski and Powers 1996, Roehrdanz et al. 1998, Szalanski et al. 1999).

To date, no molecular genetic studies have resolved the phylogenetic relationships within *Diabrotica*. The goal of this study was to infer phylogenetic relationships among five economically important *Diabrotica* species and subspecies using DNA sequences of the nuclear ribosomal DNA ITS1 region and a portion of the mtDNA cytochrome oxidase I and II genes.

MATERIALS AND METHODS

Origin of specimens used in this study are listed in Table 1. Corn rootworm beetles were preserved in 70% ethanol or frozen at -20°C. Frozen voucher specimens are maintained at the USDA-ARS, Red River Valley Agricultural Research Center, Biosciences Research Laboratory, Fargo, ND.

DNA was extracted from individual legs or thoraces using Puregene DNA isolation kit D-5000A (Gentra, Minneapolis, MN) or using the high salt procedure of Cheung et al. (1993). The 3' portion of the mtDNA cytochrome oxidase (CO) I gene, tRNA leucine, and a 5' portion of the CO II gene was amplified with the primers C1-J-2797 (5'-CCTCGACGTTATTCAGATTACC-3') (Simon et al. 1994) and C2-N-3400 (5'-

TABLE 1. TAXONOMIC AND COLLECTION INFORMATION.

Sample	Origin	Date collected
Diabrotica virgifera virgifera (WCR)	Brookings Co., SD	1997
D. v. zeae (MCR)	Uvalde Co., TX	1997
D. barberi (NCR)	Howard Co., NE	1998
D. undecimpunctata howardi (SCR)	Lancaster Co., NE	1998
D. balteata (BCB)	Warton Co., TX	1999
Cerotoma trifurcata (BLB)	Lancaster Co., NE	1998
Colaspis brunnea	Lancaster Co., NE	1999

TCAATATCATTGATGACCAAT-3') (Taylor et al. 1997). The 5' ends of these primers were located at bp 2797 and 3400 of the *Drosophila yakuba* mtDNA map (Clary and Wolstenholme 1985), respectively. The 3' portion of the 18S nuclear rDNA gene, the entire ITS1 region, and the 3' region of the 5.8S gene was amplified with the primers $rDNA_2$ (5'-TTGATTACGTCCCTGCCCTTT-3', Vrain et al. 1992) and $rDNA_{1.58s}$ (5'-ACGAGCCGAGTGATCCACCG-3', Cherry et al. 1997) per Taylor and Szalanski (1999). The mtDNA PCR protocol was 35 cycles of 94°C for 45 s, 42°C for 45 s, and 72°C for 90 s. The nuclear DNA PCR protocol was 40 cycles of 94°C for 45 s, 55°C for 45 s, and 72°C for 120 s. Amplified DNA from individual beetles was purified, concentrated, and sequenced per Szalanski et al. (1999). A previous study on the population genetic structure of WCR and MCR revealed a lack of genetic variation within and among populations (Szalanski et al. 1999). In NCR, ITS1 DNA sequence variation does occur (Roehrdanz et al. 1998), but at a level insufficient to influence its relationship relative to the other *Diabrotica* taxa. For the phylogenetic analysis, only one representative of WCR, MCR and NCR were obtained from Szalanski et al. (1999). GenBank accession numbers for the taxa sequenced in this study are AF195193 to AF195202.

The DNADIST program of PHYLIP v3.57C (Felsenstein 1993) was used to calculate genetic distances according to the Kimura 2-parameter (Kimura 1980) model of sequence evolution (Table 2). *Diabrotica* DNA sequences were aligned using two chrysomelids, grape colaspis *Colaspis brunnea* (Fabricius), and bean leaf beetle (BLB), *Cerotoma trifurcata* (Forster) as the outgroup taxa. Maximum likelihood and unweighted parsimony analysis on the alignments was conducted with PAUP* 4.0b2 (Swofford 1999). Gaps were treated as missing characters for all analysis. The reliability of trees was tested with a bootstrap test (Felsenstein 1985). Parsimony bootstrap analysis included 1000 resamplings using the Branch and Bound algorithm of PAUP*. For maximum likelihood analysis, the heuristic search and Hasagawa-Kishino-Yano (HKY) model of sequence evolution were used (Hasagawa et al. 1985). Par-

TABLE 2. PAIRWISE ITS1 (ABOVE DIAGONAL) AND COI/COII (BELOW DIAGONAL) DISTANCE MATRIX FOR *DIABROTICA* FROM DNADIST IN PHYLIP 3.5.

	Sample	WCR	MCR	NCR	BCB	SCR
WCR	*D. virgifera virgifera*	—	.0016	.0190	.0767	.0746
MCR	*D. v. zeae*	.0000	—	.0206	.0803	.0763
NCR	*D. barberi*	.0542	.0542	—	.0745	.0741
BCB	*D. balteata*	.1147	.1147	.1326	—	.0368
SCR	*D. undecimpunctata howardi*	.1240	.1240	.1322	.0886	—

ameters for the maximum likelihood test were Ti/Tv = 2, and (parameter of gamma distribution = 4.28 for the rDNA ITS1 sequences and 5.12 for the mtDNA sequences). For the bootstrap analysis of the maximum likelihood trees the heuristic setting was used with 100 resamplings.

Results and Discussion

The ITS1 amplicon for the five *Diabrotica* taxa ranged from 642 to 758 bp long. The mtDNA amplicon was 581 bp long for all five *Diabrotica*. The average base frequencies were A = 0.29, C = 0.17, G = 0. 21, and T = 0.33 for the entire rDNA amplicon, and A = 0.36, C = 0.15, G = 0.11, and T = 0.38 for the mtDNA amplicon. The aligned DNA data matrix, including the outgroup taxa, (available upon request, and at the web site http://ianrwww.unl.edu/ianr/plntpath/nematode/aszalans.htm) resulted in a total of

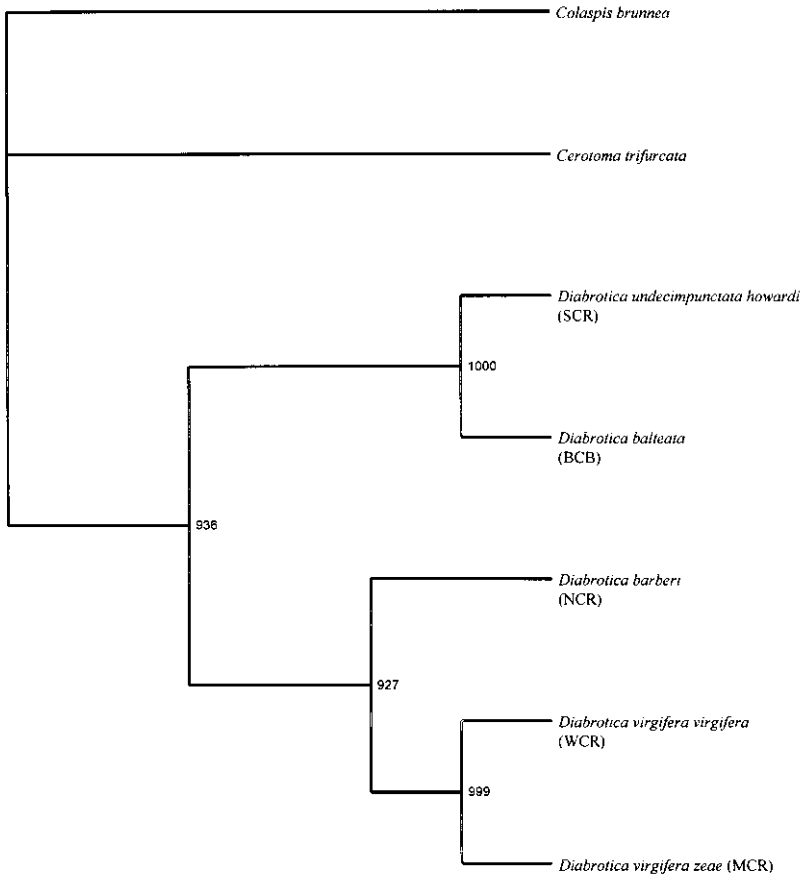

Fig. 1. A phylogenetic tree for *Diabrotica* based on DNA sequence analysis of the nuclear rDNA ITS1 region, derived from parsimony analysis and rooted by the outgroup taxa *Colaspis brunnea* and *Cerotoma trifurcata*. Bootstrap values are provided.

879 characters for ITS1 and 583 characters for COI/COII, including gaps. Of the 879 ITS1 characters, 194 characters (22%) were variable and 175 (20%) were parsimony informative characters. For the 583 COI/COII characters, 255 characters (44%) were variable and 76 (13%) characters were parsimony informative.

The rDNA dataset had only one most parsimonious tree (Fig. 1), (length = 335, CI = 0.96, CI excluding uninformative sites = 0.84). *Diabrotica undecimpunctata howardi* was depicted as the sister to *D. balteata*, with *D. barberi*, *D. virgifera virgifera*, and *D. v. zeae* representing a sister clade (Fig. 1). All of the inferred relationships were supported in >90% of the 1000 bootstrap replications. The maximum likelihood tree (-Ln likelihood = 2608.11827) yielded a phylogenetic relationship identical to the parsimony tree (Fig. 1). Parsimony (length = 360, CI = 0.89, CI excluding uninformative sites = 0.74) and maximum likelihood (-Ln likelihood = 2255.76826) analysis of the mtDNA dataset was identical to that of the ITS1 dataset (Fig. 1).

Results of the present study were congruent with those derived from allozyme and morphological data (Krysan et al. 1989, Krysan and Smith 1987). Our study supports the allozyme (Krysan et al. 1989) UPGMA phylogeny with southern corn rootworm and banded cucumber beetle forming a distinct clade (fucata group) relative to northern, western, and Mexican corn rootworm (virgifera group). The close relationship between NCR and WCR is supported by field observations of attempted interspecific mating (Krysan and Guss 1978).

This study provides a baseline for the phylogenetic relationships of this economically important genus. The ITS1 and COI/COII markers contain adequate information for phylogenetic assessment of the five *Diabrotica* studied and should prove useful for understanding the relationship of other diabroticites, and could provide the basis for species specific molecular diagnostic markers.

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REDESCRIPTION OF *NEOTERMES MONA*, A DAMPWOOD TERMITE (ISOPTERA, KALOTERMITIDAE) FROM THE CENTRAL WEST INDIES

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ABSTRACT

The winged imago of *Neotermes mona* (Banks) is described for the first time and the soldier caste is redescribed as two size morphs. The distribution of *N. mona* includes Hispaniola, Turks & Caicos Islands, Puerto Rico, and Virgin Islands. It is the largest kalotermitid in this region.

Key Words: taxonomy, Caribbean, Neotropics, distribution, imago

RESUMEN

Se describen por primara vez los adultos alados de *Neotermes mona* (Banks) y se redescribe la casta de soldados como formas de dos tamaños. La distribución de *N. mona* incluye Española, las Islas Turcas y Caicos, Puerto Rico y las Islas Vírgenes. Este es el mayor kalotermitido de esta región.

For his original description of *Neotermes* (=*Kalotermes*) *mona* from Mona Is., Puerto Rico, Banks (1919) offered little more than a brief soldier comparison with *Incisitermes* (=*Kalotermes*) *schwarzi* (Banks) and *N.* (=*K.*) *jouteli* (Banks) (Banks & Snyder 1920). The description of *N. mona* lacked measurements and was accompanied only by a simple line drawing of a soldier's head and pronotum that resembles Krishna's (1961) definition of the genus *Neotermes*. In light of recent collections of *N. mona* from the Turks and Caicos Is. (Scheffrahn et al. 1990), Mona Is. (Ramos 1946, Jones 1993), Dominican Republic, Puerto Rico, and Guana Is., B.V.I. (Scheffrahn et al. 1994, Collins et al. 1997), and now Vieques Is. (Puerto Rico) and St. John, U.S.V.I., we herein redescribe the soldier as a dimorphic caste and describe the winged reproductive for the first time.

MATERIALS AND METHODS

Morphometrics of specimens preserved in 85:15 ethanol:water were made with a stereomicroscope fitted with a calibrated ocular micrometer. Specimens for measurement were selected from 81 colony series collected during 1988-1999 from 50 localities on 10 islands in the West Indies (Fig. 1). Measurements of the large and small soldier morphs are presented separately, but other characters do not differ sufficiently to warrant separate descriptions.

Scanning electron micrograph prints were scanned at 600 dpi, and the digital image outline traced using photograph-enhancing software (Photo Magic, Micrografx, Inc., Richardson, TX). The background was converted to black, and the scale bar was

digitally redrawn. Latitude and longitude coordinates of collection sites were converted to decimal degrees and mapped (Fig. 1) using ArcView GIS version 3.0a software and relevant map data from Digital Map of the World version 1.0 (Environmental Systems Research Institute, Inc. Redlands, CA).

Neotermes mona (Banks)

Kalotermes mona Banks 1919: 478 [soldier; Fig. 6].
Kalotermes (Neotermes) mona; Snyder *in* Wolcott 1948: 62.
Kalotermes mona; Snyder 1949: 18.
Neotermes mona; Krishna 1961: 322.

Imago (Fig. 2 A-B, Table 1).

In dorsal view, general color almost uniformly ferruginous, except for darker, chestnut brown frons and anterior vertex in majority of specimens, and dark chestnut brown posterior halves of three posterior abdominal tergites. Mandibles dark chestnut brown. Anteclypeus yellowish. Antennae ferruginous orange except for chestnut brown third article. Compound eyes almost black. Chevron pattern on pterothorax faint and wide. Femora yellowish, tibiae ferruginous. Sclerotized wing venation ferruginous, remainder of wings, arolia, and abdominal sternites pale ferruginous orange.

In dorsal view, head capsule suboval with sides rectate and faintly converging to anterior especially in ventral aspect; posterior of head capsule broadly rounded. In oblique view, frons broadly concave, with raised lateral margins, and with delicate striations. In lateral view, frons plane continuous with plane of vertex. Compound eyes large and protruding, subcircular, with long subrectate or slightly concave margins along antennal sockets. Ocelli slightly protruding; comparatively large, oval; broadly contacting eyes. Mandibular bases with striations. Shallow, small, and circular depression centered at intersection of epicranial suture. Head, pronotum, wing scales, abdominal tergites, and sternites with numerous and long setae. Antennae with 19 to 22 articles, usually 21 or 22, relative length formula 2 > 3 > 4 = 5. Pronotum about

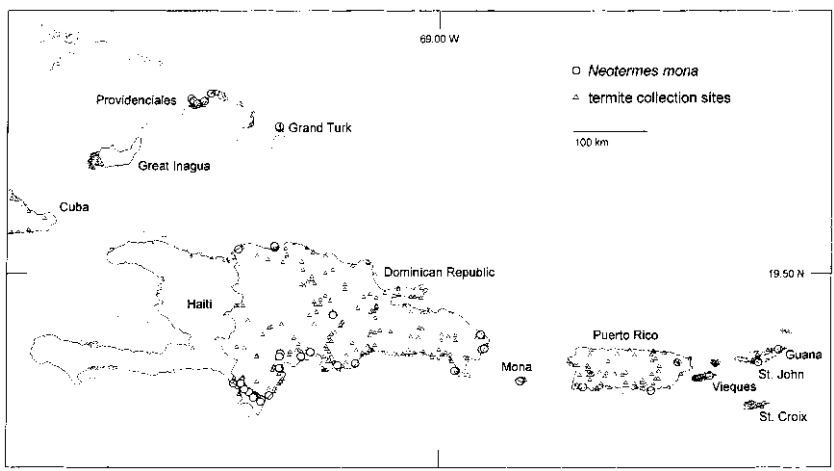

Fig. 1. *Neotermes mona* localities and termite collection sites from 1988-1999.

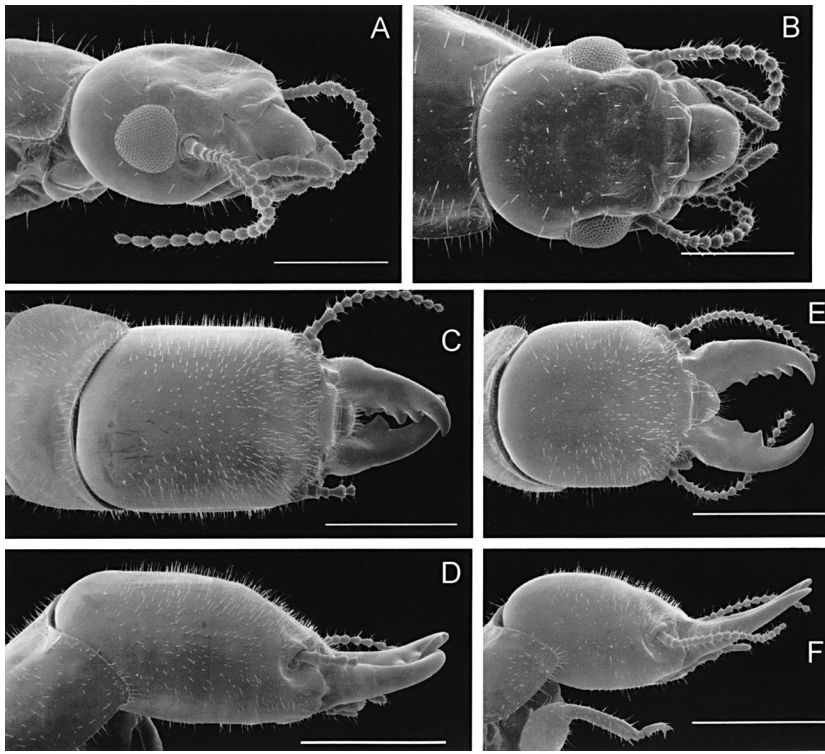

Fig. 2. Scanning electron micrographs of *N. mona*. Oblique (A) and dorsal (B) views of an imago head from Guana Island. Dorsal (C) and lateral (D) views of a large soldier from Guana Island. Dorsal (E) and lateral (F) views of a small soldier from Mona Island. Scale bar equals 1 mm for A-B and 2 mm for C-F.

twice as wide as median length; anterior and lateral margins with raised and rounded rim. Anterior margin of pronotum concave; posterior margin slightly concave. Anterior wings with very long subcosta and radius; subcosta terminating at costal margin near ½ of wing length from suture; radius reaching costal margin at ⅔ of wing length. Radial sector with 4-5 branches along distal half of wing. Sclerotized media with several fine transverse branches to radial sector; posteriorly, few short diagonal and sclerotized branches fade into membrane except for most distal branch that terminates at wing margin. Texture of wing membrane with very faint nodulations. Arolia large.

Comparisons

The alate of *N. mona* resembles that of *N. jouteli*, but the former is larger. Head width at eyes in *N. mona* is ≥2.00 mm, while in *N. jouteli* it is ≤1.81 mm; maximum pronotum width in *N. mona* is ≥2.22 mm versus ≤2.05 mm in *N. jouteli*, and pronotum maximum length is ≥1.49 mm and ≤1.32 mm for *N. mona* and *N. jouteli*, respectively. Total length with wings of the *N. mona* alate is ≥17.89 mm compared to ≤16.05 mm in *N. jouteli*; and wing length from suture is ≥13.35 mm and ≤11.79 mm, respectively. The imago of *N. mona* differs from all other West Indian congeners by its darkened three

TABLE 1. MEASUREMENTS OF *NEOTERMES MONA* IMAGO.

Measurement in mm (n = 5 males, 5 females from 8 colonies)	Range	Mean ± S.D.
Head length with labrum	2.14-2.52	2.38 ± 0.12
Head length to postclypeus	1.63-1.97	1.83 ± 0.10
Head width, maximum at eyes	2.00-2.17	2.10 ± 0.051
Head height without postmentum	1.11-1.21	1.15 ± 0.032
Labrum width, maximum	0.73-0.89	0.82 ± 0.049
Eye diameter with sclerite, maximum	0.57-0.67	0.62 ± 0.033
Eye to head base, minimum from sclerite	0.29-0.38	0.34 ± 0.027
Ocellus diameter, maximum	0.22-0.27	0.24 ± 0.014
Ocellus diameter, minimum	0.16-0.20	0.17 ± 0.011
Eye sclerite to ocellus, minimum	0	0
Pronotum, maximum length	1.49-1.68	1.58 ± 0.068
Pronotum, maximum width	2.22-2.47	2.35 ± 0.095
Total length with wings	17.89-22.01	19.26 ± 1.17
Total length without wings	9.09-11.08	10.08 ± 0.65
Fore wing length from suture	13.35-16.47	14.81 ± 0.80
Fore wing, maximum width	3.56-4.15	3.87 ± 0.17
Hind tibia length	1.77-1.91	1.85 ± 0.041

posterior abdominal tergites. The imago of *N. mona* has a generally darker, ferruginous coloration compared with a lighter ferruginous orange color in *N. jouteli*. The *N. mona* imago has dense pilosity composed of long setae (≤0.3 mm) on the head, pronotum, wing scales, and abdominal sternites and tergites, while the *N. jouteli* imago is adorned with sparse short setae (≈0.03 mm long). The setal follicles of *N. mona* are strikingly lighter than the surrounding cuticle, while in *N. jouteli* the follicles are unapparent. The frons of *N. mona* is on an even plane with the anterior vertex, while in *N. jouteli* there is about a 15° slope between the planes of the frons and vertex.

Although alate pilosity characters of *N. mona* are similar to those of *N. castaneus* Burmeister, *N. castaneus* is smaller overall, has much smaller compound eyes than *N. mona*, and its head color is brownish compared to the ferruginous *N. mona* head. The frons of the *N. mona* alate is faintly concave and delicately striate; in *N.castaneus* the frons is faintly convex and striations are absent.

Soldier (Figs. 2 C-F, Tables 2-3).

The soldier caste consists of two distinct morphs, large and small, both usually present in mature colonies. Other than size, there are few distinguishing characters that separate small and large soldiers of *N. mona* compared with some congeners and species in several other kalotermitid genera.

Head capsule generally ferruginous in dorsal view, in some specimens postclypeus, frontal carinae and antennal carinae darker, chestnut brown. Thorax and abdominal dorsum ferruginous orange. Mandibles glossy, almost black, with very dark chestnut brown areas near articulations. Epicranial suture faint or absent. Eyes almost black. Femora yellow-white; remaining sternum pale ferruginous orange. Darker ferruginous postmentum contrasting with ferruginous orange genae.

TABLE 2. MEASUREMENTS OF *NEOTERMES MONA* SMALL SOLDIER.

Measurement in mm (n = 10 from 9 colonies)	Range	Mean ± S.D.
Head length to tip of mandibles	4.37-5.76	4.85 ± 0.52
Head length to postclypeus	2.77-3.42	3.04 ± 0.22
Head width, maximum	2.31-3.13	2.66 ± 0.24
Antennal carinae, outside span	2.18-2.80	2.40 ± 0.19
Head height, excluding postmentum	1.52-1.93	1.83 ± 0.13
Labrum, maximum width	0.64-0.87	0.71 ± 0.069
Postclypeus width, maximum	0.88-1.18	0.98 ± 0.079
Left mandible length, tip to most distant visible point of ventral condyle	2.24-2.84	2.46 ± 0.18
Postmentum, length in middle	1.88-2.34	2.08 ± 0.14
Postmentum, maximum width	0.78-1.06	0.89 ± 0.077
Postmentum, minimum width	0.44-0.64	0.52 ± 0.056
Pronotum, maximum width	2.73-3.28	2.99 ± 0.18
Pronotum, maximum length	1.63-2.02	1.82 ± 0.10
Hind tibia length	1.60-2.15	1.76 ± 0.16
Total length	9.94-13.35	11.39 ± 1.01

In dorsal view, head capsule subsquare, slightly longer than wide, with sides subparallel in large soldiers, faintly convex in small ones; posterior corners of both morphs rounded; median posterior of head capsule rectate. In some individuals of both morphs, sides of head capsule faintly converging anteriorly. Head capsule covered

TABLE 3. MEASUREMENTS OF *NEOTERMES MONA* LARGE SOLDIER.

Measurement in mm (n = 10 from 8 colonies)	Range	Mean ± S.D.
Head length to tip of mandibles	5.69-6.49	6.07 ± 0.30
Head length to postclypeus	3.81-4.31	4.04 ± 0.17
Head width, maximum	2.87-3.43	3.13 ± 0.20
Antennal carinae, outside span	2.57-3.10	2.87 ± 0.17
Head height, excluding postmentum	1.88-2.47	2.27 ± 0.17
Labrum, maximum width	0.72-0.83	0.78 ± 0.044
Postclypeus width, maximum	1.05-1.19	1.13 ± 0.048
Left mandible length, tip to most distant visible point of ventral condyle	2.67-3.07	2.87 ± 0.13
Postmentum, length in middle	2.77-3.10	2.90 ± 0.12
Postmentum, maximum width	0.96-1.14	1.06 ± 0.067
Postmentum, minimum width	0.49-0.54	0.52 ± 0.022
Pronotum, maximum width	3.37-3.96	3.60 ± 0.21
Pronotum, maximum length	2.00-2.37	2.22 ± 0.12
Hind tibia length	1.93-2.20	2.04 ± 0.091
Total length	11.64-15.62	13.48 ± 1.51

with dense mat of setae except on occiput. Body also covered with dense mat of setae. Frons flattened, usually faintly concave. In small soldiers, frons surface smooth; in some of large soldiers frons with very faint reticulate rugosity. Frontal carinae lobed with short pointed tubercle. Labrum linguiform. Mandibles comparatively long and robust; in large soldiers, slightly more robust, with faint, and slightly pilose basal hump; dentition distinct. Antennae with 13 to 19 articles, usually 16 or 17 in both morphs; in small soldiers often only 13 or 14 articles present; third antennal article subclavate, terminal articles usually markedly elongated; antennal formula $2 < 3 > 4 = 5$. Antennal carinae markedly protruding and rugose. Pronotum about twice as wide as long. Anterior margin of pronotum deeply concave; sides of pronotum slightly convex; posterior margin weakly emarginate. All soldiers with short wing pads on meso- and metathorax.

In lateral view, head capsule slightly dorso-ventrally flattened; frons plane sloping 20° from plane of vertex; mandibles moderately curved upward; eyes moderately elongated or less often subcircular, with peripheral satellite facets. Pilosity of frons and anterior vertex much more dense than on occiput. Hind femora moderately broadened in small soldiers and noticeably inflated in large ones. Postmentum narrowed near middle in large soldiers.

Comparisons

Because of size overlap, biometrical separation of small soldiers of *N. mona* from those of *N. jouteli* is possible only on examination of a series of specimens. Both small and large soldiers of *N. mona* tend to be larger than those of *N. jouteli*. In large soldiers, the following measurements do not overlap between these two species. The maximum head width is ≥2.87 mm and in *N. jouteli* ≤2.70 mm, left mandible length is ≥2.67 mm and ≤2.42, maximum width of pronotum is ≥3.37 mm and ≤3.03 mm, and maximum length of pronotum is ≥2.00 mm and ≤1.85 mm, in *N. mona* and *N. jouteli,* respectively. In large soldiers, the mandibles of *N. mona* are more robust but with less developed basal humps and pilosity than those of *N. jouteli*. In small soldiers, the mandibles are more robust in *N. mona* compared to *N. jouteli*, while pilosity and hump proportions are similar. The body of *N. mona* is generally much more pilose than that of *N. jouteli.* The frontal carinae and adjacent frontal area of *N. mona* soldiers exhibit much denser pilosity than in *N. jouteli* in both morphs, especially in large soldiers. The tergum and sternum of *N. mona* soldiers are conspicuously more pilose than in *N. jouteli*.

Material Examined and Measured

USA. Puerto Rico. All samples collected by J. Chase, J. Mangold, J. de la Rosa and R. Scheffrahn. Bosque de Aguirre; 17.93°N, 66.15°W; 1-VI-1993; 1 small soldier (PR-175); 2 large soldiers (PR-176); 1 small, 2 large soldiers, 3 alates (PR-177). Mona Island. All samples collected by S. Jones. Uvero Beach; 18.06°N, 67.90°W; 11-XI-1992; 1 large soldier (PR-409); S. W. airstrip; 18.06°N, 67.91°W; 12-XI-1992; 1 small soldier, 1 alate (PR-416); same data; 1 small soldier (PR-417). British Virgin Islands. Guana Island. North slope near resort; 18.49°N, 64.44°W; 27-X-1992; J. Krecek; 1 small soldier (no. VI-59); same site; X-1991; L. Hernández; 1 large soldier, 1 alate (no. VI-60); same site; 19-X-1992; Krecek, light trap; 1 alate (no. VI-61). British West Indies. Turks & Caicos Islands. Grand Turk Island. 21.46°N, 71.14°W; 6-II-1990; Scheffrahn, and B. Diehl; 1 small soldier, 1 alate (TC-21). Dominican Republic. Barahona Prov., Cabral/ Barahona Hwy; 18.23°N, 71.13°W; 20-VI-1991; Chase, Mangold, de la Rosa, and Scheffrahn; 1 small, 1 large soldier (DR-27); La Altagracia Prov., Juanillo; 18.48°N,

68.42°W; 11-VI-1992; Chase, Mangold, de la Rosa, and Scheffrahn; 2 small, 1 large soldier (DR-562); Pedernales Prov., 25 km E. Pedernales; 17.92°N, 71.53°W; 28-X-1993; Chase and de la Rosa; 1 alate (DR-864); Puerto Plata Prov., Punta Rucia; 19.88°N, 71.20°W; 21-VIII-1994; Chase, Krecek, de la Rosa, and Scheffrahn; 1 small, 1 large soldier (DR-946); Peravia Prov., 5 km W. Bani; 18.30°N, 70.12°W; 4-VIII-1995; Chase; 1 alate (DR-1209); Pedernales Prov., Pedernales, beach, forest; 18.03°N, 71.74°W; 3-XI-1996; Chase and Krecek; 1 large soldier (DR-1300); Saona Island (new record). La Romana Prov., Punta Catuano; 18.20°N, 68.78°W; 14-III-1995; Chase and de la Rosa; 1 alate (DR-1130).

Additional Material Examined

Paratype: Puerto Rico. Mona Is. No date or collector given; 1 large soldier, 5 small soldiers, 1 presoldier, and many nymphs (MCZ Type 10076). Vieques Island (new record)**.** Between Red Beach and U.S. Navy observation post installation; 21.90°N, 65.37°W; 24-VII-1999; Scheffrahn, Maharajh, and Chase; 1 nymphoid supplementary, many soldiers and nymphs, 2 larvae (PR-648, 650). U.S. Virgin Islands. St. John (new record)**.** Terminus of paved road, Hwy 107; 18.31°N, 64.71°W; 29-VII-1999; Chase; 1 nymphoid supplementary, many soldiers and nymphs (no. VI-97).

Discussion

Long considered endemic to Mona Is. (Wolcott 1948), *N. mona* is now recorded from a wide geography of the central West Indies (Fig. 1). Within this region, Haiti, the larger Caicos Is., and many of the Virgin Is. have not yet been satisfactorily surveyed for termites (Fig.1) and may support populations of *N. mona*. Surveys of Cuba, Jamaica, the Bahamas, and the Lesser Antilles have not yielded collections of *N. mona* (Scheffrahn & Krecek, unpubl. data). A record of *N. mona* from Barbados by Bennett & Alam (1985) is almost certainly based on misidentification. A *Neotermes* species listed as "nr. *mona*" from Cuba (Scheffrahn et al. 1994) is now recognized to be new species (Krecek & Scheffrahn, unpubl. data).

Neotermes mona is the largest kalotermitid in the West Indies. Snyder (1959) mentions that the alate of *N. araguaensis* Snyder, comparable in size with *N. mona*, is the largest *Neotermes* in the New World. At 22, the maximum number of antennal articles for the *N. mona* imago exceeds Krishna's (1961) diagnoses of ≤21 antennal articles for the *Neotermes* and the Kalotermitidae.

Dispersal flights of *N. mona* are nocturnal. On several occasions, JK observed alates flying around lights between 0100 and 0200 hours in the Dominican Republic and Guana Is. in October and December. Compared with some Kalotermitidae (e.g., *Cryptotermes* and *Incisitermes*), the alates of *N. mona* exhibited robust flight behavior and lacked the tendency to shed wings shortly after alighting.

Neotermes mona is usually a coastal inhabitant where it colonizes substantial woody growth of dry littoral forests, including arboreal cacti and mangroves. This species has also been collected from wood in service (Wolcott 1948, Scheffrahn et al. 1990), however its economic significance appears limited. Galleries of *N. mona* infestations occasionally extend into the xylem elements of living trees or near the tidal zone of dead mangrove trunks; possibly as moisture refugia during drought. Collins et al. (1997) rank *N. mona* as the termite species from the British Virgin Is. having the greatest moisture requirements. Their ranking was based on climatological factors of the 19 islands surveyed and not on experimental data. We contend that, contrary to the rankings of Collins et al. (1997), *N. mona* has a substantially lower moisture re-

quirement than sympatric termite species in the families Rhinotermitidae and Termitidae that have soil access.

In a study of the phylogeny of 10 kalotermitid species, Luykx et al. (1990) selected 13 morphological characters (7 imago and 6 soldier) for cladistic analysis. In their data matrix, the eye pigmentation character for the *N. mona* soldier was erroneously scored as being absent, when it is indeed heavily pigmented. As a result, there are no morphological differences for the selected characters among *N. mona* and its primarily allopatric congeners, *N. jouteli* and *N. luykxi* (Nickle and Collins). Therefore, the morphological cladogram of Luykx et al. (1990) must be revised to show these three *Neotermes* as sister species.

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LARVAL MORPHOLOGY AND BIOLOGY OF A NORTH AMERICAN AND AN ISRAELI *ALTICA* SPECIES (COLEOPTERA: CHRYSOMELIDAE: ALTICINAE)

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ABSTRACT

The mature larvae of *Altica bicarinata* (Kutschera) and *A. marevagans* Horn, collected in Israel and North America, respectively, are described and illustrated in detail for the first time. Some remarks on their taxonomy and biology are also given along with some discussion of the state of knowledge of alticine larvae.

Key Words: *Altica,* larvae, Florida, Israel, *Rubus*, *Oenothera*

RESUMEN

Las larvas maduras de *Altica bicarinata* (Kutschera) y *A. marevagans* Horn, colectadas en Norte América e Israel, estan descritas e ilustradas en detalle por primera vez. Algunos comentarios sobre su taxonomía y biología están incluidos, así como también una discusión sobre el estado de conocimiento de las larvas de Alticinae.

Alticinae larvae, including forest and agricultural pests, were studied by many workers from morphological and biological perspectives. Ogloblin & Medvedev (1971), Kimoto & Takizawa (1994), and Steinhausen (1994) studied many genera of alticine larvae taxonomically using the chaetotaxy of the anal plate. Some workers conducted a variety of studies: Rupertsberger (1894); Sanderson (1902); Henriksen (1927); Reed (1927); Böving & Craighead (1931); Grandi (1932, 1938); Newton (1933); Anderson (1938); Paterson (1931, 1943); Dobson (1960); Yano (1963, 1965); Giljarov & Medvedev (1964); Steinhausen (1966, 1978, 1994); Welch (1972); Westdal & Romanov (1972); Zaitev & Medvedev (1977); Medvedev & Zaitev (1978); Vig (1989); Lawson (1991); Lee (1992); Medvedev (1992); Doguet (1994); Lee et al. (1998); but the majority of the studies have been done recently (i.e., since 1970). For a review of most of these see Steinhausen (1996). The present authors describe and illustrate the mature larvae belonging to two Alticinae species collected in North America and Israel; *A. marevagans* (Horn) and *Altica bicarinata* (Kutschera), respectively.

Since studies of chrysomelid larvae conducted by Henriksen (1927), Böving (1927, 1929), and Böving and Craighead (1931) have indicated that there are very few detectable differences between larvae of Galerucinae and Alticinae (see also Marshall 1980 and Lawrence & Britton 1991, but see Lawson 1991 showing differences), these two largest chrysomelid subfamilies often have been treated together when discussing the larvae. Böving (1927), apparently following the classification scheme of Leng (1920), suggested that if the Diabroticini and Phyllobroticini (whose larvae were eas-

ily separated from the rest of the Galerucinae) were removed from the subfamily Galerucinae and placed with the Systenini, Crepidoderini, and Psylliodini of the subfamily Halticinae, then it would be possible to separate the rest of the larvae into the traditional two subfamilies of Galerucinae and Alticinae as with the adults. Later, in order to solve this problem, Böving and Craighead (1931) used a classification with the family Galerucidae containing three subfamilies: Galerucinae; Diabroticinae (containing *Phyllobrotica* Chevrolat); and Halticinae. These larval studies by Böving were done with the material available at the U.S. National Museum, which at that time contained 6 of the 12 Galerucinae tribes. The studies of the Alticinae larvae were apparently done using only 14 genera, primarily of species from the U.S.A. but with a few from Denmark.

Böving (1927) said that the Halticini [containing *Altica* Geoffroy] were well known because of the various publications by W. C. Woods and considered typical of all other Halticinae. However, Böving (1927) said that "in general aspect and structural details the Halticini larvae are more similar to the main bulk of the Galerucinae larvae than these latter [Galerucinae] are to the Diabroticini and Phyllobroticini larvae and more than the Halticini larvae themselves are to the Halticinae tribes Systenini, Crepidoderini, and Psylliodini." Unlike most other Alticinae (root feeders), *Altica* [Halticini-*sensu* Leng (1920) and Böving (1927)] are external leaf feeders and are generally quite easy to rear. Therefore, it is interesting that it is only recently that most of the western Palearctic species of *Altica* larvae have been described (Bartkowska & Warchalowski 1978, Steinhausen 1994, 1996). The percentage of described larvae in North American is much smaller. In the western Palearctic Region, only 19% of the Alticinae larvae are known (Steinhausen, 1996), and many of these are either external leaf feeders, leaf miners (e.g., *Argopus* Fisher, *Dibolia* Latreille, *Mantura* Stephens, *Sphaeroderma* Stephens, etc.—relatively easy to rear) or species of significant agricultural importance (e.g., *Phyllotreta* Chevrolat, *Psylliodes* Latreille, etc.).

Materials and Methods

All specimens used in this study were collected by the second author and preserved in 70% ethyl alcohol. The final instar larvae were macerated in KOH solution for 30 minutes, rinsed in water, and dissected under an Olympus stereoscopic microscope. For morphological studies of the minute structures, the parts were mounted on slides and observed through the compound microscope (Leitz). The terminology of setae in this study is adopted from Anderson (1947). Biological observations were made by the second author in the field or in captivity during rearing activities. Voucher specimens of the larvae of both species have been deposited in the National Museum of Natural History, Washington, D.C.

Historical Review of Larval Taxonomic Studies of the Genus *Altica*

Five North American species of *Altica* larvae (*A. bimarginata* Say, *A. corni* Woods, *A. rosae* Woods, *A. torquata* LeConte and *A. ulmi* Woods) were studied by Woods (1917, 1918). Urban (1928) only superficially described *H. lythri* Aubé and *H. brevicollis* Foudras, without any illustrations. *Altica bimarginata* was briefly illustrated by Böving & Craighead (1931). Paterson (1931) briefly described and illustrated *Haltica lythri*. *Haltica cuprea* Jacoby was also described by Paterson (1943). *Altica chalybea* Illiger was briefly described and illustrated by Peterson (1960). *Altica chalybea* and *A. corni* were illustrated by Lawson (1991). Oglobin & Medvedev (1971) made a key to two Palearctic species: *Haltica oleracea* (Linnaeus) and *H. tamaricis* Schrank). Bart-

kowscka & Warchalowski (1978) made a taxonomic key to 9 European species. Medvedev & Zaitzev (1978) illustrated only 1 species (*Altica oleracea*), using dorsal tubercles of the abdominal segments. Phillips (1977) discussed color changes, phenology, and morphology of spined tubercles of *A. lythri*. Phillips (1979) only very briefly described the color of *A. ericeti* (Allard), *A. lythri, A. oleracea,* and *A. palustris* Weise. Two Japanese species, *Altica caerulescens* (Baly) and *A. cirsicola* Ohno, were fully described and illustrated by Lee (1992). Only the dorsal part of the tubercles of 9 European species were illustrated by Steinhausen (1994). Kimoto & Takizawa (1994, 1997) illustrated and provided keys for 12 eastern Palearctic species. Most significant larval studies of species of *Altica* were done only recently (1978 and since).

Larval Descriptions and Notes

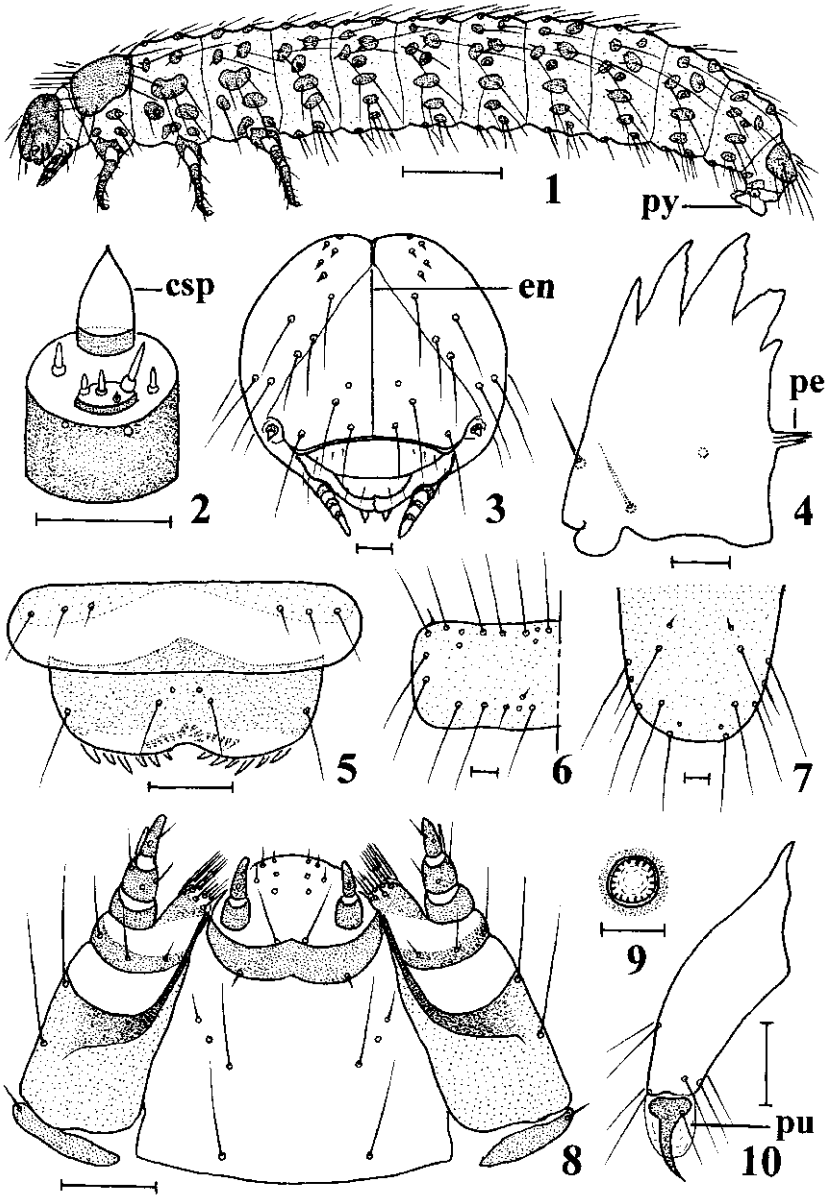
Altica bicarinata (Kutschera)
(Figs. 1-10)

Mature larva (Fig. 1). Body blackish brown, nearly straight, elongate, micro-sculptured and densely covered with setae; head and mandibles dark brown, pronotum, tubercles, spiracles and legs pale brown; head (Fig. 3) hypognathous, rounded, slightly sclerotized; frontal suture narrowly divergent and straight; hind corner of epicranium slightly produced; coronal suture short; epicranium with 10 pairs of dorsal setae (4 pairs are minute), 2 pairs of lateral setae and 1 pair of dorsal sensilla; frons with 3 pairs of frontal setae and 1 pair of frontal sensilla; endocarina distinct for full length; epistomal suture developed; stemmata absent; antenna (Fig. 2) 2-segmented, segment 1 with a large conical sensory papilla, 2 setae and 2 sensilla, segment 2 with 4 setae; clypeus with 3 pairs of clypeal setae; labrum slightly incised in the middle of anterior margin, with 2 pairs of labral setae and 1 pair of labral sensilla; epipharynx with 6 pairs of epipharyngeal setae; hypopharynx with many hypopharyngeal spinules; mandible (Fig. 4) palmate, well sclerotized, with 5 distal teeth, 2 mandibular setae, 1 sensillum and 3 sharp penicilli; maxillary palp (Fig. 8) 3-segmented, segment 1 without seta, segment 2 with 2 setae and 1 sensillum, segment 3 with 2 setae and 1 sensillum; palpifer with 3 setae; stipes with 2 setae; cardo with 1 seta; galea with 8 setae; lacinia with tightly bunched group of 8 setae located behind galea; labial palp 2-segmented; prementum and postmentum separated by sclerotized membrane; prementum with 4 pairs of setae and 1 pair of sensilla, postmentum with 4 pairs of setae and 1 pair of sensilla; pronotum (Fig. 6) brown, well sclerotized, with 14 pairs of setae and 5 pairs of sensilla; mesothoracic spiracles (Fig. 9) annuliform, situated on epipleural anterior part, with peritreme strongly sclerotized; epipleuron with 3 setae; legs (Fig. 10) rather long and slender; tibia with 7 setae; tarsungulus falciform, slightly curved anteriorly, enlarged base with 1 seta; pulvillus whitish, bladder-like; typical abdominal segments with two folds; epipleuron with 2 setae; abdomen with 8 pairs of spiracles; anal plate (Fig. 7) with 7 pairs of setae and 1 pair of sensilla; pygopod (Fig. 1) well developed.

