SOIL SURFACE APPLICATIONS OF CHEMICALS FOR THE CONTROL OF NEONATE *DIAPREPES ABBREVIATUS* (COLEOPTERA: CURCULIONIDAE) AND THEIR EFFECT ON ANT PREDATORS

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ABSTRACT

The root weevil, *Diaprepes abbreviatus,* as a larva, inflicts feeding injury to the bark of all root parts of a citrus tree, thereby impairing root function and supplying infection courts for soil-borne root rot diseases. Ideally, larvae should be controlled at the soil surface before they reach the root zone. In screenhouse and field experiments conducted in central Florida from 1996-99, the synthetic pyrethroid, bifenthrin, at 0.54 g/m^2 (0.554 kg ai/ha) and RPA107382, an analog of fipronil, at 0.156 and 0.312 ml/m^2 (0.242-0.466 kg ai/ha), were applied uniformly to the soil surface beneath the tree to form a chemical barrier against neonates of *D. abbreviatus.* By comparison to the control, larval populations were reduced by 80-100% within one week and these reductions persisted for 4-8 weeks. In an open screenhouse, bifenthrin gave excellent root protection of container-grown trees during a 22 week period when neonates were added to containers weekly for 12 weeks. RPA107382 was highly effective for about 2 weeks but lacked residual effect. The accumulation of leaf litter beneath the tree impaired coverage of the soil by bifenthrin resulting in reduced control. According to weekly baited trap counts, both chemicals reduced non-target foraging ants, particularly *Solenopsis invicta Buren*. The reduction in *S. invicta* was temporary however, but it did allow time for other foraging ants to re-establish and increase.

Key Words: Chemical control, bifenthrin, citrus root weevil, ant predators

RESUMEN

El picudo *Diaprepes abbreviatus*, en etapa de larva, inflige daño al comer de la corteza de todas las partes de la raíz de un árbol cítrico, así perjudicando la función de las raíces y supliendo sitios de infección para enfermedades por suelo de podredumbre radical. Idealmente, las larvas deberían ser controladas en la superficie del suelo antes de alcanzar la zona radical. En invernaderos y experimentos hechos en la Florida central de 1996-99, el piretroide sintético bifenthrin, a 0.54 g/m^2 (0.554 kg ai/ha) y RPA107382, un análogo de fipronil, a 0.156 y 0.312 ml/m^2 (0.242-00.466 kg ai/ha), fueron uniformemente aplicados a la superficie del suelo bajo el árbol para formas una barrera química contra neonatos de *D. abbreviatus*. Populaciones larvales fueron reducidas de 80-100% y estar reducciones persistieron de 4-8 semanas de acuerdo a bioensayos de varias pruebas de campo. En un a casa abierta de tela metálica, bifenthrin dio excelente protección radical a árboles criados en potes durante un periodo de 22 semanas donde neonatos fueron añadidos a los potes semanalmente por 12 semanas. RPA107382 fue altamente efectivo por alrededor de 2 semanas pero careció efecto residual. La acumulación de materia de hojas bajo el árbol perjudico la cobertura del suelo por el químico resultando en control reducido. De acuerdo con cuentas semanales de trampas cebadas, ambos químicos redujeron hormigas forrajeras no-objetivo, particularmente *Solenopsis invicta* Buren. Sin embargo, la reducción de *S. invicta* fue temporera, pero si permitió tiempo para que otras hormigas forrajeras se reestablecieran e incrementaran. Este comportamiento sugiere que control de *S. invicta* puede ser beneficioso.

Diaprepes abbreviatus L., a root weevil native to the Caribbean islands (O'Brien & Wibmer 1984, Woodruff 1985), has gradually become a major localized pest of citrus, many ornamental plants, and some agronomic crops since its introduction into Florida in 1964 (McCoy 1999). It can be a univoltine species on citrus, however, the life cycle can vary greatly in time. The adult, egg, and neonate stage appear on the host plant above ground, and all larval stages, the pupa and teneral adult occur below ground. At hatch, neonates fall from the leaf to the soil surface beneath the tree where they enter the soil (Wolcott 1936). Numerous instars feed on fibrous and woody roots, forming deep grooves in the latter as they consume the outer bark, including the cambium layer. Larvae remain on the roots for 8-15 months, reaching 1.3-2.5 cm in length (Wolcott 1936, Quintela et al. 1998). Injuries caused by *D. abbreviatus* larvae serve as preferred infection courts for root rot diseases of citrus caused by soil-borne fungal pathogens such as *Phytophthora* spp. (Graham et al. 1996). The interaction between root weevils and soil-borne fungal pathogens of the roots results in

one of the most severe decline syndromes affecting citrus. Therefore, pest management of *D. abbreviatus* can require treatment of both the insect and soil-borne diseases.

Prior to the cancellation of the chlorinated hydrocarbon insecticides in the U.S.A. around 1980, citrus root weevils were controlled with persistent compounds, such as aldrin and dieldrin (Bullock 1985). These chemicals were generally broadcast on the soil beneath the tree as granules in the dry fertilizer mix. By forming a chemical barrier beneath the tree, invasive neonates were killed before reaching the root system (Bullock 1985). Subsequently, organophosphate and carbamate substitutes for the chlorinated hydrocarbons were found to be less effective because of their shorter residual.

In the past decade, entomopathogenic nematodes, infectious to all soil-inhabiting stages of the weevils, have been applied as biopesticides one or more times per year in Florida citrus (McCoy et al. 2000). Since larval control with nematodes varies in the field and likely occurs in the rhizosphere after larvae are already feeding on the roots (Duncan et al. 1999), various chemical and non-chemical agents for combating neonates at the soil surface have been under investigation. Greenhouse and screenhouse studies using container-grown citrus plants as indicators of neonatal feeding by *D. abbreviatus* have been conducted with systemic and contact pesticides of various formulations. Chlorpyrifos as a slow release granule, imidacloprid and bifenthrin have been shown to be effective against neonates as soil drench or soil-incorporated treatments (McCoy et al. 1995). Bifenthrin is currently recommended for use in citrus nurseries to prevent larval invasion of container-grown plants (Simpson & McCoy 1996).

Bifenthrin is a pyrethroid with a broad-spectrum of activity against insects and mites. In view of its toxicity to neonate root weevils and persistence on the soil surface, screenhouse and field studies were conducted during the past 4 yr with two formulations, Brigade 10WSB® 100% and Capture® 2L, to determine residual control of neonate *D. abbreviatus*. Since bifenthrin is toxic to the imported fire ant, *Solenopsis invicta* Buren, an important predator of *D. abbreviatus* found in citrus groves, ant populations were monitored using baited traps to assess non-target effects.

Materials and Methods

Screenhouse Experiment

Sixty-three, 3-yr-old Parson Brown orange trees, grafted to Cleopatra mandarin rootstock, were cleared of soil and pruned slightly for transplant into 56.8 liter plastic containers with a 0.16 m^2 surface area. Each tree was planted in sieved Candler soil (Entisol type: 92% sand, 2.9% clay, 2.0% silt) and placed on a bench in open sunlight. One month after planting, trees were fertilized using liquid 8:4:8 NPK at 60 ml per tree. Trees were watered only when rainfall failed to supply adequate moisture to prevent wilt. Any weeds were periodically removed by hand. Leaf litter, collected from a commercial grove, was scattered on the soil surface to a depth of 1.27 cm of nine trees to compare treatments with and without leaf litter.

Each treatment, Brigade 10WSB at 0.134, 0.269, and 0.54 g/m^2 (high rate equivalent to field rate) and Admire 2L at 0.54 g/m^2, were applied uniformly to the soil beneath the tree in 50 ml of H_2O with a B&G hand held sprayer. Two untreated controls were included in the experiment, one with larval infestation and one without. The treatment with leaf litter received Brigade 10WSB at 0.54 g/m^2. The soil surface of all containerized trees was moistened just prior to treatment and 100 ml of water per tree added immediately after application using a sprinkling can. Each treatment was replicated 9 times. All treatments were applied on May 8, 1996.

At 2 days post-treatment and weekly thereafter, for 12 weeks, 25 neonatal *D. abbreviatus* (48-h-old) were scattered on a moist soil surface of each container. Each container received 325 larvae over time. Neonates used in the study were obtained from field-collected adult females held in screened cages in the greenhouse at 27 ± 2°C.

On October 15, about 22 weeks after treatment, each tree was carefully removed from the container and the soil around the roots washed through a sieve to recover larvae. Soil remaining in the container was also wet-sieved to assure larval recovery. After recording larval number, the root symptoms of each tree were rated visually on a scale from 1 to 5; 1 = no visible injury, 2 = normal fibrous root density, slight tap/lateral root channeling, 3 = moderate fibrous root density and tap/lateral root channeling, 4 = severe fibrous root loss and tap/lateral root channeling, and 5 = no fibrous roots and severe tap/lateral root channeling and stem girdling. In addition, fibrous roots were removed from each tree, dried, and weighed to determine dry root weight. Differences in larval survival/treatment and dry fibrous root weight among different chemical treatments were compared by ANOVA and Tukey's Studentized Range (HSD) test (SAS Institute 1988). Root rates were presented as treatment averages.

Field Test-1

The experiment was conducted in an irrigated 3-yr-old Flame grapefruit grove grafted to 'Swingle' citrumelo rootstock. The grove was located near Alturas, FL on Astatula fine sandy soil. The tree spacing was 3.7 × 6.0 m. Any leaf litter was removed prior to chemical applications with a hand held blower.

Brigade 10WSB was applied at 0.269 and 0.54 g/m^2 (0.276-0.554 kg ai/ha) to a 1.5 m^2 area beneath the tree at 500 ml of finished spray mix at 20 psi using a low pressure sprayer and a hand-held spray wand. Each treatment was comprised of 4-tree plots replicated 10 times and an untreated check. Treatments were applied on April 12, 1996. The grove was irrigated thoroughly before application and for about 1 h after application.

At 0, 31, 59, 95, and 123 days post-treatment, a laboratory bioassay was performed to determine the residual activity of the insecticide in the soil over time. One soil sample of 1.5 ml by volume per tree, 10 per treatment, was taken randomly from the soil surface to a depth of 3.2 mm. Each soil sample was assayed separately by placing each sample in a micro-centrifuge tube (1.5 ml) with 10 neonates. After a 7-day exposure at 27 ± 2°C, larval survival was recorded for each tube. Larval survival representative of each post-treatment bioassay of treated and untreated field soil were made, after the proportions surviving were transformed using arcsine $\sqrt{\chi}$, using a one way ANOVA design followed by Tukey's Studentized Range (HSD) test (SAS Institute 1988). Untransformed means are shown in all figures.