Body length: 7.8 mm (number examined: n = 5). Head width: 0.9 mm (n = 5).

Materials examined. Israel: Golan Heights, Qusbiye, 28 April 1974, larvae collected on the leaves of the perennial edible raspberry *Rubus sanctus* Schreb. (= *R. sanguineus* Frivaldszk), and determined by association with adults by D. Furth.

Remarks. The larva of this species closely resembles that of *Altica lythri* treated by Paterson (1931), but differs by having the mandible with a well-developed penicillum. The cephalic setae are arranged similarly to those of other alticine larvae, but in this species there are 10 pairs (4 pairs are minute) of setae on the vertex. Voucher specimens will be deposited in the National Museum of Natural History, Washington, D.C.



Figs. 1-10. *Altica bicarinata*: (1) mature larva, lateral view; (2) antenna, dorso-lateral view; (3) head, anterior view; (4) mandible, buccal view; (5) clypeus, labrum and epipharynx, frontal view; (6) pronotum, dorsal view; (7) anal plate, dorsal view; (8) lower mouth parts, ventral view; (9) spiracle, lateral view; (10) left hind leg, lateral view. Scale line—1.0 mm (Fig. 1); 0.5 mm (Figs. 3, 7, 8); 0.1 mm (Figs. 2, 4, 5, 6, 9, 10).

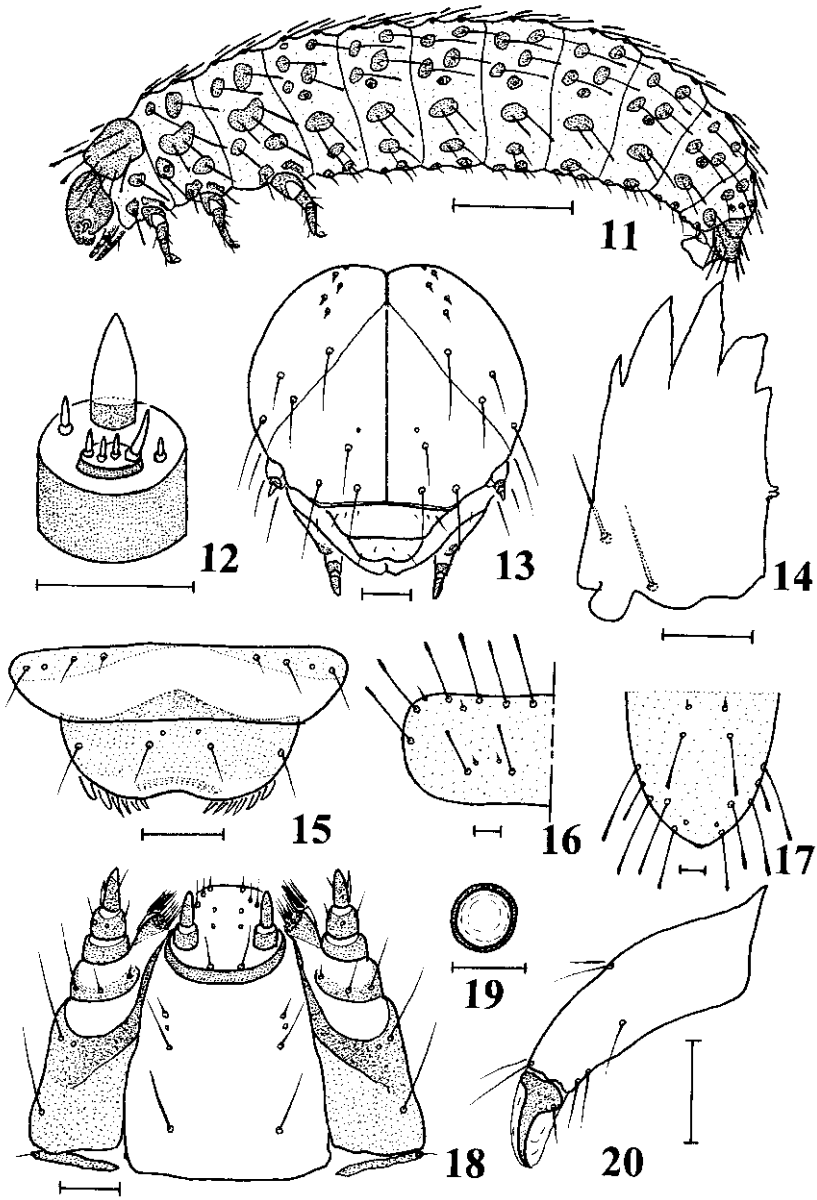
Biological Notes. Adults were collected during all months of the year in Israel (Furth 1981). The second author has examined adult specimens from the Nile River area in Egypt; however, otherwise, *A. bicarinata* is not known from west of central Israel. This species is the most common *Altica* in the eastern Mediterranean area and is monophagous feeding exclusively on *Rubus sanctus*. The food plant species is found around the Mediterranean as well as in Iran and Iraq occurring on the banks of or near rivers, streams, springs, swamps, etc. It has crossed with many other species of *Rubus* (Zohary et al. 1980). In modern times, this plant is extremely rare and relictual (high mountains) in the southern desert areas of Israel and Egypt (Negev and Sinai); however, presumably in the more moist times of the late Pleistocene it was more common and widespread across these areas (for further details see Furth 1981). Interestingly, at the Greek Orthodox monastery (Santa Katarina) on Mt. Sinai (Egypt), *R. sanctus* is the plant indicated as the supposed "burning bush" from the biblical story of Moses receiving the Ten Commandments on Mt. Sinai.

Larvae were collected by the second author in Israel from 6 March through 31 May and in Cyprus on 31 August. Eggs eclose in 7-12 days, and larvae feed (skeleonize) on both leaf surfaces. Larvae feed for about 30 days, then pupate in the soil beneath their host. Adults eclose in about 7 days (i.e., complete life cycle [egg to adult] is approximately 40-50 days). There are two to three generations per year in Israel. Food plant preference testing indicated that *A. bicarinata* is monophagous on *R. sanctus* (Furth 1981). Adults and larvae could often be found together in large numbers, especially in March and April, and to a lesser extent May. Large localized areas of the food plants were often completely defoliated and appeared "burned", but actually the leaves were skeletonized and dried out or desiccated.

Another interesting phenomenon concerning *A. bicarinata* concerns its predator *Zicrona coerulea* (Linnaeus) (Hemiptera: Pentatomidae), which is widespread throughout the Palearctic Region. The nymphs and adults of this true bug are well-known to attack the larvae of a variety of species of *Altica* as well as some other prey. The adult bug is exactly the same metallic blue/green color as the adults of *Altica*. This phenomenon may have evolved as some sort of Batesian mimicry (see Furth 1981 and Furth 1983 for a detailed discussion).

Altica marevagans Horn
(Figs. 11-20)

Mature larva (Fig. 11). Body blackish brown, slightly curved, micro-sculptured and with dorsal parts of body, except head covered with club-shaped setae; head and mandibles dark brown, pronotum, tubercles, spiracles and legs brown; head (Fig. 13) hypognathous, rounded, slightly sclerotized; frontal suture somewhat divergent and straight; hind corner of epicranium slightly produced; coronal suture short; epicranium with 8 pairs of dorsal setae (4 pairs of them minute), 3 pairs of lateral setae and 1 pair of dorsal sensilla; frons with 3 pairs of frontal setae and 1 pair of frontal sensilla; endocarina distinct for full length; epistomal suture developed; stemmata absent; antenna (Fig. 12) 2-segmented, segment 1 with a large conical sensory papilla, 2 setae, segment 2 with 4 setae; clypeus (Fig. 15) with 3 pairs of clypeal setae and 1 pair of clypeal sensilla; labrum slightly incised in the middle of anterior margin, with 2 pairs of labral setae and 1 pair of labral sensilla; epipharynx with 6 pairs of epipharyngeal setae; hypopharynx with many hypopharyngeal spinules; mandible (Fig. 14) palmate, well sclerotized, with 5 distal teeth, 2 mandibular setae and 2 short penicilli; maxillary palp (Fig. 18) 3-segmented, segment 1 without seta, segment 2 with 2 setae and 1 sensillum, segment 3 with 2 setae and 1 sensillum; palpifer with 3 setae; stipes



Figs. 11-20. *Altica marevagans*: (11) mature larva, lateral view; (12) antenna, dorso-lateral view; (13) head, anterior view; (14) mandible, buccal view; (15) clypeus, labrum and epipharynx, frontal view; (16) pronotum, dorsal view; (17) anal plate, dorsal view; (18) lower mouth parts, ventral view; (19) spiracle, lateral view; (20) left hind leg, lateral view. Scale line—1.0 mm (Fig. 11); 0.5 mm (Figs. 13, 17, 18); 0.1 mm (Figs. 12, 14, 15, 16, 19, 20).

with 2 setae and 1 sensillum; cardo with 1 seta; galea with 8 setae; lacinia with tightly bunched group of 8 setae located behind galea; labial palp 2-segmented; prementum and postmentum separated by sclerotized membrane; prementum with 4 pairs of setae and 2 pairs of sensilla, postmentum with 3 pairs of setae and 1 pair of sensilla; pronotum (Fig. 16) brown, well sclerotized, with 12 pairs of setae (8 pairs long and club-shaped); mesothoracic spiracles (Fig. 19) annuliform, situated on epipleural anterior part, peritreme well sclerotized; epipleuron with 3 setae; legs (Fig. 20) rather long and slender; tibia with 7 setae; tarsungulus falciform, slightly curved anteriorly, enlarged base with 1 seta; pulvillus whitish, bladder-like; typical abdominal segments with two folds; epipleuron with 2 setae; abdomen with 8 pairs of spiracles; anal plate (Fig. 17) with 7 pairs (6 pairs long and club-shaped) of setae and 1 pair of sensilla; pygopod well developed.

Body length: 6.5 mm (n = 5). Head width: 0.7 mm (n = 5).

Materials examined. U.S.A.: Florida, Lido Beach, 16 April1975, larvae collected on the leaves of *Oenothera humifusa* Nutt. and determined by association with adults by D. Furth.

Remarks. The larva of this species closely resembles that of *Altica cirsicola* as described by Lee (1992), but is different in the following characters: mandibles with penicillus, frons with 3 pairs of setae and prementum with 4 pairs of setae.

Biological Notes. Larvae were collected on the following dates in the Sarasota, Florida area: 16 April 1975; 9 May 1981. Adults were collected on dates given in Flowers et al. (1994). Larvae were found co-occurring with adults in April and May. The primary food plant (*Oenothera humifusa*) has succulent leaves, is low-growing and is commonly found along beaches even in areas disturbed by active public recreation.

Acknowledgments

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A NEW SPECIES OF *BASSUS* (HYMENOPTERA: BRACONIDAE: AGATHIDINAE) PARASITIC ON *SAMEA MULTIPLICALIS*, A NATURAL CONTROL AGENT OF WATERLETTUCE

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ABSTRACT

A new species of braconid (Hymenoptera: Braconidae: Agathidinae), *Bassus agathoides*, is described from Florida. The phylogenetic position of this species within *Bassus* is discussed. It is a parasitoid of *Samea multiplicalis* (Guenee) (Lepidoptera: Pyralidae), a natural control agent of waterlettuce, *Pistia stratiotes* L. (Araceae), an important aquatic weed. Characters to distinguish *B. agathoides* from other species of Nearctic *Bassus* are provided.

Key Words: Weed biological control, systematics, tritrophic interactions, *Agathis*

RESUMEN

Una nueva especie de braconido (Himenóptera: Braconidae: Agathidinae), *Bassus agathoides*, es descrita de la Florida. La posición filogenética de esta especie dentro de *Bassus* es discutida. Es un parásito de *Samea multiplicalis* (Guenee) (Lepidóptera: Pyralidae), un agente de control natural de la lechuga de agua, *Pistia stratiotes* L. (Araceae), una maleza acuática importante. Características para distinguir a *B. agathoides* de otras especies de *Bassus* cercanos al ártico son proveídos.

In Florida, *Samea multiplicalis* (Guenee) (Lepidoptera: Pyralidae) is the most common natural control agent associated with waterlettuce, *Pistia stratiotes* L. (Araceae), an aquatic weed that can affect navigation and flood control. *S. multiplicalis* is native to South America and the southeastern United States, and its larval stages can cause severe damage to *P. stratiotes* (Wheeler and Halpern 1999).

Knopf and Habeck (1976) reared several parasitoids from specimens of *S. multiplicalis* from Florida, including three ichneumonoids and a tachinid fly. Further research by G.S. Wheeler (USDA/ARS Aquatic Weed Research Unit, Ft. Lauderdale, FL, personal communication) suggests that the most common parasitoid attacking Florida populations of *S. multiplicalis* is a braconid wasp in the subfamily Agathidinae. In their rearings, 13.4% of 732 *S. multiplicalis* larvae were consumed by this agathidine wasp. This was also one of the parasitoids reared from *S. multiplicalis* by Knopf and Habeck (1976). Although Knopf and Habeck placed the parasitoid in the Agathidinae, they referred to it as an undetermined species of *Agathis*. Our study describes and names the parasitoid, and briefly discusses the phylogenetic relationship of this species with other Agathidinae species. It is hoped that this taxonomic study will facilitate future research into this economically important tritrophic system.

MATERIALS AND METHODS

The description is of the holotype female with variations in parentheses. Morphological terminology follows Sharkey (1996) and Sharkey and Wharton (1997).

DESCRIPTION

Bassus agathoides, **NEW SPECIES**

HOLOTYPE FEMALE: *Length.* 4.73 mm (females 3.63-4.73 mm, males 3.80-4.53 mm)

Color. Flagellomeres (with antennae directed anteriorly) dark brown dorsally, fading to dark orange ventrally (ventrally ranging from entirely black to yellow); anterior orbit of eye black, the posterior orbit orange (ranging to entirely black); mouthparts pale yellow with black highlights, remainder of head black dorsally with orange patches laterally (ranging from entirely black to mostly orange with dark highlights); fore leg orange with tarsus darkened distally; middle leg orange with tibia darkened distally, tarsomeres mostly dark; hind coxae dark orange (ranging to nearly black, especially in males); hind femur dark orange (ranging to black with some orange, especially in males); basal black band present on hind tibia; hind tibia black in distal half, otherwise orange; wings clear; mesosoma black with orange tegula (ranging from

black with black tegula to black with orange highlights, often with an orange spot on the mesopleuron); metasoma pale yellow ventrally (ranging to dark orange); with tergum 1 entirely black, tergum 2 black in the posterior half and orange anteriorly (or black with only the anterior margin orange), tergum 3 black with orange posterior margin, remaining terga orange with dark highlights.

Head. Number of flagellomeres = 29 (27-30); ratio, distance between ocellus and compound eye to distance between lateral ocelli = 1.2 (1.1-1.3); temple not bulging as viewed dorsally (*tm*, Fig. 1); ratio, malar space to eye height = 0.57 (0.50-0.69); gena rounded posteroventrally (*ge*, Fig. 2); median ridge connecting face and median ocellus present between antennae (*mr*, Fig. 1); interantennal space raised to converge on single point anteromedially (Fig. 1); antennal depressions shallow (*ad*, Fig. 1); median line between antennae without leather-like coriarus sculpturing.

Mesosoma. Bump of propleuron absent; notaulus crenulate to punctate (ranging to weakly punctate) along entire length (*na*, Fig. 3); posterior semicircular depression of scutellum absent; posterior transverse ridge of scutellum weak (*pr*, Fig. 3), or absent; posterior surface of scutellum rugose (*ps*, Fig. 3); metapleuron granulate (*mp*, Fig. 4); propodeum evenly rugose (Fig. 5); propodeal psuedosternite without strong transverse carina; hind coxal cavity closed, with a complete sclerite separating it from metasomal cavity (*cc* and *mf*, Fig. 6); ratio, distance between the hind coxal cavity and metasomal foramen to the diameter of the hind coxal cavity = 0.22-0.26 (hind leg not removed from holotype).

Legs. Ratio, hind femur length to hind femur width = 4.20 (3.82-4.49); spines of foretibia absent; hind tibia with eight spines (6-10) (*sp*, Fig. 7); basal lobe of tarsal claws absent (*tc*, Fig. 8).

Wings. Last abscissa of RS vein of forewing weakly curved (RS, Fig. 12); basal portion of free distal abscissa of CU of hind wing tubular to nebulus (Cu, Fig. 12).

Metasoma. Pair of longitudinal carinae on median tergum 1 absent; ratio, length of median tergum 1 to apical width of median tergum 1 = 1.04 (1.03-1.18); median terga 1, 2, and 3 granulate (Figs. 9, 10, and 11); ratio, length of ovipositor to length of metasoma = 1.64 (1.49-1.88); ovipositor sheath narrower than apex of tibia.

Hosts and Biology. First instar caterpillars of *Samea multiplicalis* (Guenee) (Pyralidae) are attacked and the parasitoid pre-pupa emerges from the last larval instar of the host (Wheeler, unpublished data).

Etymology. The specific epithet refers to the fact that this species has several features that are convergently present in many species of *Agathis* (see Discussion).

Material Examined. Holotype Female, USA: Florida: Palm Beach Co., 27-IX-96 (United States National Museum). Paratypes, USA: Florida: 16 females, 12 males, Palm Beach Co., 27-IX-96. 8 females, 3 males, Marion Co., 18-IX-96 (paratypes are deposited in the United States National Museum, the Florida State Collection of Arthropods, Gainesville, FL, and The Insect Collection of the Department of Entomology at the University of Kentucky).

DISCUSSION

Bassus agathoides has several features that are sometimes associated with species of *Agathis* and other Agathidini. These include a somewhat narrow, rostriform face (Fig.2), and the lack of a basal lobe on the tarsal claws (*tc*, Fig. 8) (Sharkey 1991). The wide sclerite between the hind coxal cavities and the metasomal foramen (*cc* and *mf*, Fig. 6) as well as the reduced size of the third labial palpomere (*pa*, Fig. 2) preclude placement in the genus *Agathis* (Sharkey 1991). The complex rugose propodeal sculpturing exhibited by *B. agathoides* (Fig. 5) is not found in species of *Agathis*, but is common in *Bassus* species (Sharkey 1991). Similarly, the distinct granulate sculp-

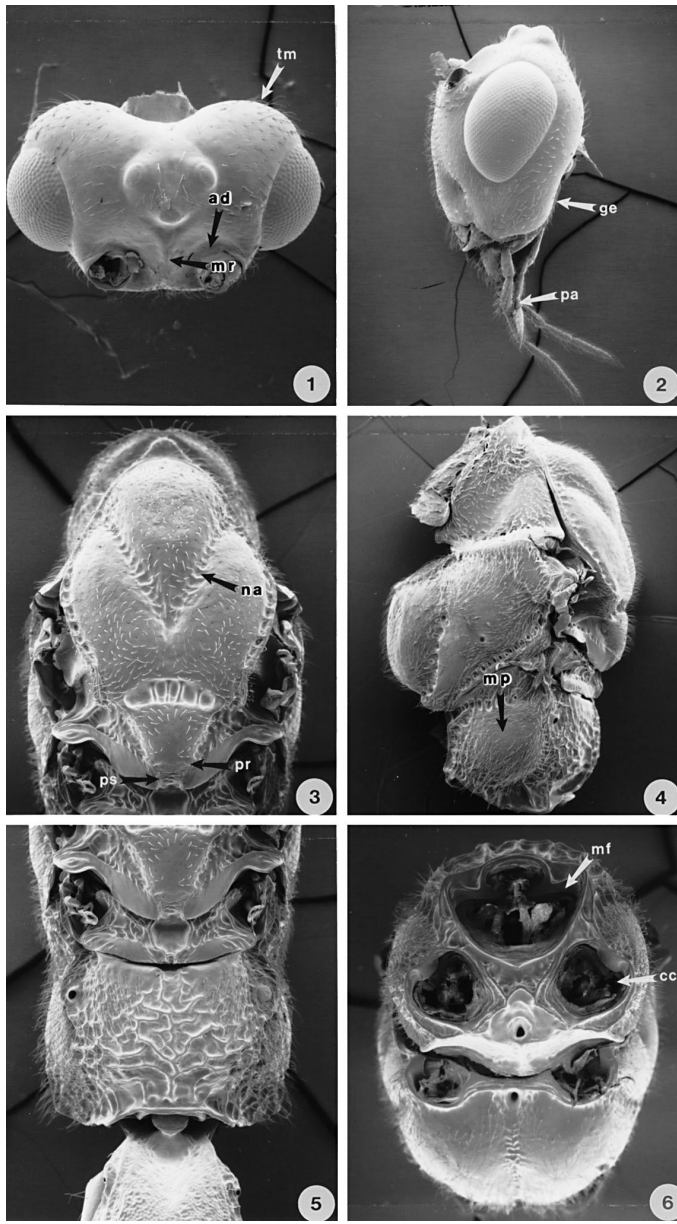

Fig. 1. Dorsal aspect of head; tm = temple; ad = antennal depression; mr = median ridge. Fig. 2. Lateral aspect of head; ge = gena; pa = third palpomere. Fig. 3. Dorsal aspect of mesonotum; na = notaulus; pr = posterior transverse ridge of scutellum; ps = posterior surface of scutellum. Fig. 4. Lateral aspect of mesosoma; mp = metapleuron. Fig. 5. Dorsal aspect of propodeum. Fig. 6. Posterior aspect of mesosoma with legs and metasoma removed; mf = metasomal foramen; cc = coxal cavity.

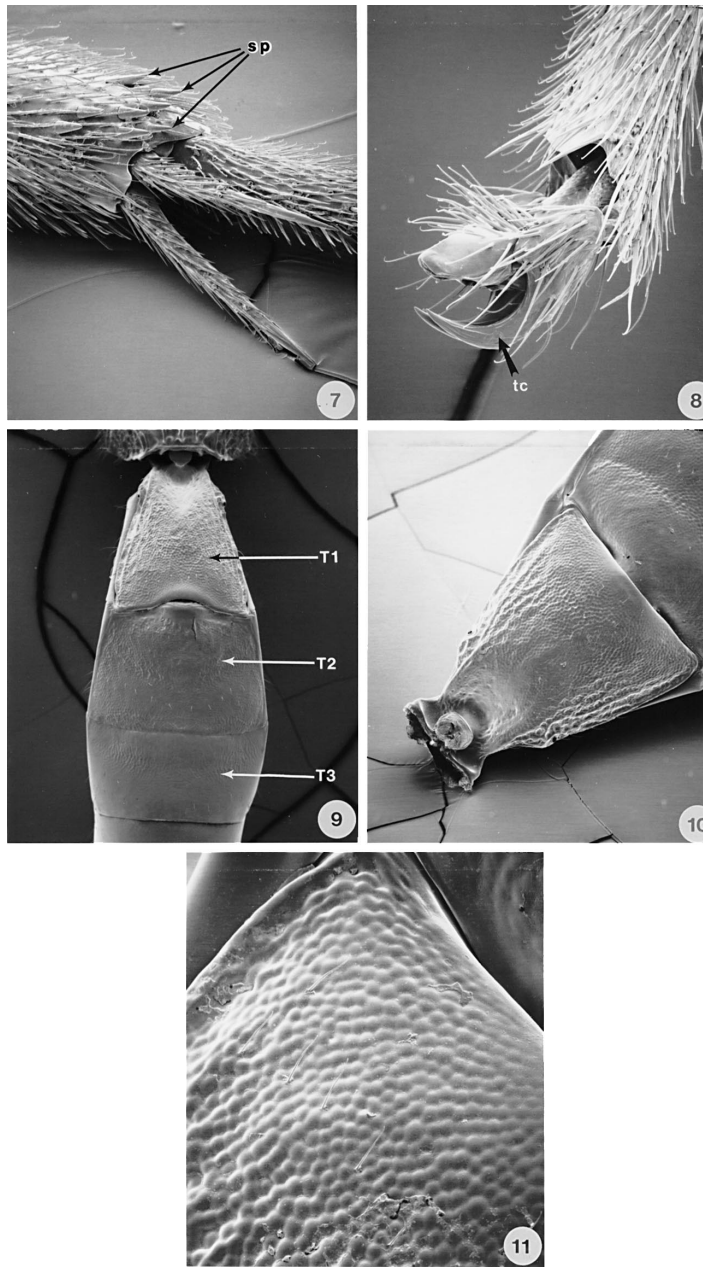

Fig. 7. Apex of third tibia; sp = spines. Fig. 8. Apex of Tarsus; tc = tarsal claw. Fig. 9. Dorsal aspect of median terga 1, 2, and 3. T1 = median tergum 1; T2 = median tergum 2; T3 = median tergum 3. Fig. 10. Dorsal aspect of median tergite 1. Fig. 11. Surface detail of median tergite 1.

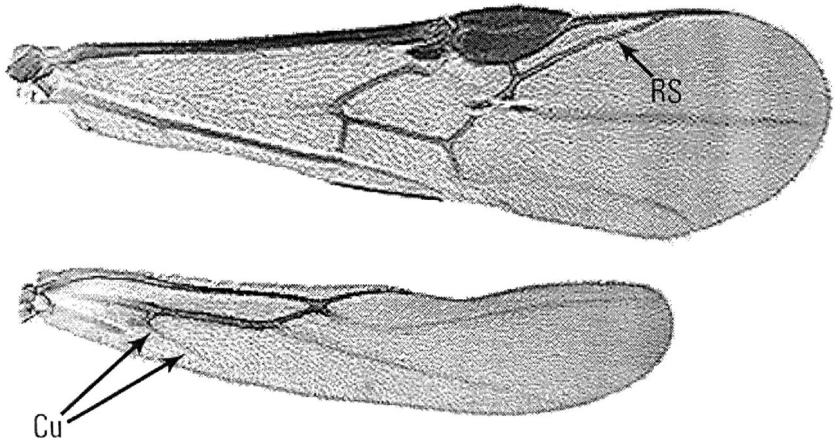

Fig. 12. Front and hind wings.

turing on metasomal terga 1, 2, and 3 (*T1*, *T2*, and *T3*, Fig. 9) and especially on the first metasomal tergum (Figs. 10 and 11) is present on many other species of *Bassus*, including *B. cintus* (Cresson), *B. discolor* (Cresson), and *B. agilis* (Cresson), but is unknown in *Agathis*. Based on outgroup analysis, this granulate sculpturing is a derived character state within *Bassus* and may define a monophyletic group.

B. agathoides runs to couplet 36 in the key to the Nearctic species of *Bassus* (Muesebeck 1927). The simple tarsal claws, lacking basal lobes (*tc*, Fig. 8), distinguish *B. agathoides* from all *Bassus* spp. in couplet 36 and following in the Muesebeck's key.

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SYMPTOMS AND POPULATION DYNAMICS OF *RHYNCHOPHORUS CRUENTATUS* (COLEOPTERA: CURCULIONIDAE) IN CANARY ISLAND DATE PALMS

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ABSTRACT

We documented the decline of a 2-hectare Canary Island date palm (*Phoenix canariensis*) nursery caused by the palmetto weevil (*Rhynchophorus cruentatus*) in Dade County, FL. External palm symptoms were defined, divided into nine categories, and representative palms were destructively harvested to assess internal weevil associations. Apparently healthy palms declined and died in a mean of 49 days. At the beginning of the study, 42% of 950 palms appeared healthy but within seven months only 3% were alive. Economic losses were estimated at $285,000-$380,000 for the nursery studied. Palm decline was patchily distributed in the field. The mean palm weevil counts ranged from 0.3 to 223.3 weevils per palm, for healthy to collapsing palms, respectively. Twenty-four weevil grubs were sufficient to kill one mature palm. External symptoms did not allow preventative diagnosis and treatment of internal *R. cruentatus* infestations. By the time that external symptoms were unambiguous, the mean total weevil counts per palm were over 100 with more than 65% as larvae and more than one quarter of these were >2.5 cm in length. Palms in these categories were dying because of irreparable damage to their apical meristems and attempts to save them would have been ineffectual. Thus, phytosanitation (palm removal and destruction) for management of *R. cruentatus* in Canary Island date palms should be implemented as soon as host leaves droop and weevil frass is observed. Growers and buyers of *P. canariensis* in regions where *R. cruentatus* exists should be aware of the potential lethal risk that it poses for this non-native palm. The costs of aggressive phytosanitation at the first symptoms of *R. cruentatus* infestation and prophylactic pesticide treatment at times of pruning, stress, or transplanting should be factored into the predicted cost of production and maintenance of Canary Island date palms in Florida.

Key Words: integrated pest management, palm decline, palmetto weevil, *Phoenix canariensis*

RESUMEN

Documentamos el deterioro de un vivero de 2-hectáreas de palmas datileras Isla Canaria (*Phoenix canariensis*) causado por el gorgojo "palmetto" (*Rhynchophorus cruentatus*) en el condado de Miami-Dade, FL. Síntomas externos de la palma fueron definidos, divididos en nueve categorías, y palmas representativas fueron cosechadas destructivamente para evaluar asociaciones internas de los gorgojos. Palmas aparentemente saludables se deterioraron y murieron en un promedio de 49 días. Al comienzo del estudio, 42% de 950 palmas parecían saludables pero dentro de siete meses solo el 3% estaban vivas. Pérdidas económicas fueron estimadas entre $285.000-$380.000 para el vivero del estudio. El deterioro de las palmas en el campo fue distribuido irregularmente. Cuentas de promedios de gorgojos variaron entre 0,3 y 223,3 gorgojos por palma, de palmas saludables a enfermas, respectivamente. Veinticuatro orugas de gorgojo fueron suficiente para matar una palma madura. Síntomas

externos no permitieron diagnosis preventivo y tratamientos de infestaciones internas de *R. cruentatus*. Para el momento en que los síntomas externos eran inequívocos, la cuenta promedio total de gorgojos por palma era sobre 100 con mas de 65% en forma de larva y mas de un cuarto de estos tenían un largo de > 2,5 cm. Palmas en estas categorías morían por daño irreparable a su meristemo apical e intentos para salvarlos hubieran resultado inútiles. Por lo tanto, fito-saneamiento (la practica de remover y destruir las palmas) para administración de *R. cruentatus* en palmas datileras Isla Canaria debería ser implementado en cuanto las hojas del huésped se inclinen y se observen residuos de daño de gorgojo. Vendedores y compradores de *P. canariensis* en regiones donde *R. cruentatus* existe deben estar al tanto de este riesgo potencialmente letal para esta palma no-nativa. El costo de fito-saneamiento agresivo en los primeros síntomas de infestación de *R. cruentatus* y tratamiento de pesticida profiláctico en momentos de podar, estrés, o transplante deben de ser facturados en los costos predichos de producción y mantenimiento de palmas datileras Isla Canaria en la Florida.

The palmetto weevil, *Rhynchophorus cruentatus* (F.) is distributed from the Florida Keys through the coastal regions of the southeastern U.S. including South Carolina and Texas (Wattanapongsiri 1966) and is co-distributed with the sabal palm, *Sabal palmetto* [Walker] Loddiges ex J. A. et Schultes (Woodruff 1967). Although not considered a major pest of palms, *R. cruentatus* has recently reached pest status in several Canary Island date palm (*Phoenix canariensis* Hortorum ex Chabaud) nurseries in southern Florida. Canary Island date palms are a valuable ornamental crop in Florida with retail values of $1,000-4,000 per palm (Anonymous 1997) for large specimen trees.

Adult *R. cruentatus* were first collected from Canary Island date palms from Florida in 1907 and recorded from Dade County, FL in 1909 (Wattanapongsiri 1966). The Canary Island date palm and sabal palm are the most commonly reported hosts for *R. cruentatus* (Giblin-Davis & Howard 1989). Other hosts include saw palmetto (*Serrenoa repens* [Bartram] Small), date palm (*P. dactylifera* [L.]), *Pritchardia* sp., *Washingtonia* sp., royal palms (*Roystonea* sp.), coconut palm (*Cocos nucifera* L.), *Latania* sp., *Caryota* sp. (Wattanapongsiri 1966, Giblin-Davis & Howard 1988) and the Florida thatch palm (*Thrinax radiata* Loddiges ex J. A. & J. H. Schultes) (A. G. B. H., unpublished data).

Rhynchophorus cruentatus usually attacks transplanted or otherwise stressed palms but can attack healthy palms. Adults are often attracted to stressed, damaged or dying palms (Wattanapongsiri 1966) and rely on semiochemicals for aggregation (Giblin-Davis et al. 1996a). Mating takes place on the host and eggs are laid deep in the petiole bases, or in wounds. Females lay 207 ± 19 eggs during a 42-day oviposition period (Weissling & Giblin-Davis 1994). Eggs hatch within 64 h and larvae bore into the palm stem. In southern Florida, *R. cruentatus* is mutivoltine and development can take less than 84 days from egg to adult emergence (Giblin-Davis & Howard 1989). Late instar larvae can kill palms by destroying the palm heart (bud) (Giblin-Davis & Howard 1988). Palms are usually asymptomatic until the apical meristem has been damaged. Therefore, weevil presence is usually not detectable until fatal damage and associated rot has occurred, making control efforts ineffective. Males can survive for 87 days and females for 74 days (Giblin-Davis & Howard 1989).

We observed a Canary Island date palm nursery for natural palm mortality caused by *R. cruentatus*. The objectives of this study were to monitor the rate of decline of infested palms and rate of infestation of healthy palms under natural field conditions, and to determine the weevil population dynamics in palms in various stages of decline.

Materials and Methods

Study Site

Sampling and monitoring was conducted from March - October 1997 at a 2-hectare Canary Island date palm field nursery in Florida City, Miami-Dade County, FL. Approximately 90% of the palms at this nursery were planted 10 years ago, and the remaining were planted 5 to 6 years ago. Ten randomly selected, healthy 10-year-old Canary Island date palms were measured at the beginning of the study to give an indication of the size and health of the trees in this nursery for future comparisons. Mean bare stem height was 3.9 cm (range 0-11.4 cm) (measured from the ground to the 'booted' [with attached petioles] portion of the stem) (Fig. 1). Mean bare stem diameter was 42.6 cm (33.0-53.3 cm). Mean booted stem height was 58.4 cm (30.5-81.3 cm) (Fig. 1). Mean maximum booted stem diameter was 56.4 cm (45.7-68.6 cm) (Fig. 1). Mean overall palm height measured from the ground to the top of the spear leaves (unexpanded frond) was 217.7 cm (182.9-251.5 cm) (Fig. 1).

The soil type was 'Krome very gravelly loam' with a plant spacing of 7.9 m × 2.7 m in 0.9 m hilled planting beds. No insecticides were used in the past 6 to 7 years, and no fertilizer or herbicides were applied or palms pruned in the year preceding this study. The surrounding area included avocado (*Persea americana* Mil.) and vegetable plantings with a natural area located just west of the palm field. Native saw palmettos were present in the area but no sabal palms were found nearby. There was a 2-hectare planting of approximately 12-year-old Chinese fan palms (*Livistonia chinensis* [Jacq.] R. Br. ex Mart.) near the study site.

Distribution and Rate of Decline

The site was mapped by assigning each of the 950 living or dead palms a row and tree number. Each palm was surveyed and visually monitored every 1 to 4 weeks for 7 months. We designated nine categories for external palm symptoms. (1) old-dead: crown and stem completely collapsed, often dry and falling apart, fronds completely necrotic (brown) and pithy, palm dead for several months or more; (2) dead: crown and stem collapsed, fronds completely necrotic; (3) recently dead: crown and stem collapsed, spear leaf and 1 to 2 adjacent leaves green, other fronds completely necrotic; (4) crown and stem collapsed but most of the fronds still green; (5) crown collapsing (spear leaf leaning >45°); (6) crown beginning to collapse (spear leaf leaning 5-45°), oldest fronds reclining; (7) 3 to 4 oldest fronds reclining; (8) apparently healthy, weevil frass detectable only after close inspection; (9) apparently healthy, no detectable weevil frass (Fig. 2). Weevil frass is easily detected at or near petiole bases in categories 1 through 7.

Weevil Population Dynamics within Palms

A total of 45 randomly selected palms from differing categories of decline were cut at the soil line with a chainsaw, placed into separately labeled 150-liter plastic containers for transportation to the laboratory and dissected to determine weevil population dynamics. Booted and bare palm stems were quartered with a chainsaw and the remaining tissue was finely sectioned with a sharp, heavy-bladed knife. Completely collapsed and dead palms (categories 3 through 1) were harvested by hand by pulling the crowns and trunks apart in the field. A chainsaw and knives were used as needed. All larvae and adults, as well as empty and occupied cocoons, were removed from dissected palms.

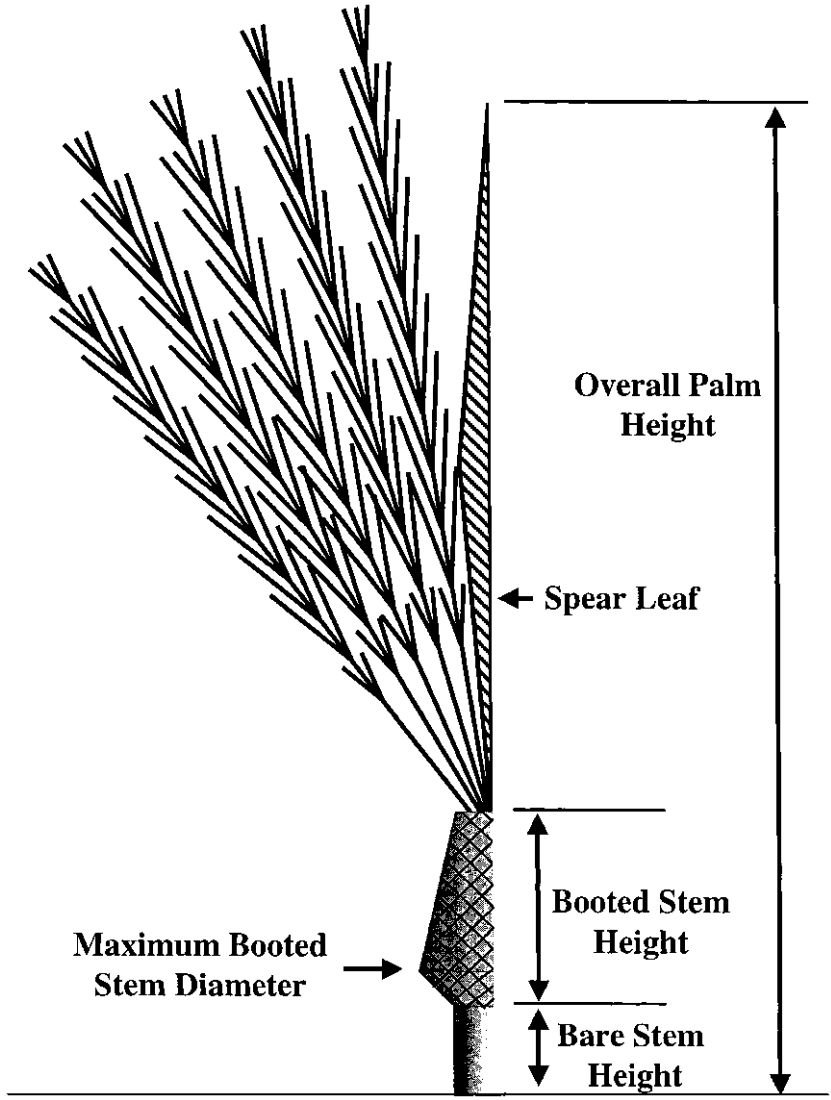

Fig. 1. Schematic drawing of *Phoenix canariensis* showing how various palm size measurements were made.

Larvae were separated by length into two categories, small (<2.5 cm) and large (>2.5 cm). All cocoons were opened to determine the stadium of the weevil (last instar larva, prepupa, pupa, or adult). Adults ready to emerge from the cocoons were sexed. Empty cocoons were counted to estimate the numbers of adults that had successfully emerged. Free-living adults found on dissected palms were also sexed and counted.

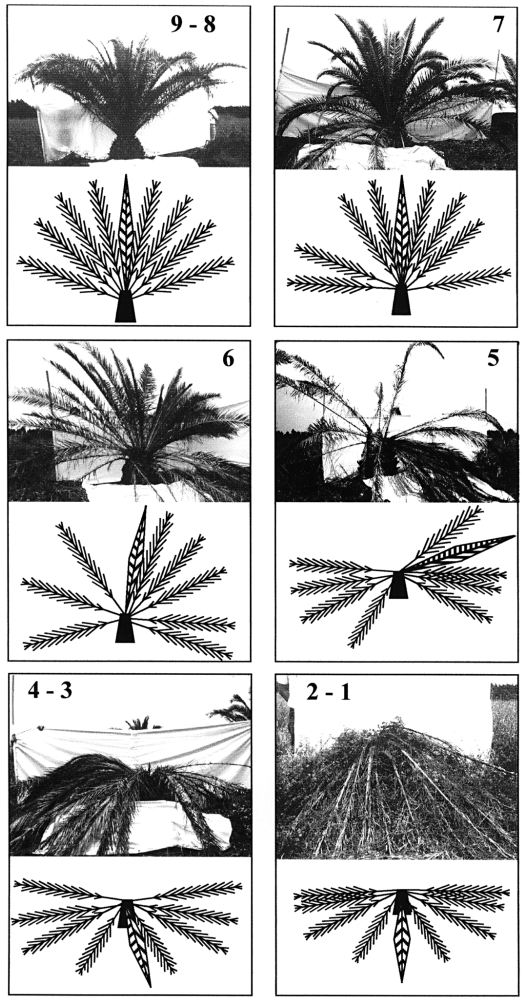

Fig. 2. Photographs and illustrations depicting the various categories of Canary Island date palm decline caused by *Rhynchophorus cruentatus* larval feeding damage. Some categories are pooled together because differentiating symptoms are not visible at this magnification or without color. Categories 9 and 8; (9) Palms healthy, asymptomatic, (8) weevil frass detected in petioles. Category 7; dying, 3 to 4 oldest fronds drooping, weevil frass detected in petioles. Category 6; dying, spear leaf and stem beginning to lean (5-45°), weevil frass detected in petioles. Category 5; dying, spear leaf and stem collapsing (>45°), weevil frass detected in petioles. Categories 4 and 3; (4) dying, spear leaf and stem completely collapsed but crown leaves still green, weevil frass detected in petioles (3); recently dead, spear leaf and 1 to 2 adjacent leaves green, other fronds completely necrotic, weevil frass detected in petioles. Categories 2 and 1; (2) dead, crown and stem collapsed, fronds completely necrotic; weevil frass detected (1); old-dead: crown and stem completely collapsed, dry and falling apart, fronds completely necrotic (brown) and pithy, weevil frass detected, palm dead for several months or more.

These represented weevils recently emerged from cocoons or weevils that flew into palms before they were harvested.

Temporal Dynamics

We compared the number of weevils and empty cocoons from palms that died before the beginning of this study (categories 1 and 2) with palms that died or were declining during the study (categories 2, 5 and 6) for differences in adult weevil production per palm.

Statistics

Temporal dynamics data were subjected to an analysis of variance (ANOVA) using PROC GLM (SAS Institute 1985) and means were separated by a Duncan's Multiple Range test when the ANOVA was significant at $P < 0.01$.

RESULTS

Distribution and Rate of Decline

Palms declined from category 9 to 3 in a mean of 49 days (±16 SD; range 11-100 days) and from category 7 to 3 in a mean of 31 days (±15 SD; range 8-80 days). Palm decline was patchily distributed throughout the study site (Table 1). When initially surveyed on March 28, 1997 (Julian Date 87), the three middle rows of the site (rows 4, 5 and 6) had the greatest proportion of dead palms (mean mortality 58, 77, 64%, rows 4 - 6 respectively) (Table 1). More dead palms were found near the ends of rows, except for row 5 where dead palms were found throughout the row. In the beginning of this study, 54.7% of all palms were dead, 3.3% were dying, and 41.8% were apparently healthy (Fig. 3). However, seven months later (October 1997; Julian Date 286), the proportion of healthy palms decreased to 3.1% (Fig. 3). Over the same time period, the proportion of dead palms (categories 1 to 3) increased from 54.7% to 88.5%. The proportion of dying palms (categories 4 through 7) was fairlyconstant, with a mean of 9.4% (range 3.3-13.1%) per month. Also, by October 13 (Julian Date 286), almost all of the palms in rows 3, 4, 5, and 6 were dead. No healthy palms were found in row 6 (Table 1).

TABLE 1. PROPORTIONS OF DEAD (CATEGORIES 3 THROUGH 1), DYING (CATEGORIES 7 THROUGH 4), AND HEALTHY (CATEGORIES 9 AND 8) CANARY ISLAND DATE PALMS BY ROW NUMBER FOR MARCH AND OCTOBER, 1997.