Field Test-2

The experiment was conducted in a 5-yr-old planting of Hamlin orange grafted to 'Swingle' citrumelo rootstock planted in Candler soil, and located on the University of Florida campus, Lake Alfred, FL. The grove was set at a 3.7 × 6.0 m spacing and had micro-sprinkler irrigation. Prior to treatment, leaf litter was removed from the soil beneath the trees. In this test, the residual control of Brigade 10SWS at 0.54 g/m^2 was compared to an untreated check. Plots consisted of 6 trees in one row. Each plot was completely randomized and replicated 4 times. Brigade was applied as a band, 1.8 m in length, to the soil beneath the tree at 369.3 liters/ha using a tractor-mounted herbicide applicator set at 0.2 mpa and traveling at 4.4 kmph. Treatment was applied on September 17, 1998 under clear sky and an air temperature of 26°C. Irrigation was applied for 3 h before application to thoroughly wet the soil and immediately after application for 1 h.

In this test, the bioassay method used to measure residual effect was changed to reflect more typical field conditions. Soil cores were collected randomly from beneath the tree to a depth of 2.54 cm midway between the trunk and dripline using a cork borer with a diameter of 1.27 cm^2. Soil samples were taken weekly, 5 samples per plot or a total of 20 samples per treatment. In the field, each soil core was carefully placed intact, into a plastic column with a screen base (20 mm mesh) just large enough for the passage of larvae through the soil into a well of a plastic tissue culture plate (McCoy et al. 2000). In the laboratory, 10 vigorous neonates (<48-h-old) were placed on the soil surface within the column. After 72 h at 28°C, the number of larvae capable of moving through the soil column into the well of the tissue culture plate was recorded. The number of live, dead, and missing from the original inoculum also was recorded by sorting through the soil. Statistical analysis was performed as described in the previous test.

Field Test-3

The experiment was conducted in a one-yr-old reset planting of Navel orange on 'Swingle' citrumelo rootstock planted in Candler soil and located on the University of Florida campus, Lake Alfred, FL. The grove was close set at a 0.9 × 6.1 m spacing for research purposes and had micro-sprinkler irrigation. Treatments were arranged in a completely randomized block design, each plot consisting of 6 trees/plot (4.6 × 0.5 m). No leaf litter was found on the soil in the experimental site. Treatments consisted of Brigade 10SWS at 0.54 g/m^2 (0.56 kg ai/ha), RPA107382 (0.38 kg EC) at 0.156 and 0.312 ml/m^2 (0.10 kg and 0.19 kg ai/ha) and an untreated check. RPA107382 is an analog of fipronil, a phenyl pyrazole with toxicity to neonatal *D. abbreviatus* (Nigg et al. 1999). Each treatment was replicated 10 times. Chemicals were applied on April 13, 1999 with a backpack CO_2 activated sprayer equipped with a hand held boom with dual fan nozzles. Materials were mixed in 2 liter quantities and applied at 387.2 LPH at 0.2 mpa. At the time of application, air temperature was 18-20°C and relative humidity was 50%. Wind conditions were calm.

At various times, from 0 to 56 days post-treatment, the previously described column bioassay method was used to measure chemical residual on the soil surface. Two soil cores per plot were taken within 15.2 cm of the tree trunk to a depth of 2.54 cm. Bioassay data were analyzed using the procedures described for tests 1 and 2.

Since bifenthrin and fipronil are toxic to *S. invicta* by contact or in bait form (Collins & Callcott 1998, Knapp 2000) and *S. invicta* is a general predator of *D. abbreviatus* (Whitcomb et al. 1982), ant populations were monitored via baited traps pre- and post-treatment to assess non-target effects. About 1.5 g of hamburger was placed on a filter paper strip that was, in turn, placed within a 40 mm plastic assay disk (Millipore) with a small hole on the side to allow for ant entry. A single trap was placed on the soil surface near each tree trunk in each plot. After exposure for 90 min, the trap was closed confining the ants within the disk. In the laboratory, the number and species of ants were recorded. Samples of ants were collected at l week pre-treatment and at 7, 14, 21, 29, 35, and 41 days post-treatment. Differences in the total number of ants between treatments was analyzed

TABLE 1. EFFECT OF DIFFERENT RATES OF BRIGADE 10WSB WITH AND WITHOUT LEAF LITTER ON SURVIVAL OF NEONATES OF *DIAPREPES ABBREVIATUS* AND PLANT ROOT HEALTH AFTER WEEKLY HOST INOCULATION FOR 12 WEEKS IN CONTAINER-GROWN CITRUS IN THE SCREENHOUSE.

Treatment	Rate (g/m^2)	Mean number surviving larvae/unit ± SD[a]	Mean fibrous roots, g dry wt/tree ± SD[a]	Mean root[b] rating (1-5)
Control (no larvae)	—	—	1133.9 ± 184 a	1.0
Control (larvae)	—	15.1 ± 9.0 bc	589.7 ± 102 c	4.2
Brigade 10WSB	0.143	8.3 ± 6.7 ab	816.5 ± 197 c	2.5
Brigade	0.269	22.8 ± 9.4 c	861.8 ± 391 bc	2.7
Brigade (no litter)	0.54	8.8 ± 4.1 ab	1179.3 ± 304 a	1.7
Bridge (litter)	0.54	23.8 ± 11.4 c	771.1 ± 164 c	3.3
Admire 2F (no litter)	0.54	6.0 ± 3.6 ab	997.9 ± 201 ab	1.3

[a]Means followed by the same letter are not significantly different at the 5% level of probability using Tukey's Studentized Range (HSD) test.
[b]Root symptoms: 1-no visible injury, 2-slight tap/lateral root channeling, 3-moderate tap/lateral root channeling, 4-severe tap/lateral root channeling, 5-severe tap/lateral root channeling and stem girdling.

statistically for each sample date via ANOVA and Tukey's Studentized Range (HSD) test.

RESULTS

Screenhouse Experiment

As expected, the control with neonates had greater root injury than the control with no larvae (Table 1). Fibrous root loss in the larval control was nearly twice that of the plant only control and overall root injury was severe. Only 5% of the original larvae introduced were recovered at the end of the test.

The presence of leaf litter on the soil surface of the containerized citrus trees reduced larval control by Brigade suggesting that the soil barrier was distorted by litter. As shown in Table l, Brigade at 0.54 g/m^2, without leaf litter, resulted in higher larval mortality and root protection com-

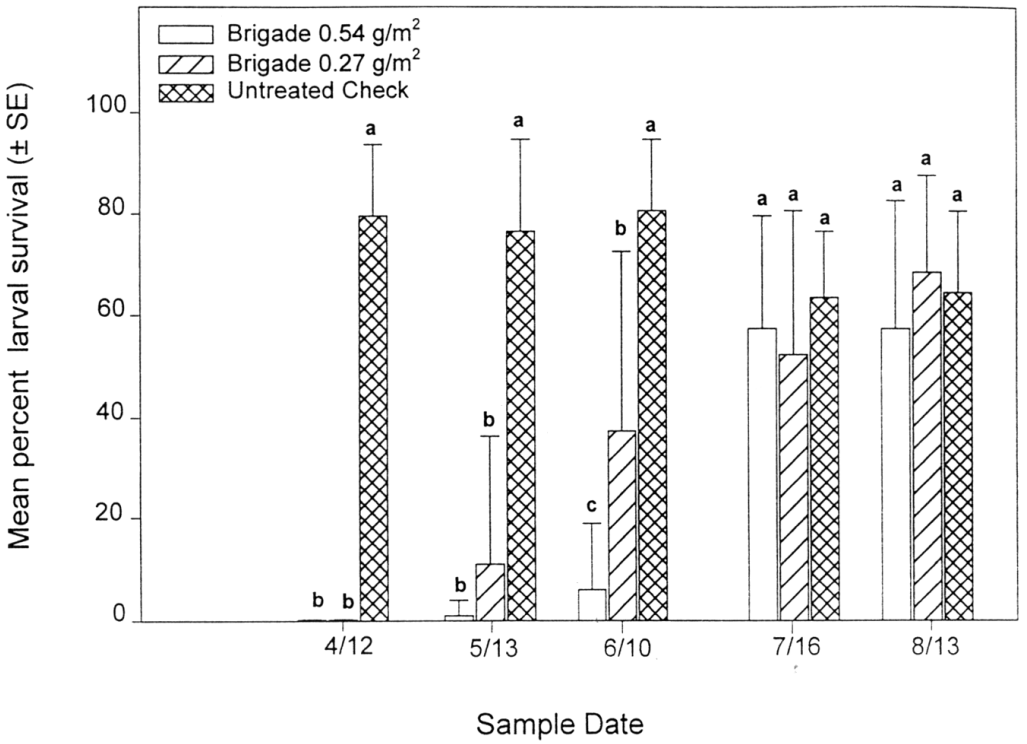

Fig. 1. Residual effect of two rates of Brigade 10SWS on neonate survival of *Diaprepes abbreviatus* based on surface soil sampling at Alturas, FL—"bars with common letters on the same sampling date are not significantly different" at the P = 0.05 level.

pared to the treatment with leaf litter; in fact, there was no significant difference in larval survival or root protection between Brigade with litter, the control without larvae, and the Admire standard. As the rate of Brigade decreased, root protection also decreased (Table 1). In view of its systemic action, Admire as a standard without litter performed as well as Brigade without litter and the control without larvae.

Field Test-1

As shown in Fig. 1, the residual control of Brigade against neonate *D. abbreviatus*, based on surface soil bioassays, was significantly longer (>59 days) at the highest rate (0.54 g/m^2) than at the lower rate (0.269 g/m^2); but, the lower rate was significantly different from the untreated check (P = 0.05). At 95 days post-treatment or longer, all treatments were the same and provided no control.

Field Test-2

In the fall study, the previously described soil column bioassay method, more typical of what invasive larvae would experience in the field, was used to monitor residual control of the chemical barrier to neonate *Diaprepes*. As shown in Fig. 2, Brigade at 0.54 g/m^2 gave 100% kill of neonates in a bioassay performed within 72 h after treatment. At 1 week post-treatment, larval survival increased to about 20% but remained significantly lower than the untreated check. Residual control varied from 40-58% compared to the untreated check during the 8-10 weeks after treatment. Significant difference between treatments was measured via bioassay for about 3 months; however, larval survival approached 80% by that time (Fig. 2).

Field Test-3

In the spring study, using the soil column bioassay, both Brigade at 0.54 g/m^2 and the 2 rates of RPA107382 at 0.156 and 0.312 ml/m^2 significantly reduced larval survival compared to the control at day 1 post-treatment (Fig. 3). In the case of Brigade, residual effect resulted in less than 30% larval survival throughout the study (8 weeks), whereas, the residual effect of RPA107382 began to fail at 4 weeks post-treatment and was less effective than Brigade thereafter, but significantly better than the control through 6 weeks post-treatment.

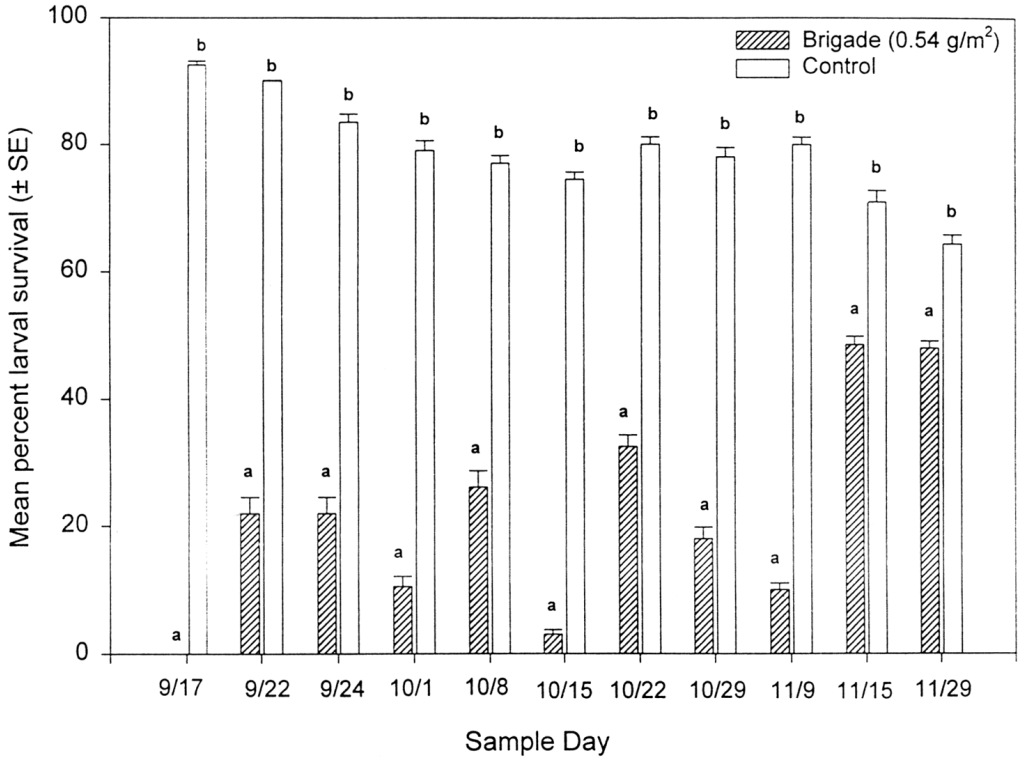

Fig. 2. Residual effect of Brigade 10SWS applied in the fall on neonate survival of *Diaprepes abbreviatus* based on soil column bioassay at Lake Alfred, FL—"bars with common letters on the same sampling date are not significantly different" at the P = 0.05 level.

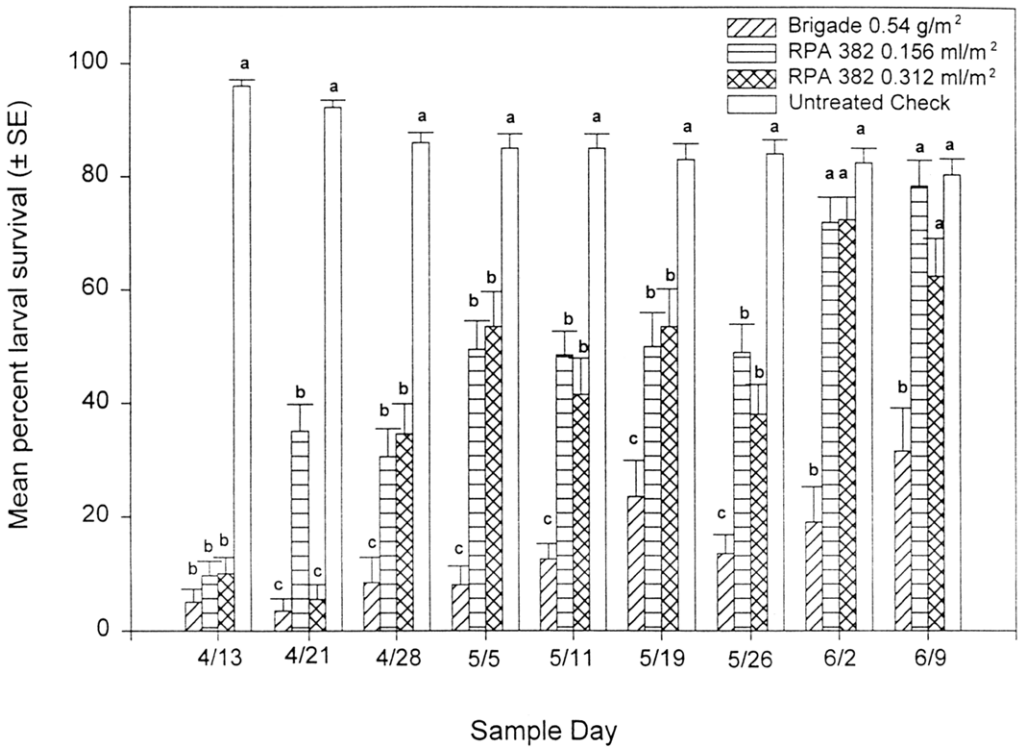

Fig. 3. Residual effect of Brigade 10SWS and two rates of RPA107382 on neonate survival of *Diaprepes abbreviatus* based on soil column bioassay at Lake Alfred, FL—"bars with common letters on the same sampling date are not significantly different" at the P = 0.05 level.

The effect of the different chemicals applied to the soil on non-target foraging ant populations over time is depicted in Fig. 4 and Table 2. In the control, *Solenopsis invicta* Buren was always most frequently trapped using hamburger bait followed by *Dorymyrmex bureni* (Trager), *D. reginicula* (Trager), *Brachymyrmex obscurior* Forel, and *Tetramorium simillimum* (F. Smith) in descending order of abundance. As shown in Fig. 4, both Brigade and RPA107382 suppressed *S. invicta*, at a very low level, through 29 days post-treatment. Thereafter, *S. invicta* gradually increased in abundance. Other foraging ants mentioned above were not eliminated and after 29 days both *S. invicta* and other ants increased together at 35 and 41 days post-treatment (Fig. 4). As shown in Table 2, *D. bureni* appeared to become the prevalent foraging ant following the chemical treatments.

Discussion

Screenhouse and field data collected at different times of the year for 4 yr using two bioassay methods all support the efficacy of bifenthrin (Brigade/Capture) as a chemical barrier against neonate *D. abbreviatus*, if leaf litter does not interfere with coverage of the soil. Since bifenthrin has the propensity to bind strongly to soil particles after drying, uniform application to a moistened substrate free of debris appears vital for maximum contact with the invasive larvae. Since young trees (<5 yr old) do not accumulate leaf litter in large quantity, a chemical barrier should be effective. Timmer et al. (2001) showed that leaf litter accumulation beneath mature trees is greatest from January through June. Unfortunately, this coincides with the spring adult emergence of *D. abbreviatus*. Removal of leaf litter by air blast using a speed sprayer appears to be a feasible way to redistribute the litter away from the tree.

According to bioassays, the most effective rate of bifenthrin to reduce neonate populations entering the soil appears to be 0.54 g/m² (0.554 kg ai/ha). A rate of 0.269 g/m² will reduce neonates within 7 days after soil application, however, residual effect is lesser in the field. Effect of bifenthrin on other instars and teneral adults is unknown. Obviously, the adult stage would be exposed to the chemical barrier at the time of emergence.

Although bifenthrin and RPA107382 reduced *S. invicta* populations following soil application, this reduction appeared to favor the re-establishment of more diversity at baits in the ant fauna among the treatments (Fig. 4). Data suggest that this faunal shift at baits occurred following a significant reduction of *S. invicta*. In view of its dom-