	Rows							
March 28, 1997	1	2	3	4	5	6	7	8
% Palms Dead	57.1	43.4	41.6	57.8	73.5	63.8	47.5	56.0
% Palms Dying	4.8	2.8	4.4	2.2	3.8	3.8	2.9	5.0
% Palms Healthy	38.1	53.8	54.0	40.0	22.0	32.3	49.6	39.0
October 13, 1997								
% Palms Dead	85.7	89.5	87.6	94.0	96.2	93.8	82.7	90.0
% Palms Dying	9.5	6.3	6.6	3.0	2.3	6.2	13.7	6.0
% Palms Healthy	4.8	4.2	5.8	3.0	1.5	0	3.6	4.0

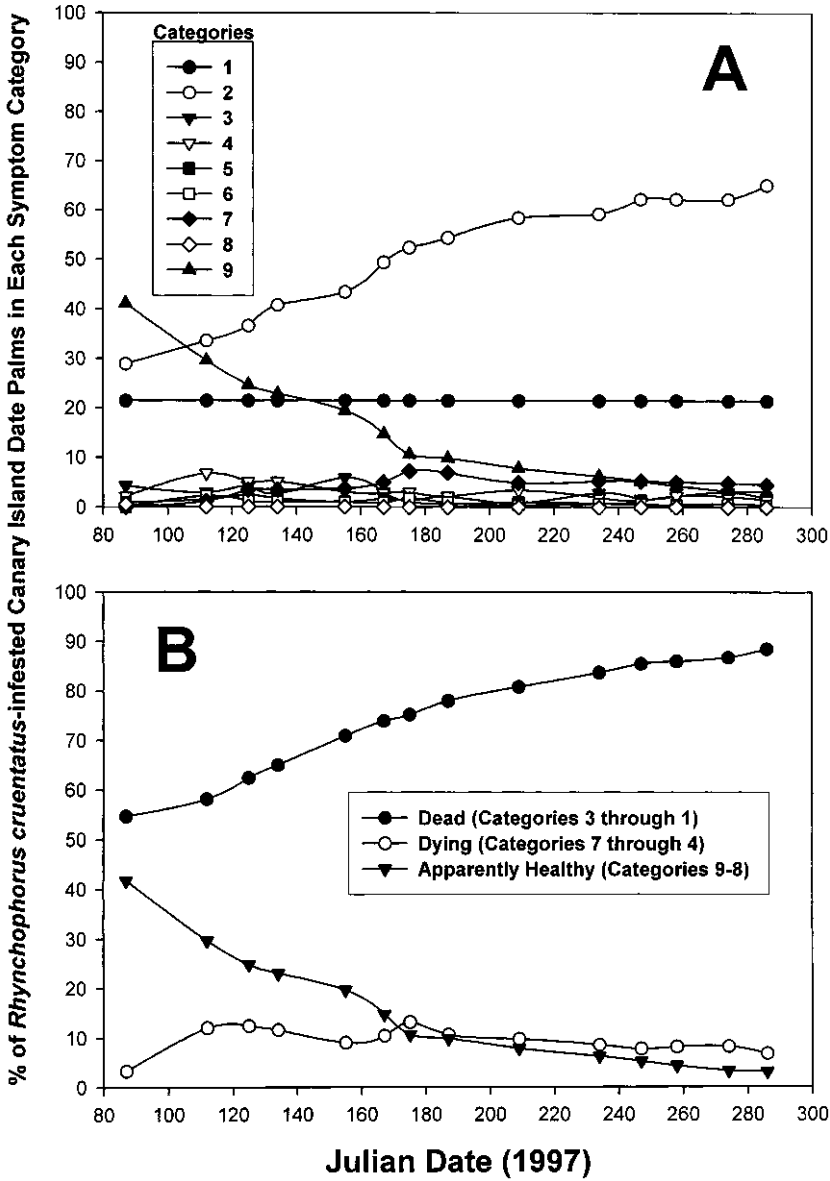

Fig. 3. Plots of the percentage of *Rhynchophorus cruentatus*-infested field-grown Canary Island date palms in each symptom category for each Julian date in 1997 from a nursery in southern Florida. See Figure 2 for descriptions of the symptom categories. A. Palm symptom categories 9 through 1. B. Palm symptom categories consolidated.

Weevil Population Dynamics within Palms

We found that as few as twenty-four *R. cruentatus* larvae were capable of killing a 10-year-old Canary Island date palm. Only two early instar larvae were found in a healthy (category 9) dissected palm with no associated internal damage (Table 2). Adults [1:1 (M:F)] were found within debris collected at the petiole bases of all of the healthy palms surveyed. Palms in category 8, where the palm appears healthy except for larval frass, were rare (Fig. 3) and none were dissected (Table 2). This category was difficult to detect because externally visible frass was normally associated with larger larvae preparing to pupate.

Eighty to 92% of the total live weevils from palms beginning to decline (categories 7 and 6) were larvae and most of these were small (Table 2). As symptoms progressed, the percentage of total live weevils that were pupae and prepupae increased from 11.5% to 38.7% (categories 7 to 3, respectively). Palms categorized as 7, when symptoms were first noticed, had large numbers of weevils (>100 live weevils per palm) (Table 2). The greatest number of weevils recovered was 308 (mostly immatures) in a palm whose crown was just starting to collapse (category 6). On the average, palms with collapsing crowns (category 5) had the most weevils (>200 per palm) (Table 2). Palms with completely collapsed crowns (category 4) also contained large populations of larvae (mean = 113.4 per palm) (Table 2). Recently dead palms (category 3) still had larvae (mean = 29.0 per palm) compared with palms that had been dead for awhile which had less than 1 larva per palm (Table 2). Dead palms (categories 2 and 1) contained mostly empty cocoons (89-99% of the total weevils per palm) (Table 2). Up to two generations of weevils were found within many palms indicating the continued recruitment of adults to infested palms or recidivism. Dead palms had the fewest total weevils per palm (mean = 40.0, 88.3, 75.5; categories 1 through 3, respectively). For all palms, the sex ratio was 1:1 (M:F) for adults inside cocoons.

Temporal Dynamics

Palms that died in the year before this study was started had been infested with a lower ($F = 5.33$; df = 2,18; $P = 0.0152$) number of weevils than palms that died during the study (Table 3). A mean of 40.0 weevils per palm was recovered in palms that died before the spring 1997, 88.3 weevils in palms that died during the spring of 1997, and 115.0 weevils in palms that died during the summer of 1997 (Table 3).

The number of empty cocoons within trees served as an estimator of the adult weevil production potential of Canary Island date palms (killed by lethal infestations of weevils) because each empty cocoon represented an adult that emerged. The adult weevil production per palm was related to when the palms were infested. It was a maximum of 148 weevils (mean = 78.5) for those palms that died during the spring-early summer of 1997 (pre-spring 1997 infestation) compared with a maximum of 142 weevils (mean = 105.6) for palms that died during the summer 1997 (spring 1997 infestation) and a maximum of 59 (mean = 39.5) for palms that were infested and died prior to the spring of 1997 (Table 3). Because these observations involved palms that died over the course of 18 months, host size could have been a factor. However, gross comparisons of stem size did not confirm that the trees had grown very much during this time.

Palms (category 6) (Table 3, season of infestation = spring 1997) were selected and some were harvested while others of this cohort were allowed to decline and were subsequently harvested as category 5 and 2 palms at different times in 1997. There was a decrease ($F = 9.35$; df = 4, 22; $P = 0.0001$) in total weevil counts as palms declined (Table 3). The mean total weevils per palm in categories 5 and 6 were 223.3 and 183.0, respectively. In contrast, category 2 palms that had been infested at the same time

TABLE 2. MEAN NUMBER OF *RHYNCHOPHORUS CRUENTATUS* DISSECTED FROM FIELD-GROWN CANARY ISLAND DATE PALMS IN SOUTHERN FLORIDA.

Palm health category[1]	(n)[2]	Mean (±SE) no. weevils per palm								
		Larvae		Pupae		Adults in cocoons		Total live weevils	Empty cocoons[3]	Total weevils[4]
		Small	Large	Prepupae	Pupae	Females	Males			
DEAD										
1	4	0	0.5 (0.5)	0	0	0	0	0.5 (0.5)	39.5 (7.3)	40.0 (7.1)
2	12	0	0.6 (0.3)	0	2.3 (1.0)	3.3 (0.7)	3.6 (0.9)	9.8 (1.0)	78.5 (9.3)	88.3 (10.6)
3	2	0.5 (0.5)	28.5 (26.5)	7.5 (7.5)	14.0 (7.0)	2.0 (1.0)	3.0 (2.0)	55.5 (26.5)	20.0 (15.0)	75.5 (15.5)
DYING										
4	5	44.0 (21.5)	69.4 (21.7)	11.4 (4.6)	19.2 (2.4)	6.4 (0.8)	4.8 (1.6)	155.2 (23.5)	17.2 (5.3)	172.4 (23.4)
5	3	89.7 (15.4)	85.3 (8.5)	10.0 (4.4)	14.7 (5.8)	7.3 (2.3)	10.7 (3.7)	217.6 (20.0)	5.7 (1.5)	223.3 (19.4)
6	3	111.0 (43.8)	51.7 (15.7)	3.3 (1.5)	6.0 (4.0)	3.0 (1.0)	2.3 (0.7)	177.3 (62.5)	6.0 (3.1)	183.3 (62.3)
7	3	62.3 (13.3)	23.7 (10.7)	7.7 (2.3)	4.7 (3.7)	4.7 (4.7)	4.3 (3.3)	107.4 (34.2)	1.3 (1.3)	108.7 (34.7)
HEALTHY										
8	0									
9	7	0.3 (0.2)	0	0	0	0	0	0.3 (0.2)	0	0.3 (0.2)

[1]See Figure 2 for legend.
[2]n = number of palms dissected.
[3]Empty cocoon = emerged weevil.
[4]Total weevils = total live weevils + empty cocoons.

TABLE 3. COMPARISON OF NUMBER OF *RHYNCHOPHORUS CRUENTATUS* DISSECTED FROM DEAD AND DECLINING PALMS INFESTED IN DIFFERENT SEASONS.

Season of infestation	Palm health category[1]	Palms harvested (n)	Mean number (Range) of larvae per palm			Percentage of total weevils[3]	Mean number (Range) of pupae per palm			Percentage of total weevils
			Small	Large	Total[2]		Prepupae	Pupae	Total	
Pre-spring 1997	1	4	0 (0)	0.5 (0-2)	0.5b	1.3	0 (0)	0 (0)	0b	0
	2	12	0 (0)	0.6 (0-3)	0.6b	0.7	0 (0)	2.2 (0-12)	2.3b	2.6
Spring 1997	2	5	0 (0)	0.8 (0-4)	0.8b	0.7	1.0 (0-2)	3.0 (0-7)	4.0b	3.5
	5	3	89.7 (65-118)	85.3 (72-101)	175a	78.4	10.0 (2-17)	14.7 (5-25)	24.7a	11.1
	6	3	111.0 (50-196)	51.7 (26-80)	162.7a	88.8	3.3 (1-6)	6.0 (2-14)	9.3b	5.1

Season of infestation	Palm health category	Mean number (Range) adults in cocoons			Percentage of total weevils	Mean number (Range) of empty cocoons	Percentage of total weevils	Total weevils
		Females	Males	Total				
Pre-spring 1997	1	0 (0)	0 (0)	0b	0	39.5 (25-59)bc	98.8	40.0c
	2	3.1 (0-7)	3.6 (0-9)	6.9b	7.8	78.5 (21-148)ab	89.0	88.3bc
Spring 1997	2	1.0 (0-4)	1.0 (0-4)	4.6b	4.0	105.6 (51-142)a	91.8	115.0b
	5	7.3 (3-11)	10.7 (6-18)	18.0a	8.1	5.7 (3-8)c	2.6	223.3a
	6	3.0 (2-5)	2.3 (1-3)	5.3b	2.9	6.0 (0-10)c	3.3	183.3a

[1]See Figure 2 for legend.
[2]Means in a column followed by a different lower case letter are significantly different according to a Duncan's Multiple Range test.
[3]Total weevils = total live weevils + empty cocoons.

had a significantly lower mean total number of weevils (115.0 per palm) (Table 3) suggesting unknown mortality or other factors. Most of the weevils in category 5 and 6 palms were larvae (78.4 and 88.8%, respectively); whereas, category 2 palms contained 0.7% larvae (Table 3).

Discussion

This study has confirmed that apparently healthy Canary Island date palms are suitable and susceptible hosts for *R. cruentatus* (Giblin-Davis & Howard 1989, Giblin-Davis et al. 1996a,b). This contrasts with most other species of palms that appear to be suitable and susceptible to *R. cruentatus* infestation only after some major stress (Giblin-Davis & Howard 1989). Adult *R. cruentatus* seek harborage between palm sheaths or in rotten parts of the palm, presumably in search of moisture and oviposition sites (Weissling & Giblin-Davis 1993, 1994). *Rhynchophorus cruentatus* may attack healthy Canary Island date palms because of their large and tender leaf bases which may be more semiochemically apparent and easily infested by neonates than the split and hardened petioles of palms such as *S. palmetto* (R. M. G.-D., unpublished data). None of the palms (Chinese fan palm or saw palmetto) in areas next to the study site declined. *Rhynchophorus cruentatus* appeared to be the sole cause of death for all dead or dying Canary Island date palms (922 of 950) observed during this study. In a similar study of 197 six to eight-year-old Canary Island date palms in Indian River County, FL during 1994-1995, 61% died with heavy infestations of *R. cruentatus* (R. M. G.-D. & J. T., unpublished data). At that site, none of the > 100 *S. palmetto* (aged 5 to 10 years old), > 300 *Syagrus romanzoffiana* (Chamisso) Glassman (Queen palm) (aged 5 to 8 years old), > 500 *Aceolorrhaphe wrightii* (Grisebrach & H. A. Wendland) (Paurotis palm) (> 5 years old), > 200 *P. reclinata* N. J. Jacquin (Reclinata palm) (> 5 years old), 214 *Livistonia australis* (R. Brown) Martius (Australian fan palm) (> 5 years old), and > 30 *Washingtonia robusta* H. A. Wendland (Washington palm) (> 5 years old) declined due to *R. cruentatus* infestations during or within 3 years of the study (R. M. G.-D. & J. T., unpublished data).

A few adult *R. cruentatus* may initially be found on a palm, but recruitment occurs when male-produced aggregation pheromones and kairomones from stressed, damaged, or dying trees are released (Giblin-Davis et al. 1996a). When healthy and weevil-infested Canary Island date palms in this study were dissected, flying *R. cruentatus* were attracted to the area within minutes of cutting. In most palms, *R. cruentatus* infestations are secondary to some major stress factor such as pruning, transplanting, drought, and/or earlier damage from the West Indian sugarcane borer, *Metamasius hemipterus sericeus* (Olivier) (Giblin-Davis et al. 1996b). However, we found *R. cruentatus* attacking apparently healthy Canary Island date palms that had not been pruned within the past year. The population increase of *R. cruentatus* may have started after hurricane Andrew occurred in August, 1992 causing severe damage to vegetation. Damaged palms at the study site may have provided resources for an increase in the population of this weevil that went unnoticed and became an epizootic. At high densities, *R. cruentatus* may be more of a threat to healthy Canary Island date palms than when present at low densities.

Canary Island date palms are also a suitable host for *M. h. sericeus,* but it does not cause lethal damage (Giblin-Davis et al. 1996b). There was some old *M. h. sericeus* damage and empty cocoons (mean = 3.6 per palm) in the dried petioles of *R. cruentatus*-infested palms in this study. Because of similar chemical ecology, infestation and damage by *M. h. sericeus* can result in the recruitment of the more damaging *R. cruentatus* to palms (Giblin-Davis et al. 1996a).

The symptom categories proposed in this study were ineffective for designating Canary Island date palms that had sub-lethal or potentially lethal internal infestations of *R. cruentatus.* Palms did not react to weevil infestations until there was an accumulation of late instar larvae (>20) (Table 2). As a result, substantial damage occurred before there was any observable manifestation of injury by the palm (Wolfenbarger 1958). The earliest infestation category (8) proved rare and unreliable because of the cryptic nature of *R. cruentatus.* Frass production, the most reliable external symptom of *R. cruentatus* infestation, was not easily observed until palms were classified as category 7. The attached petiole bases of *P. canariensis* obscure visibility making the discovery of frass difficult until large numbers of late instar larvae begin to pupate. Removal of petiole bases before they have completely dried and are ready for abscission to discover *R. cruentatus* is laborious and creates wounds that could attract more weevils.

There are several possible scenarios for category 8 palms where frass was detected before the palm declined. First, an apparently healthy host palm could have been near category 7, but the large number of larvae had not done sufficient damage to critical zones of the palm to induce symptoms. Palms are monocots with large numbers of vascular bundles that connect leaves to roots. Borers can do a lot of random mechanical damage to these vascular elements before enough are destroyed to induce a systemic decline. This would help explain the short time difference between apparently healthy plants (category 9) through death (category 3) (49 days) versus onset of frond reclining (category 7) through death (category 3) (31 days). Second, there might have been a smaller weevil infestation where the weevils had metamorphosized and frass was fortuitously deposited where it could easily be observed. This would explain the long time to death from category 9 through 3 in some palms (range up to 100 days). A palm in this situation, would be the most likely candidate for preventative systemic insecticide treatment, if external symptoms were more reliable and there were proven systemic insecticides available. When a palm in this situation is left untreated, the next generation of adult weevils recruit new weevils or mate among themselves and produce progeny that may kill the palm.

Category 7 was a reliable indicator of a dying palm but some variability existed in the time to death from category 7 through 3 palms (range 8-80 days) suggesting differences in weevil-host dynamics. Fast host death is consistent with a host that was on the verge of severe decline with large numbers of mature weevils when it was rated (Table 2). Slow host death is consistent with a palm that had been structurally compromised by a few weevils allowing for early display of symptoms. The lack of reliability of asymptomatic palms in categories 9 and 8, the similarities of weevil-host dynamics and time to death for categories 7 through 4 and categories 3 through 1 (Table 2), all suggest that the nine categories designated at the start of this study can be consolidated into the following three categories for diagnostic purposes; APPARENTLY HEALTHY (categories 9 and 8), DYING (categories 7 through 4), and DEAD (categories 3 through 1) (Fig. 3).

External symptoms did not allow preventative diagnosis and treatment of internal *R. cruentatus* infestations in *P. canariensis*. By the time that external symptoms were unambiguous (categories 7 through 4), the mean total weevil counts per palm were over 100 with more than 65% as larvae and more than one quarter of these were >2.5 cm in length (Table 2). Palms in these categories were dying because of irreparable damage to their apical meristems and attempts to save them would have been ineffectual. Thus, phytosanitation (palm removal and destruction) for management of *R. cruentatus* in Canary Island date palms should be implemented as soon as host leaves droop and weevil frass is observed.

Weevil populations during the present study were high in the late spring and early summer of 1997 (a total of 3,016 *R. cruentatus* and 3,043 *M. h. sericeus* adults were captured and killed in semiochemical-baited traps [5 traps per hectare] over the course of the seven month study [unpublished data]). We hypothesize that the populations expanded in 1997 because of significant increases in the number of empty cocoons harvested in spring of 1997 from category 2 palms compared with category 1 palms from pre-spring 1997 (Table 3). The lack of chemical control and/or phytosanitation were the most likely factors responsible for the weevil population increase. Additionally, the semiochemicals released from dying palms and adult weevils may have recruited more *R. cruentatus* from surrounding areas into the site. Even though >3,000 *R. cruentatus* were mass-trapped from the site, the within field populations of *R. cruentatus* did not decrease enough during the summer to prevent most of the palms at the site from being destroyed by this weevil. Adult weevil density estimates for the entire site were 34,390 (417 palms with 78.5 empty cocoons per palm, category 2; 57 palms with 20.0 empty cocoons per palm, category 3; 30 palms with 17.2 empty cocoons per palm, category 4) between April - May 1997 (Fig. 3 and unpublished data). Therefore, the mass trapping efforts removed about 9% of *R. cruentatus* adults present. We speculate that the *M. h. sericeus* that we trapped were recruited from other sites because we did not find any immatures in dissected palms. The only phytosanitation done at this site was the removal of palms for dissection and represented about 5% of the total suggesting that semiochemical-based mass trapping was ineffective for small field plot control of *R. cruentatus* without aggressive concurrent phytosanitation, especially during a weevil epizootic. Replicated studies are needed to verify the usefulness of mass trapping in small and large stands of Canary Island date palms. Care should be taken when implementing mass trapping in small plots of highly susceptible palms, such as Canary Island date palms, because pheromone could call more weevils into a site.

The theoretical *R. cruentatus* yield for this site for 1997 was 82,696 adult weevils (522 palms, mean = 64.1 weevils per palm; 428 palms, mean = 115.0 weevils per palm). Loss to this grower was estimated at $285,000-$380,000 (based on the number of palms per hectare and a $300-$400 wholesale price for this size palm). Growers and buyers of *P. canariensis* in regions where *R. cruentatus* exists should be aware of the potential lethal risk that it poses for this non-native palm. The costs of aggressive phytosanitation at the first symptoms of infestation by *R. cruentatus* and prophylactic pesticide treatment at times of pruning, stress or transplanting (Giblin-Davis & Howard 1989) should be factored into the predicted cost of production and maintenance of Canary Island date palms in Florida. To prevent the spread of *R. cruentatus* populations, Canary Island date palms shouldn't be transplanted from sites with an epizootic because early weevil infestations are not easily diagnosed and stressing of palms can call in colonizing weevils before removal from the nursery.

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A REVIEW OF *CLIGENES* WITH THE DESCRIPTION OF A NEW GENUS, *VALERIS* (HEMIPTERA: RHYPAROCHROMIDAE: ANTILLOCORINI)

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ABSTRACT

Cligenes grandis (Lygaeoidea: Rhyparochromidae: Antillocorini), a new species from Mexico and Central America, is described and illustrated. New geographic records are given for *Cligenes distinctus. Valeris,* a new genus, is described and illustrated for *Cligenes subcavicola* Scudder, Darlington, and Hill.

Key Words: Hemiptera, Lygaeoidea, Lygaeidae, Antillocorini, *Cligenes, Botocudo, Valeris*, cave, bat, *Ficus*, seeds

RESUMEN

Se describe e ilustra *Cligenes grandis* (Lygaeoidea: Rhyparochromidae: Antillocorini), una especie nueva de México y Centroamérica. Se reportan nuevas localidades

de *Cligenes distincuts*. El género nuevo *Valeris* es descrito e ilustrado para la especie *Cligenes subcavicola* Scudder, Darlington, and Hill.

Slater (1964) included 35 species in the Neotropical lygaeoid genus *Cligenes* in his Catalogue of the Lygaeidae of the World. All but the type species, *Cligenes distinctus* Distant, and *C. subcavicola* Scudder, Darlington, and Hill, were subsequently assigned to other genera (see Slater and O'Donnell [1995]). *Cligenes* is distinguished from other antillocorine genera by a groove on the prosternum where the labium lies at rest. This character was not included in the original description of *Cligenes* by Distant (1893). It was mentioned under the name of "rostral groove" by Scudder (1962) to distinguish *Botocudo* from *Cligenes.* However, when describing *Cligenes subcavicola*, which lacks this character, Scudder et al. (1967) concluded that the rostral groove was not a diagnostic generic character for *Cligenes* because it was variable. I consider the prosternal groove as an autapomorphic character for *Cligenes* that defines this genus and is of high value since no other antillocorine is known to have it.

A new species of *Cligenes* is described below.

Cligenes subcavicola was originally placed in *Cligenes* because of its explanate pronotal lateral margins; however, in addition to the lack of a prosternal groove in *C. subcavicola* these margins are upturned. *Cligenes subcavicola* also differs from other *Cligenes* by having a caudal projection on the genital capsule of the males. *C. subcavicola* is here removed from *Cligenes* and designated as the type species of a new genus, *Valeris*.

All measurements are in millimeters.

The following abbreviations are used in the text: AMNH (American Museum of Natural History, New York); BMNH (The Museum of Natural History, London); CASC (California Academy of Sciences, San Francisco, CA); EMEC (Essig Museum of Entomology, Berkeley, California); FSCA (Florida State Collection of Arthropods, Gainesville, Florida); RMB (R. M. Baranowski collection, Homestead, Florida); UNAM (Colección Entomológica, Instituto de Biología, Universidad Nacional Autónoma de México, D.F., México); NMNH (National Museum of Natural History, Washington, D.C.).

Cligenes grandis Brambila, **NEW SPECIES**
(Figs. 1, 3, 6-15)

Diagnosis. A reddish brown antillocorine with a longitudinal groove on prosternum; anterior lobe of pronotum carinate, punctate, and strongly convex; and corium creamy white with apex brown. Measuring 2.30 to 3.20 mm in total body length it is one of the largest species among the Antillocorini and larger than most *Cligenes distinctus*.

Description. Male. Head brownish black. Anterior lobe of pronotum reddish brown with collar and lateral margins yellowish brown; posterior lobe yellowish brown with meson and humeral angles reddish brown and creamy white on each side of meson and anterior to humeral angles. Scutellum dark yellowish brown mesally, becoming dark brown laterally, apex white (Fig. 3). Clavus creamy white. Corium creamy white with apex brown and with light brown marking at midpoint next to margin. Membrane translucent white. Body below reddish brown with capsule yellowish brown. Antennae reddish brown, distal ends of segments II-IV yellowish brown and labium yellowish brown. Legs pale brownish yellow, coxae yellowish brown.

Dorsum of head rugose; tylus reaching middle of first antennal segment. Gula narrow reaching anterior margin of prosternum, contiguous with prosternal groove (Figs. 1 & 7). Labium reaching mesocoxae.

Pronotum with surface shining, glabrous, and punctate, with row of punctures along carina at lateral margins, row at indentation separating lobes, and irregular row of punctures marking a collar. Anterior lobe of pronotum strongly convex, nearly 2× longer than posterior lobe (Fig. 6). Lateral margins explanate and indented at area of transverse impression; posterior margin concave. Scutellum evenly punctate, except apex impunctate. Thoracic pleura with large punctures. Scent gland auricle on metapleuron curved posteriorly; evaporative area surrounding auricle covering less than half of metapleuron (Fig. 10). Meso- and metasternum with a median keel.

Clavus with three rows of punctures. Corium mesally with two rows of punctures parallel to clavus, followed laterally by smooth area, then by irregular rows of punctures except for uniform outer-most row. Lateral corial margins explanate with anterior half upturned and slightly sinuate; apical margin with mesal half deeply concave (Figs. 3 & 6). Abdominal sternum with decumbent setae; trichobothria on abdominal sternite V linear, anterior to spiracle V, and closer to each other than to trichobothria of segment IV (Fig. 8). Fore femur moderately incrassate (1.5× as wide as middle femur) with row of 7 ventral spines distally (Fig. 9). Genital capsule, parameres, and spermatheca as in Figs. 11-15.

Head length 0.44, width across eyes 0.60, interocular distance 0.33. Pronotal length 0.70, width across humeral angles 1.11. Scutellar length 0.60, width 0.66. Length of claval commissure 0.18. Wing length from base of corium 1.92. Length of antennal segments I 0.26, II 0.43, III 0.34, IV 0.42. Length of labial segments I 0.32, II 0.46, III 0.5, IV 0.22. Total body length 2.72.

All specimens are macropterous. Total body length range: 2.30 to 3.20 mm. Several specimens have the posterior lobe of pronotum nearly entirely creamy white or yellowish white. Some specimens have a diffuse brown macula on the corium adjacent to the lateral margin at midpoint; some have the wing membrane clear and colorless. Females are similar to males, except they have with fewer spines on fore femur.

HOLOTYPE: ♂ Mexico, *OAXACA*, Chacahua, 31-V-1987, L. Cervantes (UNAM). The holotype is in good condition, glued on its right side to a paper point, with the genital capsule removed and stored in a vial with glycerin. In UNAM.

PARATYPES: 19 ♂, 19 ♀. MEXICO, *OAXACA*: 1 ♀ Chacahua, 31-V-1987, coll. E. Barrera (UNAM). 1 ♀ Puerto Escondido, 23-VII-1975, Noct., coll. H. Brailovsky (UNAM); *CHIAPAS*: 1 ♂, 1 ♀ Tapachula, 19-IV-1983, coll. H. Brailovsky (UNAM); 1 ♀ Tapachula, 19-IV-1983, coll. H. Brailovsky, (UNAM); 5 ♂, 1 ♀ Tapachula, 19-IV-1983, coll. E. Barrera (UNAM); 1 ♀ 5 Mi. N.E. of Chiapa, W92°58': N16°45', 22-VIII-1966, colls. J. & W. Ivie (AMNH); 1 ♀ Rosario, Izapa, 20-IV-1983, coll. H. Brailovsky (UNAM); 1 ♀ Frontera [=international border with Guatemala], 6-IV-1979, 400 m., coll. E. Barrera (UNAM); and 1 ♀ El Zapotal. 2 Mi. S. Tux. Gutierrez, 5-VII-1957, coll. P. D. Hurd (EMEC). EL SALVADOR: 1 ♂ San Salvador, 31-V-1959, coll. P. A. Berry (NMNH). COSTA RICA: 1 ♂ Prov. San Jose, 8 Km. S. Orotina, 16-II-1983, colls. R. M. Baranowski, F. Gilstrap (RMB); 1 ♂ Guanacaste, Prov. Sta. Rosa National Park, 22-V-1985, colls. Doyen & Powell (EMEC). PANAMA: 1 ♀ Cabima, 22-V-?1 [might be 1911], coll. August Busck (NMNH); 1 ♂ Coco Solo Hosp., Canal Zone, light trap, 5-V-1974, coll. D. Engleman (J. A. Slater Collection); 1 ♀ Coco Solo Hosp., C. Z., light trap, 20-VI-1975, coll. D. Engleman (UNAM); 1 ♀, 1 ♂ Coco Solo, 20-VI-1975, Noct., coll. D. Engleman (UNAM); 1 ♂, 1 ♀ Coco Solo Hosp., C. Z., 21-V-1976, light trap, coll. D. Engleman (UNAM); 7 ♂, 6 ♀ Coco Solo Hosp., C. Z., 21-V-1976, light trap, coll. D. Engleman (J. A. Slater Collection). In AMNH, EMEC, NMNH, UNAM, J. A. Slater and R. M. Baranowski collections.

Discussion

This species was first discovered among specimens from Mexico believed to be *Cligenes distinctus* because of the prosternal groove. Comparison of the capsules, parameres and spermathecae revealed that these specimens were not conspecific with *C. distinctus* (Figs. 11-15, 20-24). *Cligenes grandis* n. sp. is larger and lighter in coloration than *C. distinctus* (with the exception of some specimens of the latter from Trinidad); the body size range for *C. distinctus* is 1.80 to 2.85 mm. An excellent illustration of the latter species is in Slater and Baranowski (1990). *Cligenes distinctus* is extremely variable in pronotal color and shape, making comparisons difficult. Although both species have four pale markings on the posterior lobe of the pronotum, *C. distinctus* usually has most of the posterior lobe concolorous with the anterior lobe (Fig. 4) while specimens of *C. grandis* n. sp. have most of the posterior lobe pale (Fig. 3). Antennal segment IV is reddish brown in *C. grandis* n. sp. but usually white in *C. distinctus*. *Cligenes distinctus* has two distinct brown maculae on each wing while most *C. grandis* n. sp. have only an apical macula and at most a diffuse macula at midpoint. The genital capsules of males differ in part by the absence in *C. grandis* n. sp. of posterior-pointing decumbent thick setae seen in *C. distinctus* ventrally, that is, below the cuplike sclerite (Fig. 22); furthermore, the arms of the cuplike sclerite are closer to each other and meet at a sharp angle on *C. grandis* n. sp.(Fig. 15) while in *C. distinctus* this angle is rounded and the arms are farther apart (Fig. 22).

ETYMOLOGY. The specific name refers to the body size of this species, larger than most *Cligenes distinctus*.

DISTRIBUTION. Mexico (southern states of Chiapas and Oaxaca), Guatemala, El Salvador, Costa Rica, and Panama, i.e. Mesoamerican distribution.

BIOLOGY. Unknown. Several specimens were captured at night in light traps.

New Localities of *Cligenes distinctus* Distant

Cligenes distinctus is sympatric with *C. grandis* n. sp. in Mexico and Central America (Fig. 35). *Cligenes distinctus* was described from Panama (Distant 1893) and has also been reported from Cuba (Barber 1954) and Florida (Blatchley 1926) and as *Tomopelta munda* (Uhler 1893), a junior synonym, from St. Vincent Island. In Florida it is known from Brevard, Dade, and Monroe counties (Slater and Baranowski 1990). However, it is widespread. The following are new country records (numbers in parentheses refer to the number of specimens):

MEXICO: (1) Veracruz, Puente Nacional, 6 Mi. S.E. Rinconada, 30-IX-1975, at light, colls. J. Powell & J. Chemsak (EMEC). NICARAGUA: (1) Dept. Rivas, 10 Km. N.W. Sapoa, Rio Canas Gordos, 9-VI-1964, colls. Blanton, Broce (RMB). BAHAMAS, *GRAND BAHAMA ISL.*: (1) Freeport, 20-27-VI-1987, colls. W. E. Steiner, M. J. & R. Molineaux (NMNH); *MAYAGUANA ISL.*: (1) 27-VIII-1963, black light trap, coll. C. Murvosh (FSCA). DOMINICA: (1) 5 mi. E. Dublanc, 1250', 20-VIII-1986, C. W. and L. O'Brien (O'Brien Collection); (2) 4 mi. E. Salisbury, 19-VIII-1986, C. W. and L. O'Brien (O'Brien Collection); (1) Morne Trois Pitons N. P., Freshwater Lake Rd., 2600', 13-VIII-1986, C. W. and L. O'Brien (O'Brien Collection); (1) Trafalgar Falls, ca. 1200', 12-VIII-1986, C. W. and L. O'Brien (O'Brien Collection). DOMINICAN REPUBLIC: (1) Prov. Barahona, Barahona, 9-VI-1998, black light trap, colls. P. H. Freytag, B. K. Dozier, & R. E. Woodruff (R. E. Woodruff Collection). GUADELOUPE: (2) Duclos, 25-VI-1971, colls. J. A. Slater, R. M. Baranowski, J. E. Harrington (J. A. Slater Collection). JAMAICA: (1) Parish of St. Ann, 3 Mi. W. Ocho Rios, 4-VII-1971, colls. J. A. Slater, R. M. Baranowski, J. E. Harrington, A. [adults] and N. [nymphs] under *Ficus* sp. (UNAM); (1) Parish of St. Catherine, Worthy Park, 10-VI-1975, black light trap, coll. R. E. Woodruff (FSCA). MARTINIQUE: (1) 12 km. N. Fort de France (N-3), 23-VIII-1986, C. W. and L. O'Brien

(O'Brien Collection). PUERTO RICO: (1) Municipio de Lares, near Lares, at cross of roads 129 and 134, from leaf litter and soil picked at mouth of Cueva Golondrinas (across from Cueva Catedral), 31-VII-1999, coll. J. Brambila (FSCA). SABA: (1) Mt. Scenary [Mount Scenery], 800-840 m., 12-14-I-1968 (UNAM). TRINIDAD AND TOBAGO, *TRINIDAD*: (2) Arima Valley, 800-1200 ft., 10-22-II-1964, colls. Rosen & Wygodzinsky collectors (AMNH); (3) St. George Co., Simla, Arima Valley, 12-VII-1978, black light trap, coll. M. Ramla (NMNH). BRAZIL: (6) Pernambuco, Caruaru, 900 m., IV-1972, coll. M. Alvarenga (AMNH); (1) same, V-1972 (AMNH); (4) same, V-1972, J. Lima (AMNH); (1) [State of Rio de Janeiro], Guanabara, Corcovado, XI-1971, coll. M. Alvarenga (AMNH).

The following are previously unpublished collection records from Cuba, St. Vincent Isl., and Panama (unpublished records from Florida are numerous and will be presented in a different manuscript): CUBA: (1) Baraguá, T.P.R.F., Ent. No. 379, at light, coll. C. F. Stahl (AMNH). ST. VINCENT ISL.: (4) Charlotte Parish, 3 Mi. N.W. Georgetown, 21-VI-1973, 2000', under *Ficus* sp., colls. R. Baranowski, F. O'Rourke, V. Picchi, J. Slater (UNAM). PANAMA: (1) Barro Colorado [Isl.], CZ [Canal Zone], VIII-IX-1949, Berl. funnel, Zetek 5427 (NMNH); (1) Cerro Campana, 800 m., R. de Pan. [Republica de Panama], 8°40'N, 79°56'W, 28-IV-1973, coll. Engleman (J. A. Slater Collection).

Valeris Brambila, **NEW GENUS**

Type species: *Cligenes subcavicola* Scudder, Darlington & Hill, 1967. Monobasic.

Gula wide and shallow with bucculae meeting in a round arc (Fig. 25). Pronotum with lateral margins sinuate, explanate and upturned (Figs. 5 & 26), posterior margin concave. Transverse division between pronotal lobes moderately impressed. Metathoracic scent gland auricle straight, with apex pointed, elevated, and directed posteriorly at a diagonal (Fig. 27). Anterior half of lateral corial margin expanded and upturned. Trichobothria on abdominal tergites IV and V in linear configuration, with trichobothria on tergite V closer to each other than to trichobothrium on segment IV, and posterior trichobothrium of segment V directly below spiracle of segment V to slightly caudad (Fig. 28). Fore femur with two rows of spines (Fig. 29), spines of posterior row larger in males than in females. Male genital capsule, paramere, and spermatheca as in Figs. 30-34; capsule with a median caudal projection (Fig. 33).

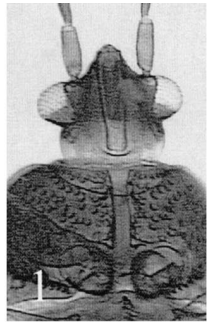
ETYMOLOGY. The name Valeris is from a Russian dancer. Learning about dance history is one of the author's interests.

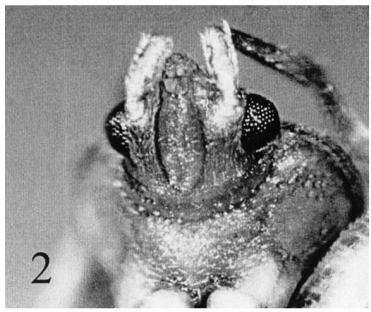
Valeris subcavicola was originally placed in the antillocorine genus *Cligenes* due to the explanate pronotal lateral carina. However, *Valeris* differs from *Cligenes* by lacking a groove for the labium on the prosternum (Fig. 26) and by having a caudal projection on the genital capsules of the males (Fig. 33). It differs from *Cligenes* also by having only the anterior trichobothrium on abdominal sternal tergite V anterior to the spiracle of tergite V (Fig. 19) and by having two rows of spines on the fore femur instead of a single row (Fig. 18). *Valeris* also differs from *Botocudo* Kirkaldy because the type species of *Botocudo* (*B. diluticornis* [Stål]) has the two posterior trichobothria on segment V located dorso-ventrally in a diagonal relative to each other, lacks spines on the fore femur, and the pronotal lateral carinae are not explanate and upturned.

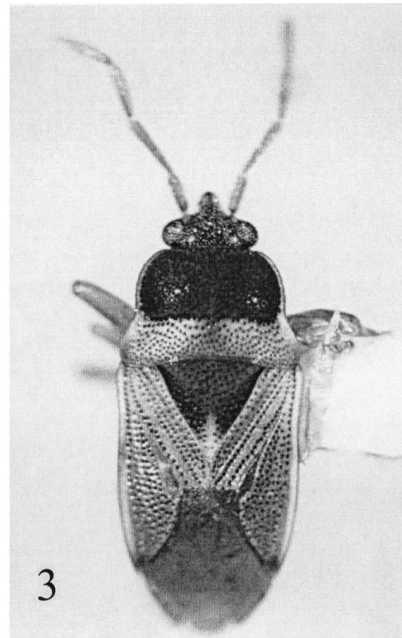
Valeris subcavicola (Scudder, Darlington & Hill), **NEW COMBINATION**
(Figs. 2, 5, 25-34)

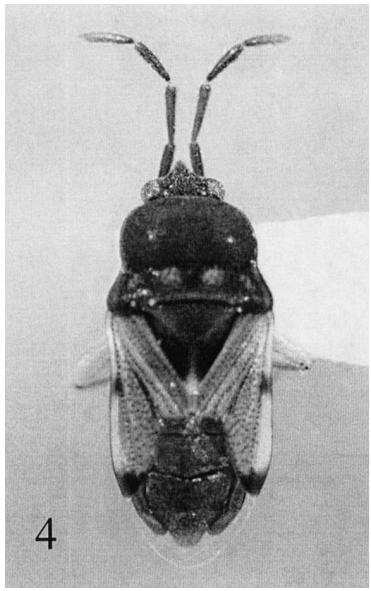
Cligenes subcavicola Scudder, Darlington and Hill, 1967: 465-469

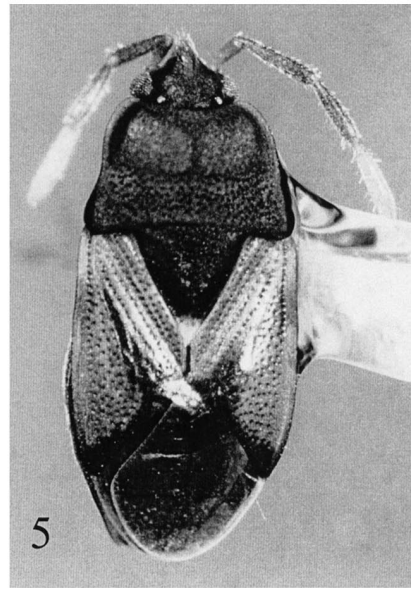
Male, female, immatures, and eggs were described by Scudder, Darlington and Hill, but not illustrated. For antillocorines, *V. subcavicola* is large, with the holotype male











Figs. 1-5. 1: *Cligenes grandis*, n. sp., ventral view of prosternum, photograph. 2: *Valeris subcavicola*, n. comb. (Trinidad), ventral view of head, photograph. 3: *Cligenes grandis*, n. sp., dorsal view, photograph of holotype. 4: *Cligenes distinctus* (Trinidad), dorsal view, photograph. 5: *Valeris subcavicola*, n. comb., dorsal view, photograph.

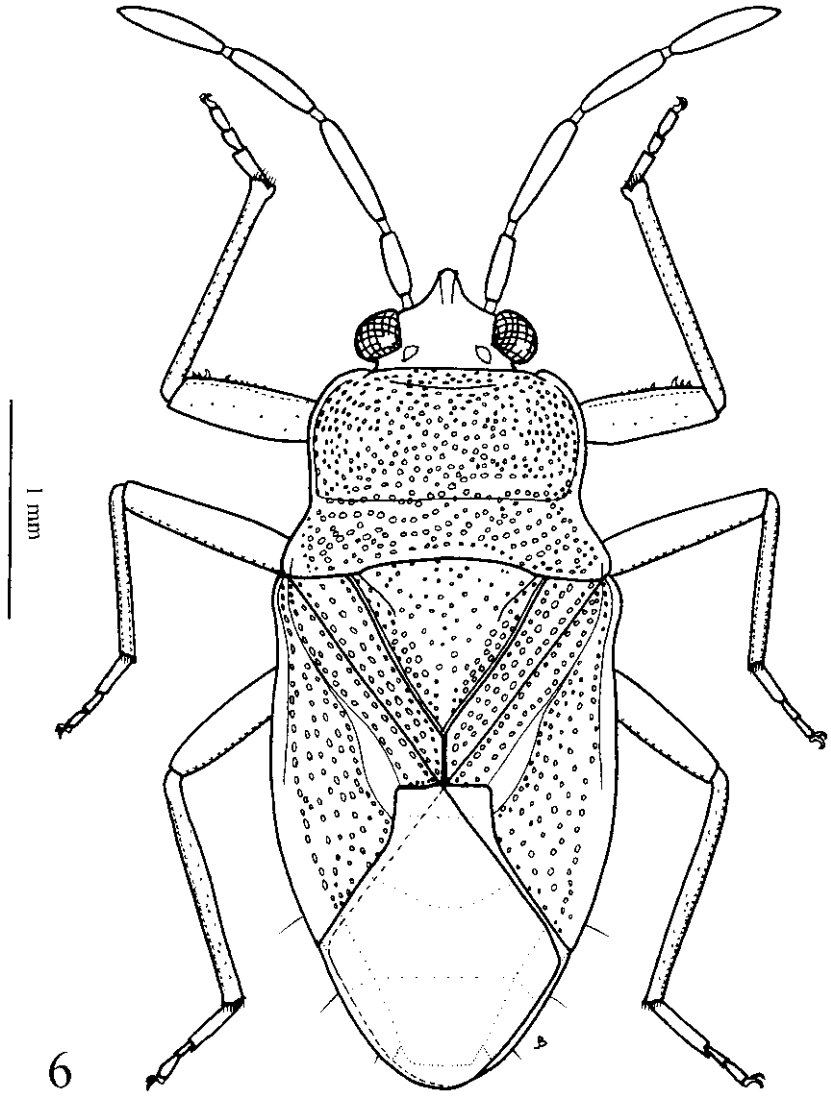
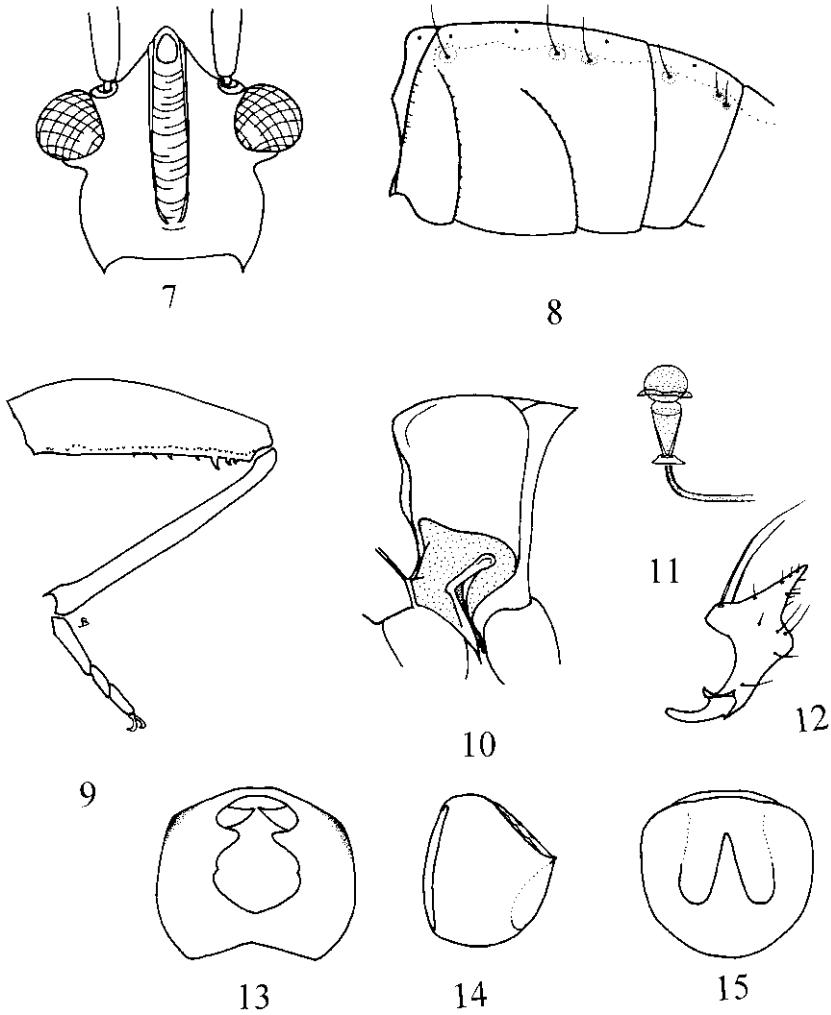


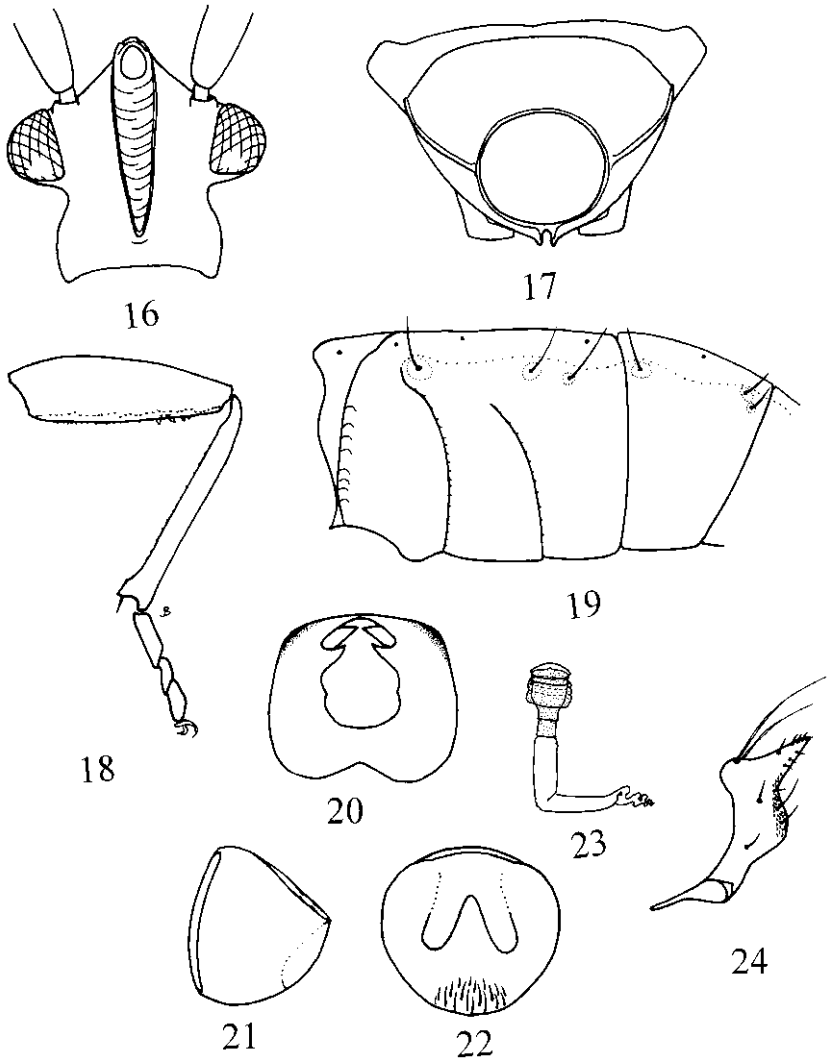
Fig. 6: *Cligenes grandis*, n. sp., dorsal view, illustration.

3.10 mm and a female 3.11 mm in length, both measured to the end of the membrane. Specimens from Peru are even larger, reaching 3.54 mm to the end of the body. Scudder, Darlington and Hill indicated that the mesosternum and metasternum of only *C. subcavicola* has a median irregular keel. However, examination of other antillocorines, including *C. distinctus*, shows this to be a widely shared character, not unique to *C. subcavicola*; furthermore, the median keel is also present on the prosternum in *Valeris* and in other antillocorine genera, though usually visible only between the forecoxae.



Figs. 7-15. *Cligenes grandis*, n. sp., illustrations, not to scale. 7: head, ventral view; 8: abdominal sternites 3-6, lateral view; 9: fore leg, anterior view; 10: metathorax, scent gland auricle, evaporative area; 11: spermatheca; 12: right paramere; 13-15: genital capsule dorsal view, lateral view, and caudal view.

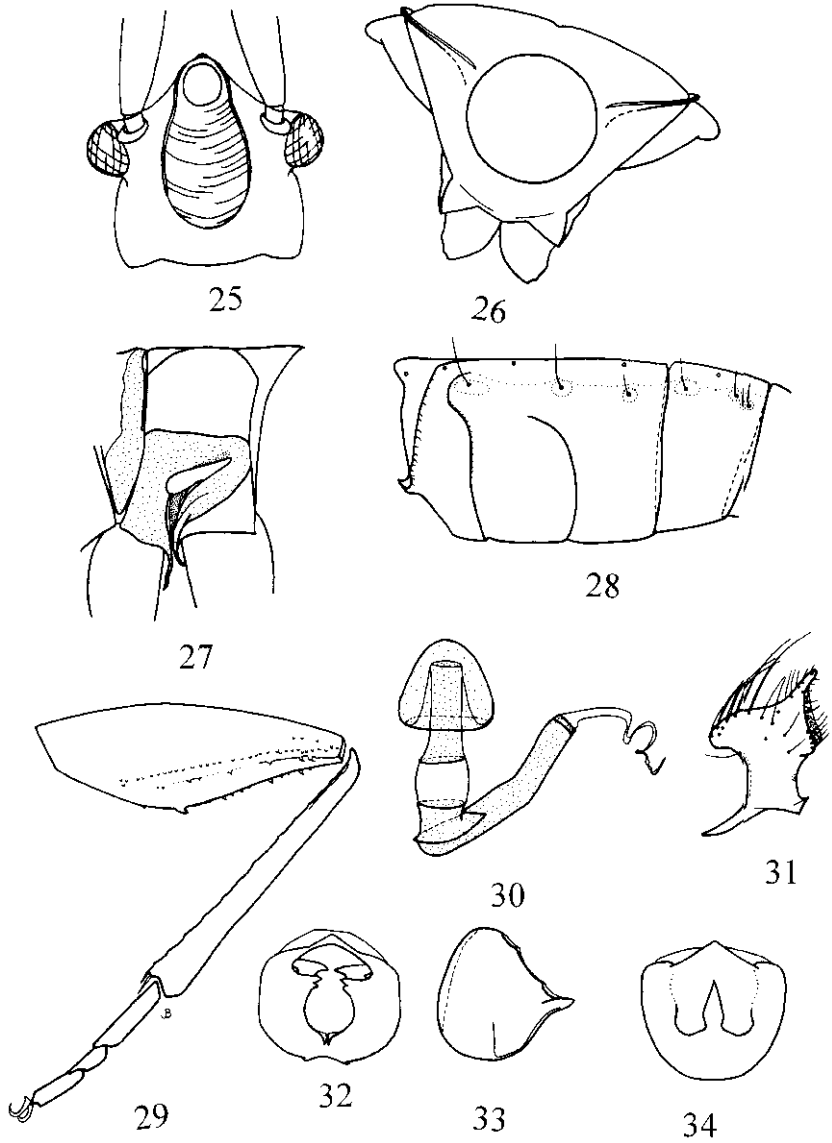
These authors indicated as well that males differed from females by having "fore tibia slightly curved and crenulate to inside"; however, both males and females have a crenulated inner surface of the tibia and only an occasional male has the fore tibia slightly curved. *Valeris subcavicola* is apparently quite variable in pronotal shape and color; the pronotum color ranges from yellowish brown, to reddish brown, to very dark brown, with the anterior lobe varying in amount of convexity in profile. No reliable structural differences have been found. I believe that the above variants belong to a single species.



Figs. 16-24. *Cligenes distinctus*, illustrations, not to scale. 16: head, ventral view; 17: pronotum, anterior view; 18: fore leg, anterior view; 19: abdominal sternites 3-6, lateral view; 20-22: genital capsule dorsal view, lateral view, and caudal view; 23: spermatheca; 24: right paramere.

DISTRIBUTION. This species is now known to occur in Trinidad, Panama, Venezuela, Brazil, and Peru (Fig. 35).

BIOLOGY: *Cligenes subcavicola* was described from 145 specimens collected in the Tamana Caves in the Central Range Forest Reserve in Trinidad on 28-VI-1966 by J. P. E. C. Darlington and S. B. Hill. Interestingly, in 1954, thirty-seven specimens of



Figs. 25-34. *Valeris subcavicola*, n. comb., illustrations not to scale. 25: head, ventral view; 26: pronotum, anterior view; 27: metathorax, scent gland auricle, evaporative area; 28: abdominal sternites 3-6, lateral view; 29: fore leg, anterior view; 30: spermatheca; 31: right paramere; 32-34: genital capsule dorsal view, lateral view, and caudal view.

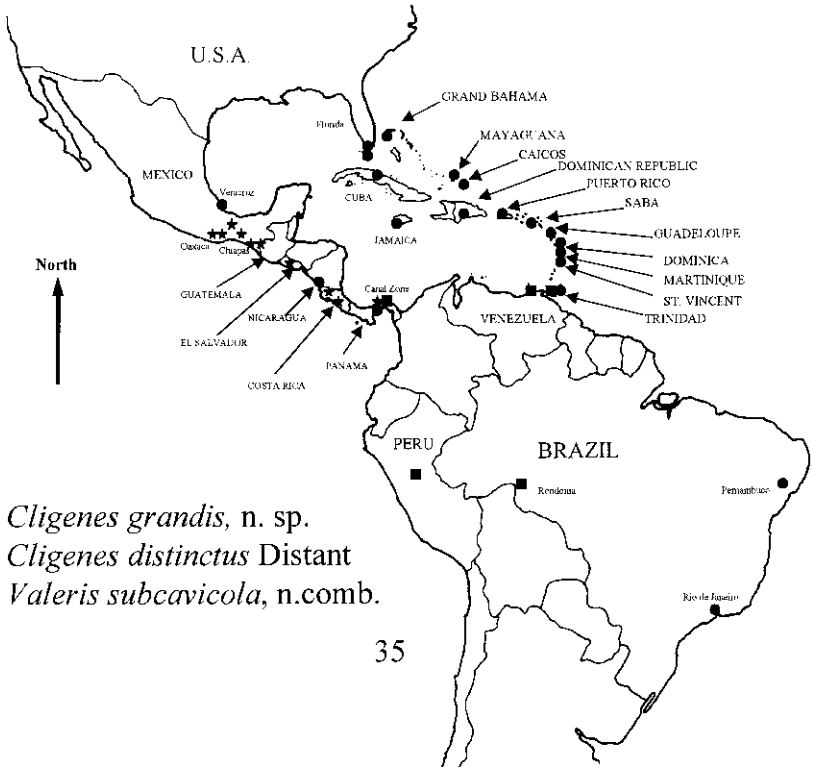


Fig. 35. Collection sites of *Cligenes grandis* n. sp. (stars), *Cligenes distinctus* (circles), and *Valeris subcavicola* n. comb (squares).

this species had been collected in the Monson Cave in Peru. It has subsequently been collected in other caves in Trinidad, Peru, and Venezuela, and in an abandoned building in Trinidad, as explained below. In Brazil, however, it was collected in 1992 and 1993 only in ultraviolet and mercury vapor light traps. Scudder et al. (1967) mentioned that rearing in the laboratory was done for months with "nothing but the guano and its associated fauna", not indicating if they fed upon seeds or other organisms in the bat guano. Slater (1984) reported observations in 1971 by Dr. R. T. Schuh in Lechuzas Cave in Peru that this species was confined to the outer-most chamber, not deeper and not immediately outside of the cave either. Schuh described the guano as containing thousands of tiny seeds mixed with soil and bat and parrot guano, a great proportion of the seeds being of one of more species of *Ficus*. Slater (1984) reported this species in great numbers feeding in the upper layers of bat guano in an abandoned building at Simla, Trinidad, which housed a large colony of bats. The guano contained many seeds of *Piper*. Slater observed that small seeds were seen carried on the end of the rostrum, as I also have seen with *Cligenes distinctus* in Florida.

This species was reported by Scudder, Darlington and Hill (1967) as the first record of Lygaeidae living and breeding in caves. Slater (1984) described a second cave dwelling species, *Botocudo cavernicola*, from New Guinea, this species and *V.*

subcavicola being "the only lygaeids thus far known to live in caves where both feed on mature seeds that have passed through the digestive tracts of frugivorous bats." However, neither of the species show "any of the adaptations usually associated with true cavernicoles such as loss of body pigmentation and reduction of the wings, eyes, and ocelli" (Slater 1984).

Ueshima and Ashlock (1980) illustrated the chromosomes of *Valeris subcavicola* and reported that chromosome cytology during meiosis was unusual, differing from that in other known antillocorines. During metaphase I in *V. subcavicola* the X and Y chromosomes locate in the center of the autosomal ring, while the micro-chromosome pair, which does not pair during meiotic prophase, tends to locate on the periphery with the 6 pairs of autosomes. The two m-chromosomes normally locate in the center of the autosomal ring together with the sex chromosomes.

MATERIAL EXAMINED: TRINIDAD: (324) St. George Co., Arima-Blanchisseuse Rd., Simla, 23-IX-1979, feeding on seeds in bat guano in old building, coll. R. M. Baranowski (293 RMB, 31 NMNH); (115) St. Andrew Co., Tamana Caves, 27-IX-1979, coll. R. M. Baranowski (100 RMB, 15 NMNH); (13) St. Andrew Co., Tamana Main Cave, Upp. Pt. 6, in guano, 25-II-1989, coll. J. P. E. C. Darlington (AMNH); (1) St. George Co., Arima, Guanapo Valley Rd., guano, Berlese funnel, 15-VII-1979, coll. L. N. Sorkin (AMNH); (1) Simla, 23-VII-1982, in dry bat guano, colls. J. A. Slater, R. M. Baranowski, R. Clayton (UNAM); (9) St. George Co., Guanapo Cave, in guano, 8-VII-1989, coll. Darlington (AMNH); (12) St. George Co., Lopinot, Darceuil Cave, 11-IX-1989, coll. J. P. E. C. Darlington (AMNH); (11) St. George Co., Lopinot, Colada Cave, 4-X-1989, coll. J. P. E. C. Darlington (AMNH). Also examined were the following paratypes: (5) Trinidad, Tamana Caves, Main Cave, on bat guano, 28-IV-1966, colls. J. Darlington & S. E. Hill (4 AMNH, 1 UNAM). PERU: (3) Cueva de las Lechuzas, ca. Tingo maria, 12-VII-1968, colls. L. & C. W. O'Brien (NMNH); (5) Huanuco Prov., Cueva de Lechuzas, near Tingo Maria, on floor cave, 12-VII-1968, colls. C. W. & L. B. O'Brien (AMNH); (42) Huanuco, Cueva de las Lechuzas, 10 km NW Tingo Maria, 30-XI-1971, colls. R. T. & J. C. Schuh (AMNH); (2) Peru (RMB); (4 on one card), Dep. Huan., Cueva de las Lechuzas, Tingo Maria, 800 m., Bordon leg, 16-V-1972 (UNAM); (9) Depto. Huanuco, Cueva de las Lechuzas, Tingo Maria, 3-IV-1974, coll. P. Reyes C. (UNAM); (48) Tingo Maria, in dry bat guano, 20-VII-1980, coll. M. J. W. Cock (RMB); (37, including 6 nymphs), Monson Cave, Tingo Maria, 15-XII-1954, colls. E. I. Schlinger & E. S. Ross (36 CASC, 1 UNAM). BRAZIL: 1 ♀ Brazil, Rondonia, 62 Km. S.W. Ariquemes, nr Fzda. Rancho Grande, mercury vapor & black lights, 30-III-10-IV-1992, coll. J. E. Eger (NMNH); 1 ♀ Brazil, Rondonia, 62 Km. S.W. Ariquemes, nr Fzda. Rancho Grande, 5-17-X-1993, black light trap, coll. J. E. Eger (FSCA); 1 ♀ Brazil, Rondonia, 62 Km. S.W. Ariquemes, nr. Fzda. Rancho Grande, black light trap, 8-IX-1993, coll. U. Schmitz (FSCA). VENEZUELA: 2 ♀ Edo. Miranda, 20 Km. W. Curiepe, Cueva Alfredo Jahn, 200m., guano, 7-III-1971, coll. S. Peck (NMNH). PANAMA: 1 ♀ Coco Solo Hosp., C. Z., light trap, 9-VI-1973, coll. D. Engleman (J. A. Slater Collection).

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SWIMMING BEHAVIOR OF AN AQUATIC WEEVIL, *LISSORHOPTRUS ORYZOPHILUS* (COLEOPTERA: CURCULIONIDAE)

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ABSTRACT

The swimming behavior of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) is unique in comparison to that of most other aquatic weevils. Propulsion during swimming is provided only by the mesothoracic legs. The legs are moved synchronously during protraction and retraction. The pro- and metathoracic legs serve as diving planes and provide stability. The average rice water weevil swimming speed was 1.53 (±0.15 SE) cm per s with a range of 0.88 to 2.52 cm per s. Weevils averaged 5.67 (±0.22 SE) strokes per s.

The mode of swimming by *L. oryzophilus* differs from those described for *Phytobious leucogaster* (Marsham) (= *Litodactylus leucogaster), P. comari* (Herbst), *Bagous cavifrons* LeConte, *B. americanus* LeConte and *B. limosus* Gyllenhal. It also differs from descriptions of swimming for other aquatic Coleoptera and Hemiptera. Furthermore, *L. oryzophilus* swims below the surface and was observed at depths of 18.0 cm in the laboratory. This brings the modes of free swimming (exclusive of skating) to at least 3 by adult aquatic curculionids.

Key Words: Rice water weevil, barrier trap, aquatic weevils, swimming behavior

RESUMEN

El comportamiento de natación del gorgojo acuático de arroz, *Lissorhotrus oryzophilus* Kuschel (Coleoptera: Curculionidae) es único en comparación a la mayoría de los gorgojos acuáticos. La propulsión durante la natación es proveída solamente por las piernas del mesotórax. Las piernas son movidas sincrónicamente durante la protracción y retracción. Las piernas del pro- y metatórax sirven como planos de inmersión y proveen estabilidad. La velocidad de natación promedio del gorgojo acuático de arroz fue 1,53 (±0,15 SE) cm por s con una variación entre 0,88 hasta 2,52 cm por s. Los gorgojos tuvieron un promedio de 5,67 (±0,22 SE) patadas por s.

El modo de natación en *L. Oryzophilus* difiere de otros descritos para *Phytobious leucogaster* (Marsham) (=*Lytodactylus leucogaster*), *P. Comari* (Herbst), *Bagous cavifrons* LeConte, *B. Americanus* LeConte and *B. Limosus* Gyllenhal. También difiere de descripciones de natación para otros acuáticos de Coleptera y Hemiptera. Además, *L oryzophilus* nada bajo la superficie y fue observado a profundidades de 18,0 cm en el laboratorio. Esto eleva los modos de natación libre (exclusivo de patinaje) hasta por lo menos 3 por adultos acuáticos de Curculionidae

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The rice water weevil *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) is the key insect pest of rice, *Oryza sativa* L., in the U.S. (Way 1990). This weevil is native to North America (O'Brien & Wibmer 1982), but has been introduced into

Japan, Korea, Taiwan, India and China (Nagata 1990, Barwal et al. 1994). This weevil is about 2 mm in length and overwinters as an adult. Reproduction is sexual in its native range and parthenogenetic in California and areas where introduced (Takenouchi 1978). The aquatic adults feed on rice leaves, although rice is not its natural host plant. The fully aquatic larvae feed on rice roots and can cause yield reduction. Even though it is the major insect pest of rice in the U.S., published information about adult behavior is limited (Stout et al. 2000). More is known about larval *L. oryzophilus* aquatic behavior and adaptations than adult aquatic behavior and adaptations. The larvae have six pairs of dorsal hooks on abdominal segments two through seven which are associated with the tracheal system (Isely & Schwardt 1930). These hooks are thought to tap root tissues to obtain air. They may also aid in larval locomotion.

Lissorhoptrus LeConte typically have curved blade-like mesotibia equipped with long swimming hairs on the inner and outer margins (O'Brien 1996). Underwater respiration by adult *L. oryzophilus* is accomplished by a plastron (Hinton 1976).

Nachtigall (1974, 1985) reviewed swimming in adult insects, but descriptions for swimming in weevils were lacking. O'Brien & Marshall (1979) described swimming in the weevils *Bagous cavifrons* LeConte and *B. americanus* LeConte. These weevils swim with "dog paddle" strokes with the prothoracic legs and push with the alternation of the meso- and metathoracic legs against the surface tension. This was consistent with the description given for the mode of swimming in *B. limosus* Gyllenhall (Angus 1966, Menier 1970). Furthermore, *Bagous lunatoides* Blatchley and *B. pictus* Blatchley do not swim (O'Brien & Marshall 1979). These weevils were reported to walk on the upper and lower side of the surface tension. *Litodactylus leucogaster* (Marsham), a junior synonym of *Phytobius leucogaster* (Marsham) (O'Brien & Wibmer 1982), swims on the surface using all three pairs of legs for propulsion (Buckingham & Bennett 1981). Legs on the same segment are typically moved synchronously with the prothoracic legs being retracted while the meso- and metathoracic legs are being protracted. The metathoracic legs of *P. leucogaster* did not appear to contribute much power to propulsion in comparison to the pro- and mesothoracic legs. *Phytobious comari* (Herbst) efficiently swims by using all 6 legs (Read 1985). *Eubrychius velatus* Beck (= *Phytobious velatus*) was reported to be an excellent swimmer (Ruter 1978, Morris 1991). The genus name literally means "good swimmer" and the specific epithet means "velvet" referring to the plastron formed by the hydrofuge scales (Morris 1976, 1991). Langer & Messner (1984) described the plastron of *E. velatus*, *B. longitarsis* Thompson, *B. argillaceus* Gyllenhal, *B. binodulus* Herbst, *B. glabrirostris* Herbst, and *B. puncticois* Boheman. However, descriptions of swimming behavior in *E. velatus* are lacking in the literature. Swimming by *Euhrychiopsis lecontei* (Dietz) was reported (Solarz & Newman 1996), but descriptions of the mode of swimming are lacking.

Two basic modes of swimming have been described in aquatic beetles which are different from swimming systems described for aquatic weevils. Hughes (1958) studied the leg movements of free swimming *Dytiscus marginalis* (L.) (Coleoptera: Dytiscidae) and *Hydrophilus piceous* (L.) (Coleoptera: Hydrophilidae) from films. Further studies of dytiscids were done by Gewecke (1980, 1985) and Gewecke & Rostock (1986). Typically, medium to larger dytiscids use the meso- and metathoracic legs for swimming with the pair on the same segment protracting and retracting simultaneously (Nachtigall 1974, 1985). The mesothoracic legs may row alternately or synchronously with the metathoracic legs. In hydrophilids, retraction of a left mesothoracic leg occurs simultaneously with the right metathoracic leg, and the right mesothoracic leg retracts simultaneously with the left metathoracic leg. Meso- and metathoracic legs play an important part in swimming in *D. marginalis* and *H. piceos* with the prothoracic legs held stationary close to the thorax.

Lissorhoptrus oryzophilus has a unique swimming behavior in comparison to most other aquatic insects. Information on the adult swimming behavior of *L. oryzophilus* was needed to aid in the development of an aquatic intercept trap to monitor adult populations in flooded rice fields. Such a trap may help to determine the need for and appropriately time applications of the adulticide λ-cyhalothrin (Karate®, Zeneca Ag Products, Wilmington, DE) or the ovicide diflubenzuron (Dimilin®, Uniroyal Chemical Company, Middleburry, CT) and prevent unnecessary applications. The larvicide carbofuran (Furadan®, FMC, Philadelphia, PA) was no longer registered for use in rice after 1998, and new population monitoring methods compatible with λ-cyhalothrin and diflubenzuron are urgently needed (Stout et al. 2000). The objectives of this study were to 1) describe the swimming behavior of *L. oryzophilus*, 2) determine *L. oryzophilus* swimming speed, depth and response to barriers encountered, and 3) compare *L. oryzophilus* swimming behavior and survival in water with that of terrestrial weevils and other aquatic insects.

Materials and Methods

Adult *L. oryzophilus* were collected from newly flooded rice fields at the Rice Research and Extension Center in Stuttgart, AR 8 June 1998 and 9 August 1999. The weevils were placed in containers with rice plants and transported to Fayetteville, AR. Adults of the plum curculio *Conotrachelus nenuphar* (Herbst), and the rice weevil *Sitophilus oryzae* (L.), were collected near Fayetteville, AR.

Adult weevil swimming sequences of 25 *L. oryzophilus*, 10 *C. nenuphar* and 10 *S. oryzae* were videotaped from a: 1) dorsal view in a Petri dish, 2) lateral view in an aquarium, and 3) ventral view in a Petri dish. Videotaping equipment consisted of an Optem Zoom 70 macro lens (Optem International, Fairport, New York) mounted on a CCD color video camera and a S-VHS tape deck. The Petri dish had graduations on the bottom to determine swimming speed of the weevils. Videotaping was conducted while the weevils swam freely between 10:00 a.m.-2:00 p.m. and 4:00 p.m-8:00 p.m. with an air and water temperature of 24°C. The video tape was evaluated in real time and by manual advancing to determine leg movements during swimming sequences. *Lissorhoptrus oryzophilus* swimming movements were compared to descriptions of swimming of dytiscid (Hughes 1958), hydrophilid (Hughes 1958), curculionid (O'Brien & Marshall 1979, Buckingham & Bennett 1981), belostomatid (Lauck 1959), nepid (Wendler et al. 1985) and notonectid adults. Videotape sequences of 20 weevils were used to determine average weevil swimming speeds.

Individuals of *L. oryzophilus* were placed in an aquarium (18.9 liters) with a water depth of 18.0 cm to determine the weevils response when encountering a 10.0 cm by 35.0 cm screen barrier positioned perpendicular to the surface of the water. This experiment was replicated with 100 weevils. Reactions of swimming weevils were recorded when the screen barrier was encountered. An event recorder (Unwin & Martin 1987) was used to calculate the amount of time each weevil spent swimming at depths of 0-3.0, 3.0-6.0, 6.0-9.0, 9.0-12.0, 12.0-15.0, and 15.0-18.0 cm for a 5 min period per weevil.

Thirty weevils of each species were placed in an aquarium with no resting places and monitored every 12 h to determine the status (alive or dead) until all weevils were dead or 120 h had elapsed. Notes were taken on the status (alive or dead) of 9,416 *L. oryzophilus* weevils removed from 32 aquatic barrier traps every 24 h over a 9 d period during August 1999. The trap design is described by Hix et al. (2000).

Results and Discussion

Lissorhoptrus oryzophilus swims beneath the surface film. Propulsion for *L. oryzophilus* during swimming is provided only by the mesothoracic legs. The legs are

moved synchronously during protraction (Fig. 1a-d) and retraction (power stroke) (Fig. 2a-c). The swimming hairs on the mesotibia were deployed at the onset of retraction. The prothoracic legs (extended forward) and metathoracic legs (extended backwards) serve as diving plains and stabilizers (Figs. 1 and 2). Turning is accomplished with the mesothoracic leg opposite the direction of the turn going through normal protraction and retraction sequences and the mesothoracic leg on the turn side going through a shorter protraction and retraction sequence as depicted in Fig. 3. Paddling on the turn side tends to be across the body. The average rice water weevil swimming speed was 1.53 (±0.15 SE) cm per s with a range of 0.88 to 2.52 cm per s. Weevils averaged 5.67 (±0.22 SE) strokes per s with a stroke consisting of a complete protraction and retraction.

The terrestrial weevil *C. nenuphar* was able to swim only marginally by using tripod type movements associated with insect walking as described by Hughes (1952). The other terrestrial weevil *S. oryzae* was less successful at using tripod type movements for swimming and frequently struggled in the surface film.

Lissorhoptrus oryzophilus spent 82.9% of their time swimming between the surface film and a depth of 6.0 cm and 17.1% between 6.0 and 18.0 cm (Fig. 4). Only 5.3% of the weevils swam deep enough to actually go under the 10 cm by 35 cm barrier. When encountering the barrier during swimming, 53 weevils turned right and mi-

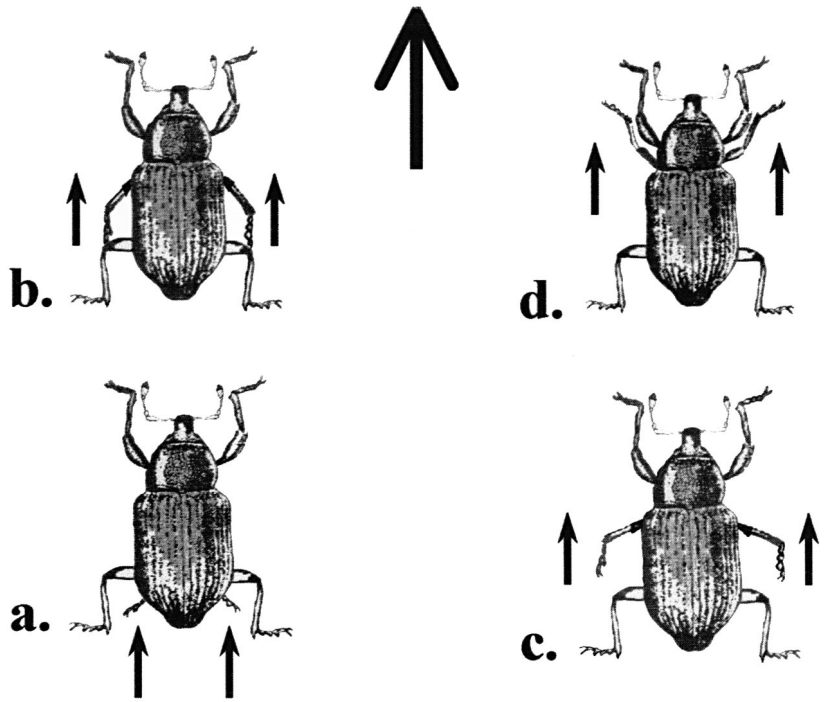

Fig. 1. Protraction sequence (a-d) by *Lissorhoptrus oryzophilus* during swimming. Large arrow indicates the direction of insect travel. Small arrows indicate direction of mesothoracic leg movement. Swimming hairs are folded during this sequence.

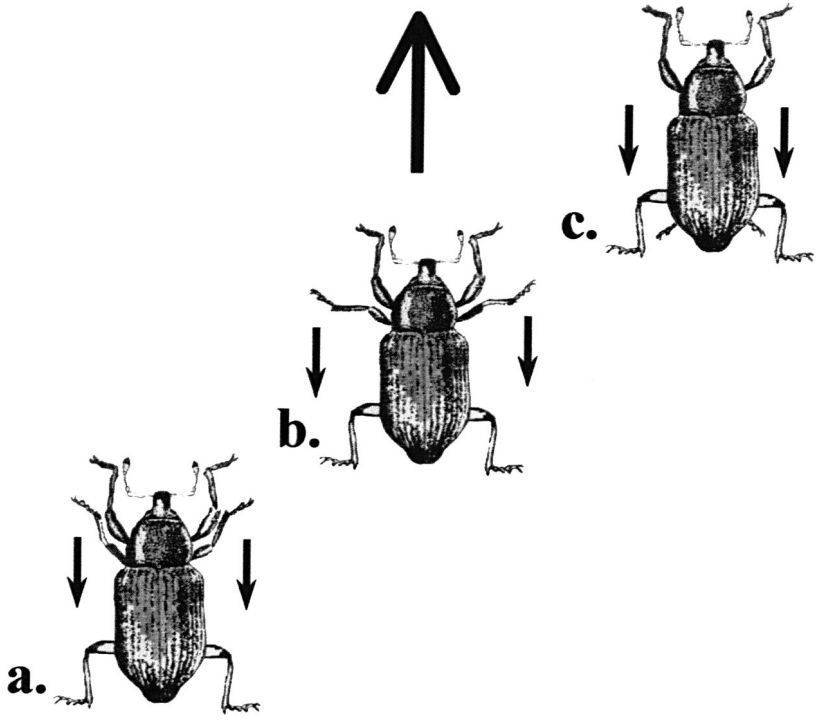

Fig. 2. Retraction sequence (power stroke) by *Lissorhoptrus oryzophilus*. Large arrow indicates direction of insect travel. Small arrows indicate direction of movement of mesothoracic legs. Swimming hairs on the mesotibia are deployed between a and b.

grated along the barrier, 39 weevils turned left and migrated along the barrier, 7 weevils clung to the barrier, and 1 weevil failed to contact the barrier.

Twenty-seven *S. oryzae* expired by 12 h and all 30 had expired by 24 h. Seven *C. nenuphar* expired by 24 h, and all had expired by 36 h. All 30 *L. oryzophilus* placed in the aquarium were still alive and swimming after 120 h which was consistent with the reports by Blatchley & Leng (1916) that *L. simplex* (Say) could stay submerged for over 96 h. In a revision of *Lissorhoptrus,* Kuschel (1952) recognized *L. simplex* (Say) as *L. simplex* and *L. oryzophilus*. Of the 9,416 *L. oryzophilus* removed from the barrier traps in August 1999, only 38 of them had expired.

The mode of swimming in *L. oryzophilus* is different from those described for *P. litodactylus, B. cavifrons*, and *B. americanus* (O'Brien & Marshall 1979, Buckingham & Bennett 1981). It is also different from descriptions of swimming for other aquatic Coleoptera and Hemiptera. Furthermore, *L. oryzophilus* swims efficiently beneath the surface film and was observed at depths of 18.0 cm in the laboratory.

It appears unique for adult beetles in a family to have more than 1 mode of free swimming. There are at least 3 modes of free swimming by adult aquatic curculionids. In addition, some aquatic curculionids can walk on either side of the surface tension (O'Brien & Marshall 1979). An informal generic group of aquatic weevils in the tribe Stenopelmini, subfamily Erirhininae are referred to as the "rice water weevils"

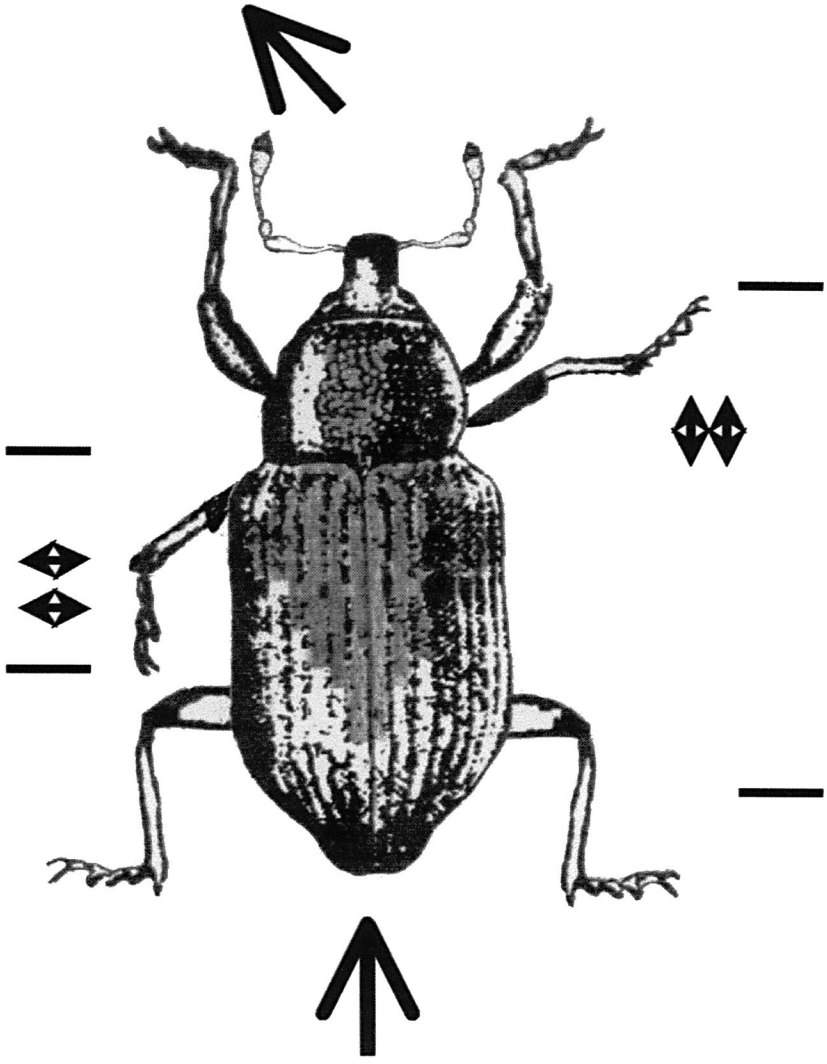

Fig. 3. Left turn sequence by *Lissorhoptrus oryzophilus*. Large arrows indicate direction of insect travel. Small double arrows indicate direction of mesothoracic leg movements. Lines mark the range of leg movement during turn. Mesothoracic leg movement is shorter on the turn side with turn side strokes across the body at an oblique angle.

(O'Brien 1990). This informal group consists of the following New World genera: *Bagoidellus* Hustache, *Bagoidus* Kuschel, *Helodytes*° Kuschel, *Hydrotimetes** Kolbe, *Ilyodytes** Kuschel, *Lissorhoptrus**, *Neobagoidus* O'Brien, and *Oryzophagus** Kuschel. Adults in the "rice water weevil" group for which swimming behavior is known (indicated by *) have a similar mode of action to the one described in this paper for *L. oryzo-*

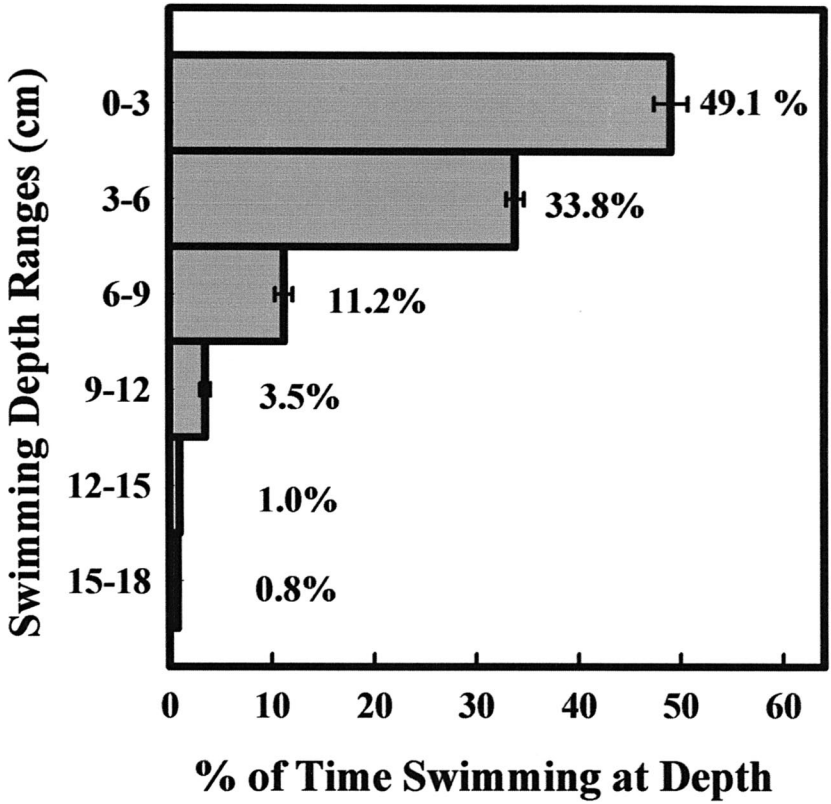

Fig. 4. Percentage of time that adult *Lissorhoptrus oryzophilus* spent swimming at 3.0 cm intervals to a maximum depth of 18.0 cm. The observation period for each weevil was 5 min (n = 100). Error bars represent S**EM**.

philus (C. W. O'Brien, Center for Biological Control, Florida A & M University, personal communication). Furthermore, some skate on the surface. *Poophagus sisymbrii* (F.) skates by using each pair of legs as sculls (Morris 1976, 1991, 1995). It is apparent that swimming and skating behavior is diverse in adult aquatic curculionids and more studies are needed in this area of weevil behavior.

The information learned from these studies was used in part to develop an aquatic barrier trap to sample *L. oryzophilus,* a key pest of rice in the U.S., within 10 d after applying permanent flood to rice fields. The barrier trap functions passively by intercepting swimming weevils much like a Malaise trap functions by intercepting flying insects. Development of the sampling tool for *L. oryzophilus* adults is an important part of the future integrated pest management program for rice.

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NOTES ON THE LIFE HISTORY AND MATING BEHAVIOR OF *ELLYCHNIA CORRUSCA* (COLOEPTERA: LAMPYRIDAE)

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ABSTRACT

Population dynamics and reproductive activity were examined in a Massachusetts population of the common diurnal firefly, *Ellychnia corrusca*. Although closely related to nocturnal beetles in the genus *Photinus*, *Ellychnia* lack adult light organs. A mark-recapture study of overwintering adults demonstrated low winter mortality and supported the hypothesis that adults overwinter for a single year. By dissecting males and females sampled throughout late winter and spring, it was found that adults become reproductively active in early March, when male seminal vesicles first contained sperm and female ovaries first contained mature oocytes. Both sexes mated multiply during the approximately six-week mating season (early April through mid-May), and copulations lasted up to 28 h. Adults collected in fall had higher abdominal fat body volumes than those collected in spring, and females contained more fat body than

males. The life history and mating behavior of *E. corrusca* are discussed in comparison to *Photinus* fireflies.

Key Words: diapause, firefly, *Photinus*, population dynamics

RESUMEN

Dinámicas de población y actividad reproductiva fueron examinadas en una población de Massachussets de la luciérnaga común diurna, *Ellychnia corrusca*. Aunque están cercanamente relacionados a escarabajos en el genero nocturno *Photinus*, adultos de *Ellychnia* carecen órganos de luz. Un estudio de marca-recaptura de adultos que sobre-inviernan demostró mortalidad baja en invierno y apoyo la hipótesis que adultos sobre-inviernan por solo un año. Al disecar machos y hembras muestreados durante un periodo tarde en el invierno y primavera, se encontró que adultos se convierten activos reproductivamente temprano en Marzo, cuando las vesículas seminales contienen esperma por primera vez y los ovarios de las hembras contienen oocitos maduros por primera vez. Ambos sexos aparearon múltiples veces durante la temporada de apareamiento de aproximadamente seis semanas (temprano en Abril hasta mitad de Mayo), y copulaciones duraron hasta 28 h. Adultos colectados en otoño tuvieron volumen de grasa de cuerpo abdominal mas altos que esos colectados en primavera, y las hembras contuvieron mas grasa de cuerpo que los machos. La historia de vida y comportamiento de apareamiento de *E. corrusca* es discutido en comparación a luciérnagas de *Photinus*.

The *Ellychnia corrusca* L. species complex enjoys a wide geographical distribution across the eastern United States (Fender 1970). These beetles are conspicuous early spring inhabitants of forest habitats, yet little has been published on their life history or mating behavior. Williams (1917) reported that captive *E. corrusca* adults overwintered and mated in early spring. Adults have been described feeding on maple sap in spring, and on aster and goldenrod flowers in fall (Dillon & Dillon 1972).

In contrast to most other lampyrids, adult *Ellychnia* are diurnally active and are not luminescent, although light organs are present in larvae (Williams 1917). Based on external morphology, the genus *Ellychnia* has been placed in the same subtribe (Photinina) as the nocturnal firefly genus *Photinus* (LeConte 1881, McDermott 1964). A recent phylogeny based on mitochondrial cytochrome oxidase II sequence confirms a close association between *Ellychnia* and *Photinus*, and suggests quite recent divergence of these two genera (van der Reijden 1996).