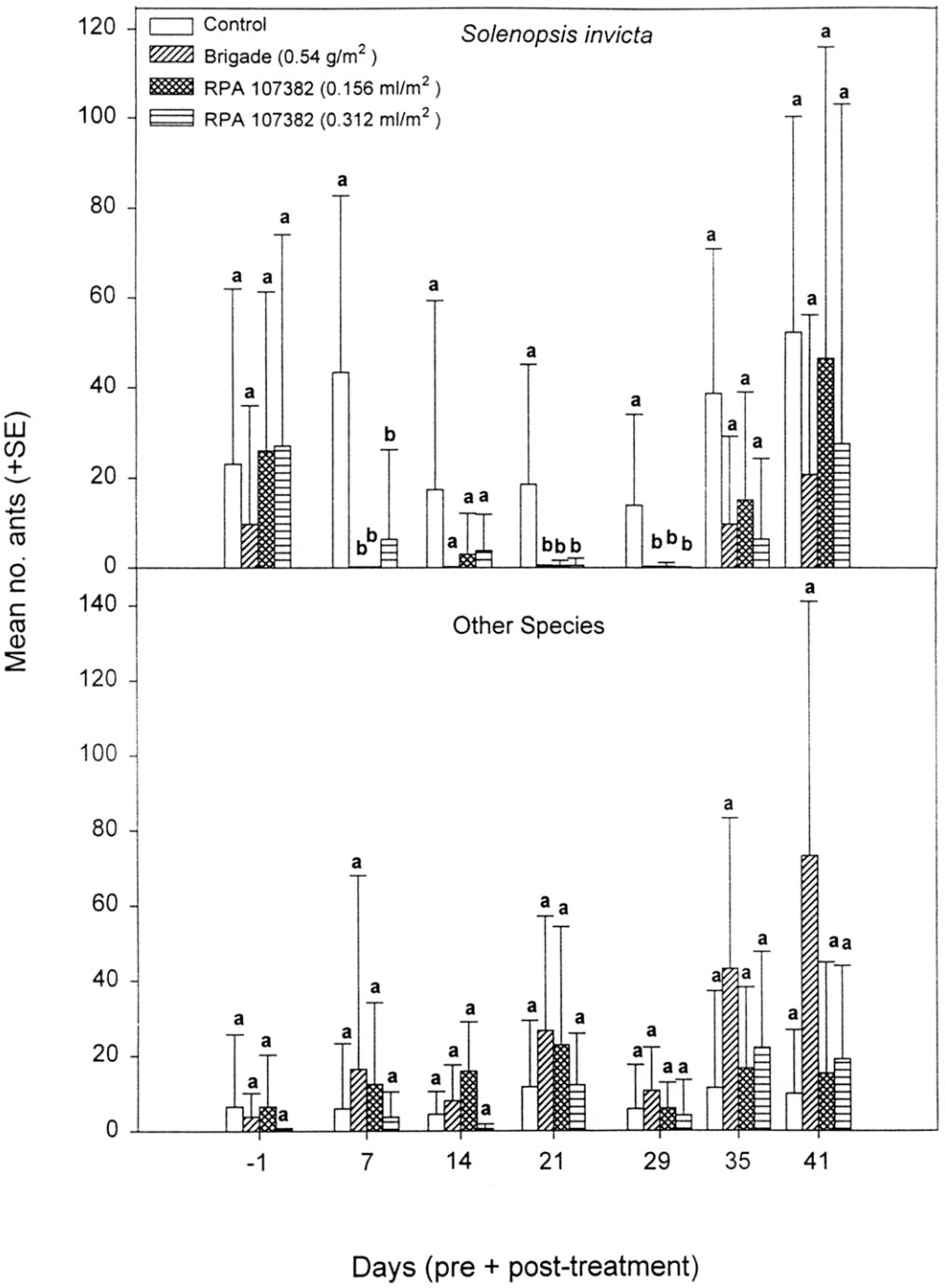

Fig. 4. Mean number of *Solenopsis invicta* and other foraging species trapped over time on the soil surface via baited traps following the field application of Brigade and RPA107382 for root weevil larval control, Lake Alfred, FL. Application made at zero days—"bars with common letters on the same sampling date are not significantly different" at the P = 0.05 level.

inance in disturbed habitats such as citrus groves (Tschinkel 1988), its reduction could have caused the shift and therefore, might be beneficial, if the re-establishment of a more diverse ant community improves predation on neonates. These data and other unpublished work show that *S. invicta*

TABLE 2. TOTAL PERCENTAGE OF DIFFERENT ANT SPECIES TRAPPED ON THE SOIL SURFACE VIA BAITED TRAPS AFTER 41 DAYS FOLLOWING FIELD APPLICATION OF SOIL INSECTICIDES, LAKE ALFRED, FL.

Treatment	Species	%
Control	*Solenopsis invicta*	74.8
	Dorymyrmex bureni	10.2
	Dorymyrmex reginicula	10.3
	Brachymyrmex obscurior	0.3
	Tetramorium simillimum	4.4
Brigade 10SWS (0.54 g/m^2)	*Solenopsis invicta*	18.1
	Dorymyrmex bureni	69.7
	Brachymyrmex obscurior	3.8
	Tetramorium bicarinatium	8.4
RPA 107382 (0.156 ml/m^2)	*Solenopsis invicta*	48.8
	Dorymyrmex bureni	43.8
	Brachymyrmex obscurior	2.7
	Tetramorium simillimum	4.7
RPA 107382 (312 ml/m^2)	*Solenopsis invicta*	53.6
	Dorymyrmex bureni	41.4
	Brachymyrmex obscurior	1.1
	Tetramorium bicarinatium	3.9

will recover however, and re-establish its dominance at baits within a few weeks, suggesting that periodic treatment for *S. invicta* could be a positive management practice. Further research is appropriate.

Hamburger was a successful bait for capturing *S. invicta* and other foraging ants. It should be pointed out however, that some selection of ant species likely occurred because of a preference for meat and aggressive dominance at baits by particular species.

Seasonal population dynamics of adult *Diaprepes* based on trapping data suggest that peak emergence occurs in April through mid-June in irrigated citrus groves in central Florida with some emergence throughout the year (Stansly et al. 1997, McCoy & Duncan 2000). Since adults are most abundant at this time of the year, one can assume that oviposition and subsequent neonatal invasion of the soil is also at a high level, particularly in view of the fact that ovipositing adults apparently live 3-4 months in the field and food is abundant. According to this biological information, it would appear that the use of bifenthrin should begin in late April to early May to maximize its residual effect on invasive larvae. Studies are currently underway to evaluate this strategy over time.

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AN OPTOELECTRONIC SENSOR FOR MONITORING SMALL MOVEMENTS IN INSECTS

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ABSTRACT

Optical movement detectors are often used in laboratory studies of insect behavior. They offer advantages of time resolution and ease of analysis compared with video. However, design and construction have rarely been described in enough detail to allow the devices to be built easily by others. We describe a simple optoelectronic system for measuring rapid movements in one dimension, such as the protraction of an insect leg. The leg casts a bar-shaped shadow onto a photodiode chip that is masked to expose a triangular area. Movement of the leg changes the total area of the triangle that is shaded. A preamplifier converts the change in photoelectric current to a voltage signal. The preamplifier includes an optional circuit for removing 120 Hz ripple resulting from AC-powered light sources by subtracting the output of a second, reference photodiode. We have used the system to quantify leg movements in an acoustic startle response of a field cricket (*Teleogryllus oceanicus* LeGuillou). This system could be adapted for a wide range of other applications in laboratory and field research.

Key Words: leg motion, position detector, photodiode, optoelectronic photodetector, cricket acoustic startle response

RESUMEN

Detectores ópticos de movimiento han sido usados frecuentemente en estudios de comportamiento de insectos en el laboratorio, donde ofrecen ventajas de resolución de tiempo y facilidad de análisis comparado con video. Sin embargo, su diseño y construcción han sido raramente descritos en suficiente detalle para permitir que otros puedan construir estos aparatos fácilmente. Describimos un sistema optoelectrónico para medir movimientos rápidos en una dimensión como la protracción de una pata de insecto. La pata forma una sombra en forma de barra a un chip fotodiodo que esta cubierto para exponer una área triangular. El movimiento de la pata cambia el área total del triangulo que esta sombreado. Un preamplificador convierte el cambio en corriente fotoeléctrica a una señal de voltaje. El preamplificador incluye un circuito para nulificar ondulación de 120 Hz de fuentes de luz con electricidad AC al restar la producción de fotodiodo de referencia. Hemos usado el sistema para cuantificar movimientos de pata en una respuesta de susto acústica del saltamontes *Telegryllus oceanicu* (LeGuilou). Elementos de este sistema pueden también ser adaptados para otras aplicaciones en estudios de laboratorio y de campo.

Optoelectronic position detectors may be used to quantify behavior in a wide variety of settings. Optoelectronic methods have two advantages over video: (1) Temporal resolution is not limited by video frame rate, and (2) The detector can measure a single parameter of movement or position that would require extensive labor or computer processing to extract from video records. Descriptions of optoelectronic devices in the biological literature generally emphasize the unique features of a particular detector without providing details of design and construction. Potential users may be discouraged from applying these methods if they lack the practical electronics background to adapt the circuits found in electronics cookbooks or technical literature from chip manufacturers. We describe a photodetector and amplifier designed for monitoring leg protraction in a tethered flying Polynesian field cricket (*Teleogryllus oceanicus* LeGuillou), and readily adaptable to other uses as described in Results and Discussion.

We are studying an ultrasound-induced escape response in crickets, a flight turn that is a defense against echolocating bats (Moiseff et al. 1978). A cricket is flown on a tether and given pulses of ultrasound from a loudspeaker mounted to its left or right. We monitor one component of the startle response, a lateral outward swing of the metathoracic leg contralateral to the source of ultrasound (May & Hoy 1990). This movement has ~30 ms latency and 45 to 65 ms time-to-peak, too rapid to quantify with conventional video. We designed an

optoelectronic detector to convert leg position to a continuous voltage signal that indicates position without the need of further processing. The design uses a triangular detection surface in such a way that movement of the leg's shadow produces a change in illumination, and incorporates a method for canceling the light ripple that is found in AC powered light sources. These features are demonstrated below (Results and Discussion).

This device has performed well in measurements of the cricket acoustic startle response (e.g., Engel & Hoy 1999). Movement of the metathoracic femur is faithfully represented as a voltage signal, and ripple due to AC line power is eliminated. The circuit is conservatively designed using parts that are readily available in electronics stockrooms or outlets such as Radio Shack (electronics vendors and photodiode suppliers are listed in Appendix A). The circuit and photodetector are described in sufficient detail to be built as they are, and they could also be adapted to a variety of other purposes. It is our hope that descriptions such as this will enable more widespread use of optoelectronic methods in entomology and in biological research in general.

Materials and Methods

This section describes the essential features of design and construction. Additional notes are provided in Appendix A, along with a list of parts and suppliers. For an introduction to electronic components, schematic diagrams, and assembly techniques see Mims (2000) or other basic texts.

Movement Detector

There are several approaches to optoelectronic movement detection. (1) Use of small arrays of discrete photodectors to determine the position of a light or shadow (e.g., Kittmann 1991; Erber & Kloppenburg 1995; Roberts 1995). (2) Use of a linear position-detector photodiode chip (e.g., Helversen & Elsner 1977; Hedwig 1988; Kelly & Chapple 1988; Mayer et al. 1988; Hedwig & Becher 1998). (3) Use of a simple photodetector chip to measure a moving shadow (e.g., Meyer et al. 1987; Rüsch & Thurm 1989; Clark et al. 1990; Götz 1987; May 1990). The first two approaches are relatively complicated, and reports have not given sufficient details for circuits to be constructed readily. Our device is a refinement of the third approach.

If a shadow has a single moving edge, then a simple rectangular photodiode can act as a position sensor because the shaded area varies linearly with position, resulting in a linear change in the output of the photodiode (Meyer et al. 1987; Rüsch & Thurm 1989; Clark et al. 1990). However, when the shadowing object has both leading and trailing edges, as an insect appendage does, the shadow's area does not change with position. In this case, a mask with a triangular or crescent-shaped opening can be interposed into the light path between the appendage and the photodetector (Götz 1987; May 1990; May & Hoy 1991). As the appendage's shadow moves to a wider part of the triangular opening, the shaded area of the photodetector increases. This makes a simple and effective position indicator, as we show below (Results and Discussion). In the cricket leg position detector described here, a triangular mask is affixed directly to the photodetector surface, as in May (1990), eliminating the need for optics between the mask and the photodetector, as in Götz (1987).