E. corrusca also shows internal reproductive anatomy similar to that described for several *Photinus* species (van der Reijden et al. 1997, Rooney & Lewis 1999). During copulation, males transfer a complex, proteinaceous spermatophore to females. The male spermatophore is internally digested over the next several days within the female reproductive tract. Allocation of spermatophore-derived protein differs markedly between *E. corrusca* and *Photinus ignitus* (Rooney & Lewis 1999): *E. corrusca* females allocate male-derived protein primarily to somatic tissue (particularly fat body), while *P. ignitus* females allocate such nutrients mainly to maturing oocytes.

This study was conducted to elucidate additional aspects of *E. corrusca* life history and mating behavior. Overwintering survival was studied using mark-recapture methods, and reproductive status was monitored by dissecting males and females sampled at intervals throughout the winter and spring. Additional observations of feeding and mating behavior were made both in the field and laboratory.

Materials and Methods

Study Populations

The main study population occurred in a mixed pine and deciduous forest at the Habitat Sanctuary of the Massachusetts Audubon Society, located in Belmont, MA. Additional feeding observations were conducted on field populations at Wellesley College, Wellesley, MA, and additional observations of mating behavior were conducted in Lincoln, MA. The taxonomy of *Ellychnia* species has been difficult to resolve, especially within three complexes in the eastern United States (Fender 1970). Following Fender (1970), we refer to these large-bodied *Ellychnia* as *E. corrusca*, and individuals in this population ranged from 6 to 13 mm elytral length (Fig. 1).

Mark-recapture Study

The Belmont site was chosen for mark-recapture because the *E. corrusca* population is largely confined to a discrete area, occupying grooves in the bark of three Eastern black oaks (*Quercus velutina*): on adjacent trees there were few or no beetles. To estimate monthly survival of overwintering adults, *E. corrusca* were marked and resampled approximately every month from their fall appearance (October 1997) to spring dispersal (April 1998). Beetles were given date-specific marks on their left or

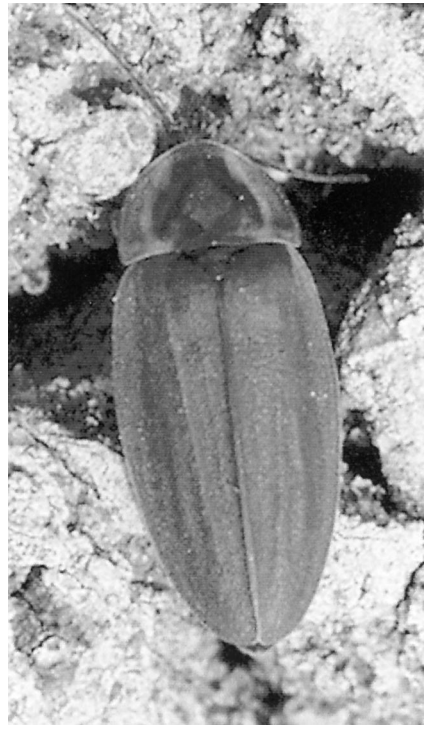

Fig. 1. Adult *E. corrusca* in overwintering position on bark of *Quercus velutina* (beetle length 1.3 cm).

right elytron using different colors of Mitsubishi UniPaint Fine Line PX-21 markers. At each census, the three *Q. velutina* trees were carefully searched from the ground up to 2 m height, and all observed *E. corrusca* adults were marked. Existing marks were recorded and used to determine for each beetle when it had most recently been caught. A total of 825 individuals were marked. Survival was estimated using Jolly-Seber methods designed for open populations (Greenwood 1996). Emigration out of the marked population during winter months was probably negligible since no *E. corrusca* adults were observed flying between late September and mid-March. Beetles did show limited walking movement along the bark surface during this time, but were never observed moving between trees. Thorough search of tree surfaces at each census and low overall mortality/emigration helped ensure that the Jolly-Seber assumptions of equal catchability of marked and unmarked beetles and no effect of marking on mortality or emigration were both met.

The proportion of the population surviving (and remaining in the study area) from the i^{th} to the $(i + 1)^{th}$ census, Φ_i, was calculated as:

$$\Phi_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i}$$

where $\hat{M}$ is the number of known previously-marked individuals present, m_i is the number of previously-marked individuals sampled at the i^{th} census, and R_i is the number of individuals released after the i^{th} census (Greenwood 1996).

Timing of Reproductive Activity

To determine when *E. corrusca* adults become sexually mature, 10 males and 10 females were collected biweekly from 26 Feb to 19 April 1998, and monthly from August 1998 to November 1999. Individuals were frozen and later dissected to determine their reproductive status. Van der Reijden et al. (1997) provide details of male and female reproductive anatomy for *Photinus ignitus,* which closely resembles that of *E. corrusca* (Rooney and Lewis 1999). In males presence/absence of sperm bundles within the seminal vesicles and presence/absence of a pre-spermatophore within the spiral accessory glands were recorded. In females the number of mature oocytes (distinguished by diameter ≥600 μm) and presence/absence of developing follicles within the ovarioles were recorded. In addition, presence/absence of sperm in the female's spermatheca (sperm storage organ) was assessed by examining spermathecal contents at 400X.

To examine seasonal changes in stored resources for overwintering *E. corrusca* adults, the volume of abdominal fat body was estimated using the same beetles collected above. For each beetle, fat body nodules were carefully dissected out and placed in a graduated 1.5 ml microcentrifuge tube; samples were spun 30 s at 1000 rpm (Eppendorf microcentrifuge model 5415C), after which total fat body volume (in μl) was measured to the nearest 10 μl. Fat body differences between fall (August through November) and spring (late February through May), as well as sex differences, were examined using a fixed effects two-way ANOVA.

Mating and Feeding Behaviors

Feeding observations on *E. corrusca* adults were made in May 1997 and April-June 1998 at the Wellesley and Belmont sites. General behavioral observations were made throughout winter 1998-99 at the Belmont site. Mating behavior was observed at

times ranging from 0500 to 2100 hours during spring 1998 at Lincoln and Belmont sites. During April and May 1998, copulation durations and frequency of remating were determined from beetles kept in the laboratory in population cages and in pairs under natural photoperiod at room temperature (18-24°C).

RESULTS

Overwintering Mortality and Population Dynamics

Survival of overwintering *E. corrusca* adults estimated by mark-recapture at the Belmont site was high, with monthly survival ranging from 88% to 99% (Fig. 2). In spite of this high overall survival, additional observations suggest freezing and predation may be potential sources of mortality. During periods of below-freezing temperatures, several immobile, intact, adults were found on their backs in snow; some revived when warmed but one individual was dead. In addition, detached *E. corrusca* wing covers (some with V-shaped notches) were found at the base of overwintering trees in January and again in mid-April. In neither case was there any apparent mortality bias for marked vs. unmarked beetles.

While the *E. corrusca* population remained fairly constant through the winter (November through March), number of adults on trees declined dramatically beginning in April and continuing through May (Fig. 3). During late fall and winter (from 28 September to 7 March) adults were never observed to fly and could not be induced to do so, but by 18 March beetles flew back to the tree when held a short distance away and released. Starting in early March, adults also showed increased movement along the bark surface. Mating pairs were observed on trees from early April to mid-May.

From June through July 1998, no *E. corrusca* adults were found on trees at the Belmont study site, but adults began to congregate on the same three *Q. velutina* trees the following August (Fig. 3). Although a total of 825 *E. corrusca* adults had been marked the previous winter and spring, there were no marked beetles among these fall adults.

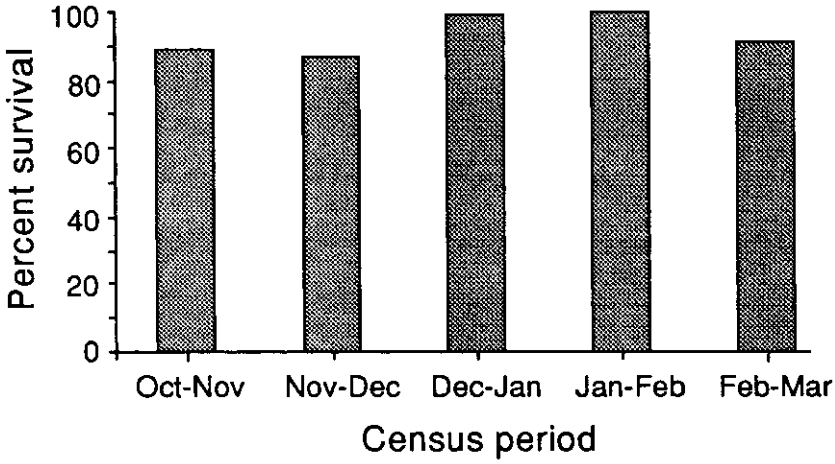

Fig. 2. Monthly survival determined by mark-recapture in a population of *E. corrusca* adults in Belmont, Massachusetts during 1997-98.

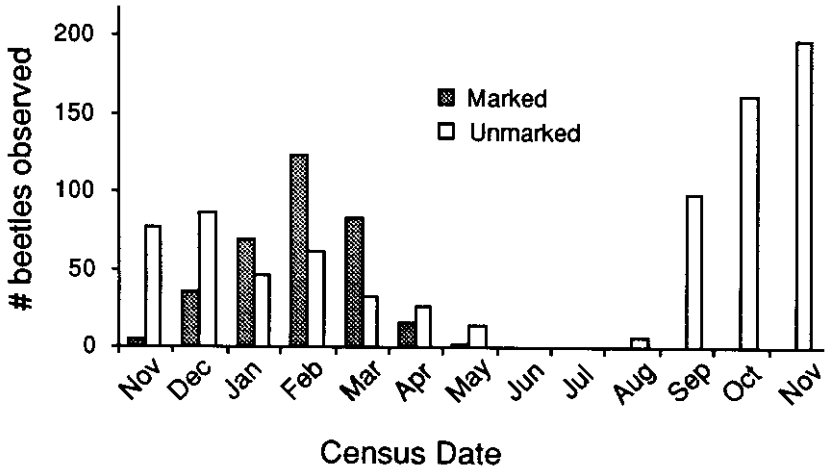

Fig. 3. Number of marked and unmarked *E. corrusca* adults during monthly censuses in Belmont, Massachusetts population during 1997-98.

Timing of Reproductive Activity

Although no mating pairs were observed until early April, there was a steady increase in reproductive readiness exhibited by both sexes beginning in mid-March. In females, this was marked by increasing numbers of mature oocytes present in female reproductive tracts (Fig. 4A) as well as by an increase in the percentage of females that contained sperm in their spermatheca (Fig. 4B). In contrast, females collected in fall and late winter were reproductively inactive, lacking both mature oocytes and any developing follicles. Fall-collected females also lacked sperm in their spermathecae.

A similarly-timed increase in reproductive readiness was observed for males, measured by the presence or absence of sperm in the seminal vesicles (Fig. 5). Males collected in fall and late winter lacked sperm in their seminal vesicles, while beginning in early March an increasing percentage of males contained sperm. Similarly, all spring-collected males contained pre-spermatophores in their spiral accessory glands, while pre-spermatophores were absent from all males collected during late winter or fall.

Fall-collected beetles (August through November) had higher mean volume of abdominal fat body compared to individuals collected in spring (February through May) (Fig. 6; fall vs. spring 2-way ANOVA $F_{(1,186)} = 179.9$, $p < 0.0001$). Fat body volume was higher for females across sampling dates (male vs. female, $F_{(1,186)} = 5.03$, $p = 0.026$; no significant interaction, $F_{(1,186)} = 0.2$, $p = 0.684$). Both sexes retained nearly 50% of maximum fat body volume when the mating season ended in May.

Feeding Behavior

Adult *E. corrusca* at the Wellesley site fed actively in early May on floral nectaries of *Acer platanoides L.* (Norway maple). At the Belmont site, adults were found in early April near sap flows on *Acer saccharum* (sugar maple) trees that had not been used for overwintering sites, and *E. corrusca* are commonly found drowned in sap-collecting buckets (Wihbey 1999). Throughout spring mating season, both males and females

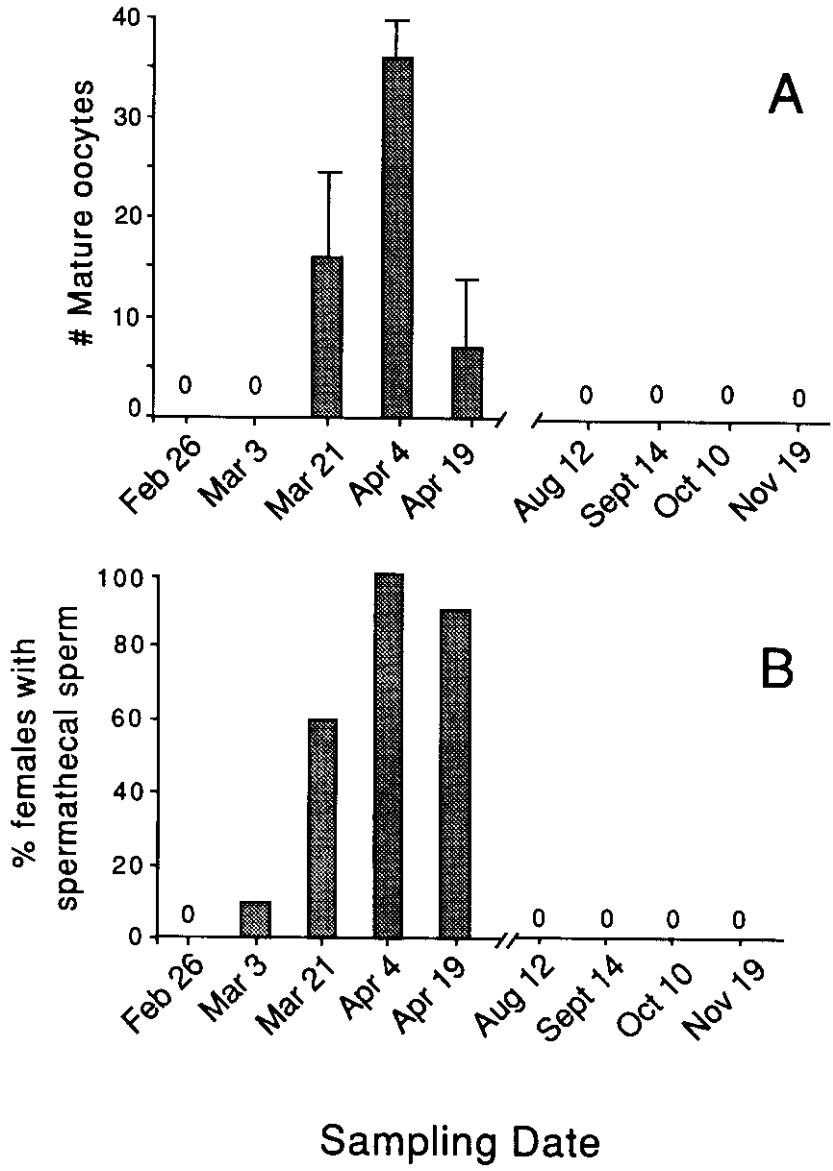

Fig. 4. Reproductive activity of *E. corrusca* females collected from Belmont, Massachusetts in 1998 (n = 10 females per sampling date). A) Mean (+1 SEM) number of mature oocytes (diameter ≥600 μm). B) Percent of females with sperm present in spermatheca (sperm storage organ).

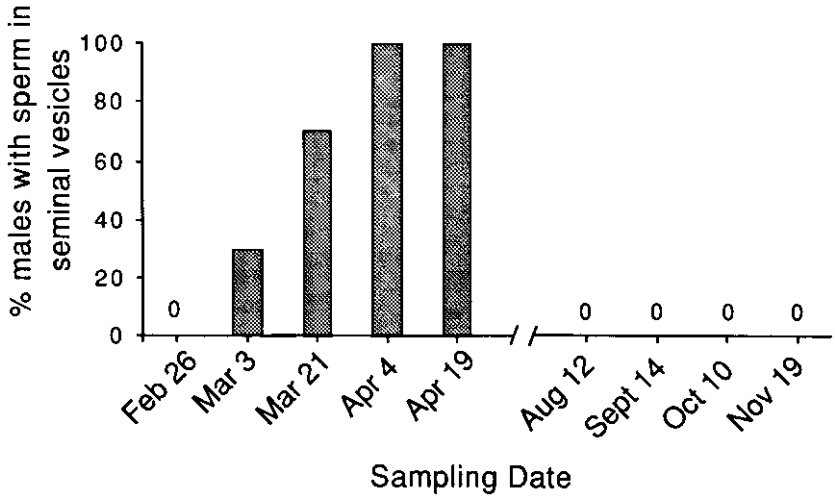

Fig. 5. Reproductive activity of *E. corrusca* males collected from Belmont, Massachusetts as percentage of males with sperm present in seminal vesicles (n = 10 males for each sampling date).

were occasionally found on soil at the base of trees, apparently drinking interstitial fluid. Although previous work has reported that *E. corrusca* adults appear on goldenrod and aster flowers in fall (Dillon & Dillon 1972), no beetles were observed on these flowers in late summer or fall, although these plants were abundant near known overwintering trees.

Mating Behavior

Copulating pairs were first found in the field on 7 April, although pairs mated in the lab as early as 17 March. The mating season lasted approximately six weeks, with the latest observed field copulation occurring on 21 May. *E. corrusca* mating took place primarily on tree trunks, but pairs were occasionally found at tree bases. Observations revealed two distinct stages of copulation, similar to those described for *Photinus* fireflies (Lewis & Wang 1991). During stage I, which lasted from 2 to 30 min, the male mounted the female dorsally, actively wiping his antennae across the female pronotum while contacting the junction between the female's pronotum and elytra with his maxillary palps. Stage II began when the male swiveled around to face in the opposite direction, and lasted for several hours. During stage II pairs often moved considerable distances. Because of their mobility it was difficult to measure field copulation durations; two monitored field copulations lasted 23.5 h and more than 15.5 h.

Copulation initiation was not limited to any specific time of day, as pairs were observed beginning stage I from 0730 h to 1800 h. Both males and females walked actively along the tree surface, and often contacted many beetles of the opposite sex before males initiated stage I by dorsally mounting a female. During stage II copulating pairs frequently contacted other adults, but no apparent interactions were observed.

In the lab males and females mated repeatedly, and field-collected adults lived up to 21 days. Individual males in either population cages or pairs observed in the lab

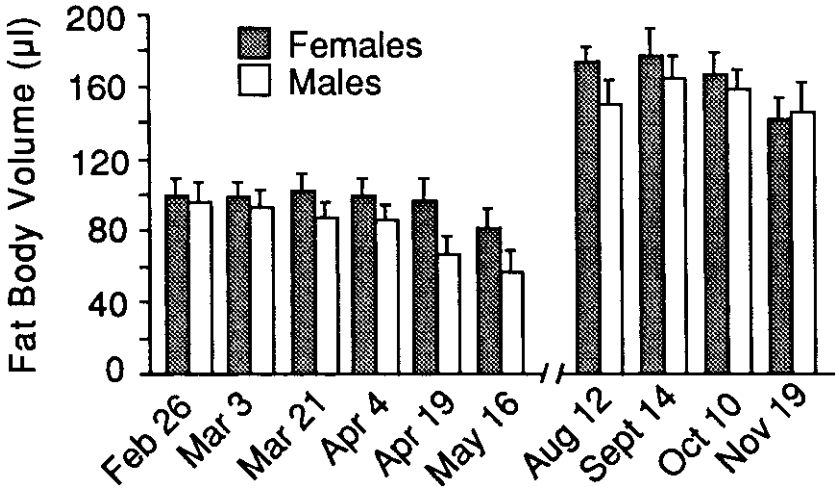

Fig. 6. Mean (+1 SEM) volume of fat body in male and female *E. corrusca* collected from Belmont, Massachusetts in 1998-1999 (n = 10 of each sex for each sampling date, except n = 5 of each sex for 16 May).

mated between 0 and 11 times, with a median of 3 lab matings per male (n = 9 males). Males that mated more than once often mated on consecutive days, with a median 2 d interval between matings (based on 32 matings for 7 males that mated more than once). Females mated between 1 and 11 times, with a median of 4 matings per female (n = 7 females), and a median inter-mating interval of 1.5 d (based on 32 matings for 5 females that mated more than once). In population cages or pairs, copulation durations ranged from 1.7 h to 28 h, with a median of 12.5 h (n = 34 copulations). Females oviposited in moss and on moist filter paper, and greater than 90% of eggs kept at 28°C and 70%RH hatched in 16 (±2) d.

Discussion

This mark-recapture study revealed high overwintering survival of *E. corrusca* adults, confirming Williams' (1917) limited observations based on 18 adults confined in a windowbox. Our field observations also indicate that some overwintering mortality may be caused by freezing and predation (possibly by birds or small mammals). However, predation on *E. corrusca* adults may be minimized by chemical deterrents. When disturbed, *E. corrusca* adults exhibit reflex bleeding similar to that described for other lampyrids (Blum & Sannasi 1974), and their extremely bitter taste (personal observation) suggests the presence of lucibufagins (Eisner et al. 1978) or related compounds.

This study suggests that in New England *E. corrusca* spends approximately 10 months as adults (August through May), overwintering a single year. *E. corrusca* collected in fall exhibit extensive fat body reserves typical of pre-diapausing adults (Leather *et al.* 1993), and reduced fat body in spring-collected adults suggest a portion of stored reserves are used for metabolic maintenance during overwintering. *E. corrusca* mate in early spring on their overwintering trees, with onset of reproductive activity perhaps triggered by temperature or daylength cues (Leather *et al.* 1993). Adults die in late spring or early summer, and *E. corrusca* adults that appear on trees

the following fall probably represent newly emerging individuals from eggs laid in spring. Several lines of evidence support this interpretation of *E. corrusca* life history. While 825 overwintering adults were marked in fall and winter 1997-98, no marked individuals were found among hundreds of adults observed on the same trees between August 1998 and June 1999. Additional evidence suggesting that fall- collected *E. corrusca* adults have recently emerged is that these females appear to have not yet mated, based on their inactive ovaries and absence of sperm in their spermathecae.

Several aspects of *E. corrusca* life history, including their diurnal activity, adult feeding and overwintering, and early spring mating period distinguish them from most other lampyrids (Lloyd 1997). However, in reproductive anatomy and occurrence of male spermatophores *E. corrusca* closely resembles *Photinus* fireflies (Lewis & Wang 1991, van der Reijden *et al*. 1997, Rooney & Lewis 1999). This study demonstrates further similarities in copulatory behavior, with *E. corrusca* exhibiting two copulatory stages described for *Photinus* (Lewis & Wang 1991), and spermatophore transfer occuring approximately 1 h after stage II begins (J. A. R., unpublished data). Copulation durations lasting up to 24 h beyond the time required for spermatophore transfer may function as copulatory mate guarding (Alcock 1994) in *E. corrusca*.

The life-history differences described in this study may explain some differences in female allocation of spermatophore-derived protein between *P. ignitus* and *E. corrusca*. *P. ignitus* females allocate 62% of male-derived protein to their developing oocytes, with 27% allocated to female somatic tissue (Rooney & Lewis 1999). In contrast, *E. corrusca* females allocate male-derived protein primarily to somatic tissue (64%), particularly fat body, with lower allocation to oocytes (21%). Thus, *E. corrusca* females may rely on both male-donated nutrients and adult feeding to support egg production over the course of their mating season.

E. corrusca is unusual among lampyrid beetles in its diurnal activity period and lack of bioluminescent courtship signals (Lloyd 1997). This shift in activity period may be associated with low nightly temperatures during the early spring mating season, which may preclude nocturnal flight and bioluminescent courtship display. Future studies on lampyrid phylogeny will help shed light on the evolution of life histories and mating behavior within this family.

Acknowledgments

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STATUS OF PIGEONPEA AS AN ALTERNATIVE HOST OF *PIEZODORUS GUILDINII* (HEMIPTERA: PENTATOMIDAE), A PEST OF SOYBEAN

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ABSTRACT

Pigeonpea, *Cajanus cajan* (L.) Millsp. (Leguminosae), was found hosting *Piezodorus guildinii* (Westwood) (Hemiptera: Pentatomidae) in Paraná State, Brazil. In the laboratory, nymphs performed better on immature pods of soybean, *Glycine max* (L.) Merrill (Leguminosae), than on immature pods of pigeonpea. Although nymphs required similar time to complete development, and attained similar weights at adult emergence, mortality was much lower on soybean (57.7%) than on pigeonpea (94.4%). Adult *P. guildinii* also performed better on soybean than on pigeonpea. Females and males showed similar longevity on both foods, but 34.5% of females oviposited on soybean compared to 10.3% on pigeonpea, with an oviposition delay of 26 days on pigeon-

pea compared to soybean. Fecundity (eggs/females) was 6.5× greater on soybean than on pigeonpea, and adult body weight gain after 14 and 28 days was 13-23% greater on soybean than on pigeonpea. *P. guildinii* also showed greater feeding activity on, and greater feeding preference for, soybean than pigeonpea. Bugs colonized soybean during summer and early autumn (January-March), and pigeonpea during autumn, early winter (April-July), and spring (October-November). These results indicate that pigeonpea, although a less preferred and less suitable plant food source of *P. guildinii* in Brazil, plays an important role to the bug's life history by serving as a temporary host.

Key Words: *Cajanus cajan, Glycine max,* food effect, food preference, seasonal abundance, stink bug

RESUMO

O guandu, *Cajanus cajan* (L.) Millsp. (Leguminosae) foi encontrado abrigando *Piezodorus guildinii* (Westwood) (Hemiptera: Pentatomidae) no Estado do Paraná, Brasil. Em laboratório, as ninfas tiveram um desempenho melhor quando alimentadas com vagens imaturas de soja, *Glycine max* (L.) Merrill (Leguminosae), do que quando alimentadas com vagens de guandu. Embora as ninfas tenham requerido um tempo semelhante para completar o desenvolvimento e obtido pesos semelhantes na emergência, a mortalidade foi menor em soja (57,7%) do que em guandu (94,4%). Os adultos de *P. guildinii* mostraram um desempenho melhor em soja do que em guandu. Fêmeas e machos tiveram longevidades semelhantes em ambos alimentos; 34,5% das fêmeas ovipositaram em soja e 10,3% em guandu, com um atrazo na oviposição de 26 dias no guandu em comparação com a soja. A fecundidade (ovos/fêmeas) foi 6,5× maior em soja do que em guandu, e o ganho de peso dos adultos após 14 e 28 dias foi de 13 a 23% maior em soja do que em guandu. *P. guildinii* também mostrou maior atividade alimentar em, e maior preferência alimentar por, soja do que guandu. Os percevejos colonizaram a soja durante o verão e início do outono (janeiro a março), e o guandu durante o outono e início do inverno (abril a julho) e durante a primavera (outubro a novembro). Esses resultados indicam que, no Brasil, o guandu, embora sendo uma planta menos preferida e menos adequada para *P. guildinii*, desempenha um papel importante na história da vida desse percevejo, servindo como um hospedeiro temporário.

The neotropical stink bug *Piezodorus guildinii* (Westwood) (Hemiptera: Heteroptera: Pentatomidae) feeds on several species of wild and cultivated plants, mostly legumes. Among the wild plants, legumes of the genus *Indigofera* are preferred (Panizzi 1992), while among the cultivated plants, soybean, *Glycine max* (L.) Merrill, is the most important host throughout South America and particularly in Brazil (Panizzi & Slansky 1985).

We have recently observed *P. guildinii* feeding and reproducing on pigeonpea, *Cajanus cajan* (L.) Millsp. (Leguminosae), near Londrina (latitude 23°11'S, longitude 51°11'W), in Paraná State of Brazil. This legume is grown commercially on several continents (Lateef & Reed 1990). Pigeonpea is attacked by several species of pentatomids (Lateef & Reed 1990, Panizzi & Oliveira 1998, Shanower et al. 1999). In Central America, *P. guildinii* is reported to occur on this legume (Saunders et al. 1983). Because *P. guildinii* was also observed to feed and to reproduce on this legume, and because its biology has never been investigated on pigeonpea, a study was carried out on the nymph and adult performance and adult feeding preference, using soybean for comparison. We also surveyed the population of *P. guildinii* on pigeonpea to determine its abundance on this host plant throughout the seasons, and on soybean during its reproductive period.

Materials and Methods

Laboratory Study, Nymphs

During December 1997 and January 1998, adults of *P. guildinii* were obtained from a soybean culture established in the Embrapa Field Experiment Station, at Londrina Co., northern Paraná. They were taken to the laboratory and placed in plastic boxes (11.0 × 11.0 × 3.5 cm), and fed with soybean pods (immature) cultivar 'BR-16'. Egg masses were collected on the day of oviposition and placed in 9.0 × 1.5 cm Petri dishes with moistened filter paper. On the 1st day of the second stadium (first instars do not feed), nymphs were removed and placed individually in Petri dishes. Immature pods of pigeonpea (cv. 'IAPAR-43') and soybean (cv. 'BR-16') were offered. Ninety nymphs were used for each food.

Petri dishes were placed at random in an environmental chamber maintained at 25 ± 1°C and 65 ± 5% r.h. with a photoperiod of L14:D10. From January to March 1998, daily observations were made on moulting and mortality, and food was replaced every 2 days. Nymphal development time and percentage mortality from 2nd instar to adult were calculated. Fresh body weight at adult emergence was taken using an electronic balance. Data on nymphal development time and fresh body weight at adult emergence were analyzed and means compared using student's *t* test.

Laboratory Study, Adults

During March 1998, *P. guildinii* adults were collected using a sweep net from hairy indigo, *Indigofera hirsuta* L., growing on roadsides in the Londrina area. Adults were taken to the laboratory and placed in plastic rearing boxes (12.0 × 12.0 × 3.8 cm). Adults and their progenies were fed immature pods of hairy indigo. When nymphs reached adulthood, single female/male pairs were each placed in a plastic rearing box with moistened filter paper. Twenty nine pairs were fed immature pods of pigeonpea and another 29 immature pods of soybean. Food was replaced every 2 days.

During April-June 1998, daily observations were made on adult survival and reproduction. Female age at first oviposition, number of females ovipositing, numbers of egg masses, numbers of eggs/mass, and numbers of eggs hatching were counted. Adults were weighed at days 1, 14, and 28 of adult life. Data of these reproductive parameters and weight gain on both foods were analyzed using one-way ANOVA and means compared using student's *t* test and Duncan's multiple range test ($P \leq 0.05$).

From additional adults obtained in the laboratory reared on hairy indigo, feeding preference tests comparing the feeding activity on pigeonpea and on soybean seeds were conducted. In the first test, after 5 days of adult emergence, bugs were held without food for 1 day in the presence of water, and on the 7th day they were placed singly in 9.0 × 1.5 cm Petri dishes with moistened filter paper and put in an environmental chamber maintained at 25 ± 1°C and 65 ± 5% r.h. with a photoperiod of L14:D10. They were offered mature seeds (turgid seeds previously embebbed in water for 12 hours) of pigeonpea (cv. 'IAPAR-43') and soybean (cv. 'Ocepar-16'), and were allowed to feed for 2 days. For each food 45 seeds were used. After this period the seeds were removed, embebbed in an acid fuchsin solution (1%) for 30 minutes. The excess of fuchsin was removed with running tap water, the seeds were air dried and examined under a dissecting microscope, and the number of flanges or external parts of the stylet sheaths (Nault & Gyrisco 1966) recorded. Mean number of flanges deposited on each type of food was calculated and compared using student's *t* test.

A second test was run, following the same procedures described above, except that in this case the seeds of pigeonpea and soybean were offered separately.

Field Survey

An additional study to survey the population of *P. guildinii* nymphs and adults on pigeonpea was conducted. From May 1996 to April 1997, weekly samples (each sample = 10 sweeps with an insect net) were taken on a pigeonpea plantation (unknown cv) at the Embrapa Station. The mean (±SEM) number of *P. guildinii*/sample/month was calculated. Data are expressed as the mean number of bugs for each month throughout the year.

From December1996 to March 1997 weekly samples (n = 15 weeks) were taken on soybean using the Boyer & Dumas (1963) plant-shake method as modified by Shepard et al. (1974). It consisted of bending the soybean plants of l m of two parallel rows over a heavy plastic sheet put on the ground. Insects were dislodged by shaking the plants and were counted and recorded. Based on 10 weekly samples (2 m of soybean row each); the mean number of bugs/month/sample was calculated.

RESULTS

Laboratory Study, Nymphs

Nymphal development time for each stadium and for total nymphal period were similar on pigeonpea and soybean, however, the 3rd stadium showed statistically significantly differences (Table 1). Total nymphal mortality was much greater on pigeonpea (94.4%) than on soybean (57.7%); the majority of nymphs died during the 2nd instar on both foods (Table 1) At adult emergence no significant differences in fresh body weight were observed (Table 1).

TABLE 1. MEAN ±SEM DEVELOPMENTAL TIME, % NYMPHAL MORTALITY, AND FRESH BODY WEIGHT OF 1-D-OLD ADULT *PIEZODORUS GUILDINII* FEEDING ON IMMATURE PODS OF PIGEONPEA OR SOYBEAN IN THE LABORATORY.

	Host[1]					
	Pigeonpea			Soybean		
Life State	Stadium duration, d	Fresh body weight, mg	Mortality[2] (%)	Stadium duration, d	Fresh body weight, mg	Mortality[2] (%)
2nd instar	6.0 ± 0.26	—	88.9	5.5 ± 0.13	—	40.00
3rd instar	5.8 ± 0.96[3]	—	3.3	4.6 ± 0.14[3]	—	8.9
4th instar	5.4 ± 0.68	—	0.0	5.2 ± 0.15	—	3.3
5th instar	7.8 ± 0.49	—	2.2	7.5 ± 0.14	—	5.5
Adult male	25.3 ± 1.85	38.0 ± 2.64	—	22.4 ± 0.54	42.7 ± 1.17	—
Adult female	22.5 ± 0.50	52.5 ± 3.50	TM = 94.4	23.0 ± 0.62	48.4 ± 1.43	TM = 57.7

[1]Initial number of 2nd instars n = 90 on each host.
[2]Mortality for 2nd through 5th instars of males plus females was 94.4% for pigeonpea and 57.7% for soybean
[3]The only significant difference (P ≤ 0.05, students t- test) was between hosts for duration of 3rd instar.

Laboratory Study, Adults

Like nymphs, adult *P. guildinii* performed better when fed soybean compared to pigeonpea. Female and male total longevities were similar on both foods, although females tended to live longer on pigeonpea, and males to live longer on soybean (Fig. 1); females survivorship, measured every 10 days, decreased faster on soybean than on pigeonpea, while males showed similar reduction in survivorship with time on both foods. More females oviposited when fed soybean (34.5%) than when fed pigeonpea (10.3%), and those that oviposited took 26 days longer to start oviposition when reared and maintained on pigeonpea compared with soybean (Table 2). Fecundity was

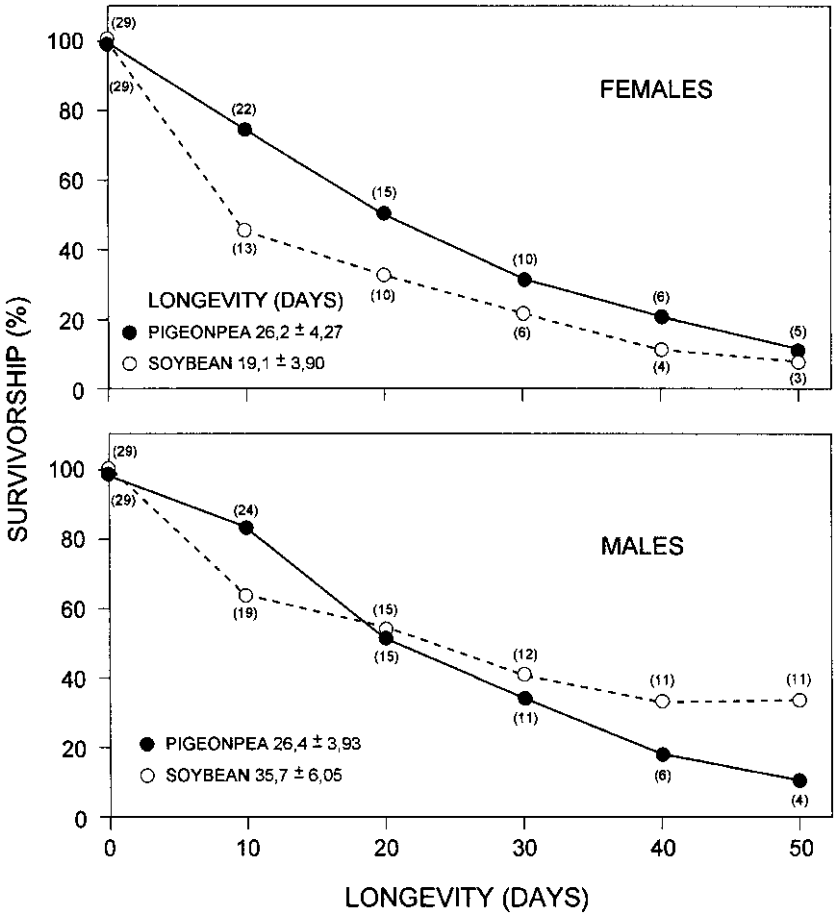

Fig. 1. Survivorship up to 50 days and total longevity of female and male *Piezodorus guildinii* feeding on immature pods of pigeonpea or soybean in the laboratory (initial number on each food $n = 29$; number of adults at each time interval in parentheses). No significant differences in longevity according to student's t test ($P \leq 0.05$).

TABLE 2. REPRODUCTIVE PERFORMANCE OF *PIEZODORUS GUILDINII* FEMALES FEEDING ON IMMATURE PODS OF PIGEONPEA OR SOYBEAN IN THE LABORATORY.

Food	Females ovipositing %	Female age (days) at first oviposition[1] (x ± SEM)	No. per female[1]		Egg hatch (%)[1]
			Egg masses (x ± SEM)	Eggs (x ± SEM)	
Pigeonpea	10.3 [3][2]	44.0 ± 9.6*	2.0 ± 1.0*	11.0 ± 8.5*	11.9 ± 11.9*
Soybean	34.5 [10][2]	18.0 ± 2.4	6.9 ± 1.8	72.2 ± 22.5	68.7 ± 8.1

[1]Means (in each column) followed by an asterisk differ significantly according to student's *t* test (P ≤ 0.05).
[2]Brackets mean number of female ovipositing.

much greater on soybean (4.9 egg masses and 61.2 eggs more) than on pigeonpea, with a difference in egg hatch of 56.8%.

After 2-4 weeks, adults were significantly heavier on soybean than on pigeonpea (Fig. 2). In general, females and males gained weight during the first 2 weeks on soybean, and maintained this higher weight after 4 weeks; on pigeonpea they did not gain weight, and males tended to lose weight.

The feeding preference tests indicated that, when foods were offered simultaneously, adults *P. guildinii* preferred to feed on soybean seeds, making a significantly (P ≥ 0.05) greater number of punctures (flanges) on soybean (1.87 ± 0.45) than on pigeonpea seeds (0.11 ± 0.06). When both foods were given alone, bugs also produced a greater number of flanges on soybean (3.04 ± 0.71) than on pigeonpea (0.07 ± 0.05).

Field Survey

P. guildinii colonized soybean during summer and early autumn (January-March). On this host plant nymphs peaked during February and adults during March (Fig. 3). As soybean matured, bugs started to move to pigeonpea during April, and remained on this host until early winter (July). Both nymphs and adults peaked on pigeonpea during May. No bugs were found during August and September, but during spring, in October and November, a few adults were captured on pigeonpea (Fig. 3).

DISCUSSION

Data from the laboratory and field studies suggest that pigeonpea is not a good host for *P. guildinii*, allowing only poor nymphal survival, and a much lower adult reproduction when compared to soybean. Also, pigeonpea serves only as a temporary host, particularly after the soybean harvest; most of the year *P. guildinii* was not found on pigeonpea. The percentage of nymphs reaching adulthood on pigeonpea (i.e., 5.6%) is much lower than what has been reported on other host plants, such as *Indigofera endecaphylla* Jacq. (88%), *Sesbania aculeata* Pers. (75%), *I. truxillensis* H.B.K. (73%), and *I. hirsuta* L. (42%), and more similar to what was reported on *I. suffruticosa* Mill. (16%) (Panizzi 1987, 1992). On soybean, the percentage of nymphs reaching adulthood (42.3%) was similar to what has been previously reported (47.5%) (Panizzi 1987). Nymphal mortality >50% on soybean is commonly observed, despite the high abundance of bugs on this crop in the field. Nymphal developmental time (stadia 2 through 5) on pigeonpea and on soybean (22.4-25.3 days) is similar to that reported for other hosts, except *I. suffruticosa* (28.5-30.3 days). The similar fresh body

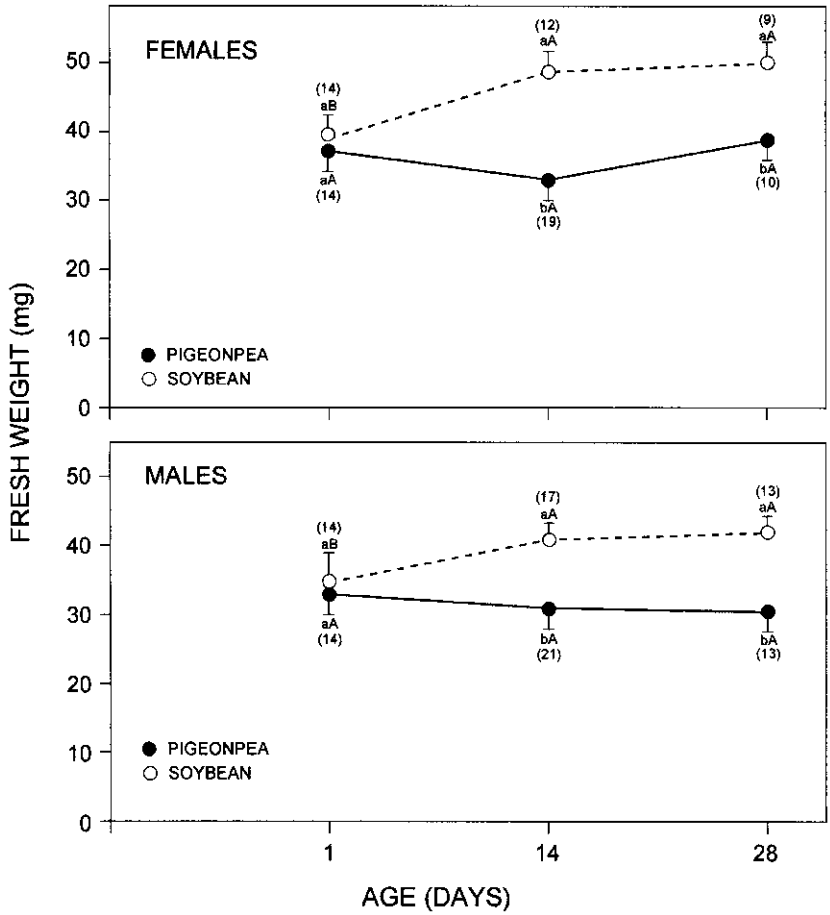

Fig. 2. Mean (±SEM) % of fresh body weight of *Piezodorus guildinii* at days 1, 14, and 28 of adult life, on immature pods of pigeonpea or soybean in the laboratory. Means followed by the same lower case letter (between foods at each age), and upper case letter (among ages for each food) do not differ significantly using student's *t* test and Duncan's multiple range test ($P \leq 0.05$), respectively. Number of adults in parentheses.

weight at adult emergence on pigeonpea and soybean suggests that those nymphs that are able to reach adulthood on pigeonpea are able to overcome the lower quality of this food.

The fact that adult longevity was similar on both foods suggests that even when feeding on a less suitable food (pigeonpea), *P. guildinii* adults tend to have normal longevity by reducing fecundity. Another indication of the lesser quality of pigeonpea as food compared to soybean, was that *P. guildinii* adults did not gain weight on pigeonpea. Therefore, the strategy of adult *P. guildinii* seems to be to survive on pigeonpea, with a strong reduction in reproduction, to save energy to pass the unfavourable season, and wait for the next summer to colonize its main host plant, soybean. This neo-

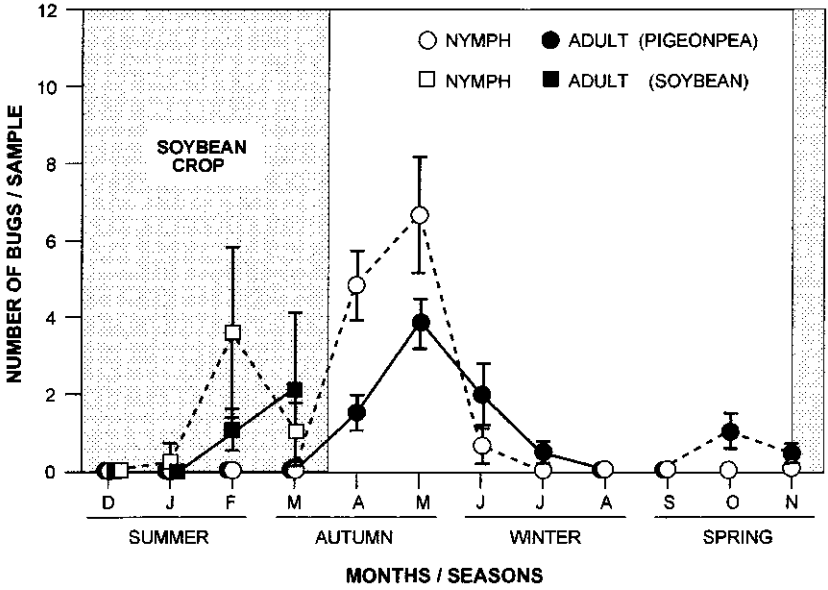

Fig. 3. Seasonal abundance of *Piezodorus guildinii* per month (mean ± SEM) captured on pigeonpea and soybean during 1996-97 in northern Paraná. On pigeonpea, one sample = 10 sweeps with an insect net; on soybean, one sample = 2m of row using the beat cloth method (Shepard et al. 1974).

tropical pentatomid has been exposed to soybean for a relatively short period of time (soybean has been cultivated in Brazil on a large scale for the last 30 years), and is not perfectly adapted to it, showing a much better performance on native legumes, such as some of the indigo species and native crotalaria (Panizzi & Slansky 1985, Panizzi 1992). Additional evidence is the fact that the many attempts to rear and maintain colonies of this bug continuosly in the laboratory on soybean pods have not succeeded (A. R. Panizzi, unpublished; C. J. Rossetto, personal communication to ARP).