Our photodetector uses a 10×20 mm unpackaged silicon photodiode chip (EG&G Vactec, St. Louis, MO, VTS 3081). A predecessor of our design used a CdS photoconductor chip in a voltage-divider circuit (May 1990). We chose a silicon photodiode because of its superior frequency response and uniform surface geometry compared with CdS photoconductors (*Photodiodes*, Hamamatsu, Bridgewater, NJ, 1997). For structural support, the chip is fastened with double-sided foam tape to an IC (integrated circuit) mount (Fig. 1C) with the chip lead wires soldered to the pins. A second IC mount serves as a socket, with wires leading to the amplifier. In our setup this socket is attached to a swivel ball joint mounted on a rod. The small size of the detector assembly allows it to be placed around electrodes for simultaneous neural and behavioral recording from a flying cricket (J.E.E., unpublished data) and minimizes disturbance of the acoustic field.

The photodiode chip is masked with black graphics tape (Chartpak, Leeds MA) to leave a triangular area exposed (Fig. 1C). The tethered cricket is illuminated from above with a fiber-optic light guide, so that the metathoracic femur casts a bar-shaped shadow onto the photodetector, which is 1 to 2 cm below the leg. As the leg pivots laterally, its shadow moves to a wider part of the triangle. The area of the shadow on the triangle, and the resulting change in photocurrent from the photodetector, are proportional to the magnitude of lateral movement (see Results and Discussion).

Position Amplifier

A photodiode produces a current directly proportional to the amount of illumination (*Photodiodes*, Hamamatsu, Bridgewater NJ, 1997, p. 5). The amplifier (Fig. 1A) converts this current signal to a more conveniently analyzed voltage signal with the desired level of gain. The first operational amplifier (op amp), IC1, of the position amplifier converts current (i) to voltage (v). The current-to-voltage gain is determined by feedback resistance R, with the relationship $v = i\mathrm{R}$. The value of R is best chosen by trial and error

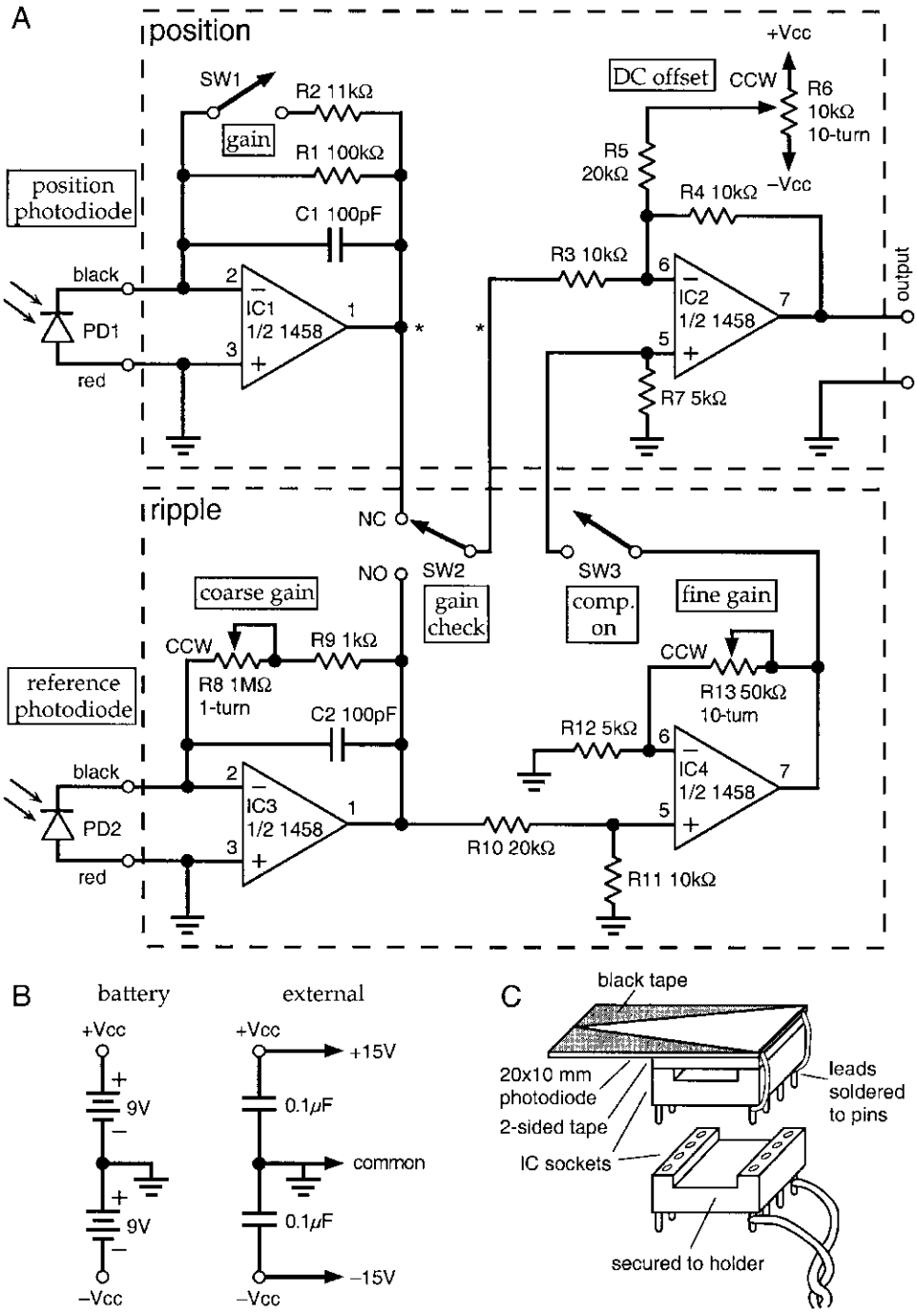

Fig. 1. Position detector design. A. Amplifier circuitry. The two components, the position amplifier and the ripple-compensation amplifier, are outlined in dashed boxes. If the position amplifier is built alone, the points indicated by asterisks are connected. Each IC is half of a 1458 dual op-amp package, with numbers indicating pin assignments. In R6, R8, and R13, CCW indicates the lead that has zero resistance when the potentiometer is turned fully counterclockwise. Abbreviations: C, capacitor; CCW, counterclockwise; IC, integrated circuit; NC, normally closed; NO, normally open; PD, photodiode; R, resistor; SW, switch; Vcc, power supply voltage. See Appendix A for a list of parts. B. Power can be provided by two 9 V batteries (left) or an external DC power supply not exceeding ±18 V (right). Open circles labeled +Vcc and –Vcc are nodes to be connected to the op-amp packages (pins 8 and 4, respectively) and to the terminals of R6. C. Photodetector. A photodiode is masked to expose a triangular area and mounted to an 8-pin integrated circuit (IC) socket for physical support. A second IC socket serves as a connector to the amplifier.

because the appropriate gain depends upon the strength of the light and the size and sensitivity of the photodiode. In our setup, R is 10 or 100 kΩ, set by R1 or by R1 and R2 in parallel ($R = R1 \times R2/(R1 + R2)$). If lower light levels or a smaller photodiode are used, an R of several megaohms might be required. Switch SW1 allows switching between two gain settings during operation.

The second op amp (IC2) adds a DC offset to the signal, allowing the baseline of the output voltage to be adjusted to the middle of the input range of a recording device or oscilloscope. Potentiometer R6 controls the amount of DC offset, functioning as a voltage divider together with resistor R5. IC2 also inverts the voltage signal. In our setup the anode of the photodiode (red lead) is connected to the positive input of IC1 so that a leg swing away from the body (which increases shadow area) causes a negative photocurrent fluctuation leading to a negative voltage signal. IC2 inverts this so that the lateral leg swing of an escape response produces a positive output signal. If a negative-going signal were desired, the photodiode leads would be connected in the reverse orientation. Either orientation is permissible because the photodiode is not voltage-biased in this circuit.

Ripple Compensation

Light from AC-powered lamps can have a pronounced ripple at twice the line frequency (120 Hz in North America). In our setup a standard fiber optic light source (Dolan-Jenner, Woburn MA, Series 180) provides strong illumination with low heat and allows the lamp housing to be kept outside of the Faraday cage. However, the optic ripple is considerable (Fig. 2B).

This ripple can be cancelled electronically (Fig. 2B). A reference photodiode is placed near the movement detector but out of the path of the cricket's shadow. Both photodiodes pick up the light ripple, and the movement detector also senses a change in illumination as the leg moves. Ripple is eliminated by subtracting the reference signal from the movement signal. The reference photodiode need not be identical to the movement detector photodiode, nor need their levels of illumination be matched, because the gain of the reference signal can be adjusted over a large range. Appendix B shows a straightforward method for adjusting the gain so that the reference signal exactly cancels the ripple in the movement signal.

The first op amp (IC3) of the ripple compensation amplifier converts the reference photocurrent to a voltage signal (Fig. 1A). Coarse gain control is adjusted at this stage by potentiometer R8, and fine gain control is adjusted at the second op amp (IC4) by potentiometer R13. The reference signal is subtracted from the movement signal by feeding it into the positive input of the position amplifier's second op amp (IC2). To build the position amplifier only, without ripple compensation, connect the points marked with asterisks in Fig. 1A and omit all components in the ripple section.

An alternative to electronic subtraction of light ripple is use of a DC-powered light source (Fig. 2B). We converted our Dolan-Jenner fiber optic light source to DC power by cutting the wires that connect the variable transformer to the lamp, diverting the transformer output to a DC converter in a separate housing, and feeding the DC power back to the lamp. The DC converter consists of a full-wave rectifier protected with a heat sink, with the output leads connected across 93,000 μF of capacitance in parallel to the lamp. Because the cost of capacitors increases with voltage rating, 15 V capacitors were used and the power supply transformer is kept in the lower end of its range. This provides ample light for our purposes.

Testing Linearity and Ripple Compensation

To show that the voltage signal is a linear function of shadow area, a metal rod (2 mm diameter) was mounted on a motor so that it swung across the photodetector 1.5 times per second (Fig. 2A). The far edge of the photodiode was 108 mm from the axle, giving the rod a speed of 1 m/s as it passed over the photodiode. The output of the amplifier was recorded without ripple compensation and with electronic compensation (Fig. 2B, left and center traces). Then, with electronic compensation inactivated, the DC converter was switched into the lamp power supply without otherwise altering the setup (Fig. 2B, right trace).