In the Londrina area, *P. guildinii* produces two to three generations on soybean during spring-summer. Two additional generations are produced on indigo legumes, one just after soybean harvest in autumn, and another preceeding the summer (Panizzi 1997). The fact that nymphs were also found on pigeonpea during autumn, indicates that they reproduce on this host as well, but at a low rate which was confirmed by plant examination in the field. Our data from the field survey add the legume pigeonpea as a host of *P. guildinii*. In contrast to another pentatomid, the neotropical *E. heros*, which overwinters for several months during autumn-winter, *P. guildinii* moves to more preferred hosts during this time, such as native indigo and crotalaria legumes, or remains somewhat inactive on tree hosts in the woods (e.g., Sapindaceae) (Ferreira & Panizzi 1982).

The fact that *P. guildinii* was more abundant on soybean during the summer (February and March) toward the end of the reproductive period is a typical behaviour of pentatomid populations on this crop (Todd & Herzog 1980, Panizzi 1985). The movement of bugs to pigeonpea is forced by the crop maturation and harvest during April.

Finally, these laboratory and field data indicate that pigeonpea is a minor component of the life history of *P. guildinii* in the northern area of Paraná state. Nymphs and adults performed poorly on this plant, compared to soybean, on which they also preferred to feed. Therefore, pigeonpea may be considered a secondary host plant that is used as food source when the main preferred hosts, such as the indigo and crotalaria native legumes or soybean are not available in the field.

ACKNOWLEDGMENTS

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A NEW *AUTOMERIS* FROM THE MANANTLAN RESERVE IN MEXICO (LEPIDOPTERA: SATURNIIDAE: HEMILEUCINAE)

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ABSTRACT

Automeris manantlanensis new sp. is described from the Biosphere Reserve Sierra de Manantlán between Jalisco and Colima states in western Mexico. It belongs to the *Automeris io* group, and is the darkest species in the group. Male and female genitalia are figured, and specific characters are compared with those of closely related species.

Key Words: *Automeris manantlanensis* new sp., Colima, distribution, Jalisco, Lepidoptera

RESUMEN

Automeris manantlanensis especie nueva es descrita de la Reserva de la Biosfera Sierra de Manantlán entre los estados de Colima y Jalisco en el occidente de México. Pertenece al grupo de *Automeris io*, y es la especie más obscura del grupo. Se ilustran los genitales masculinos y femeninos, y se discuten y comparan caracteres específicos con los de las especies más cercanas.

The Neotropical genus *Automeris* Hübner contains 124 described species (Lemaire 1996). The "ocellar patches" on the hindwings and the cryptic leaf-like pattern of the forewings can easily identify most species in this genus. Lemaire (1971, 1973, 1974) summarized all the information known for the genus in his outstanding revision. However, it is very interesting that in 20 years, 21 new species have been described.

Recent trips to mountain ranges in southwestern Mexico have resulted in the discovery of several new species of saturniids, such as this one, endemic to mid-elevation montane forests (Lemaire 1992, Lemaire and Wolfe 1993). In his review of the genus, Lemaire proposed eight species groups; of these, the *A. io* group contains 13 described species distributed from Northern US south into Costa Rica. The new species belongs in this group of small to medium sized saturniids characterized by the yellow or gray periocellar area.

Automeris manantlanensis Balcázar, **New Species**
(Figs. 1-4)

DIAGNOSIS.—This new species is closely related to *Automeris stacieae* Lemaire & Wolfe, but can be easily separated from it and any other species in the group by its very dark ground color.

Description.—Forewing length: ♂ 31-32 mm ($\bar{x}$ = 30.8, n = 6). ♀ 35-41 mm ($\bar{x}$ = 39.7, n = 7).

Male (Fig. 1).—*Head:* Cinnamon brown; frontal area amber; labial palpi three-segmented, amber; antennae cinnamon brown, quadripectinate almost to the apex (first

Figs. 1-2. *Automeris manantlanensis* Balcázar, new sp.: 1) Holotype ♂ (forewing length: 31 mm), dorsum. 2) Allotype ♀ (forewing length: 40 mm), dorsum.

30 segments, only last two are not pectinated). *Thorax:* Cinnamon brown; legs amber; tibiae very hairy; epiphysis present, reaches almost to tip of tibia; hind tibia with one pair of apical spurs, with two subapical spurs (one shorter). *Abdomen:* Cinnamon, not ringed. *Forewing:* Dorsally cinnamon brown; antemedial line very faint; postmedial line dark brown, straight, continuous, reaching costa about 5-6 mm from apex; proximally underlined with tawny; submarginal band lunular, dark brown, distally under-

lined with tawny; discal spot dark brown, surrounded with five to seven small black dots. Forewing ventrally clay color, with a pale pinkish area along the inner side of the wing; antemedial line absent; postmedial line clearly marked, reaches costa about 3 mm from apex, black, concave; discal spot strong, black around a small white center; veins clay color turning black from the postmedial line towards the outer margin. *Hindwing:* Dorsally clay color, with a brick red to pinkish area along the inner margin; postmedial line black, convex, not underlined; submarginal band cinnamon; basomedial area brick red to pink; costal area pale pinkish; marginal area clay; inner side clay; fringes clay; area between postmedial line and submarginal band yellowish clay; ocellus typical of the *A. io* group, black with central diffuse white spot. Hindwing ventrally clay color, costal area with a burnt umber narrow area with a cream line on the margin; postmedial line black, straight, not underlined; discal spot weak, a small white dot without black, black ring of dorsal ocellus not visible. *Male genitalia* (Fig. 3): Uncus very prominent, bent ventrally, with two apical folds; valves with two lobes, apical process bent medialy, inner spine prominent; gnathos reduced to a subtrapezoidal plate (very sclerotized); saccus very long; vinculum with anterolateral borders prominent; aedeagus straight, delicate, bulbus ejaculatorius about two thirds as long as aedeagus.

Female (Fig. 2).—*Head:* Mars brown; antenna shortly bidentate (rami very reduced). *Thorax:* Mars brown; legs mars brown; tibiae hairy; epiphysis absent; hind tibia with one pair of apical spurs; with a single subapical spur. *Abdomen:* Tawny; not ringed. *Forewing:* Dorsally mars brown; antemedial line very faint; medial band grayish next to the postmedial line; postmedial line dark brown; proximally underlined

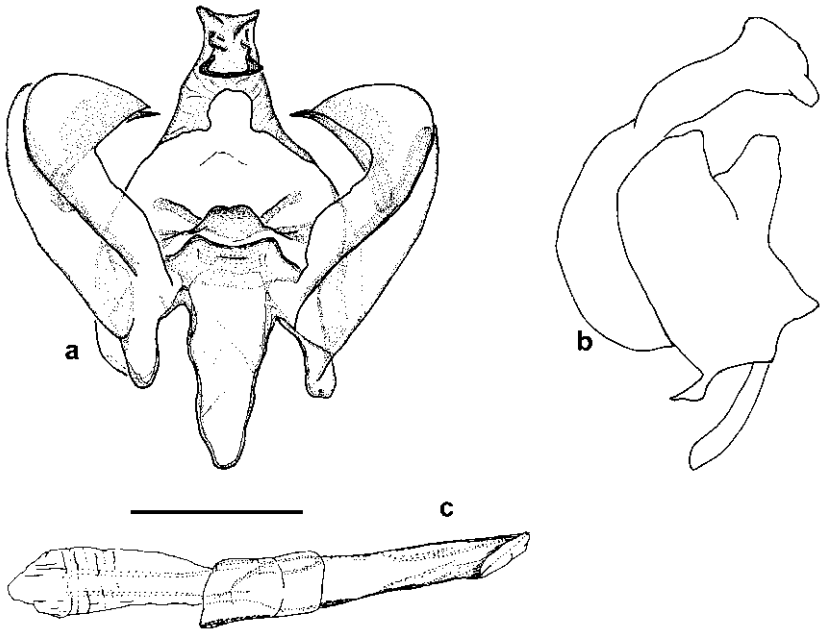

Fig. 3. *Automeris manantlanensis* Balcázar, new sp., ♂ genitalia: a) ventral view, aedeagus removed; b) lateral view; c) lateral view of aedeagus (line = 1 mm).

with tawny, straight; submarginal band continuous, very wavy, dark brown, distally underlined with tawny; discal spot dark brown, surrounded with four to six small black dots. Forewing ventrally antique brown; antemedial line absent; postmedial line clearly marked, black, concave; discal spot very strong, black around a small white center; veins clay color turning black from the postmedial line towards the outer margin. *Hindwing:* Dorsally clay color; with a brick red to pinkish area along the inner margin; postmedial line black; submarginal band dark grayish brown; basomedial area brick red to pink; costal area pale pinkish; marginal area clay; inner side very pale pink; fringes cinnamon rufous; area between postmedial line and submarginal band clay; ocellus typical of the *A. io* group, black with central diffuse white spot. Hindwing ventrally antique brown; costal area burnt umber with a cream line on the margin; postmedial line black, straight; discal spot weak, a small white dot without black, black ring of dorsal ocellus visible; veins clay color turning black from the postmedial line towards the outer margin. *Female genitalia* (Fig. 4): Ventral plate trident shaped, with medial plate very short, lateral branches long, slightly recurved anteriorly; postapophyses-anapophyses about the same length; ductus bursae membranous, short; corpus bursae almost twice as long as anapophyses; ductus seminalis arising right.

IMMATURE STAGES.—Unknown.

TYPES.—*Holotype* ♂: MEXICO: Jalisco, Autlán, Sierra de Manantlán, 19°41'30"N, 104°22'30"W, 1450, 18-20 Jun 1995 (coll. G. Nogueira)—CNIN LEP 066626.

Allotype ♀: MEXICO: Jalisco, Autlán, Sierra de Manantlán, 19°41'30"N, 104°22'30"W, 1450, 18-20 Jun 1995 (coll. G. Nogueira)—CNIN LEP 066617.

Paratypes: MEXICO: Jalisco, Autlán, Sierra de Manantlán, 19°41'30"N, 104°22'30"W, 1450, 18-20 Jun 1995 (coll. G. Nogueira)—CNIN LEP 066635 ♂; 15-16 Jun 1996 (coll. G. Nogueira)—CNIN LEP 066618 À, CNIN LEP 066619 ♀, CNIN LEP 066620 ♀, CNIN LEP 066621 ♀, CNIN LEP 066622 ♀, CNIN LEP 066623 ♀, CNIN LEP 066624 ♂, CNIN LEP 066625 ♂, CNIN LEP 066627 ♂, CNIN LEP 066628 ♂.

The holotype and allotype are deposited in the National Collection of Insects (CNIN), Instituto de Biología, UNAM; one male paratype will be deposited in the United States National Museum, the Muséum national d'Histoire naturelle (Paris) and another one in the Natural History Museum (London).

ETYMOLOGY.—The name of this species refers to the region of Manantlán.

DISTRIBUTION.—*A. manantlanensis* is known only from the Manantlán Reserve at moderate elevation (1450 m) in a *Quercus resinosa* forest.

FLIGHT PERIOD.—The type specimens were collected in June in 1995 and 1996.

VARIATION.—Almost no variation was observed among the type series; while 6 females are 40-41 mm in forewing length, one is smaller (35 mm); one male has a pale yellowish cast.

DISCUSSION

This new species belongs to the *A. iris* subgroup within the *A. io* group of species as defined by Lemaire & Wolfe (1993), which presently includes five species besides the new one (*A. iris* (Walker), *A. daudiana* Druce, *A. boudinotiana* Lemaire, *A. lemairei* Beutelspacher and *A. stacieae* Lemaire & Wolfe), distinguished from other species in the group by the continuous, instead of lunular, postmedial line of the forewing. *A. manantlanensis* is the darkest species in the group; both sexes have falcate forewings, but the pointed apex is less produced than in *A. stacieae.* It has a straight postmedial line on the forewings as *A. lemairei*, but the latter is larger and the darker specimens are light tan in the male and light brown in the female.

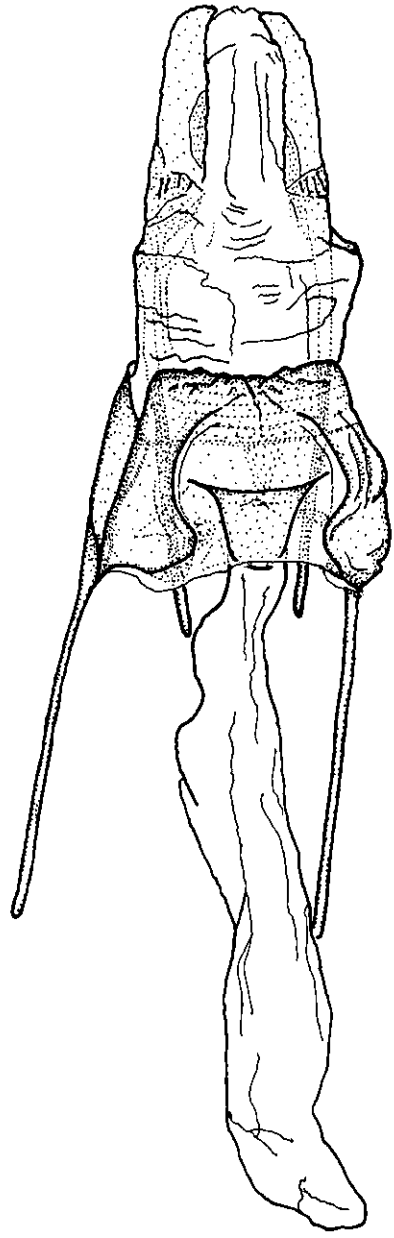

Fig. 4. *Automeris manantlanensis* Balcázar, new sp., ♀ genitalia, ventral view (line = 1 mm).

The male genitalia of *A. manantlanensis,* similarly to that of *A. stacieae,* has a less dorsally folded uncus than *A. iris* and *A. lemairei*; the rounded and slightly spatulate extreme of the uncus is unique.

The Biosphere Reserve Sierra de Manantlán is an area with a high richness and concentration of endemic species. In spite of the difficult access to the area, good faunistic studies have been done for several zoological groups (especially vertebrates), since the reserve was established in 1987 (CONABIO 1999). At least nine species of insects have been described recently from this quite isolated and topographically complex region (Vargas F. 1998).

Acknowledgments

I thank Guillermo Nogueira for the donation of specimens of Saturniidae to the CNIN; among which were the type series of this new species. This study was possible in part thanks to CONABIO grant FB269/H021/96.

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DISCOCORIS DOMINICANUS, A NEW SPECIES OF PALM BUG FROM DOMINICAN AMBER (HETEROPTERA: THAUMASTOCORIDAE)

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ABSTRACT

Discocoris dominicanus is described as a new species from amber from the Dominican Republic. It is related to, and differentiated from the extant species *Discocoris fernandenzi* from Venezuela. Figures of dorsal and ventral views and the amber cabochon are included. The relationships to *Paleodoris*, the only other thaumastocorid known from Dominican amber, is discussed.

Key Words: Heteroptera, Thaumastocoridae, *Discocoris*, amber fossil, Dominican Republic

RESUMEN

Discocoris dominicanus es descrito como una nueva especie en ámbar de la Republica Dominicana. Esta relacionado y diferenciado de la especie existente *Discocoris fernandenzi* de Venezuela. Ilustraciones de vista dorsal, ventral, y el cabochón de ámbar estan incluidas. Las relaciones a *Paleodoris*, el único otro miembro de Thaumastocoridae procedente de ámbar Dominicano, es discutido.

The genus *Discocoris* has been previously known to include four extant species, all confined in distribution to South America. All of the species whose biology is known feed on various species of palms as does the related *Xylastodoris luteolus* Barber which is known from Cuba and southern Florida.

Recently Poinar & Santiago-Blay (1997) have described the first known fossil thaumastocorid, interestingly also found, as is the present species, in Dominican amber. These authors recognized their species as a new genus and species, *Paleodoris lattini*, and related it most closely to *Xylastodoris luteolus* Barber.

Poinar & Santiago-Blay (ibid) reviewed the pertinent literature on the family which will not be repeated here other than bring attention to the recent paper by Cassis, Schuh & Brailovsky (1999) where 6 genera and 19 species are recognized in the family. These authors include an important discussion of host plant relationships for species from both hemispheres. Poinar & Santiago-Blay (ibid) speculated that *Paleodoris* and *Xylastodoris* represent the "most primitive" members of the family, that the distribution is Gondwana-like and that the family may have been derived from a "group of plant bugs similar to, or belonging to, the Progonocemicidae Handlirsch (Permian and Mesozoic)".

The specimen of *Paleocoris lattini* is believed to have originated "from the northern mountain ranges in the Dominican Republic. . . . from mines in the El Mame forma-

tion" (Upper Eocene) and the amber is believed to possibly be between 20 and 40 million years old.

The present specimen is from eastern deposits in Yanigua in the area of El Valle. Dr. Robert E. Woodruff has kindly indicated to us that these deposits are probably younger than those from the Santiago region and are probably Miocene dating from 20-30 million years ago. He notes that material from the El Valle area has a different composition than that from the Santiago area and that some authors, in fact, believe that all Dominican amber is actually Miocene, but that the El Valle material is relatively recent even within this restricted time period. Anderson (1999) has recently described a species of Veliidae (*Micovelia polhemi*) also from the El Valle area which he locates in the eastern part of the Dominican Republic. He states that the exact age of the Dominican amber deposits is still not known but cites studies that agree with Dr. Woodruff's comments and suggest a range from 15-30 million years.

Discocoris dominicanus described below, although also taken in Dominican amber is not closely related to *Paleodoris*, but rather appears to be a typical species of *Discocoris*. It keys to *D. fernandezi* Slater & Brailovsky in Slater & Brailovsky (1983).

Discocoris differs from *Paleodoris* in having the juga (= mandibular plates) barely exceeding and not convergent beyond the apex of the tylus (= clypeus) (a feature that Cassis, Schuh and Brailovsky (1999) believed to be diagnostic for the Australian genus *Onymocoris* Drake & Slater), in having the ocelli located on a line near the posterior margin of the compound eyes, rather than far behind the eyes as they are in *Paleodoris*. The lateral pronotal margins are relatively straight in this Dominican amber species of *Discocoris* but are very strongly arcuate in *Paleodoris*. Other differences are the more strongly obovate and less flattened body of *Discocoris*, The labium is somewhat obscured in *Discocoris dominicanus*, but appears to reach, or nearly reach, the metacoxae. In any event the first labial segment reaches the base of the head whereas in *Paleodoris* the apex of the labium "barely reaches the fore coxae".

We agree with Poinar and Santiago-Blay (1997) in placing their amber specimen as a distinct genus more closely related to *Xylastodoris* than to *Discocoris*.

All measurements are given in millimeters.

Discocoris dominicanus Slater & Baranowski, **New Species**
Figs. 1, 2, 3

Broadly ovate. Head broad, non-declivent. Juga strongly arcuate, slightly exceeding tylus but not convergent before it. Tylus slightly tapering anteriorly. An acute, thick, inwardly curving spine present at anterior angle of each eye, extending only to near middle of first antennal segment. Ocelli located on a line near posterior margin of compound eyes. Head, pronotum, scutellum and corium with conspicuous coarse, closely placed punctures, those on head and pronotum closer to one another than intervening spaces. Clothed above with short upright setiferous hairs. Length head 0.50, width 0.52, interocular space 0.28. Anterior margin of pronotum straight mesally, laterally with antero-lateral angles produced forward as a broad curving lobe almost to level of middle of compund eye. Lateral pronotal margins broadly explanate with lateral edge straight for most of length with a few minute teeth present. Posterior pronotal margin deeply concave with humeral angles broadly rounded, not strongly elevated. Length pronotum at midline 0.30, maximum length 0.50, width across humeral angles 1.00. Scutellum lacking a median elevation. Length scutellum 0.42, width 0.40. Clavus with three rows of punctures. Length claval commissure 0.28. Hemelytra broadly arcuate and moderately convex. Length hemelytron 1.48. Hemelytra considerably exceeding apex of abdomen. Femora incrassate, dark brown, constrasting with pale coloration of tibiae and tarsi. Antennae slender, filiform, fourth

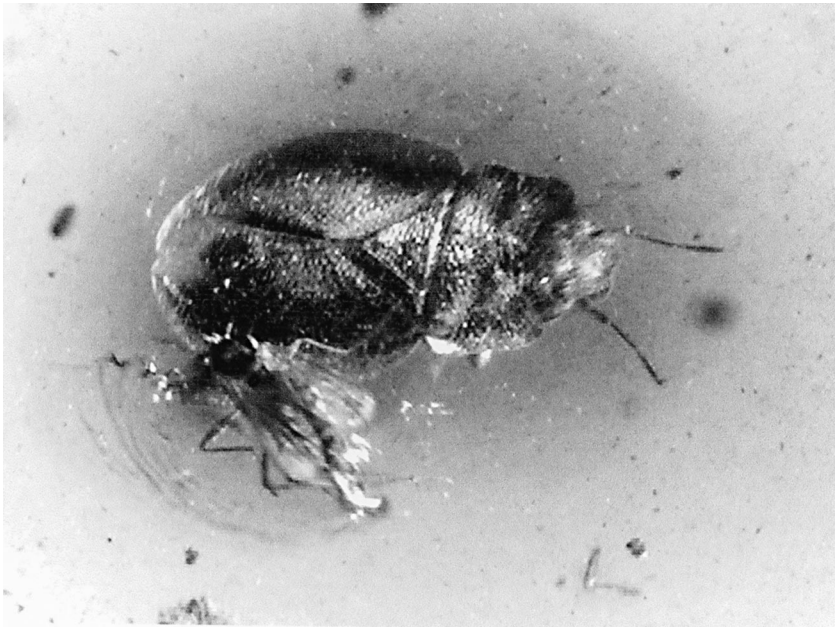

Fig. 1. *Discocoris dominicanus* Slater & Baranowski, new species. Dorsal view.

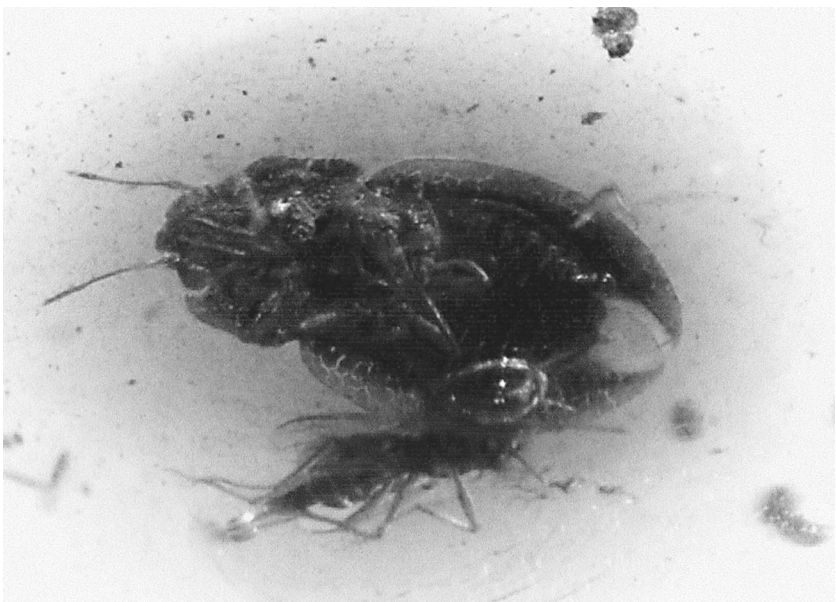

Fig. 2. *Discocoris dominicanus* Slater & Baranowski, new species. Ventral view

Fig. 3. Amber cabochon containing *Discocoris dominicanus* Slater & Baranowski, new species.

segment infuscated on apical half. Length antennal segments I 0.04, II 0.12, III 0.16, IV 0.22. Total body length 2.20.

Holotype: Dominican Republic: Yanigua, in the area of El Valle. This specimen will be in the junior author's possession until a depository is selected by Mr. Jake Brodzinsky, owner of the specimen.

This species keys to *D. fernandezi* in Slater & Brailovsky (1983), but is a smaller species, clothed above with conspicuous upright setae. In contrast to *D. fernandezi* the juga exceed the apex of the tylus, the head is relatively narrow and the pronotum much shorter. It is however definitely most closely related to *D. fernandezi* agreeing in the size of the spine laterally on the head, the large coarse punctures, the juga and tylus extending anteriorly nearly the same distance, the forward extension of the antero-lateral pronotal angles and the general shape of the lateral pronotal margins.

Etymology: Named for its occurrence in the Dominican Republic on the island of Hispaniola.

ACKNOWLEDGMENTS

We are grateful to Mr. Jake Brodzinsky (Santo Domingo, Dominican Republic) for graciously allowing us to study this specimen, to Dr. R. E. Woodruff, Entomologist Emeritus (Florida Dept. of Agriculture and Consumer Services, Gainesville, Florida) for bringing it to our attention and to Dr. R. T. Schuh (American Museum of Natural History) for bringing the paper of Poinar and Santiago-Blay to our attention. Florida Agricultural Experiment Station Journal Series No. R-07741.

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GROWTH OF WILD *PSEUDOPLUSIA INCLUDENS* (LEPIDOPTERA: NOCTUIDAE) LARVAE COLLECTED FROM BT AND NON-BT COTTON

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Cotton varieties genetically engineered to express Cry1Ac, a delta-endotoxin protein from *Bacillus thuringiensis* with insecticidal properties to many Lepidopterans, are now commercially available to aid in the control of the tobacco budworm, *Heliothis virescens* F. (Lepidoptera: Noctuidae). Most of the resistance-management strategies for Bt cotton have focussed on this primary pest, and *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), to a lesser degree. Because Cry1Ac is continually expressed in all tissues of the cotton plant, many Lepidopteran insects feeding on Bt cotton may experience selection pressure for improved tolerance of this insecticide. In addition to the major pests of cotton, secondary pests could also develop resistance to Cry1Ac when feeding on Bt cotton. Currently, there is little available information concerning the best strategy to manage resistance to Cry1Ac in these secondary pests (Gould and Tabashnik 1998).

Soybean loopers, *Pseudoplusia includens* (Walker) (Lepidoptera: Noctuidae) are occasional foliage feeders of cotton and have the potential to develop resistance to Cry1Ac (Mascarenhas et al. 1998). We took advantage of a natural infestation of soybean loopers (SBL) in the Mississippi Delta to investigate how well SBL larvae tolerated Cry1Ac expressed in the leaves of Bt cotton. Comparisons were made of the numbers of larvae found in Bt and non-Bt cotton and also comparisons of the growth of larvae feeding on Bt and non-Bt cotton. We also looked at the variability in tolerances of individuals feeding on Bt cotton.

Two varieties of cotton were used in this study. NuCOTN 33B (Bt cotton, treatment = 'BT') and SG125 (conventional cotton, treatment = 'NBT') were planted (9 May 1998) in a randomized design totaling 7 plots of each variety. Plot dimensions were approx. 9 × 9 m and plots were arranged in a 3 × 5 plot grid. Each plot was separated from the others by 2 m of unplanted space. On 6 July 1998, we observed a sizeable infestation of SBL larvae (first and second instars in BT and NBT treatments). Larvae from all plots were manually removed (23 July 1998), placed in plastic bags containing foliage from the plant on which each larva was feeding, and immediately brought back to the lab to be scored and weighed. The number of larvae from each plot was tabulated. Counts of larvae were log-transformed to enhance normality and to homogenize the variances in the BT and NBT treatments. A t-test was used to compare NBT and BT counts. Data are presented as untransformed average numbers per plot. In addition, larvae from 5 and 4 randomly chosen BT and NBT plots, respectively, were weighed to the nearest hundredth of a mg to look for developmental differences in SBL larvae feeding on BT and NBT foliage. Log-transformed weight (mg) data were subjected to ANOVA to determine if there were any differences in the developmental rates of larvae collected from BT and NBT plots. Bt treatment (BT vs. NBT cotton) was considered a fixed effect and plots nested within treatments [plots(treatment)] effects were considered a random source of variation (PROC GLM; SAS 1985). Satterthwaite's approximation was used to estimate the denominator degrees of freedom.

Significantly more SBL larvae were collected from NBT plots than BT plots (Fig. 1; $t = 3.336$, df = 12, $P = 0.006$). Larvae from NBT plots were also significantly larger than larvae from BT plots ($F = 238.96, df = 1, 104.5, P < 0.0001$). The weights of larvae

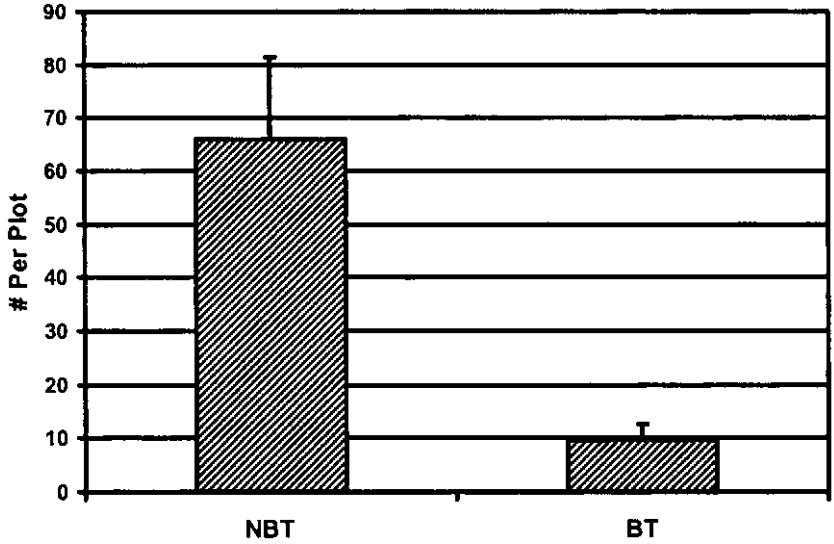

Fig. 1. The average number (±SD) of SBL larvae per plot on non-Bt cotton and Bt cotton.

for plots within treatments did not differ (Plots(treatments), $F = 0.506$, df = 7, 268, $P = 0.830$). The average weight of larvae collected from NBT plots was an order of magnitude larger than the mean weight of larvae collected from BT plots ($\bar{x}$ = 189.6 and 21.2 mg, NBT and BT, respectively). There was very little overlap in the log weights (mg) of larvae collected from NBT and BT cotton (Fig. 2). In addition, there was a great deal of variation in log weights among individuals collected from BT cotton (Fig. 2; CV = 30.4% vs. 15.4% for BT and NBT, respectively).

Although Bt cotton was developed primarily for the control of *H. virescens* in southeastern and mid-south cotton, it does have some effect on SBL. Most larvae collected from non-Bt cotton were close to pupation, in contrast to the range of sizes we observed in larvae collected from Bt cotton. Not only were SBL larvae collected from Bt cotton an order of magnitude smaller than larvae collected from non-Bt cotton, but there was also an order of magnitude difference in the log weights of the smallest and largest larvae collected from Bt cotton. The size (almost 80mg) of some of the SBL larvae feeding on Bt cotton was rather striking. Because SG125 is not the parental variety of NuCOTN 33B, it should be noted that other causes, in addition to Bt expression, might account for the differential growth of larvae on the two cotton varieties. However, in leaf tests with beet armyworms, we have seen similar differences between the growth of larvae feeding on NuCOTN 33B and its parent variety DP5415 (Sumerford, in prep).

Many quantitative traits governed by polygenes are normally distributed and populations often exhibit a large amount of variation in the trait of interest (Falconer and Mackay 1996). The log-weight distribution (mg) of collected larvae from Bt cotton was also normally distributed (Kolmogorov-Smirnov, D = 0.108, P > 0.15; Sokal and Rohlf 1996). We had planned to select for tolerance (based on growth of larvae as determined by weight) in both directions using the weighed individuals from our BT treatment. This would have given an estimate of the response to selection, and therefore

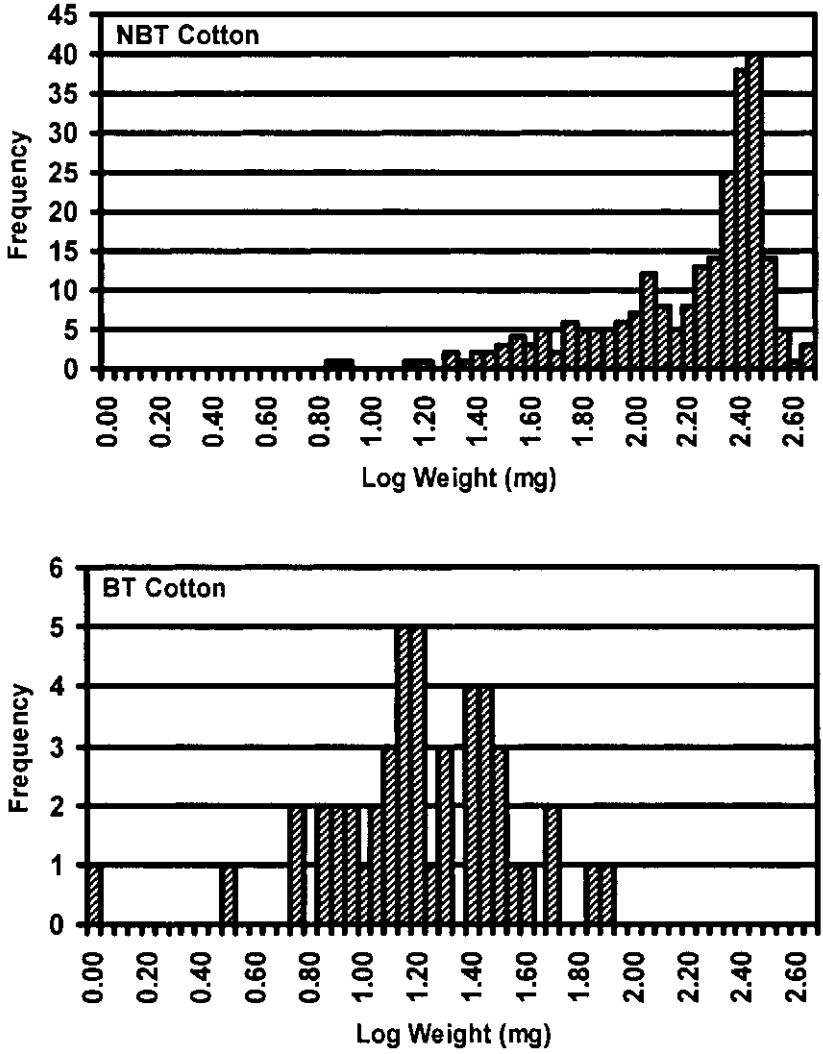

Fig. 2. Frequency distributions of log weights (mg) from SBL larvae collected from non-Bt and Bt cotton.

an estimate of the heritability of growth on the Cry1Ac toxin. However, we had difficulty obtaining viable eggs from adults in our BT and NBT treatments. If the developmental differences observed in SBL larvae from our Bt cotton are a consequence (at least in part) of oligo- or polygenic inheritance, it is unclear whether strategies designed to retard the evolution of resistance in *H. virescens* will also slow resistance development in SBL populations. Selection experiments and quantitative genetic studies would help in understanding the genetic architecture of Cry1Ac tolerance in SBL populations.

SUMMARY

Soybean looper larvae from the Mississippi Delta were collected from Bt and non-Bt cotton to determine the numbers of loopers in each variety and also to compare the rate of larval development on the two cotton varieties. There were significantly fewer larvae collected from Bt cotton than non-Bt cotton ($P < 0.01$) and the weights of these larvae were, on average, an order of magnitude smaller than larvae collected from non-Bt cotton ($P < 0.0001$). There was also an order of magnitude difference among the weights of larvae collected from Bt cotton, indicating considerable variability in the tolerance of the Bt toxin, Cry1Ac.

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FIRST COLLECTION OF BROWN CITRUS APHID (HOMOTERA: APHDIIDAE) IN QUINTANA ROO, MEXICO

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The brown citrus aphid, *Toxoptera citricida* (Kirkaldy), primary vector of citrus tristeza virus, has been present in Belize since 1996 (Halbert 1996). During the first week of April, 2000 we surveyed commercial and dooryard citrus in central regions of the state of Yucatan, Mexico from Merida south to Oxkutzcab and Tzucucab close to the border with Quintana Roo without detecting BCA. We then extended our search eastward into northern portions of the state of Quintana Roo where the aphid was rumored to be present. Our first positive detection occurred at km 255 on highway 30 in the town of Santo Domingo, about 30 miles west of Cancun. A single roadside sweet orange tree was observed with heavy growth of sooty mold on some branches. Closer examination revealed large numbers of aphid cadavers adhering to terminal twigs. Several live brown citrus aphid colonies were subsequently discovered some 40 meters distant on a flushing mandarin orange tree. Voucher specimens were sent to

Dr. S. Halbert of Department of Plant Industry, Gainesville, FL for confirmation. We then proceeded northward to inspect some small commercial and subsistence citrus groves around Kantunilkin but did not find any evidence of recent aphid activity. However, it should be noted that the entire region was nearing the end of a dry season with very little new growth on citrus trees available for aphid colonization. We did find evidence of some previously heavy aphid populations and some live aphids on dooryard trees in the town of Leona Vicario, also on highway 30. These are the first confirmed collections of brown citrus aphid in Mexico.

Summary

Brown citrus aphid, *Toxoptera citricida*, is recorded for the first time in Mexico from the state of Quintana Roo.

Acknowledgments

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A COMPARISON OF SOME ARTHROPOD GROUPS ON MONOCROPPED AND INTERCROPPED TOMATO IN BAJA VERAPAZ, GUATEMALA

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There is evidence that intercropping with certain plant species can be used to increase numbers of beneficial insects by providing them with food sources such as pollen, nectar, and alternate prey (Pimentel 1961, Root 1973, Altieri and Letourneau 1982, Corbett 1998). In 1998, a survey was carried out in the Salamá valley, a tomato-growing region in central Guatemala, to determine if levels of arthropods were different on tomato (*Lycopersicon esculentum* Mill.) intercropped with cilantro (*Coriandrum sativum* L.), roselle (*Hibiscus sabdariffa* L.), and velvetbean (*Mucuna deeringiana* (Bort.) Small) compared to levels on monocropped tomato. Three pesticide subplot treatments were included to assess pesticide effects on non-target arthropods.

The research was carried out at the Instituto de Ciencia y Tecnología Agrícolas (ICTA) field station in San Jerónimo (15°03'N, 90°15'W, elevation 1000 m), Baja Verapaz, Guatemala. A split-plot design was used with two whole-plot treatments (monocrop and intercrop tomato) and three subplot pesticide treatments (imidacloprid, a detergent/oil rotation, and control). Each treatment was replicated four times.

Whole plots contained nine rows, 17 m in length. Between-row spacing was 1.0 m. Monocrop plots consisted of eight rows of tomato, cv Elios. Intercrop plots consisted of nine rows of the tomato/intercrop mix. Spacing between plants was 20 cm for cilantro and velvetbean and 40 cm for tomato and roselle. Intercrop species were planted 25-26 March. Tomato was transplanted 28 April-6 May.

Each whole plot was divided into 3 sections, each 5.67 m in length. These sections were randomly assigned to the imidacloprid treatment, the detergent and oil treatment, or the control. Imidacloprid (Confidor 70 WG, Bayer, Germany) was prepared at a rate of 0.73 g/liter of water. Approximately 10 cc of this mixture (73 mg imidacloprid) was applied to the base of each tomato plant on three occasions (Smith 1999). Olmeca® vegetable oil (Olmeca S.A., Guatemala) and Unox® laundry detergent (Quimicas Lasser S.A., El Salvador) were applied at a rate of 1%, or 16 cc/16 liter spray tank (Calderón et al. 1993). Detergent or oil was applied in rotation every five days.

On 3 July, one beat cloth sample per subplot was collected at random from each row of cilantro, roselle, and velvetbean. One beat cloth sample was taken from intercrop tomato in rows two and four of each subplot. These rows were situated between velvetbean and roselle and roselle and cilantro, respectively. One beat cloth sample was taken from monocrop tomato in rows two and four of each subplot. Tomato was producing flowers and green fruit, and cilantro was flowering when the samples were collected. Roselle and velvetbean had foliage only.

To collect beat cloth samples, a 1.0-m × 0.75 m plastic sheet (Olefinas, S. A., Guatemala) was spread out on a wooden board at the base of the crop row. The plants were struck manually four times to dislodge arthropods toward the sheet. Arthropods were grouped as spiders, insect predators, hemipteran herbivores, and Coleoptera. Most insects and spiders were classified to family. Pentatomids were grouped as phytophagous or predaceous based on buccal morphology (Slater and Baranowski 1978).

Analysis of variance (SAS 1996) was used to compare numbers of arthropods among main effect treatments and among intercrop species. Tukey's studentized range procedure was used to separate means when appropriate.

Insect predators consisted primarily of both adult and immature *Geocoris* (Lygaeidae), assassin bugs (Reduviidae), and ladybird beetles (Coccinellidae) (Table 1). *Engytatus modesta* (Distant) (Miridae), the tomato bug, comprised 92% of herbivorous Hemiptera recovered, and was found predominantly on tomato (Table 1). About 68% of the herbivorous Coleoptera recovered belonged to the Chrysomelidae and Elateridae. Proportions of various groups were influenced by the fact that four times as many samples were taken from tomato (48) as from each of the other crops (12).

There were too few insect predators on intercropped and monocropped tomato for meaningful comparisons. There were no differences ($p > 0.1$) between monocropped and intercropped tomato in total numbers of spiders, hemipteran herbivores, or Coleoptera (Table 2). Spiders were the primary predatory group found on tomato (Table 2). Spider levels were higher ($p < 0.05$) on unsprayed tomato than on tomato that had been treated with imidacloprid or the detergent and oil rotation (Table 2). Numbers of hemipteran herbivores were higher ($p < 0.1$) on tomato treated with detergent and oil than the other two treatments.

When arthropod levels on different intercrop species were compared, it was evident that levels of insect predators were highest ($p < 0.05$) on cilantro. Hemipteran herbivores (primarily *Engytatus modesta*) were most numerous ($p < 0.05$) on intercropped, unsprayed tomato. Beetle densities were highest ($p < 0.05$) on roselle and velvetbean. Spiders were unaffected by plant species.

These preliminary observations suggest that the arthropod groups on tomato were apparently unaffected by the proximity of different crops supporting distinct arthropod communities. The data also demonstrate the predominance of spiders as preda-

TABLE 1. ARTHROPOD GROUPS COLLECTED FROM SAMPLES ON FOUR CROPS IN BAJA VERAPAZ, GUATEMALA.

Family	Individuals	Crops[1]
ARANEAE		
Thomisidae	34	Cilantro, tomato, velvetbean
Lycosidae	18	Cilantro, tomato, velvetbean
Oxyopidae	22	Cilantro, roselle, tomato
Tetragnathidae	8	Tomato
Theridiidae	7	Roselle, tomato, velvetbean
Salticidae	6	Cilantro, tomato
Oxyopidae	4	Tomato
Araneidae	3	Cilantro, tomato
Philodromidae	2	Cilantro, tomato
Theridiidae	2	Tomato
Corinnidae	1	Velvetbean
Dictynidae	1	Tomato
HEMIPTERA		
Lygaeidae (*Geocoris*†)	46	Cilantro, roselle, tomato, velvetbean
Reduviidae†	27	Cilantro, roselle, tomato, velvetbean
Pentatomidae (herbivore)	19	Cilantro, tomato, velvetbean
Lygaeidae (herbivore)	14	Tomato, velvetbean
Pyrrhocoridae	13	Roselle, velvetbean
Largidae	7	Cilantro, tomato
Coreidae	5	Tomato
Pentatomidae†	2	Tomato, velvetbean
COLEOPTERA		
Chrysomelidae	49	Cilantro, roselle, tomato, velvetbean
Elateridae	28	Roselle, velvetbean
Coccinellidae†	18	Cilantro, roselle, tomato, velvetbean
Cicindellidae†	16	Velvetbean
Anthicidae	8	Cilantro, roselle
Meloidae	7	Cilantro, velvetbean
Erotylidae	4	Roselle, tomato, velvetbean
Nitidulidae	3	Cilantro, roselle
Cleridae	3	Cilantro
Lampyridae	2	Tomato
?	5	Cilantro
Staphylinidae	1	Tomato
Tenebrionidae	1	Velvetbean
Histeridae	1	Cilantro
Mordellidae	1	Cilantro
DIPTERA		
Syrphidae†	9	Cilantro, tomato
NEUROPTERA		
Chrysopidae†	2	Roselle, tomato

[1]Four times as many beat cloth samples were taken from tomato (48) as from each of the other crops (12).
†Indicates insect predator.