To demonstrate adjustment of ripple compensation (Fig. 3), the position photodetector was set up to monitor the left metathoracic femur of a tethered flying cricket. The reference photodetector was a fragment of a broken solar cell (~0.15 cm^2 lit area). Voltage outputs were digitally sampled at 5 kHz and 0.3 mV resolution. To show escape responses in both directions (Fig. 3E), a second photodetector and amplifier (also with ripple compensation) monitored the right metathoracic femur. Both photodetectors were in place throughout the series of records in Figure 3. Ultrasound pulses were 20 kHz carrier frequency, 10 ms duration. The cricket preparation and acoustic setup have been described elsewhere (May & Hoy 1991; Wyttenbach & Hoy 1997); as previously, hind wings were cut short so they would not interrupt the light path.

Results and Discussion

Linearity of Movement Detection

Photodiode chips have a uniform photosensitive surface (in contrast to photoconductors, which have a zigzag ribbon of photosensitive material).

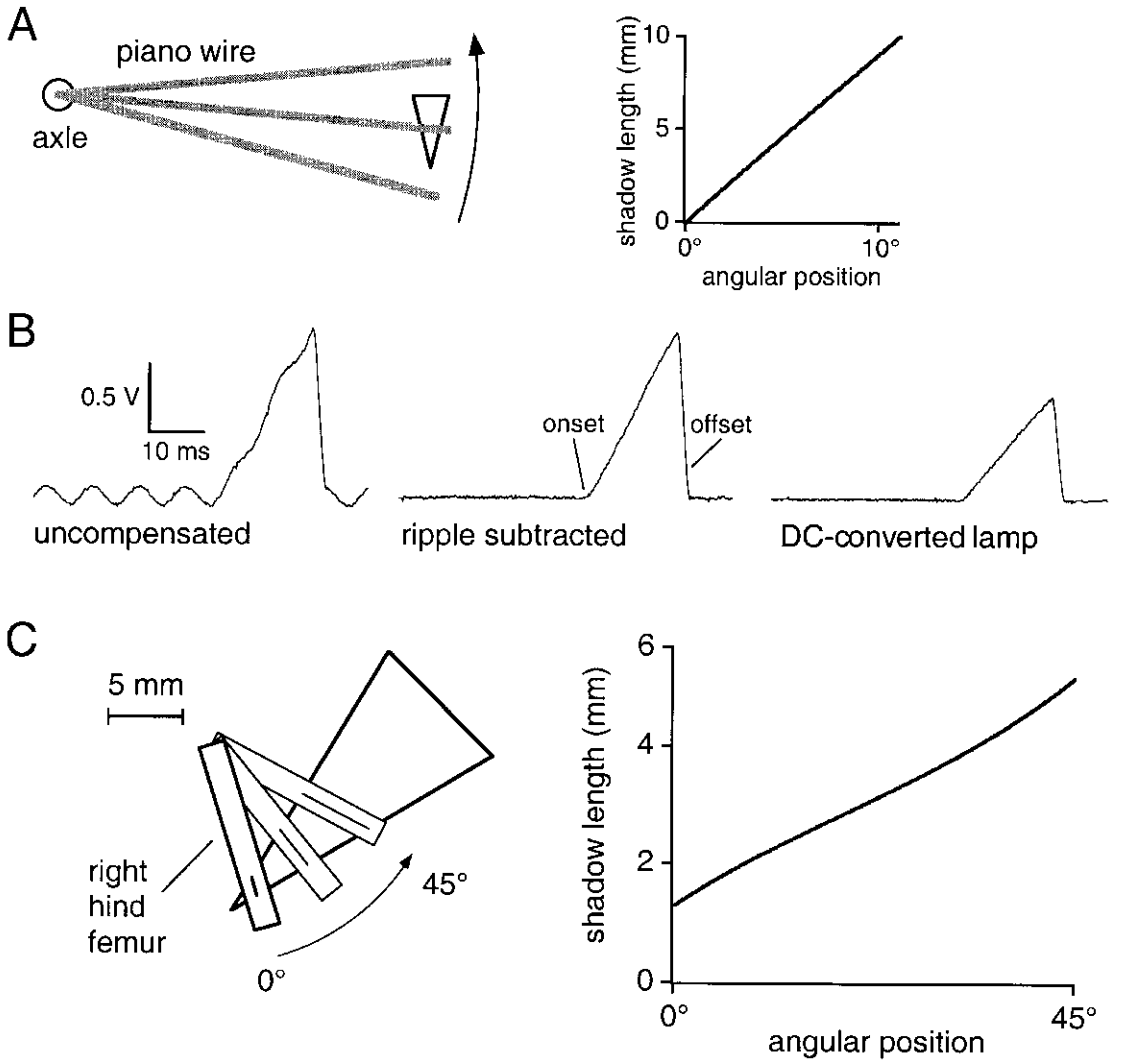

Fig. 2. System performance. A. Linearity testing. A 2mm thick rod passed across the photodiode at a speed of 1 m/s. The shadow's area is proportional to its length on the triangular photodetector. The graph shows the calculated length of the rod's shadow as a function of its angular position. B. Ripple compensation. Using the above setup, records were made without compensation for light ripple (left), with electronic compensation (center), and with the light source converted to DC operation (right). The two compensated traces are linear, as predicted in part A. Onset and offset are not instantaneous because of the 2 ms time required for the full width of the shadow to enter or leave the triangle. C. Calculations for a cricket leg. The metathoracic femur is essentially rectangular when viewed from above. As long as its shadow crosses the entire triangle, the area of the shadow on the triangle is proportional to its midline length. The calculated midline length is an approximately linear function of angular position over a range of at least 45°.

The photocurrent output of a photodiode should be a linear function of the area that is illuminated (or the area that is shaded). To test this, a rod about as thick as a cricket hindleg femur was moved across the triangular detector such that the area of the rod's shadow on the photodetector increased uniformly with time (Fig. 2A). The output signal increased uniformly as well (Fig. 2B), indicating that the output signal is a linear function of shaded area.

For the output signal to faithfully indicate leg deflection, however, the shaded area itself must be a linear function of the angular movement of the femur. This assumption holds rather well, provided that the photodetector is positioned so that the femur is perpendicular to the axis of the triangle when the femur is in the middle of its range of motion (Fig. 2C). This was demonstrated with a trigonometric model. The shadow of the femur on the photodetector can be represented as a

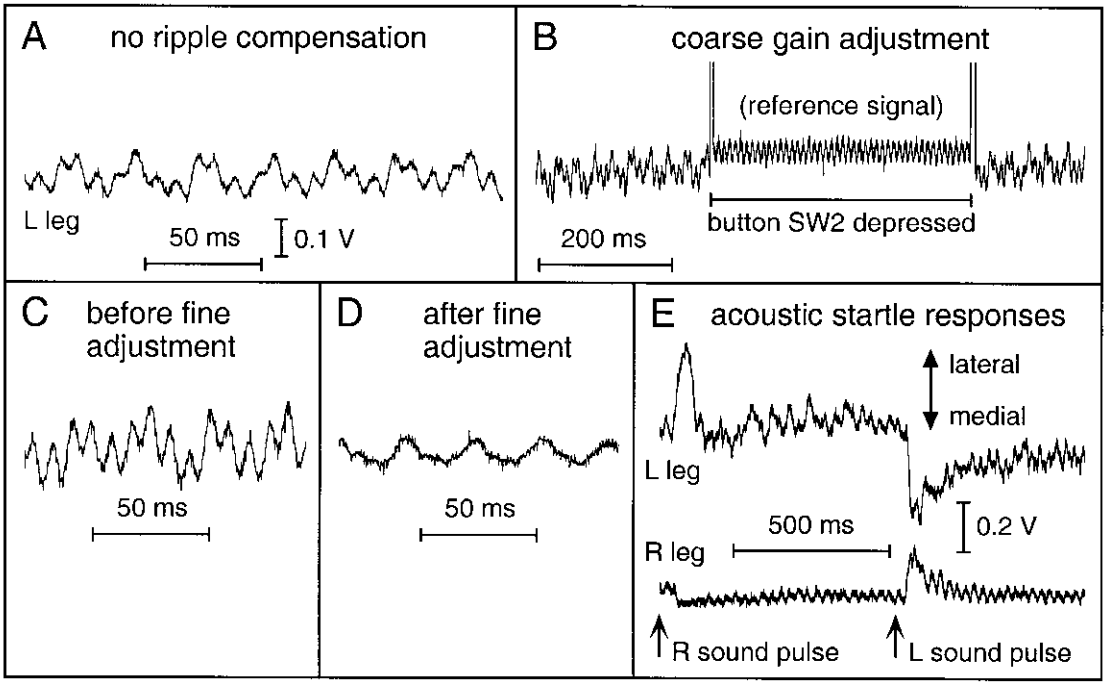

Fig. 3. Adjustment of ripple compensation. The position photodetector monitored the left metathoracic femur of a tethered flying cricket. Voltage scale of Panel A applies to all panels except E. A. Signal without ripple compensation (SW3 open). Fluctuations are a combination of light ripple (120 Hz) and leg vibration due to wing beats (~35 Hz). B. Coarse gain (R8) is adjusted to minimize the jump of the trace when the reference signal is switched into the movement amplifier path using pushbutton SW2. C. Ripple compensation is engaged (SW3 is closed) but fine gain has not been properly balanced to eliminate ripple. D. Fine gain (R13) has been adjusted to minimize ripple. Remaining fluctuations reflect real leg movements due to wing vibration. E. Escape responses in the same preparation. A second photodetector and amplifier monitored the right metathoracic femur. For both legs, a positive voltage signal indicates lateral deflection. Ultrasound pulses from the right and then the left side (arrows) evoked outward lateral movements of the contralateral hind legs. Differences in amplitudes of vibration and escape response between the two legs were real (not an artifact of using two different detectors and amplifiers).

bar of uniform thickness (Fig. 2C). As long as this bar crosses two sides of the triangle, the area of the shadow on the triangle will always be proportional to the length of the shadow at its midline. The trigonometric model shows that with optimal positioning of the photodetector, this midline length is an approximately linear function of angular movement over a range of 45° (Fig. 2C) (leg movement in the escape response rarely exceeds 20°, Miles et al. 1992).

In our experiments it is not necessary to determine the relationship between the degree of movement and the amplitude of the voltage signal. We are concerned with relative changes in the amplitude of the leg response in a habituation paradigm. The habituated responses are simply normalized to control responses within the same trial. However, the position-to-voltage scale for a trial could be determined by moving the cricket's femur to different angles using forceps, recording the resulting voltage output levels, and measuring the leg angles from videotape recordings made during the same manipulations.