TABLE 2. EFFECT OF CROPPING TREATMENT, CROP SPECIES AND PESTICIDE TREATMENT (APPLIED TO TOMATO ONLY) ON ARTHROPOD NUMBERS PER 0.75-M^2 BEAT CLOTH SAMPLE COLLECTED IN BAJA VERAPAZ, GUATEMALA.

Treatment	Spiders	Insect predators	Hemipteran herbivores	Beetles
Cropping treatment				
Intercrop tomato	1.00 ± 1.15a	0.04 ± 0.21a	8.04 ± 7.47a	0.35 ± 0.67a
Monocrop tomato	1.67 ± 1.61a	0a	11.88 ± 11.88a	0.33 ± 0.64a
Pesticide treatment				
Imidacloprid	0.81 ± 0.98a[1]	—	9.67 ± 8.76a	0.40 ± 0.74a
Detergent/oil	1.07 ± 1.27a	—	13.36 ± 14.32b	0.29 ± 0.61a
Control	2.12 ± 1.67b	—	7.50 ± 5.87a	0.33 ± 0.62a
Intercrop species				
Tomato	1.75 ± 1.39a[1]	0.75 ± 0.71b	6.25 ± 4.89a	0.33 ± 0.82b
Cilantro	3.75 ± 3.40a	6.50 ± 5.26a	2.25 ± 0.96b	2.00 ± 2.16ab
Roselle	0.74 ± 0.50a	1.25 ± 0.50b	2.25 ± 3.20b	5.50 ± 3.11a
Velvetbean	1.25 ± 0.50a	1.50 ± 1.00b	1.25 ± 0.96b	4.00 ± 1.83a

[1]Data are means ± SD of eight replications (two main plot treatments and four replications). Means for each effect within a column followed by the same letter do not differ ($p < 0.1$) according to Tukey's studentized range test.

tors on tomato, and indicate the negative effect of some pesticides on spider numbers. The results suggest that cilantro may be a useful crop for augmenting levels of generalist predators in some cropping systems, although movement to target crops could be problematic.

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Summary

Levels of insect predators and spiders did not differ on monocropped tomato from levels on tomato intercropped with cilantro, roselle and velvetbean. Among the intercrop plants tested, cilantro supported the highest number of predators.

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NEW HOST FOR THE PARASITIC ANT *SOLENOPSIS DAGUERREI* (HYMENOPTERA: FORMICIDAE) IN ARGENTINA

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The parasitic ant *Solenopsis daguerrei* (Santschi) has been reported as an inquiline of fire ants in South America. It lacks a worker caste, so all adults are reproductive males and females. The parasite queens and occasionally some virgin females attach themselves to the host queens, and divert resources from them. The fire ant workers tend *S. daguerrei* in a manner similar to their own mother queens (Bruch 1930). The host workers also feed and maintain the brood of *S. daguerrei*. According to Silveira-Guido et al. (1973) this parasite inhibits the egg production of the fire ant mother queen, thus causing the ant colony to collapse and eventually die out. Recently it was reported that multiple-queen colonies of fire ants parasitized with *S. daguerrei* have fewer queens than non parasitized ones (Calcaterra et al. 1999). Because of these findings, this parasitic ant is a candidate for introduction for the biological control of imported fire ants in the United States and is under quarantine conditions at the USDA-ARS CMAVE, Gainesville, FL. However, before *S. daguerrei* can be released from quarantine, its host specificity must be determined.

Surveys on fire ant natural enemies in South America revealed that *S. daguerrei* has been found in Argentina, Uruguay, and Brazil, in colonies of *S. richteri* Forel, *S. invicta* Buren, *S. saevissima* F. Smith, and *S. macdonaghi* Santschi (Silveira-Guido et al. 1973, Briano et. al. 1997, Pesquero et al. 1998, Calcaterra et al. 1999). Here we report a new host species for *S. daguerrei*.

As part of the study of the specificity of *S. daguerrei*, a field host range survey was conducted in San Eladio (60 km W of Buenos Aires), Argentina, the only place where *S. daguerrei* has been found consistently since 1995. This area had the highest abundance (7% of fire ant colonies) of *S. daguerrei* recorded in South America to date (Briano et al. 1997).

The surveys were conducted from December 1996 to May 1997 and from November 1997 to May 1998 and consisted in walking through the pastures to visually detect the ant colonies. When an ant nest was found, it was excavated, scattered on the ground, and thoroughly examined for *S. daguerrei* adults. Some colonies were excavated and put into 10-liter buckets for separation in the laboratory by flotation (Banks et al. 1981). The floated colonies were put in rearing trays (40 by 30 by 15 cm) and examined later.

Alcohol samples were kept of most ant species found. Samples of 34 parasitized fire ant colonies were preserved in hexane to confirm their identification by gas chromatography analysis of cuticular hydrocarbons and venom alkaloids (Vander Meer & Lofgren 1988). Voucher samples were deposited at the USDA-ARS, SABCL collection and at the USDA-ARS, CMAVE, Gainesville, FL.

We sampled a total of 4,316 ant colonies of 9 different species in 4 subfamilies, however 96% of them were fire ants. Other species examined were: *Pheidole bergi* Mayr, *Acromyrmex lundi* Guérin, *A. ambiguus* Mayr, *Camponotus punctulatus* Mayr, *Neivamyrmex pertyi* Shuckard, *Linepithema humile* Mayr, and *Brachymyrmex* sp.

S. daguerrei was found exclusively in 161 colonies of fire ants (Table 1). Taxonomic studies revealed that 95% of the parasitized colonies corresponded to *S. richteri*. The

TABLE 1. FIELD HOST RANGE OF *S. DAGUERREI* IN SAN ELADIO, ARGENTINA

Ant Species Visually Detected	No. of Colonies Examined and (%) Parasitized by *S. daguerrei*		
	1996/7	1997/8	Total
Myrmicinae			
Solenopsis spp.	2,580 (5.1)	1,551 (1.9)	4,131 (3.9)
Pheidole bergi	67	45	112
Acromyrmex spp.	10	28	38
A. ambiguus	—	11	
A. lundi	—	17	
Formicinae			
Camponotus punctulatus	8	21	29
Brachymyrmex sp.	1	0	1
Dolichoderinae			
Linepithema humile	1	0	1
Ecitoninae			
Neivamyrmex pertyi	0	4	4
Total	2,667	1,649	4,316

remaining 5% was identified by the senior author as *Solenopsis quinquecuspis* Forel. This agrees with Trager (1991), who reported that the fire ant species present in the study area are effectively *S. richteri* and *S. quinquecuspis*. This is the first report of *S. quinquecuspis* as host of *S. daguerrei*.

The field observations reported here showing specificity of *S. daguerrei* to the genus *Solenopsis* are limited to one area and few ant species. Consequently, further surveys will be conducted to confirm this finding.

We thank David Oi, Lloyd R. Davis and Robert Vander Meer (USDA-ARS, CMAVE, Gainesville, FL) for taxonomic identification of most ant species. Also David Oi, Nancy Epskey (USDA-ARS, CMAVE, Gainesville, FL) and Willie Cabrera (USDA-ARS, SABCL, Hurlingham, Argentina) for reviewing the manuscript. This work was partially supported by a subcontract of USDA-APHIS grant 95-8100-0229 to the University of Arkansas-Monticello.

SUMMARY

A field host range study was conducted in San Eladio, Buenos Aires Province, Argentina. *Solenopsis daguerrei* (Santschi) was found exclusively parasitizing 3.9% of the colonies of *Solenopsis richteri* Forel and *Solenopsis quinquecuspis* Forel. *S. quinquecuspis* is reported as a new host for *S. daguerrei*.

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ODONTOTA ANNULIPES WATERHOUSE 1881 IS TRANSFERRED TO *XENOCHALEPUS* (COLEOPTERA: CHRYSOMELIDAE: HISPINAE)

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As part of my ongoing study on the taxonomy of New World Hispinae (Coleoptera: Chrysomelidae) I was awarded a grant from the Thomas Lincoln Casey Fund to study types at The Natural History Museum. While at The Natural History Museum, I examined the holotype of *Odontota annulipes* Waterhouse 1881 and found it belonged in *Xenochalepus* Weise, 1910 [type species: *Odontota omogera* Crotch] because it has 10 complete rows of punctures on each elytron plus a short scutellar row, the elytral margins not constricted after the middle, the apex of the fifth abdominal sternum emarginate, the labrum prominent, and the last tarsal segment triangularly produced between the tarsal claws.

Xenochalepus is divided into two subgenera, *Neochalepus* Staines & Riley 1994 and *Xenochalepus* s. str. *Xenochalepus* s. str. has two complete elytral costae with costae on intervals four and six obsolete. *Neochalepus* [type species: *Odontota medius* Chapuis] has three complete elytral costae and a fourth visible at the base and apex. *Xenochalepus annulipes* belongs in the subgenus *Neochalepus* because each elytron has three complete costae and a fourth visible at the base and apex.

Xenochalepus (Neochalepus) annulipes (Waterhouse) **n. comb.**
(Fig. 1)

Odontota annulipes Waterhouse 1881:268 [Holotype: Type (white disc with red border)/ Sarayacu, E. Ecuador, C. Buckley 91-97 (BMNH)].

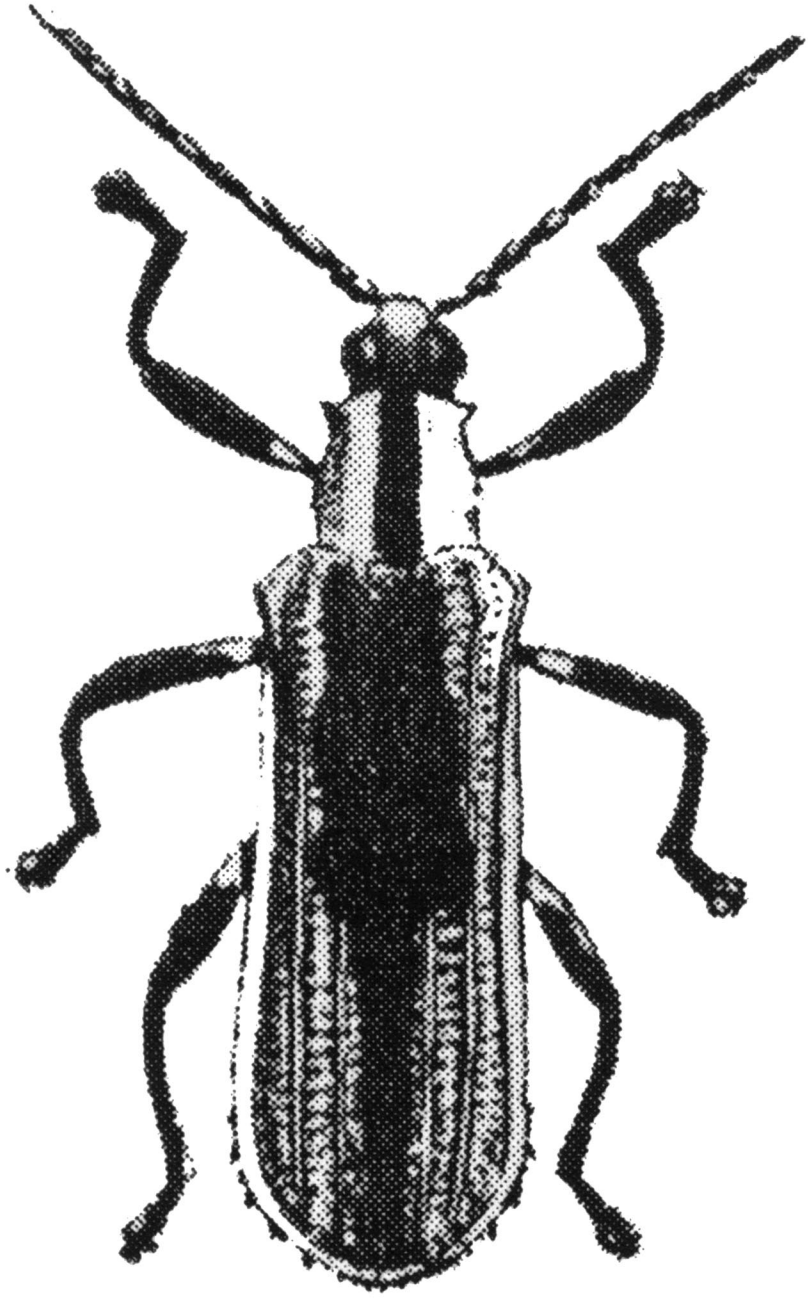

Fig. 1. *Xenochalepus annulipes*.

Chalepus annulipes. Weise 1910:139, 1911a:28, 1911b:90; Uhmann 1957:92.

Head: black; vertex trisulcate, micropunctate; frons tuberculate. Antennae: black, each segment reddish at base; segment I large, subglobose; II short, transverse; III and IV longer, subequal in length, slightly incrassate; V long but shorter than III or IV; VI to VIII transverse; X cylindrical; XI longer than X; VII to XI setose, remaining segments with sparse setae in punctures. Pronotum: yellowish orange with medial vitta and lateral margins black; obconical; sides convex, disc flattened; lateral margins sinuate; small rectangular tooth present in each anterior angle; large, deep, transverse basal impression present; strongly punctate laterally; disc sparsely punctate. Scutellum: black; quadrate; micropunctate. Elytra: yellowish orange with sinuate black medial mark until middle, thence to apex only with black sutural vitta; lateral margins dentate; apical margins strongly dentate; each elytron with 10 rows of strongly impressed punctures with a short scutellar row at base; interspaces 2 and 4 strongly costate for entire length, 6 costate at base and apex, 8 slightly raised for entire length, suture raised; humeri produced, expanded over lateral margins. Venter: pro-, meso-, and metasterna, and abdominal sternite 1 yellowish medially, black laterally; abdominal sterna 2 to 5 black medially, yellow laterally. Legs: femora punctate with a pale yellow band basally. Total length: 10 mm.

Specimens examined: ECUADOR: Sarayacu (BMNH). PERU: no further data (BMNH) **New Country Record**. Total: 2.

I thank Martin J. D. Brendell for access to the collection at The Natural History Museum (BMNH). Figure 1 was scanned from Waterhouse (1881).

Summary

The holotype of *Odontota annulipes* Waterhouse 1881 was examined. The species is here redescribed and transferred to the genus *Xenochalepus* Weise, 1910. The species is reported from Peru for the first time.

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DISTRIBUTION AND KNOWN HOST RECORDS FOR *PLANCHONIA STENTAE* (HEMIPTERA: COCCOIDEA: ASTEROLECANIIDAE)

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With the current emphasis on international travel, free trade agreements, and extensive importation of products such as lumber, ornamental plants, fruits, and vegetables, invasions by exotic species such as scale insects into new areas of the world can significantly impact the local flora. The South African pit scale, *Planchonia stentae* (Brain), has recently become a major pest in Florida on both introduced and native plant species (A. Hamon, personal communication). This species has now spread from its native range in South Africa into North and South America (Table 1).

Planchonia stentae was initially described from specimens on *Caralluma caudata* N.E.Br., *Huernia transvaalensis* Stent, and *Stapelia* sp. in South Africa by Brain (1920) and assigned to the genus *Asterolecanium*. Later, Russell (1941) illustrated the adult female from specimens on *Asclepias fruticosa* L., *C. caudata*, *Caralluma* sp., *Huernia bicampanulata* Verdoorn, *H. transvaalensis*, *Huernia* sp., and *Stapelia* sp. from South Africa and Kenya (Table 1). Borchsenius (1960) then placed the species into the genus *Planchonia* based on the presence of marginal 8- shaped pore bands, quinquelocular pore bands, and a marginal row of simple disk pores on both the dorsum and venter.

Gill (1993) reported this species (as *Asterolecanium stentae*) from California and cited plants in the families Euphorbiaceae and Asclepiadaceae as hosts. We also obtained specimens on *Euphorbia* sp. and *Lantana* sp. from California. In a study of material from the Florida State Collection of Arthropods, we identified *P. stentae* on a variety of host plants in Florida (Table 1). Also, we discovered specimens of this species on *Pueraria phaseoloides* (Roxb.) from Colombia. This exotic tropical vine was imported into South America to reduce soil erosion. In addition, we identified *P. stentae* on *Chamaesyce hirta* (L.)Millsp. from material collected in Puerto Rico. Damage to the host plant is in the form of open galls (pits) on the host plants (Gill 1993), which is typical for species in the family Asterolecaniidae. This pest species has a potential to cause serious problems on tropical and subtropical ornamental plants grown in the U.S.

SUMMARY

The South African pit scale, *Planchonia stentae* (Brain 1920) is reported from 49 ornamental plant species in Colombia and the United States for the first time. Based on its wide host range, this species is a potential threat to several ornamental plants within subtropical regions.

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TABLE 1. HOST PLANTS AND GEOGRAPHICAL DISTRIBUTION OF *PLANCHONIA STENTAE*.

Family	Host plant[1]
Acanthaceae	*Megaskepasma erythrochlamys* Lindau[2], *Ruellia* sp.[2]
Aquifoliaceae	*Ilex cassine* L.[2]
Asclepiadaceae	*Asclepias* sp.[2], *Calotropis gigantea* (L.) W. T. Aiton[2], *Hoya* sp.[2], *Stephanotis floribunda* Brongn.[2], no species information[3], *Stapelia* sp.[4,5], *Asclepias fruticosa* L.[5], *Caralluma caudata* N. E. Br.[5], *Caralluma* sp.[5], *Hoodia* sp.[5], *Huernia bicampanulata* Verdoorn[5], *H. transvaalensis* Stent[5], *Huernia* sp.[5]
Asteraceae	*Bidens pilosa* L.[2], *Chrysanthemum frutescens* L.[2], *Solidago* sp.[2], *Steirodiscus chrysanthemoides*[5]
Convolvulaceae	*Evolvulus glomeratus* Nees & Mart.[2], *Ipomoea carnea* Jacq.[2], *I. carnea* subsp. *fistulosa* (Mart. ex Choisy) D. F. Austin[2]
Crassulaceae	*Echeveria* sp.[2], *Kalanchoe beharensis* Drake[2], *Kalanchoe* sp.[2]
Cucurbitaceae	*Cucurbita moschata* (Duchesne ex Lam.) Duchesne ex Poir.[2]
Euphorbiaceae	*Chamaesyce hirta* (L.) Millsp.[2,6], *C. hyssopifolia* (L.) Small[2], *C. maculata* (L.) Small[2], *C. ophthalmica* (Pers.) D. G. Burch[2], *Euphorbia lactea* Haw.[2], *E. trigona* Haw.[2], *Euphorbia* sp.[2,3], no species information[3]
Fabaceae	*Cajanus cajan* (L.) Millsp.[2], *Chamaecrista fasciculata* (Michx.) Greene[2], *Crotalaria* sp.[2], *Desmodium tortuosum* (Sw.) D. C.[2], *Indigofera hirsuta* L.[2], *Pediomelum canescens* (Michx.) Rydb.[2], *Pueraria phaseoloides* (Roxb.)[7]
Gesneriaceae	*Gloxinia sylvatica* (Kunth) Wieler[2]
Lamiaceae	*Coleus blumei* Benth.[2], *Dicerandra frutescens* Shinners[2], *Monarda punctata* L.[2], *Piloblephis rigida* (W.Bartram ex Benth.) Raf.[2]
Oleaceae	*Fraxinus caroliniana* Mill.[2]
Portulacaceae	*Portulaca* sp.[2]
Solanaceae	*Solanum seaforthianum* Andrews[2]
Verbenaceae	*Nashia inaguensis* Millsp.[2], *Lantana* sp.[3]

[1]Names verified with Wunderlin (1998), the W[3] Tropicos Search Base of the Missouri Botanical Garden (http://www.mobot.org), and the Gray Card Index Query of Harvard University (http://www.herbaria.harvard.edu).
[2]Florida, [3]California, [4]Kenya, [5]South Africa, [6]Puerto Rico, [7]Colombia.

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A METHOD FOR HARVESTING AND SHIPPING LIVE CITRUS RUST MITES (ACARI: ERIOPHYIDAE)

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Field populations of citrus rust mite, *Phyllocoptruta oleivora* Ashmead in Florida have shown resistance to dicofol (Omoto et al. 1994) and shifts in susceptibility to abamectin (Bergh et al. 1999). Resistance monitoring of eriophyid mites has not been widely practiced, limiting the availability of reference strains and technical expertise. This study was prompted when a company expressed interest in testing the susceptibility of citrus rust mite populations from Texas to their acaricide. Under normal conditions, citrus rust mites do not live long off of the host (J. C. B., unpublished data), and importing them into Florida on citrus fruit or foliage requires quarantine. However, importing mites off of host plant tissue reduces the risk of introducing a new pest or plant pathogen and does not require their quarantine.

Our objective was to develop methods for removing large numbers of citrus rust mites from their host and shipping them live to other locations. Toward this end, we capitalized on two aspects of their biology. First, mites disperse by leaping from the plant and are borne away on air currents (Bergh and McCoy 1997). This behavior also occurs on excised pieces of citrus leaf as the tissue deteriorates (Omoto et al. 1994). Second, rust mites in Florida are regularly submerged in rain or dew and can withstand extended periods of immersion, remaining motionless until dried (J. C. B., personal observation).

Mites were harvested from 'Sunburst' mandarin leaves from seedlings maintained in a greenhouse at the Citrus Research and Education Center (CREC), Lake Alfred, FL. To examine the effect of temperature on the harvest of mites, heavily infested leaves were cut into 2 × 2 cm pieces, which were randomly assigned to 4 groups. Each piece of leaf was impaled on an insect pin and the pin was inserted into the side of a rubber stopper. Five stoppers with leaf pieces were placed in each of four translucent plastic boxes lined with wet paper towel. Each piece of leaf was positioned about 1.5 cm above the center of a filter paper disk (Whatman No. 50, 38 mm diam.) placed on the wet paper towel. The boxes were covered and placed in lighted environmental cabinets at 20, 25, 30, and 35°C. The filter paper disks were replaced at 2-h intervals from 09:00 to 17:00 hours, and the mites on each were counted using a dissecting microscope at 20×. The mean number of mites harvested on each of three days was compared among temperatures using PROC GLM of SAS (SAS Institute 1985) and the Tukey multiple range test at the 5% probability level.

To examine the effect of light on the harvest of mites, rubber stoppers with impaled leaf pieces were placed in uncovered boxes in chambers set at 30°C, with bright, overhead lights and continuous darkness. The filter paper disks were replaced at 2-h intervals from 08:00-16:00 hours and the mites were counted as described above. The *t*-test was used to compare the mean number of mites harvested in constant light and dark conditions on each of three days.

Five 2 × 2 cm pieces of peel were removed from areas on green 'Valencia' oranges heavily infested with mites, using a razor blade and flat-tipped forceps. The flavedo and albedo were separated from the edible portion of the fruit, taking care not to burst the oil glands. Each piece of peel was impaled on an insect pin and mites were harvested at 30°C, beginning at 11:30 hours on two days. The filter paper disks were replaced at 16:30 hours and at 08:30 and 16:30 hours the following day and the mites on each were counted.

The effect of cold storage on the survival of mites was measured, using mites harvested at 30°C from 5 leaf pieces between 09:00 and 13:00 hours. At 13:00 hours, each filter paper disk was placed in a 35 × 10 mm Petri dish, and a few drops of water were applied to the perimeter of each disk. A strip of Parafilm was used to seal the lid of each dish to the bottom half containing the paper disk. Twenty-five mites were also manually transferred to each of five filter paper disks, which were sealed in Petri dishes as described above. The dishes were held in a refrigerator at 6°C for 72 h, after which the disks were dried and the number of live and dead mites on each disk was recorded. The percentage of mites alive after cold storage was compared between those manually transferred to disks and harvested from leaf pieces, using the *t*-test with arcsine transformed percentages.

To determine if mites survive interstate shipment, 25-50 adult mites were transferred from fruit to six filter paper disks at the Citrus Center, Texas A&M University, Weslaco, TX. The disks were placed on two 50 mm diam circles of wet paper towel in 50 × 15 mm Petri dishes, and the dishes were sealed with Parafilm. The Petri dishes were placed in a covered Styrofoam box (30 × 20 × 18.5 cm) with Styrofoam packing and 3 ice packs. The Styrofoam box was placed in a cardboard box and surrounded by Styrofoam packing. Mites were also transferred to three other filter paper disks, which were sealed in Petri dishes with wet paper and held in a refrigerator (6°C) at the Citrus Center.

To prepare for the receipt of mites from Texas, five green 'Valencia' oranges were washed in distilled water, dried, and dipped in liquid paraffin wax, leaving an unwaxed area of about ⅓ of the surface. Approximately 24 h elapsed between when the mites were collected in Texas and delivered by courier service to the CREC in Florida. The filter paper disks from Texas were dried and the mites on each were transferred to the unwaxed area of a fruit. The fruit were placed in a covered plastic box lined with wet paper towel and held in an environmental cabinet set at 27°C and a photoperiod of 14:10 L:D. After 24 h, fruit were examined for surviving mites and eggs, and the development of mite populations was noted after 7 d.

Mites from one disk were transferred to a young (4 leaf stage) 'Sunburst' mandarin seedling, which was held in a Plexiglas cage in a naturally lighted greenhouse at 27°C. The seedling was checked after 7 d for mite population development. Upon delivery of the mites in Florida, the survival of mites that had been held in cold storage in Texas was assessed.

There was a significant effect of temperature on the number of mites harvested over 8 h (Table 1). Numerically, more mites were harvested from leaf pieces at 30°C than at other temperatures. Only 1 mite was harvested from leaf pieces held at 20°C. At 30 and 35°C, the majority of mites were harvested during the first 4 h (Table 1), whereas <50% of mites were harvested from leaf pieces held at 25°C during the same period.

At the end of the 8-h collection period there were many healthy mites feeding on the leaf pieces held at 20°C and the leaf tissue appeared fresh and succulent. At 25°C, there were many mites walking on the leaf pieces, which had slightly curled edges but did not appear overly desiccated. At 30°C, there were dead mites and a few live mites on the plant tissue, and the leaf pieces were dry and curled. At 35°C, no live mites and many dead mites were observed on leaf pieces, which were dry, curled, and crinkled.

TABLE 1. THE EFFECT OF TEMPERATURE ON THE HARVEST OF CITRUS RUST MITES FROM PIECES OF 'SUNBURST' MANDARIN LEAVES OVER EIGHT HOURS.

Date	20	25	30	35	F (df = 3,16)	P
30 March						
Mean ± SD no. harvested from 0900-1700	0.0a	11.0 ± 3.0a	43.0 ± 14.3b	15.2 ± 3.0ab	6.05	<0.01
Mean cumulative percentage ± SD harvested after 4 h	NA	24.4 ± 23.2	76.2 ± 16.4	90.6 ± 3.1		
31 March						
Mean ± SD no. harvested from 0900-1700	0.2 ± 0.2a	16.6 ± 5.5a	53.4 ± 12.9b	23.2 ± 6.5ab	8.31	<0.01
Mean cumulative percentage ± SD harvested after 4 h	NA	45.0 ± 17.4	93.3 ± 4.8	96.4 ± 4.1		
2 April						
Mean ± SD no. harvested from 0900-1700	0.0a	15.8 ± 3.6a	52.8 ± 14.4b	23.8 ± 0.7ab	8.88	0.001
Mean cumulative percentage ± SD harvested after 4 h	NA	29.5 ± 17.0	82.3 ± 6.4	90.1 ± 12.0		

[1]Means based on five leaf pieces. Mean number of mites harvested, within rows, followed by the same letter are not significantly different by ANOVA and the Tukey test at the 5% probability level.

The mean numbers of mites harvested did not differ between light and dark conditions (Table 2). The majority of mites were harvested from leaf pieces in the light and dark during the first 4 h.

At 30°C, very few mites were harvested from pieces of orange peel during the first five hours (11:30-16:30 hours); mean ± SD = 4.6 ± 7.5 and 4.6 ± 4.9 mites on 13 and 17 August, respectively. The vast majority of mites were collected between 16:30 and 08:30 hours the following day; mean ± SD = 81.6 ± 55.3 and 70.2 ± 27.1 mites on 14 and 18 August, respectively.

Following storage at 6°C for 72 h, there was no difference in the survival (mean ± SD percentage) of mites that had been manually transferred to paper disks (89.6 ± 7.8%, n = 25 mites per disk) or harvested from leaf pieces (92.6 ± 3.1%, n = 29-61 mites per disk) ($t_{0.05,(2),\,8} = 0.743$, $P > 0.20$).

The interstate shipping of mites had no adverse effect on their survival; 83.5 ± 5.4% SD and 72.3 ± 3.3% SD of mites survived shipping to Florida from Texas and cold storage in Texas, respectively. Mites shipped to Florida oviposited on fruit during the first 24 h, and all life stages were present on fruit after 7 d. A building population of mites was also evident on the young seedling to which imported mites were transferred.

This method for harvesting and shipping live citrus rust mites off of host tissue should enable work with populations from different geographical locations at one laboratory, as is often done in resistance monitoring and other research on other arthropods (Campos et al. 1996).

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TABLE 2. THE EFFECT OF EXPOSURE TO LIGHT ON THE HARVEST OF CITRUS RUST MITES FROM PIECES OF 'SUNBURST' MANDARIN LEAVES OVER EIGHT HOURS.

Date	Light	Dark	t	P
8 April				
Mean[1] ± SD no. harvested from 0800-1600	61.2 ± 60.3	48.4 ± 17.0	0.457	>0.50
Mean cumulative percentage ± SD harvested after 4 h	83.4 ± 7.2	80.8 ± 5.7		
9 April				
Mean ± SD no. harvested from 0800-1600	25.6 ± 10.2	36.0 ± 11.9	-1.479	>0.10
Mean cumulative percentage ± SD harvested after 4 h	79.1 ± 18.7	72.3 ± 19.3		
13 April				
Mean ± SD no. harvested from 0800-1600	29.2 ± 14.7	41.4 ± 14.4	-1.418	>0.10
Mean cumulative percentage ± SD harvested after 4 h	68.2 ± 13.7	51.4 ± 18.5		

[1]Means based on five leaf pieces.

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MATING FREQUENCY IN WILD FEMALES OF *COPITARSIA CONSUETA* (LEPIDOPTERA: NOCTUIDAE)

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Successful mating in females of Lepidoptera is indicated by the presence of one or more spermatophores in the bursa copulatrix (Ouye et al. 1964). The determination of mating status in lepidopteran pests has been used in studies of mating disruption by pheromones or in control systems using sterile males (Spurgeon et al. 1994). *Copitarsia consueta* (Walker) (Lepidoptera: Noctuidae) is a polyphagous insect distributed from South America to Mexico (Angulo and Wiegert 1975). Mating frequency has not been described in the field. In Mexico, this pest is present all year in association with cabbage (*Brassica oleraceae* var. Capitata). The purpose of this work was to determine the mating frequency of wild *C. consueta* females.

The study was carried out in Montecillo and Chapingo, both sites in the state of Mexico. A white light trap (WLT) and black light trap (BLT) of 15 watts each were placed at different sites in a cabbage crop (0.5 ha) for 20 d. The traps were placed at a height of 1.3 m and were switched on from 8 pm to 6 am. The traps were emptied daily and captured insects were taken to the laboratory for identification using the keys of Artigas and Angulo (1973). The number of males and females of *C. consueta* in each collection was recorded, and females were dissected to count the number of spermatophores.

[1]Becarios COFAA.

A total of 71 females were captured in both sites, and all were mated. Eight females had 4 spermatophores, forty seven females had 3, eleven females had 2 and five females only had one spermatophore (Table 1). Chapingo was the site where the highest number of females was captured (n = 43). Montecillo had less (n = 28), but the difference was not significant ($\chi^2 = 0.735$; df = 1, $P > 0.05$). The WLT captured 22 females in Chapingo and 13 in Montecillo, whereas the BLT captured 21 females in Chapingo and 13 in Montecillo (Table 1).

Mating frequency of female Noctuidae is not constant across species. For example, from 132 females of *Helicoverpa armigera* (Hubner) captured, most (117) did not mate, eleven of them only had a single spermatophore, and the rest contained between 2 and 3 spermatophores (Coombs et al. 1993). In *Helicoverpa punctigera* (Wallengren), most of the females did not mate (329 of 366), and the rest only had a single spermatophore (Coombs et al. 1993). Similar results to those found in the present study were reported for *Amphipyra pyramidea* (L.), where females mated between 2 and 4 times. However in other *Amphipyra* species, most females only mated a single time (Funakoshi 1992).

The data obtained in the present study confirm that *C. consueta* females copulate several times. Observations on the number of matings in wild females of C. *consueta* agree with those found by Rojas and Cibrián (1994) in the laboratory. In the field, *C. consueta* females mated an average of 2.7 times, while in the laboratory the average was 2.5 times. In a study of 13 species of *Euxoa*, Byers (1978) found that three species had the same frequency of mating in the field and laboratory. According to Byers (1978), the benefits of multiple mating may be to remedy an inadequate initial mating, improve genetic diversity, contribute a paternal nutritional investment and increase phenotypic variation. Although light traps may not capture a representative field population, the mean number of spermatophores per female was similar in both sites (Table 1).

Summary

Females of *Copitarsia consueta* were captured with light traps in cabbage fields in Mexico. The number of spermatophores in the bursa copulatrix determined the fre-

TABLE 1. FREQUENCY OF MATING DETERMINED BY THE NUMBER OF SPERMATOPHORES IN THE BURSA COPULATRIX OF C. *CONSUETA* FEMALES.

Site	Light trap	No. captured females	% Females w/spermatophores	No. spermatophores	No. captured males	Total moths captured
Montecillo	Black	13	38	1	15	28
			62	3		
	White	15	20	2	19	34
			60	3		
			20	4		
Chapingo	Black	21	38	2	18	39
			62	3		
	White	22	77	3	21	43
			23	4		
Total		71			73	144

quency of matings. All captured females were mated and the highest number of spermatophores found was 4 per female ($\bar{X}$ = 2.7 ± EEM 0.058).

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A NOVEL METHOD TO REAR *DIADEGMA INSULARE* (HYMENOPTERA: ICHNEUMONIDAE), A PARASITOID OF THE DIAMONDBACK MOTH (LEPIDOPTERA: PLUTELLIDAE)

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Diadegma insulare (Cresson) (Hymenoptera: Ichnuemonidae) is a solitary, host-specific endoparasitoid of diamondback moth (*Plutella xylostella*) (L.) (Lepidoptera: Plutellidae) larvae, and is considered one of its most important natural enemies (Idris & Grafius 1993). *Diadegma insulare* and related species occur naturally throughout much of the United States and in other cabbage-growing regions of the world (Lasota & Kok 1986, Idris & Grafius 1993, Muckenfuss et al. 1992, Fitton & Walker 1992). Additionally, they are augmentatively released for biological control programs.

Our laboratory is involved in developing methods to further suppress diamondback moths in Florida cabbage, including augmenting natural populations of *D. insulare* early in the season before they normally appear (Mitchell et al. 1997). To this end, we conduct research on more efficient methods of rearing *D. insulare*. An ideal rearing method would be easy, inexpensive, and produce large enough quantities of wasps. In addition, the sex ratio should be as female biased as possible, since the females are the individuals actively controlling larval populations.

We currently rear *D. insulare* on diamondback moth larvae feeding on cruciferous plants. In order to have enough plant material for our rearing operation, we grow or purchase pesticide residue-free crucifers. The material must be of the right stage, since daughter-production by *D. insulare* is sensitive to the chemistry and age of crucifers, even with other host quality parameters held constant (Fox et al. 1990). We have had little success rearing *D. insulare* on larvae feeding on artificial diet. A recent study demonstrated that the addition of collard extract to an artificial diet or to the sides of the rearing container containing the diet increased oviposition rates and the production of daughters (Sieglaff et al. 1998), but the level of parasitism was not high enough to switch to this rearing method. In addition, the age of the collard extract and the plant quality of which it was extracted from appear to have been factors in low production of *D. insulare* females (unpublished information).

We recently expanded upon the work of Sieglaff et al. (1998) with the goal of increasing the percentage of larvae parasitized (parasitism in the previous study ranged between 28-46% in the amended diets), while maintaining an adequate female sex ratio to maintain the colony and allow for experimental releases in the field. This study consisted of two treatments replicated five times, each on five different dates. Treatments were plain artificial diet (Wheat germ-based artificial diet, Shelton et al. 1991; 8 cm diameter, approx. 1.5 cm thick) versus artificial diet coated with approximately 6 g of cabbage flour (BIO-SERV, Frenchtown, NJ) immediately prior to the exposure. Cabbage flour is made from washed, blanched, dehydrated, and powdered fresh cabbage (Y. Bai, Director of Nutrition, Bio-Serv). Artificial diet cakes were infested with diamondback moth eggs approximately 5 days prior to the experiments, and maintained at 25°C under constant light. Larvae ranged between late second and early third instar, with 250-350 larvae per diet cake. Diet cakes with similar numbers of larvae were used per each

paired replicate. Treated and untreated diet cakes were placed on steel mesh (5 mm) platforms (1 cm high) in separate 5 L cylindrical plexiglass containers with an organdy cloth top for ventilation. Cages were placed near a window in the laboratory with an oscillating fan blowing at low speed over the tops of the cages. Four, four-day-old pairs of *D. insulare* were placed in each cage immediately after the addition of the cabbage flour. Wasps were provided by the rearing unit at the USDA-ARS laboratory in Gainesville, FL. Wasps were provided fresh honey and water daily for the duration of the study. After four days, wasps were removed and larvae were allowed to continue feeding on the same diet cake until pupation. The resulting parasitism data were compared using the sign test (a nonparametric test used to test the hypothesis that the median of the differences in the pairs is zero), where a positive sign was given to the treatment with the higher value for each given replicate (n = 5) (Snedecor 1956).

The percent of larvae parasitized on the amended diet cakes (93.4% ± 0.9) was significantly greater than the percentage on the plain diet (61.8% ± 15.5) (p = 0.03125); each replicate yielded a higher percentage in the treated vs. the untreated diet. The percent of daughters produced was not significantly different between the plain diet (49.5% ± 4.2) and the cabbage flour-amended diet (49.9% ± 1.9). The absolute numbers of daughters produced per female was significantly greater in the amended diet treatment (34.7 ± 3.0) than in the plain diet treatment (21.6 ± 6.1) (p = 0.03125); each replicate yielded a higher number in the treated vs. the untreated diet. In each replicate, *D. insulare* females were observed to land on and parasitize hosts on the amended diet within 45 minutes. No landings were observed on the plain diet; all observed attacks were on larvae crawling on the bottom or sides of the cage.

It is likely that the cabbage flour has a volatile chemistry similar to larval-damaged or otherwise disrupted plant material, shown to provide host location cues to *D. insulare* (Hu et al., unpublished data). Whether the cabbage flour acts a searching stimulant or if it actually aids in the location of the larvae after they ingest the material along with the artificial diet is unknown.

The results obtained suggest that cabbage flour as an artificial diet amendment may improve a *D. insulare* rearing program. It is relatively easy (larvae do not need to be transferred to plant material, plant material does not need to be grown or purchased, extracts do not need to be made and incorporated into the diet), inexpensive (the same diet cake is used for all stages of the rearing, the cabbage flour is inexpensive), and produces large numbers of female offspring while minimizing numbers of non-parasitized larvae. Also, it can be incorporated into the diet-larvae complex immediately prior to parasitism so there is less chance of the important chemical constituents breaking down, which possibly may happen with liquid extracts mixed into the diet. Studies are planned which address the long-term consequences of incorporating this method into our rearing program. We also will study the importance of natural light and airflow on the oviposition behavior of *D. insulare,* since these were not controlled for in the previous studies with collard extract, and the present results in both the amended and plain treatments were better than in the previous studies with collard extract.

We thank Joyce Leach for providing the insects used in the study. Mention of a proprietary product does not constitute endorsement by the USDA.

SUMMARY

The addition of cabbage flour to the surface of diamondback moth - infested artificial diet cakes was shown to increase the percent of parasitism and the numbers of daughters produced by the host-specific, larval-endoparasitoid *Diadegma insulare.* This may be a useful method to integrate into a *D. insulare* rearing program.

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A CHECKLIST OF THE TERMITES FROM VENEZUELA (ISOPTERA: KALOTERMITIDAE, RHINOTERMITIDAE, TERMITIDAE)

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Termites are a diverse and important group of insects in the New World, and the Neotropical Region has the second highest species diversity worldwide (Constantino 1998). Constantino (1998) reports about 543 species from Mexico and Florida (USA) to Argentina. However, little has been recorded about the Venezuelan termite species since the list of Snyder (1959). The list below is an update of Snyder's 1959 work, including some species added after Snyder (1959) by Araujo (1977) and Constantino (1998). Some species, such as *Comatermes perfectus* were recorded for the country but

without any location. Recent collections throughout the country and revisions have produced new records for Venezuelan termites and expanded geographic distribution for the known species reported. All new records and expanded geographic distributions are derived from the collection at Simon Bolivar University Museum, and herein referenced as "Issa." The list is presented by family, subfamily, species and the geographical distribution (locality and State) followed by the authority references responsible for each entry. This list is preliminary to a more comprehensive work on the termites of Venezuela, their geographical distribution, and biology.

KALOTERMITIDAE

Calcaritermes temnocephalus (Silvestri): Las Trincheras, Carabobo (Silvestri 1901).
Calcaritermes? n.sp.: Las Melenas, Península de Paria, Sucre (Scheffrahn & Krecek, pers. comm.).
Comatermes perfectus (Hagen): No locality given (Araujo 1977).
Cryptotermes brevis (Walker): Caracas, Distrito Federal; Margarita Island, Nueva Esparta (Snyder 1959).
Glyptotermes pellucidus (Emerson): No locality given (Snyder 1959).
Incisitermes (*Kalotermes*) *incisus* (Silvestri): Caracas, Distrito Federal (Snyder 1959); St. Jean, Guarico (Silvestri 1901); La Blanquilla Island (Scheffrahn & Krecek, pers. comm.).
Neotermes araguaensis Snyder: Rancho Grande, Maracay and Choroni, Aragua; El Pilar, Mt. Auyantepui, Bolívar (Snyder 1959).
N. castaneus (Burmeister): No locality given (Araujo 1977).
Neotermes sp.: La Blanquilla island (Issa).
Proneotermes (*Glyptotermes*) *latifrons* (Silvestri): Las Trincheras, Carabobo (Silvestri 1901).

RHINOTERMITIDAE

Coptotermitinae

Coptotermes testaceus (L.): Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.); El Limón, Aragua; Puerto Cabello, Carabobo (Snyder 1959); Uverito and El Merey, Monagas (Issa).
Coptotermes sp.: Canaima, Bolívar (Issa).

Heterotermitinae

Heterotermes convexinotatus (Snyder): El Limón, Aragua; Caracas, Distrito Federal; Margarita Island, Nueva Esparta (Snyder 1959).
H. crinitus (Emerson): El Limón, Aragua; Central Tacarigua, Miranda (Snyder 1959).
Heterotermes sp.: Chaguaramas, Monagas (Issa).

Rhinotermitinae

Dolichorhinotermes longilabius (Emerson): Raudal El Danto, Cuao River, Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).
Rhinotermes hispidus Emerson. Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).

TERMITIDAE

Apicotermitinae

Anoplotermes franciscoi Snyder: El Limón, Aragua; El Pilar, Bolívar (Snyder 1959).

A. meridianus Emerson: El Limón and Rancho Grande, Aragua (Snyder 1959).
A. subterraneus Emerson: El Limón, Aragua; Uruyen, Gran Sabana, Bolívar (Snyder 1959).
A. tenebrosus (Kollar): El Limón, Aragua (Snyder 1959).

Termitinae

Amitermes foreli Wasmann: Coro, Falcón (Scheffrahn & Krecek, pers. comm.), Maracaibo, Zulia (Snyder 1959).
Cavitermes tuberosus (Emerson): Suromoni, Amazonas (Issa).
Microcerotermes arboreus Emerson: Cuyagua, Aragua (Issa); El Valle, Distrito Federal (Snyder 1959).
Microcerotermes near *arboreus* Emerson. Calabozo, Guarico (Scheffrahn & Krecek, pers. comm.).
M. exiguus (Hagen): El Limón, Aragua; El Valle, Distrito Federal (Snyder 1959); Sartenejas, Miranda (Issa).
Microcerotemes near *exiguus* (Hagen): Calabozo, Guarico (Scheffrahn & Krecek, pers. comm.).
Neocapritermes brasilienzis (Emerson): El Porvenir, Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).
Neocapritermes angusticeps (Emerson): Las Melenas, Península de Paria, Sucre (Scheffrahn & Krecek, pers. comm.).
Spinitermes trispinosus (Bates): Hato El Frio, Apure (Scheffrahn & Krecek, pers. comm.).
Termes hispaniolae (Banks): Calabozo, Guarico (Issa).
Termes near *fatalis* (Harris): Calabozo, Guarico; Uverito, Monagas (Scheffrahn & Krecek, pers. comm.).
Termes sp.: Canaima, Bolivar (Issa).

Nasutitermitinae

Araujotermes sp.: Santa Rosa Castle, Margarita Island, Nueva Esparta (Scheffrahn & Krecek, pers. comm.).
Armitermes holmgreni Snyder: Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).
Constrictotermes cavifrons (Holmgren): No locality given (Snyder 1959); Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).
Cornitermes pugnax Emerson: Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).
Embiratermes (*Armitermes*) *neotenicus* (Holmgren): Guayaraca, Aunyantepui, Bolívar (Snyder 1959).
Embiratermes benjamini (Snyder): Rio Negro, Amazonas (Issa).
Labiotermes labralis (Holmgren): Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.); Moitaco, Gran Sabana, Bolívar (Emerson & Banks 1965).
Nasutitermes near *acajutlae* (Holmgren): Caracas, Distrito Federal; Calabozo, Guarico (Scheffrahn & Krecek, pers. comm.).
Nasutitermes (*Velocitermes*) *bolivari* (Snyder): Suromoni, Amazonas (Issa); Mt. Auyantepuy, Guayaraca, Bolívar (Snyder 1959).
N. corniger (Motschulsky): Tucacas, Falcón (Issa); Higuerote and Tacarigua, Miranda (Issa); Aroa, Yaracuy (Issa); Maracaibo, Zulia (Snyder 1959).
N. costalis (Holmgren): Raudal El Danto (Cauo River), Amazonas (Scheffrahn & Krecek, pers. comm.).
N. ephratae (Holmgren): Auyantepui, Bolivar (Snyder 1959); Las Trincheras, Carabobo (Snyder 1959); Tucacas, Falcón (Issa); Higuerote y Tacarigua, Miranda (Issa); Aroa, Yaracuy (Issa).
N. guayanae (Holmgren): Uruyen, Bolívar (Snyder 1959); Valencia, Carabobo (Snyder 1959); Calabozo, Guarico (Issa).

N. meinerti (Wasmann): Moitaco, Hoya del Rio Negro, Bolívar (Snyder 1959); Las Trincheras, Carabobo (Silvestri 1901); Kunana, Perijá, Zulia (Snyder 1959).
N. nigriceps (Haldeman): Cauo River, (Scheffrahn & Krecek, pers. comm.); Calabozo, Guarico (Issa); Margarita Island, Nueva Esparta (Scheffrahn & Krecek, pers. comm.); Acarigua, Portuguesa (Snyder 1959).
N. surinamensis (Holmgren): No locality given (Snyder 1959).
Nasutitermes spp.: Villa de Cura, Aragua; Hato El Frio, Apure; Coro, Falcón; Rio Chico, Miranda; La Bananera, Yaracuy (Issa).
Obtusitermes n.sp.: Canaima, Bolívar (Issa); Uverito, Monagas (Scheffran & Krecek, pers. comm.).
Syntermes aculeosus Emerson: Maraca, Movaca, Puerto Ayacucho and San Carlos de Rio Negro, Amazonas (Constantino 1995).
S. grandis (Rambur): Akuriman and Santa Elena de Guairen, Bolívar (Snyder 1959, Constantino 1995).
S. molestus (Burmeister): Akuriman, Canaima, Ciudad Bolívar; Santa Blanca de Uaren, Uruyen, Bolívar (Snyder 1959, Issa).
S. parallelus Silvestri: El Rincón, Sucre (Constantino 1995).
S. spinosus (Latreille). Sarare, Lara (Constantino 1995).
Velocitermes near *beibei* (Emerson): Uverito, Monagas; Calabozo, Guarico (Scheffrahn & Krecek, pers. comm.).
Velocitermes sp.: Suromoni, Amazonas (Scheffrahn & Krecek, pers. comm.).

The author wishes to thank Dr. Rudolph Scheffrahn and Jan Krecek for the material revision, identification of several species and additional unpublished records for Venezuela from the University of Florida Collection; and Dr. David Furth for review of the early manuscript and the National Museum of Natural History, Smithsonian Institution (Washington, D.C.) for providing facilities to examine the termite collection.

Summary

Species and geographical locations are provided for termites recorded from Venezuela. Fifty eight species from 3 families are included from the continental area and islands of Venezuela. There are 30 new records for Venezuela.

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BOOK REVIEWS

CASTNER, J. L. 2000. Amazon insects. Feline Press; Gainesville, FL. 160 p. ISBN 0-9625150-1-9. Paperback, 5.75" × 5". $15.00 (Available from Feline Press, P.O. Box 357219, Gainesville, FL 32635; shipping and handling $3 via book rate or $5 via priority mail within the U.S.A.; $5 via surface mail or $10 via airmail overseas).

This little book (14.7 cm w × 13.8 cm h) is a photographic treasure which contains 75 full-size (14.7 × 13.8 cm) close-up color photographs and 125 small size (3.7 × 2.4 cm or slightly larger) color photographs. Very nearly all of them look as if they had been taken of living insects in nature, and the quality of reproduction is excellent. This book therefore is very different from recent, expensive, large-sized books showing color plate after color plate of pinned, dead butterflies. The text accompanying the pictures is necessarily brief, but factual, and I was hard-pressed to find any errors of any sort in it. At the foot of each text page are a few lines of text in Spanish, presumably in deference to any Spanish-speaking readers. I have only two criticisms. First, why is there no Portuguese text when so much of the Amazon is in Brazil? Second, why are indications of size of insects (at top of each text page) given only in inches, when measurements in millimeters could so easily have been added for the benefit of South American readers?

This book portrays insects that the author/photographer encountered in numerous journeys to the upper Amazon. It reflects his interests in Orthoptera which are well represented, and portrays other large insects (and a few arachnids, a diplopod, a chilopod, a planarian, and an onycophoran). Small insects are ignored, although they are the majority in the Amazon as elsewhere. But, as the author points out, why should such a book offer a balanced selection of insect photographs—balanced so as to show representatives of the 75 most speciose insect families, or balanced to show the 200 most abundant insect species in the Amazon region? The non-entomologist who buys this book won't even notice the vast majority of small insects unless they bite or sting or otherwise annoy. The specialist who visits the Amazon to look for (say) termites will find this book no use for termite identification. This termite specialist may pay no attention to the small insects belonging to other taxa, but will surely notice the large and spectacular insects that this book illustrates—and will surely want to know a little more about them, so even to this specialist the book is useful.

I don't know of any comparable book. **Latin American insects and entomology** (Hogue, C. L. 1993. University of California Press; Berkeley) offers a general introduction to insects in Latin America, has far more text (and more errors), lots of references, and only 32 color photographs. **Insects of an Amazon forest** (Penny, N. D. 1982. Columbia University Press; New York) is data-rich in ecological analysis of ecosystems, but at the level of higher taxa. Neither of these books is helpful to the traveller in identifying the oh-my! insects that he or she may encounter. There is no "Field Guide to Amazon Insects." Perhaps the closest thing is the series "A Golden Nature Guide" of little books (Golden Press; New York) on various topics, which are aimed at rough identification of some of the commoner spiders and their kin, insect pests, butterflies and moths, etc. in America north of Mexico, but which lack color photographs. If you think **Amazon insects** is expensive compared with a "Golden Nature Guide", think instead of the number and quality of the photographs and the more limited market: I think it is a bargain at $15.

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GODDARD, J. 1999. Infectious diseases and arthropods. Humana Press; Totowa, NJ. xvi + 231 p. ISBN 0-89603-825-4. Hardback. $75.00.

This book is about entomological medicine rather than medical entomology. Its focus is etiology, diagnosis, and prevention and treatment of the infectious diseases transmitted to people by arthropods. Some of it is based on articles that its author published in 1996-1999 in volumes of "Infections in Medicine," and other parts are newly written. In that journal, each article focused on a disease. In this book, diseases (protozoan, bacterial, viral, and filarial) are grouped in chapters under headings mosquitoes, ticks, fleas, etc. It has more detail about diseases known from the U.S.A. than about diseases occurring in other parts of the world. It deals with possibilities of travellers arriving in the U.S.A. with diseases acquired elsewhere. Its information is up-to-date, including recent information about Lyme disease and the forms of Ehrlichiosis, and it provides a reference source for physicians and public health workers.

I wonder whether this kind of information is as close as physicians and public health workers get to a text on entomology. The author makes the point that during an outbreak of St. Louis Encephalitis, which is transmitted by *Culex quinquefasciatus* in the southern U.S.A. (except Florida), a public health worker visiting a rural community told the local people to remove containers (cans, tires, etc.) that accumulated rainwater. That public health worker was spreading misinformation and doing nothing to help control the disease, because the habitat of *C. quinquefasciatus* larvae is marshes with emergent vegetation. I heard a public health worker speaking on public television in Florida pass similar misinformation about West Nile Virus, a disease which only in late 1999 was recognized in the U.S.A. (too late to mention in this book).

Medical entomologists should have a far better appreciation of the entomology of disease vectors, and for them the book may provide additional information on the diseases. Its illustrations are black and white drawings and photographs, some of them not very well reproduced; shading and lettering on some figures is blurred, to the point where a map on p. 46 is hard to interpret. The introductory statement about La-Crosse Encephalitis (p. 52) seems to have been truncated. Typographical errors include "autochthonus" (p. 24), "W.B. herms" (p. 25), "sporozoties" (p. 36), "Psorphora columbia" (p. 45), "Boliva" (p. 62), "platlets" (p. 92), and "likliehood" (p. 157).

In addition to the chapters on arthropod groups as disease vectors, there is a 14-page introductory chapter on arthropods, and a section of 4 brief chapters on other arthropod-caused or related problems. The first is on myiasis, the second on delusory parasitosis, the third on medical conditions caused by arthropod stings or bites, and the fourth on "Why mosquitoes cannot transmit HIV." Two appendices and an index round out the book. The first appendix is an alphabetical list of symptoms of disease, and the second briefly describes 11 tests diagnostic of diseases.

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SERVICE, M. W. 1996. Medical entomology for students. Chapman & Hall; London. xi + 278 p. First edition. ISBN 0-412-71230-X. Paperback. **and** 2000. Cambridge Univ. Press; New York. Second edition. xi + 283 p. ISBN 0-521-66659-7. Paperback. $37.95.

The two editions differ little except that the second is of slightly smaller format with thicker paper, has a glossary, and has updated sections on control and references.

This book is designed as a textbook on the central subjects of medical entomology: flies (mosquitoes, simuliids, ceratopogonids, tabanids, glossinids, muscids, calliphorids and sarcophagids), fleas, lice, bugs (cimicids and triatomine reduviids), and acarines (argasids, ixodids, sarcoptids and trombiculids) that bite people (many of them transmit diseases to people), or whose immature stages develop in people. It has brief descriptions of the diseases, medical methods of controlling the diseases within the human body, and methods of reducing populations of the arthropod vectors. It also has a chapter on cockroaches. It is illustrated entirely by black and white drawings, which are well executed and entirely adequate. Lack of photographs, either black and white or color, is not a disadvantage, and undoubtedly reduces production costs (if not the sale price). The author has written clearly and has avoided unnecessary technical expressions from medicine and entomology. The book is authoritatively worldwide in scope, although its major emphasis is necessarily on the tropics, where most of the problems occur.

The book does not deal with the insects and arachnids (bees, wasps, ants, spiders, scorpions, and others) that sting and may cause anaphylaxis, or (bugs [except cimicids and triatomine reduviids] and thrips) that bite, or (flies [such as *Hippelates* gnats] and beetles) that get into human eyes and transmit disease or release toxins, or (moth and beetle larvae) that urticate and may cause pulmonary problems, or (beetles) that act as intermediate hosts of helminths, or (beetles) that blister the human skin, or (beetles and some flies not mentioned in the book) that cause canthariasis and myiasis, or delusory parasitosis, or the use of fly maggots or drugs derived from insects and used for healing chronic lesions. Perhaps these other organisms, afflictions, and uses deserve their own book ("paramedical entomology"?) because at least in America north of Mexico—where mosquito-transmitted disease has been relatively uncommon for decades—they are frequent subjects of public concern.

With one person worldwide dying of malaria every 12 seconds, there is, however, no question that the major emphasis of the book is correct. That's just one of the major diseases transmitted by mosquitoes, and only by certain species of the genus *Anopheles* at that. The author writes with great authority on the subject of mosquitoes, and has done a competent job in portraying the other insects and diseases, and their control, that the book encompasses. This book is therefore written mainly for people (medical entomologists, public health specialists, nurses and physicians in training) who will work in tropical countries where these diseases are prevalent, and for them this information is of the utmost importance; it cuts to the essentials. It is highly appropriate as the entomological component of a course in tropical medicine. For those people training in America north of Mexico and who have no intention of working in tropical countries, some supplement is needed about the various lesser afflictions caused by arthropods.

For those readers who are unfamiliar with the language of medical entomology, there are some unusual conventions to remember as exemplified in this book. Although throughout botany and zoology, generic names at second and subsequent mention are abbreviated to a single letter (such that *Homo sapiens* is abbreviated to *H. sapiens*), card-carrying mosquito specialists insist on a 2-letter generic code (such that *Culex pipiens* is abbreviated to *Cx. pipiens*). Although zoologists agree that only adult animals (with a few rare exceptions [paedogenesis]) can breed, medical entomologists, mosquito control specialists, and public health workers normally write about "larval breeding places", by which they mean larval habitats. Medical entomologists (together with ecologists, by which I mean population ecologists) use the original (A.D. 1603) definition of the word **endemic** to mean a population which is constantly present [regardless of its origin] and more or less stable as antonym of **epidemic**; this

contrasts with much later uses of the word **endemic** by zoogeographers to mean things entirely different.

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MCGAVIN, G. C. 2000. Insects[,] spiders and other terrestrial arthropods. Dorling Kindersley Handbooks. Dorling Kindersley; New York. 256 p. ISBN 0-7894-5337-1. Paperback. $18.95.

Several publishing companies have produced guides to the insects of America north of Mexico. One guide is Borror & White (1970. A field guide to the insects of America north of Mexico. Houghton Mifflin; Boston). It is well illustrated by 1300 drawings (including 16 color plates) depicting insects belonging to 579 families. It is one of the Peterson Field Guide Series and is designed to complement other books in this series such as those on mammals and eastern birds. Of course, it doesn't do the job that those on birds and mammals do, because it depicts only a tiny percentage of the >100,000 insects of America north of Mexico. So we are stuck with publishing companies wanting to produce books on insects as "companion" volumes to those on birds, mammals, etc., when this is a mismatch because of the vastly greater number of insect species. Houghton Mifflin has produced a "companion" book on beetles (which still comes nowhere near covering the subject), and eastern butterflies (which does), but we have not seen, nor are likely to see, "companion" volumes on fleas, flies, lice, or termites because those insects lack popular appeal. Entomologists recognize that such guides to insects at large play a role in helping to assign observed insects to the level of order, and to some extent to family, and that they help to educate the general public. Nevertheless, the general public still does not understand that such guides will not allow insects to be identified to the species level, as evidenced by an unjustified (in my view) negative review of Borror & White because a chrysomelid leaf beetle is there illustrated in black and white rather than color which "did not allow the reviewer to identify it" (http://www.amazon.com).

If a "guide" to insects serves just the above-mentioned purpose, then why restrict it to insects of America north of Mexico? This book by George McGavin aims at worldwide coverage of insects and other terrestrial arthropods. Armed with it, the reader can assign observed terrestrial arthropods to order, and to a limited extent to family. Families of insects (and some other arthropods) are the focus, and the information presented about each family is well organized visually. The centerpiece of each family presentation is one or more color photographs of adult insects. Although few of these photographs are of insects in nature, they are of high quality, and the paper of the book is glossy throughout to allow excellent reproduction. Labelled arrows point to distinctive structural features. Arranged around the centerpiece are a sketch of a larva or nymph belonging to that family (if it is holometabolous or if the nymphs are aquatic), and text dealing with habitus, life cycle, and distribution. In small, standardized colored boxes at top and bottom of the page are the name of the order, the name of the family represented, the approximate worldwide number of species in that family, the size range (in inches and cm) of adults of the family, and symbols indicating larval diet.

The first 45 pages are an introduction to insects and other arthropods, the organization of this book, macrohabitats and habits, form and function, and they include identification keys to the level of order. On pp. 244-245 is a glossary of essential terms,

although the text in general is written with as little use of specialized terms as possible. Furthermore, the text is written in straightforward English rather than in the bureaucratese that too many entomologists use. On pp. 246-255 is a single index of scientific and vernacular names.

It is not easy to fault this book. If I had organized it, I would not have arranged families alphabetically within orders but would have chosen an arrangement showing relationships; others would have criticized me for doing so. I would have made sure that the green lacewings shown on page 106 were not faded specimens, but had green wings. I would have used the latest concept of the families of Coleoptera rather than an outmoded one. And I would have avoided using the expression "larval breeding areas" for the habitats of ceratopogid larvae, on grounds that larvae do not breed—only adults do so. On the other hand, I like the rational use of and differentiation of the words **ectoparasite** and **ectoparasitoid** in the glossary where too many authors unthinkingly label both "**ectoparasite**." The vernacular names of all families are not all identical to the "common" names decreed by the Entomological Society of America, but could it be that some of the names used are more **common** (whose real meaning is "widely used") than those selected as "common" by that Society; do the 50 or so other English-speaking countries have to follow the decrees of the Society and set aside their (more) common names? For its price, this book is a bargain, and it has set a new, higher standard for "guides" to match.

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THE PIONEERING WORK OF GEORGE N. WOLCOTT: IMPLICATIONS FOR U.S.-CARIBBEAN ENTOMOLOGY IN THE 21ST CENTURY

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This paper is dedicated to the memory of Dr. George Norton Wolcott (Fig. 1), a most distinguished entomologist in the Caribbean. I am pleased that Dr. Wolcott's daughter, Mrs. Ann Wolcott-Martínez, and her son, Mr. David Wolcott-Martínez, are with us today to celebrate the accomplishments of Dr. Wolcott. I thank Dr. Sivinski and the Florida Entomological Society for making this occasion possible.

My objectives are to give abbreviated insights into Dr. Wolcott's educational and personal background, and highlight aspects of his contributions to Puerto Rican and Caribbean entomology. These highlights exemplify Dr. Wolcott's pioneering and visionary work in the region. I will also address Dr. Wolcott's legacy, embodied in part in his many publications describing the Puerto Rican and Caribbean entomofauna that serve as essential research references to numerous entomologists. Dr. Wolcott's extensive collaborative efforts with Caribbean entomologists and agriculturists serve as the model which many should emulate and have important implications for U.S.-Caribbean linkages as we enter the 21st century. His successes in biocontrol then, challenge us now to develop innovative approaches to solving pest problems affecting both the U.S. mainland and the countries within the Caribbean Basin [the region of the Americas inclusive of all the nations washed by the Caribbean Sea and those states of the U.S. abutting the Gulf of Mexico (USAID 1990)].

EDUCATIONAL AND PERSONAL BACKGROUND

George Norton Wolcott was born in Utica, New York, a town located near Yorkville and Whitesboro, on July 12, 1889, to David Clinton Wolcott and Marion Benedict. Upon graduation from Utica Free Academy in Utica, New York, in 1905, he obtained the Bachelor's degree in 1909 in Economic Entomology from the then New York State College of Agriculture at Cornell University and the M.S. in 1915 while studying scientific illustration under Professor W. C. Baker, Illustrator of Bailey's Encyclopedia of Agriculture. In 1925, under the guidance of Professor Needham at Cornell University, Wolcott obtained the Ph.D.

In 1919, he married Magdalen Hall (Fig. 2). They had three children: Ann (Fig. 2), David and Oliver. Ann recalls her early years in Puerto Rico and her stories suggest that her father was a wonderful curiosity and a source of amusement to his children and grandchildren.

Dr. Wolcott had a great love for the Puerto Rican outdoors. He also loved gardening and made calendars with twelve black-and-white drawings of flowers and nature scenes, which he gave to friends each year. One can only guess that his earlier training in the illustration of insects at Cornell University had an influence here. Dr. Wolcott was partial to drawing with black ink, an unusual preference in the eyes of his young daughter ("who wouldn't want calendars with brightly colored flowers?" she must have thought).

Her father's frequent pastime was walking, strolling in open fields and hiking to the top of any hill or peak on the island, particularly El Yunque, often with a well-provisioned picnic basket. His frequent hilltop picnics often brought him face to face with

Fig. 1. George N. Wolcott. Year unknown.

the many nuisances and discomforts of living in the tropics: he endured numerous mosquito bites, tropical rainstorms, and even lightning strikes. I am told that once, while he was enjoying lunch under a tree, lightning struck the tree but Wolcott held his

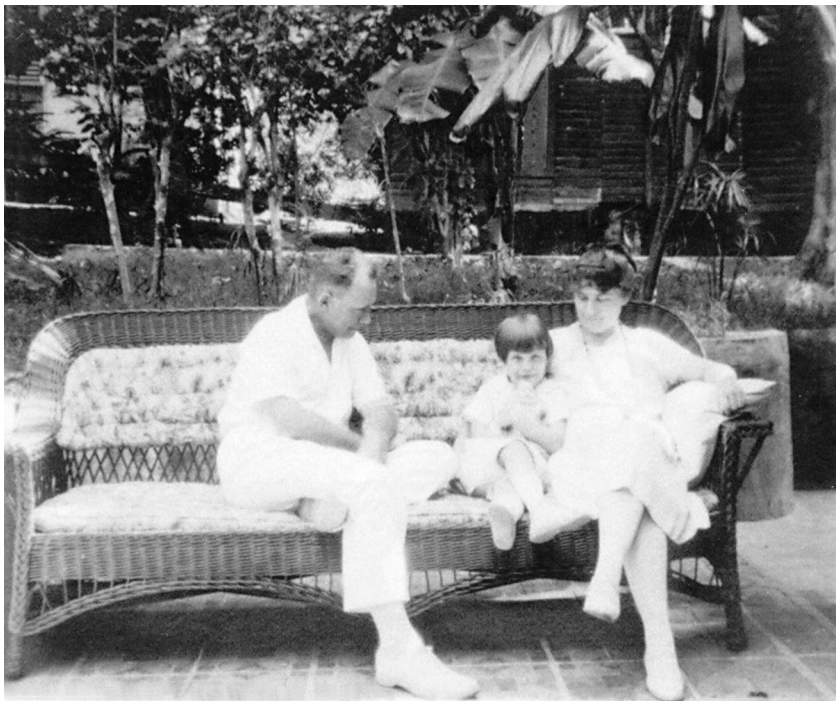

Fig. 2. From left: Dr. George Norton Wolcott, Ann (6 years old), and Mrs. Magdalen Wolcott. Photographed about 1926.

ground and finished his lunch. Whether it was out of bravery or hunger, we will never know. At picnic's end, he nonchalantly set off for home and, on arrival, casually mentioned the incident only after a family member remarked that he smelled of smoke.

Ann fondly remembers her father losing the heel of one shoe during a hiking trip to Mount Britton and sliding down the hill with one good shoe and her, perched on his shoulder, "clinging for dear life to his eye sockets". This surely is evidence that Dr. Wolcott was a loving father who shared many enjoyable experiences with his family while in Puerto Rico. His grandchildren, David and Marie, were fascinated by his orange peeling perfection, especially the cascading, unbroken orange rind falling over his sharp knife and nimble fingers. David recalls thrusting one orange after another at his grandfather, never uttering a word, in desperate effort to keep the "ribbon" in continuous motion.

WOLCOTT THE AVID ENTOMOLOGIST

His father was a lawyer, his mother adept at painting in water color, and his sister and brother were architects. So why did George become an entomologist? We may never know why, but I am told that at three or four years old he discovered some insects in a bag of rancid nuts that a grocer tried to pass off on his unsuspecting mother. While she was not amused, little George asked the grocer for more of his bugged nuts. No one knows for sure what George did with his large cache of nuts but we now know

that this boyhood avocation with insects became the lifelong occupation of George Wolcott. Later in life, he bought a cabin and named it the "Entomo-lodge". His daughter Ann reports that her father never doubted that entomology would be his life's work. It was during one of his entomological escapades (catching insects one night) that George met his future wife Magdalen, so it is probably no surprise that he never "shook the bug" habit.

Contributions to Puerto Rican and Caribbean Entomology

Dr. Wolcott had entomological appointments on the U.S. mainland and in Puerto Rico between 1910 and 1956. In Puerto Rico he worked at the Experiment Station of the Sugar Producers Association from 1910-1912, rising through the ranks from Assistant to Associate Entomologist then to Entomologist. He then served as Director of the Entomology Department of the Insular Experiment Station, Rio Piedras, from 1914-1916 and again from 1932-1956 when he retired.

Between 1919 and 1929 he held various positions as Entomologist, initially in Puerto Rico, then in the Dominican Republic, Haiti and Peru, returning each time to Puerto Rico, the place he seemed to love. In fact, in 1946 he wrote to Dr. John Allen of the Department of Education in Albany, New York, saying, "My work here is most pleasant and psychologically satisfying". From 1932 to 1956, Dr. Wolcott worked for one final time at Rio Piedras then retired and returned to the mainland.

One of his most notable undertakings was to control the lesser sugarcane borer, *Diatraea saccharalis* (F.) (Lepidoptera: Pyralidae) in Puerto Rico. Adults oviposit on sugarcane leaves and the larvae tunnel into the stalks, eating the soft tissue, thereby causing a decrease in sugar content and sugar yield (Wolcott 1915). Additionally, secondary microbial infection occurs in the larval tunnels, tainting the juice and weakening the stalks. The larvae then pupate in the tunnels from which the adults emerge. *D. saccharalis* attacks sugarcane throughout the West Indian archipelago from Guyana, Trinidad and Barbados through St. Kitts, Puerto Rico and Santo Domingo, to Jamaica, Cuba, and the southern United States.

Wolcott (1915) demonstrated that there was an inverse relationship between increased rainfall and the number of young *D. saccharalis* instars found in the field, presumably because the larvae drown in the flooded tunnels. However, the use of this information for *D. saccharalis* control was less practicable than his finding that borer infestations in fields that were burned to remove trash were 100% higher than in fields that were not burned. He presumed that the egg parasitoid *Trichogramma minutum* Riley (Hymenoptera: Trichogrammatidae), as reported by scientists in Louisiana, was being destroyed by the fire. Thus, he recommended that the burning (presumably pre-harvest burning) of trash in sugarcane fields be discontinued. Dr. Wolcott also made augmentative releases of *T. minutum* for the successful suppression of *D. saccharalis* (Wolcott 1915). His extensive collections of parasitized borer egg clusters, and studies of the development and emergence behavior of *T. minutum* adults in Texas (DeBach & Hagen 1964, Wolcott 1918), probably also contributed to his successful rearing and augmentative releases of the parasite for *D. saccharalis* suppression in Puerto Rico and later in Haiti.

The sugarcane root weevil (= sugarcane root stock weevil), *Diaprepes abbreviatus* L. (Coleoptera: Curculionidae), one of several coleopteran pests of sugarcane in Puerto Rico, was studied in great detail by Dr. Wolcott, who developed a protocol for rearing it in the laboratory in order to better understand its biology during its subterranean development. His diagrams of *Diaprepes* larvae and accounts of the life cycle of this pest (Wolcott 1937) not only provide evidence of his talents as an illustrator but of his keen observational skills and meticulous documentation of the insect's biology.

The larvae of several Coleoptera, including the sugarcane rhinoceros beetle, *Strategus barbigerus* Chapin, and the white grubs *Lachnosterna* sp. and *Phyllophaga* sp. (Coleoptera: Scarabaeidae), were exceedingly intractable pests in Puerto Rico (Wolcott 1950). In an effort to develop effective control strategies for these pests, Wolcott (1950) performed a detailed review and assessment of the effectiveness of natural enemies of grub populations on the island. These beneficials included the parasitoids *Cryptomeigenia aurifacies* Walton and *Eutrixoides jonesii* Walton (Diptera: Tachinidae), and the predacious wireworm ("cucubano") *Pyrophorus luminosus* Illiger [= *Ignelater luminosus* (Illiger)] (Coleoptera: Elateridae). His detailed analysis of the role of insect parasitoids and predators, as well as vertebrate predators, in white grub control is evidence of the thoroughness and enthusiasm with which he approached his work.

Dr. Wolcott's commitment to controlling insect pests in Puerto Rico appeared to be accompanied by the realization that pest control problems and solutions on that island were influenced by related events in neighboring islands in the Caribbean archipelago. Thus, he traveled to Guyana, Barbados, and Trinidad in 1912 to review the control strategies used there for white grubs. He developed collaborations with entomologists in those countries and imported the parasitic wasp, *Tiphia parallela* Smith (Hymenoptera: Scoliidae), from Barbados into Puerto Rico for *Lachnosterna* control (Wolcott 1950).

WOLCOTT: A VISIONARY AND PIONEER

One of Wolcott's most noteworthy undertakings was the biological control of mole crickets (Fig. 3). *Scapteriscus didactylus* (Latreille) (Orthoptera: Gryllotalpidae) ("La changa"), then presumed to be *S. vicinus* Scudder (Frank 1990), was a pervasive agricultural pest in Puerto Rico, having apparently spread from South America via the Lesser Antilles (Wolcott 1938). In 1922 Dr. Wolcott foresaw the need to improve biocontrol efforts against mole crickets in Puerto Rico. Consequently, he secured funding and organized expeditions to Trinidad and South America to find parasites. He successfully introduced the wasp *Larra americana* Saussure (Hymenoptera: Sphecidae), later identified as *L. bicolor* F. (Frank 1990) (Figs. 4 & 5), into Puerto Rico from Belem, Pará, Brazil (Wolcott 1938, 1941). This single classical biological control effort by Dr. Wolcott laid the foundation for future biological control successes against mole crickets within the Caribbean Basin region.

Efforts to import *L. bicolor* from Brazil for mole cricket control in Florida in the 1940s were unsuccessful. In 1978, however, a partial solution to the problem was found in Puerto Rico where populations of the wasp previously introduced by Wolcott were well established. The late Dr. Reece Sailer, then Graduate Research Professor in the Department of Entomology, University of Florida (UF), Gainesville, collected and released these parasitoids into five Florida locations, including Ft. Lauderdale, Tampa, and Gainesville, between 1981 and 1983 (Fig. 6). To date, *L. bicolor* is established in Ft. Lauderdale where it seems mainly to attack *S. abbreviatus* (Frank 1990, Frank et al. 1995).

Subsequently, *L. bicolor* imported directly from Santa Cruz, Bolivia, in 1988 and 1989 by Dr. F. D. Bennett, then Graduate Research Professor of Entomology at UF (Frank et al. 1995), was established in Alachua County (Gainesville) (Fig. 6) (Frank et al. 1995). The population has since spread to nearby Clay County (Fig. 6) (Frank, personal communication). No doubt, earlier success with the Puerto Rican introductions into Florida served as an incentive for the additional efforts. Thus, Dr. Wolcott's work laid the foundation for the work of Drs. Sailer and Bennett, both pioneers of biological control in Florida. The *Larra* parasitoid is now well established in Florida (Fig. 6), and this work continues under Dr. Howard Frank, UF Institute of Food and Agricultural Sciences (IFAS) Mole Cricket Control Program (Frank 1994).

Fig. 3. A mole cricket *Scapteriscus vicinus* (unparasitized), a pest of turfgrass in Florida. Slide (lent by Dr. J. H. Frank) was taken by Dr. J. Castner and reprinted with permission.

Fig. 4. An adult mole cricket being parasitized by *Larra bicolor*. Slide taken by Dr. J. Castner (lent by Dr. J. H. Frank) and reprinted with permission.

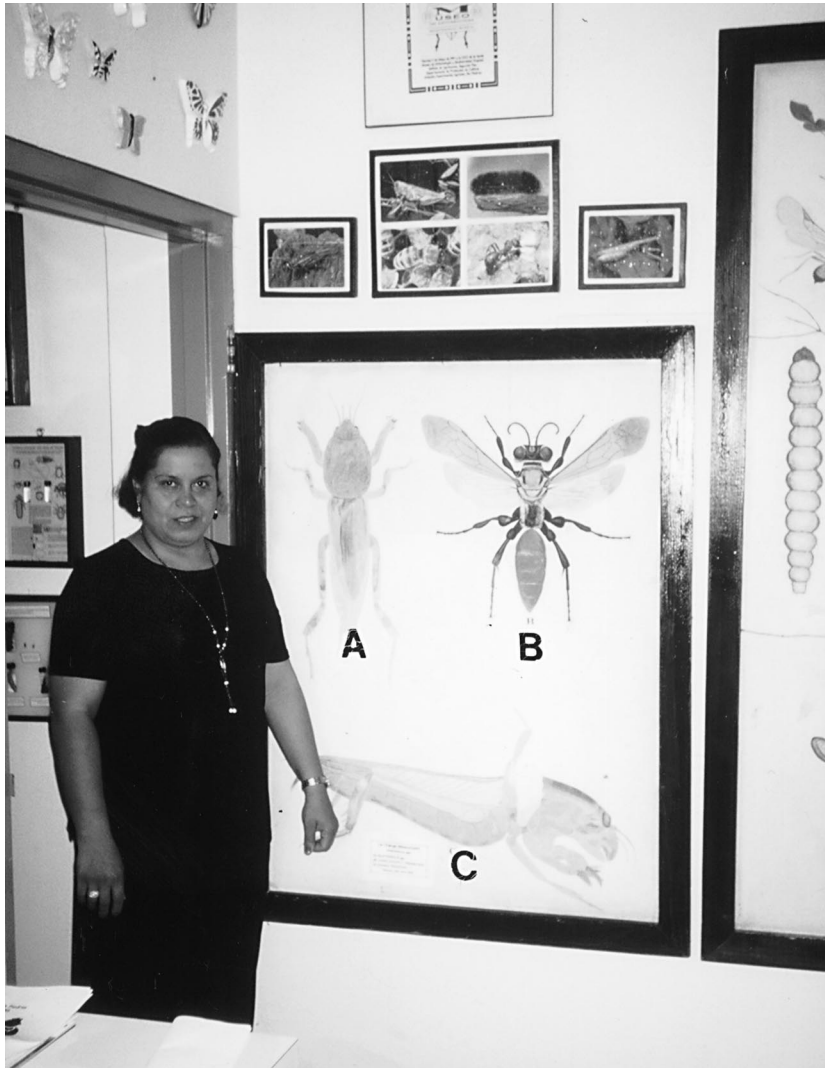

Fig. 5. Original drawing of (A) *Scapteriscus didactylus* (labeled as *S. vicinus*), (B) *Larra americana* (now known as *L. bicolor*), and (C) larva of *Larra* on *Scapteriscus* mole cricket (drawn by Francisco Sein), hangs in the collection of the Institute of Entomology, University of Puerto Rico, Rio Piedras. At left is Dr. Rosa Franqui, Curator of the Insect Collection. Photograph taken by Dr. J. H. Frank, 1999.

Wolcott not only pioneered the introduction of *L. bicolor* into Puerto Rico but also discovered that *Scapteriscus* spp. are hosts to the parasitic fly *Ormia* (= *Euphasiopteryx*) *depleta* (Wiedemann) (Diptera: Tachinidae) which he encountered in Brazil (Wolcott 1940). While this latter parasitoid apparently did not become established in

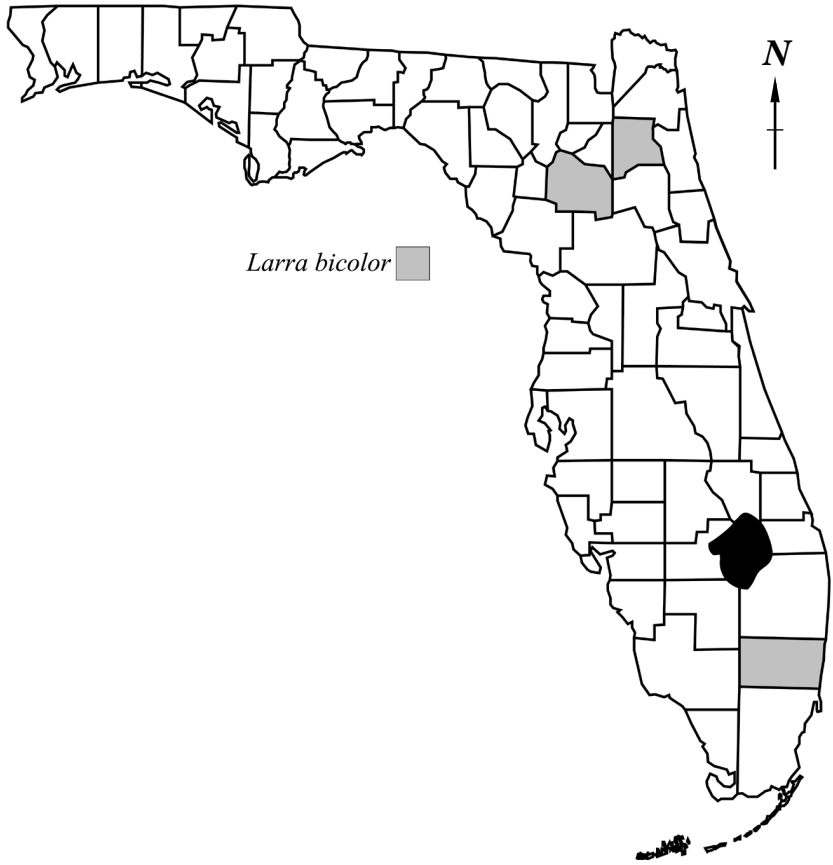

Fig. 6. Map of Florida showing the sites of *L. bicolor* establishment from the initial introduction from Puerto Rico by Dr. Reece Sailer in 1981-1983 in the south (Ft. Lauderdale, Broward County) and from subsequent introductions from Santa Cruz, Bolivia by Dr. Fred D. Bennett in 1988-1989 in the north (Gainesville, Alachua County) that later spread northeast to Clay County. Slide lent by Dr. J. H. Frank.

Puerto Rico (Frank et al. 1995), its potential as a biocontrol agent for mole crickets has since been realized. *O. depleta* was released in 1988 and 1999 against mole crickets in several Florida counties (Frank 1994).

Thus, through his knowledge of the incidence of mole crickets in Cuba, Jamaica, the Lesser Antilles, and other countries (Wolcott 1941) within the Caribbean Basin, Wolcott recognized the role of the Archipelago in the northward migration of insect pests. He collaborated with scientists in other countries and capitalized on the availability of beneficial insects like *Larra* and *Ormia* from countries within the region to address the mole cricket problem in Puerto Rico. His foresight and prior work therefore pioneered future efforts for mole cricket control in Florida.

Wolcott's pioneering work was also evidenced by his educational outreach and teaching activities. From 1924-1928, as Entomologist in the Agricultural Technical

Service of Haiti, Dr. Wolcott trained many Haitians in entomological practices, several of whom reportedly continued in the discipline. These are but a few of his many lasting accomplishments in support of the entomological sciences in the region.

His Legacy

Dr. Wolcott's legacy is embodied not only in the entomological careers he fostered but also in his 200-plus scientific publications and manuscripts which serve as a constant reference for scientists within and outside the Caribbean region. His seminal work "Insectae Borinquenses" (Wolcott 1936) is a revised annotated check-list of Puerto Rican insects that has been a classic. His books were adopted as texts by the Polytechnic Institute of San German, Puerto Rico, the College of Agriculture at Mayaguez, and the Imperial College of Tropical Agriculture in Trinidad, now the College of Agriculture, University of the West Indies.

In 1933 Dr. Wolcott revived the once defunct Entomological Society of Puerto Rico founded by Dr. Van Dine. The society continues to function to this day.

Implications of His Work for U.S.-Caribbean Entomology In The 21st Century

One of the accomplishments of George Wolcott was the extent to which he familiarized himself with the entomologists, other agricultural scientists, entomological problems and their solutions in the neighboring countries of the Caribbean. Through this knowledge, he apparently recognized the essential role of the Caribbean as the northward conduit for insect pest infestations in Puerto Rico and the U.S. mainland. Thus, he sought to forge collaborations with other scientists and train local personnel to help solve the pest problems in Puerto Rico and the Caribbean Basin as a whole.

Given Florida's location within the Caribbean Basin and Wolcott's example of cooperation, it behooves us to renew our collective efforts in pest curtailment within the region for the 21st Century. Thus, U.S. and Caribbean agencies should (1) more aggressively foster cooperation among scientists within the region, (2) train students and entomological practitioners to help identify and decrease pest infestations that threaten agriculture in the Caribbean and the U.S., and (3) provide the needed infrastructure for detection, analysis, forecast, and communication of pest population outbreaks within the Caribbean Basin. Only through such efforts can we hope to more effectively stem the rising tide of exotic pest invasions and the resulting crop damage.

As a daughter of the Caribbean who, in some ways, is a beneficiary of the work of pioneers like Dr. George Wolcott, I see new challenges for biological control in the 21st Century within the Caribbean Basin. It is in this context that I share a snapshot of my own research on yet another Caribbean pest that has also invaded the U.S. mainland.

The Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), attacks various fruits and vegetables in several islands, including Cuba and Jamaica. Flies were first found in Key West, Florida, in 1931. The parasitic wasp *Diachasmimorpha longicaudata* (Ashmead) (Dl) (Hymenoptera: Braconidae), a biological control agent that attacks fruit fly larvae, suppressed the fly populations in Florida by about 40% (Baranowski 1987). Nearly 95% of the fly populations in southern Florida are attacked by the wasp but those north of Lake Okeechobee are parasitized by *D. longicaudata* to a lesser extent (Sivinski et al. 1996).

Biocontrol approaches should not only involve the use of existing parasitoid species but also a search for new ones. To that end, the research in my laboratory focuses on a parasitic wasp and an unusual virus that, respectively, are potential candidates for Caribfly control. The wasp *Fopius arisanus* Sonan (Hymenoptera: Braconidae) is

an egg-pupal parasitoid of Old World tephritids, including the Mediterranean fruit fly (Medfly), *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), and the Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Harris & Bautista 1996). We have reared *F. arisanus* for the first time on the Caribfly, a New World tephritid (Lawrence et al. 2000), with the goal of mass-rearing and releasing the Caribfly-compatible strain of the wasp into the field.

The second possible biocontrol agent is the symbiotic entomopoxvirus (EPV) found in the accessory glands of the female *D. longicaudata* reproductive system (Lawrence & Akin 1990) and named here DlEPV (Fig. 7). The virus enters the fruit fly's hemocytes (blood cells) upon injection with the wasp egg into the Caribfly larva. Viral infection induces disruption of host blood cells and, thus, could likely cause "anemia" and compromise resistance to microbial infection. Given its large genome of 290-300 kb, DlEPV is also a potential vector for the insertion of specific genes that disrupt fruit fly egg production or other important biological functions. However, a basic understanding of DlEPV genes is needed in the near-term before the feasibility and practicality of such novel control strategies can be explored.

Numerous pests have invaded the continental U.S. via the Caribbean islands and little is known of their biology, ecology or natural control agents. Greater collaboration among scientists in the region would advance our efforts to document pest migrations and biology, and develop proactive strategies for their control.

Dr. George Norton Wolcott left a rich legacy of scientific collaboration and promotion of entomological education in the Caribbean. Through his work, as exemplified by his research on the mole cricket, white grub, and other pests, we know that solutions to entomological problems in the Caribbean have a direct beneficial impact on agriculture in Florida and the rest of the continental U.S. It is therefore fitting that the Florida Entomological Society has elected to honor him.

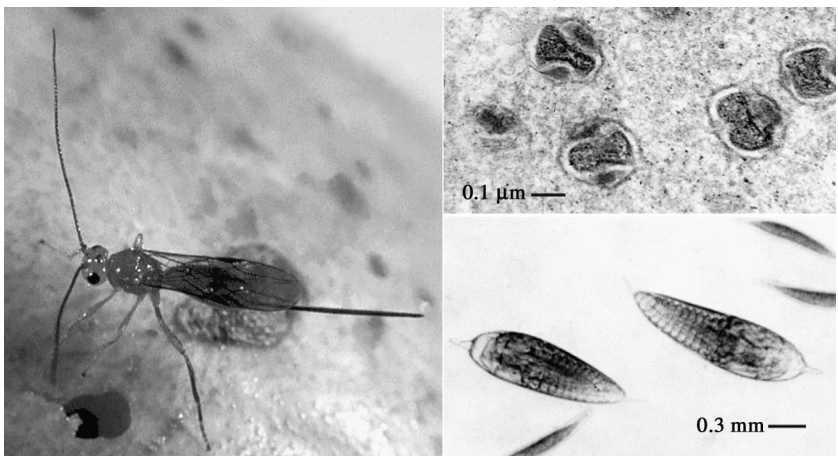

Fig. 7. Left panel: *Diachasmimorpha longicaudata* (Dl), a solitary endoparasitoid of tephritid fruit flies. Females attack larvae of the Caribbean fruit fly, *Anastrepha suspensa* in fruits. Right lower panel: Eggs of *D. longicaudata*. Top: newly oviposited egg (<24 h old); Bottom: fully embryonated egg (36-48 h after oviposition). Wasp and eggs were photographed by Dr. P. D. Greany. Right upper panel: Transmission electron micrograph (TEM) of the entomopoxvirus DlEPV injected into fruit fly larvae with wasp eggs.

As a product of the Caribbean, born and raised, and one who received her early education in Jamaica and worked on Caribbean entomological problems, I feel that in some small way I embody the Pan-Caribbean vision Dr. Wolcott tried to foster. Like Dr. Wolcott, I live in an adopted country, yet my work benefits agriculture throughout the Caribbean Basin. Thus, as we embark on the 21st Century, let us resolve to follow his outstanding example of Pan-Caribbean cooperation and promotion of entomological education in the islands and territories of the Caribbean and in neighboring U.S. mainland states. It is only through cooperation that we can hope to solve the burgeoning agricultural problems we are sure to face in the 21st Century.

Thank you for this honor.

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