Compensation for Light Ripple

When illumination is provided by an AC light source, the optic ripple adds substantial "noise" to the movement signal (Fig. 2B; Fig. 3A). We compared two methods for eliminating this ripple, subtracting it electronically or adding a DC converter to the light source. Both approaches worked well (Fig. 2B). Electronic subtraction is the most flexible method because any source of light can be used. The gain of the reference signal must be calibrated with each use, but this can be done by a simple procedure (Appendix B, Fig. 3). DC illumination is the more direct method. DC illuminators may not be commonly found in many laboratories, but an AC unit can be converted to DC operation as described above.

Other Applications

This design includes a photodetector that converts angular position to a photoelectric signal, a photodiode amplifier with DC offset compensa-

tion, and a second amplifier incorporating continuous gain adjustment and subtraction of its output from the first amplifier. These three components could be adapted to a variety of uses. (1) The photodetector could monitor other appendages such as wings or antennae, and the shape of the mask could be altered as needed to track the movement of a particular appendage (Götz 1987). Photodiodes come in several sizes, from 1×3 to 20×20 mm, and can be connected in parallel if larger areas are needed (larger solar cells may also be used). (2) The position amplifier could be used with an unmasked photodiode in applications where the timing of movement is of more interest than its spatial characteristics. For example, in the laboratory an unmasked detector could indicate the wing beat frequency of a tethered insect or detect an animal's transit past a point in a cage. The latter application could be adapted in the field for counting visits to a colony or lure. (3) The ripple compensation amplifier could serve as the basis for other applications requiring differential processing, such as automatic compensation for variation in ambient light levels. Another potential application is dual-photodiode movement detection (Crawford & Fettiplace 1985; Iwazumi 1987), in which a shadow overlaps two adjacent photodiodes and moves onto one as it moves off of the other.

The advantages of fine temporal resolution and simplicity of analysis mentioned in the Introduction make optoelectronic movement detection attractive for a variety of applications. We hope that this description will provide a point of entry for workers without much electronics background, and a starting point for those with more experience who can modify the design to suit their particular applications.

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Appendix A: Construction and Design Notes

Photodiode chips in sizes from 1 × 3 mm to 20 × 20 mm are available from Advanced Photonix (Camarillo, CA, 805-987-0146, www.advancedphotonix.com), Perkin Elmer (formerly EG&G Vactec; St. Louis, MO, 314-423-4900, www.perkinelmer.com) and Hamamatsu (Bridgewater, NJ, 908-231-0960, usa.hamamatsu.com). Solar cells of 20 × 40 mm are available from Edmund Scientific (Barrington, NJ, 800-728-6999, www.edsci.com) and Radio Shack (Fort Worth, TX, 800-843-7425, www.radioshack.com). Allied Electronics (Fort Worth, TX, 800-433-5700, www.alliedelec.com), Newark Electronics (Chicago, IL, 800-463-9275, www.newark.com), and Radio Shack are comprehensive vendors that carry all the remaining parts.

In addition to the two photodiodes, the circuit shown in Fig. 1 A requires the following parts: fixed 1/4 or 1/8 Watt resistors of 100 kΩ (R1), 11 kΩ (R2), 10 kΩ (R3, R4, R11), 20 kΩ (R5, R10), 5 kΩ (R7, R12), and 1 kΩ (R9); variable resistors of 10 kΩ (R6), 1 MΩ (R8), and 50 kΩ (R13); 100 pF capacitors (C1-2), type 1458 dual op-amp packages (IC1-4); SPST switches (SW1, SW3); SPDT momentary pushbutton switch (SW2); DPST switch (power on/off, not shown in Fig. 1). Note that R6 and R13 should be 10-turn potentiometers for greater precision in setting DC offset and ripple gain. Other parts needed to house the circuit include a case, circuit board, connection jacks (banana or BNC), and so on.

We used bipolar 1458 dual op amps (Radio Shack 276-038) because they are resilient and readily available. For biological applications requiring exceptional high-frequency or low-noise performance, this design could be refined by selecting high-performance op amps, by optimizing the feedback capacitance (C1), or by voltage-biasing the photodiode. Guidelines can be found in technical literature from photodiode manufacturers (e.g., *Photodiodes*, Hamamatsu, Bridgewater, NJ, 1997).

Resistors R1 and R2 should be at least 1 kΩ to prevent exceeding the op amp current rating, yet small enough to avoid saturating the op amp at high light intensities. The ideal values of R1 and R2 for a particular setup are best determined by trial and error. This process is made easier if R1 and R2 are plugged into an IC socket instead of being soldered directly to the circuit board. The range of gains available during normal use could be extended over several orders of magnitude by making SW1 a rotary switch and installing additional resistors. Capacitor C1 is included to prevent ringing. However, it should be noted that the feedback circuit is a low pass filter with a cutoff frequency of $f = [2\pi\ R1\ C1]^{-1}$; therefore C1 should be small enough to avoid filtering out biological signals of interest.

The maximum useful gain of the first op amp of the position amplifier is limited because the DC baseline resulting from overall illumination is amplified along with the signal due to movement. If movements of the leg shadow are small relative to the lighted area of the photodiode, the final output signal after DC compensation will also be small. This can be countered to some extent by reducing the unused lighted area of the photodetector as much as possible. At the second op amp, the baseline signal is subtracted using DC offset compensation. Therefore, an additional amplifier stage could be placed after the second op amp if more gain were needed. We have not found this to be necessary.

In the DC offset compensation circuit, R5 should not be much greater than R4 because the ratio R4/R5 is a gain factor that limits the available range of offset. At the same time, R5 must be greater than R6 to give R6 sufficient linearity as a variable voltage divider. A "voltage-follower" amplifier could be added as a buffer between R6 and R5 if desired. This would make the R6 voltage divider linear without regard to R5, and would also allow a larger R6 to be used (to reduce the current drain on batteries, for instance).

Appendix B: Adjusting Ripple Compensation

For electronic subtraction to be effective, ripple in the reference and position signals must have the same amplitude. This is achieved by adjusting the gain of the ripple compensation amplifier through the following simple procedure:

1. *Adjust position detector amplifier.* Set oscilloscope to DC mode and confirm that ripple compensation is not engaged (SW3 is open). Set the position amplifier gain (SW1) and adjust DC offset (R6) to center the signal (Fig. 3 A).

2. *Adjust coarse gain of reference signal.* Use the momentary pushbutton (SW2) to switch the reference signal into the movement amplifier path (Fig. 3 B). Adjust R8 to minimize the jump in the oscilloscope trace as SW2 is pressed and released.

3. *Adjust fine gain to minimize ripple.* Switch the oscilloscope to AC mode and engage ripple compensation by closing switch SW3 (Fig. 3 C). Adjust R13 to minimize the size of the ripple (Fig. 3 D). In this example (Fig. 3 D), light-source ripple has been effectively eliminated. The remaining "noise" is biological in origin (leg vibration due to wing beats).

4. *Readjust DC offset.* Return the oscilloscope to DC mode and adjust DC offset (R6) to center the trace.

TRAP-LURE COMBINATIONS FOR SURVEILLANCE OF *ANASTREPHA* FRUIT FLIES (DIPTERA: TEPHRITIDAE)

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ABSTRACT

Trap/lure combinations were tested against populations of *Anastrepha suspensa* (Loew) and *Anastrepha ludens* (Loew) as substitutes for the traditional glass McPhail trap. Open-bottom, plastic traps baited with a two component synthetic lure (ammonium acetate and putrescine) caught as many and sometimes more fruit flies than the McPhail trap baited with torula yeast. Sex ratio of flies caught with the synthetic lure was similar to that caught with torula yeast, i.e., generally female biased, but variable among seasons and locations. The synthetic lure attracted fewer non-target insects giving a substantial time savings in trap maintenance. Moreover, the synthetic lure was effective for ten weeks without replacement. Propylene glycol antifreeze increased captures significantly and improved preservation of specimens when used as the trap liquid compared to water. Dry jar traps and cardboard sticky traps were ineffective in comparison with the liquid baited traps.

Key Words: *Anastrepha*, traps, synthetic lure, fruit flies, pest detection

RESUMEN

Combinaciones de varias trampas con diferentes cebos fueron evaluadas contra poblaciones de *Anastrepha suspensa* (Loew) y *Anastrepha ludens* (Loew) para substituir para la tradicionál trampa vídrio de McPhail. Trampas de plastico con un cebo syntético de dos componientes (acetato amoniaco y putrescina), capturaron igual o mas moscas de fruta que la trampa McPhail cebada con torula en agua. La proporción sexuál de las moscas capturadas con el cebo syntético fue igual que las capturadas con torula; generalmente hubo mas hembras, pero, variable con respecto a ubicación y temporada. El cebo syntético atrayeron menos insectos de otros tipos por su mejor eficiéncia resultando en menos tiempo manejando las trampas. Además, el cebo syntético fue efectivo por diéz semanas sin recebar. El anti-congelante (glycol propilico), mezclado con el agua, aumenta las capturas y preserva mejor los especimenes capturadas. Trampas secas y laminas pegajosas no fueron efectivas en comparación con las trampas cebadas con líquido.

McPhail traps baited with an aqueous slurry of torula yeast have long been the industry standard for tephritid fruit fly surveillance programs (Burditt 1982; Cunningham 1989). However, trap-back studies using marked flies have shown that at the usual trap densities, around 2-4 traps per km^2, McPhail traps recapture substantially less than one percent of the released individuals (Plant & Cunningham 1991; Thomas et al. 1999). When one considers this degree of trap efficacy in the context of early detection of wild fly infestations, there is an obvious need to increase trap densities, or, to develop a more effective trap. Because the former option is the less desirable for reasons of cost, the latter potential has been investigated.

The McPhail trap is a bell-shaped, invaginated glass jar, designed to be suspended in fruit trees, with an opening at the bottom and a reservoir for fluid of about 0.5 l capacity. The fluid serves as both the attractant and the catch mechanism, with the flies attracted into the trap by the food odor, then drowning in the liquid. In an early design, McPhail (1937) employed fermenting sugar solutions, but later found success with protein based lures (McPhail 1939; Steyskal 1977). This led to the present standard of torula yeast hydrolysate with borax (Lopez et al. 1971).

Robacker & Warfield (1993), Heath et al. (1995), and Robacker & Heath (1997), found that amino acid metabolites associated with bacteria and fermenting host fruits were highly attractive to *Anastrepha* fruit flies. However, delivery systems designed to contain and release these chemicals are not easily inserted in the solid glass of

the McPhail trap. Therefore, trap devices compatible with the new lures have been designed and tested. In experiments conducted in Guatemala, Heath et al. (1997) found that a sticky trap baited with three components, ammonium acetate, trimethylamine and putrescine, caught about as many and sometimes more Medflies, *Ceratitis capitata* (Weidemann), and Mexflies *Anastrepha ludens* (Loew), than did the McPhail/torula yeast trap. Katsoyannos et al. (1999) reported that a plastic, open-bottom, trap, baited with water and the three component lure was five times more effective for catching Medflies than the same plastic trap containing protein hydrolysate. The protein based liquids are attractive to a broad range of insects which is not the case with the synthetic lures (Aluja 1999; Heath et al. 1995; Katsoyannos et al. 1999). Because far fewer of the non-target insects are caught, time spent servicing the traps is substantially reduced.

Based on these preliminary experiences, we conducted a series of tests in Florida against wild populations of Caribfly, *Anastrepha suspensa* (Loew), in Texas against released, radiosterilized, Mexflies, and in Nuevo Leon, Mexico against wild *A. ludens* in their native habitat. It is known that species of *Anastrepha* are not equally responsive to the traditional McPhail trap (McPhail 1939; Aluja et al. 1989). Ideally, one combination of trap and attractant could be deployed effectively against several different pest tephritids. The purpose of these tests was to provide direct comparisons of the more promising trap/lure combinations.

Materials and Methods

Trap Devices

The standard glass McPhail trap was included for comparison with the new trap/lure devices. Two new plastic traps were tested which in size, liquid reservoir capacity, and bottom opening diameter, were similar to the McPhail trap. One is manufactured by Florence Agri Investment Inc. (Miami FL), hereinafter referred to as the FAI trap, and the other by International Pheromone (South Wirral, UK), hereinafter referred to as the IPM trap. Both traps are of two piece construction consisting of transparent upper halves separable from yellow lower halves. They differed slightly in conformation, the IPM trap being cylindrical with a flat top, whereas the FAI trap is cylindrical but with a rounded top. Also, in the IPM trap the top half inserts within the bottom half, whereas in the FAI trap the bottom half inserts into the top. A sticky trap, called the ChamP^{R} trap (Seabright, Albany, CA) was also included in the tests. This trap consisted of a square (15 × 15 cm), folding, double-sided, perforated, yellow cardboard with glue on the outside surfaces. Developed for use in combination with fruit fly sex pheromones, this trap has a metal hook for suspension in the target host tree.

Attractants

The standard aqueous torula yeast slurry, three 5 gm yeast pellets (2% borax, manufactured by ERA International, Freeport NY) dissolved in 350 ml water, was used in the McPhail traps, and in some tests, the plastic traps. The yeast slurry was renewed weekly when the traps were serviced. A two component lure consisting of ammonium acetate and putrescine was tested in the ChamP traps and in both plastic traps. The lure is marketed as Mediterranean fruit fly lure dualpaks by CONSEP Inc. (Bend, OR). The capture liquid was either 350 ml of water with 2% borax and five droplets of Triton X-100R synthetic detergent (Fisher Scientific, Pittsburgh, PA) to break water tension, or, antifreeze (propylene glycol). The liquid, but not the lure, was renewed each week when the traps were serviced. A dry version of these traps included a ¼ inch plastic strip impregnated with pesticide (DDVP) and baited with the two component lure.

Study Sites and Test Protocols

A series of pairwise tests, or in some cases, 3-way tests, were conducted in Florida against populations of *A. suspensa* between February and July, 1998, comparing different trap/lure combinations. The duration of the tests varied from three to 12 weeks, depending on fly activity, with each test including five of each trap/lure tested, with one of each combination in the same tree following Aluja et al., 1989. It was reasoned that proximity would intensify the competition among the traps. Tests were conducted at Labelle FL with the traps hung in loquat trees, *Eriobotrya japonica* (Thunb.) with a minimum distance of 1 m separating each trap. All traps were serviced and their position within the tree alternated weekly. At Ft. Pierce FL the target host was a hedge, *Eugenia uniflora* (L.) (Surinam Cherry), with the traps spaced at 3 m and rotated weekly.

In the Rio Grande Valley of Texas, McPhail traps with torula yeast slurry, IPM traps with two component lure and antifreeze, and IPM traps with antifreeze alone, were compared during six weeks of November and December 1998. Thirty of each trap type were placed in individual trees in a large commercial citrus grove (mainly grapefruit but some oranges) targeted by the weekly sterile release program. The traps were positioned randomly with a minimum distance of 30 m (3 trees) separating each trap. The traps were rotated when the traps were serviced weekly.

Near the town of Linares in the state of Nuevo Leon, Mexico, traps were placed in yellow chapote trees, *Sargentia greggi* (Wats.), for testing against

wild populations of *Anastrepha ludens*. This test was conducted during the spring of 1999 at five sites with one of each of five trap/lure combinations. These were: 1) the standard glass McPhail trap with torula yeast, 2) the plastic IPM trap baited with the two component lure and water, 3) the plastic IPM trap with two component lure and 20% propylene glycol, 4) the dry version IPM trap with the two component lure and a vapona strip, and, 5) the ChamP sticky trap with the lure packets inside. Although the sticky traps were replaced weekly, the lure packets were simply removed from the old sticky trap and placed inside the new trap each week.

Within each site a minimum distance of at least 50 m was maintained between traps. The trap positions were designated A-B-C-D-E and each week the traps were rotated so that the trap at A was moved to B, the trap at B went to C, etc. The Mexican test continued for ten consecutive weeks so that each trap was at each position twice during the course of the test.

Statistical Analysis

Because populations and activity changed over the course of the season, the numbers of flies trapped tended to vary greatly from week to week. Because this variation could mask differences in trap efficacy statistical comparisons were made by converting the numbers captured to percent of total weekly captures following Heath et al. (1995). The mean percent weekly values were then compared by a pairwise students t-test, The t-score probabilities calculated by the software program TPROB (Speakeasy Computing 1987).

Results

Florida Tests

The results, including statistical analysis of all trap-lure combinations, are shown in Table 1 and summarized below.

Plastic vs. Glass McPhail Traps. The FAI plastic trap was tested against the McPhail trap in an area where *A. suspens*a was breeding in loquat. The test was run for eight consecutive weeks; both traps baited with aqueous torula yeast with borax as preservative. The McPhail traps caught slightly more flies on average with a capture rate of 18 flies vs. 13 flies per trap-week. The difference in captures expressed as a percent of total was not statistically significant between the traps.

Synthetic Lure vs. Torula Yeast. The two component lure was tested in the FAI plastic trap against the McPhail trap containing the torula yeast slurry. The synthetic lure trap was equivalent in effectiveness to the traditional trap capturing a weekly mean of 42 flies vs. 37 flies per trap; rates that were not significantly different. The IPM trap gave somewhat better results. At Labelle FL in loquats the IPM trap with the two component lure caught many more flies than the McPhail/torula trap, 77 vs. 34 flies per trap-week. The same result was obtained at Ft. Pierce FL in surinam cherry with the IPM trap taking 64 vs. 52 flies per trap-week. These differences when expressed as a percentage of flies caught gave a borderline t-score of 1.93 which has a p of 0.06. Importantly, the synthetic lure was effective throughout the ten week test period. The longest previous test of these lures was four weeks (Kat-

TABLE 1. FLORIDA TRAPPING RESULTS: TOTAL NUMBERS OF *ANASTREPHA SUSPENSA* CAPTURED AND MEAN PERCENTAGE OF CAPTURES BY TRAP-WEEK COMPARED BY PAIR-WISE T-TEST. MAC = MCPHAIL TRAP, IPM = INTERNATIONAL PHEROMONE TRAP, FAI = FLORENCE AGRI-INVESTMENT TRAP, TY = TORULA YEAST, AP = AMMONIUM ACETATE & PUTRESCINE, WB = WATER & BORAX, PG = PROPYLENE GLYCOL.

Trap-Lure	N	Mean ± s.d.	Trap-Lure	N	Mean ± s.d.	t	df	p
MAC-TY-WB	725	53.9 ± 10.5	FAI-TY-WB	535	46.1 ± 10.5	1.50	14	0.078
MAC-TY-WB	551	43.3 ± 8.6	FAI-AP-WB	622	51.1 ± 4.6	1.37	4	0.121
FAI-AP-WB	622	51.1 ± 4.6	FAI-AP-dry	62	5.5 ± 4.4	12.32	4	<0.001
FAI-AP-dry	62	5.5 ± 4.4	MAC-TY-WB	551	43.3 ± 8.6	6.73	4	0.001
MAC-TY-WB	509	40.5 ± 14.2	IPM-AP-WB	1165	57.5 ± 5.4	1.93	4	0.063
IPM-AP-dry	288	17.0 ± 13.7	MAC-TY-WB	509	40.5 ± 14.2	3.57	4	0.012
IPM-AP-WB	1165	57.5 ± 5.4	IPM-AP-dry	288	17.0 ± 13.7	4.76	4	0.004
MAC-TY-WB	4880	42.6 ± 22.7	IPM-AP-WB	3835	57.4 ± 22.7	1.22	12	0.123
MAC-TY-WB	975	31.8 ± 10.1	IPM-AP-PG	204	68.2 ± 10.1	5.70	8	<0.001
IPM-AP-WB	2616	38.0 ± 5.9	IPM-AP-PG	4315	62.0 ± 5.9	7.08	10	<0.001
IPM-AP-WB	6333	33.4 ± 9.0	IPM-AP-PG	11029	66.6 ± 9.0	7.37	14	<0.001
IPM-AP-WB	335	80.0 ± 7.8	FAI-AP-WB	105	20.0 ± 7.8	15.38	14	<0.001
IPM-AP-PG	5262	54.4 ± 5.4	FAI-AP-PG	4450	45.6 ± 5.4	2.84	10	0.009
IPM-AP-PG	5703	92.7 ± 2.4	ChamP-AP	443	7.3 ± 2.4	56.18	8	<0.001

soyannos et al. 1999). Also, similar to previous experience, we noted fewer non-target insects in the synthetic lure traps.

Dry vs. Wet Traps. Flies captured in aqueous solutions tend to decompose, constraining the amount of information that can be recovered from these specimens. This problem is exacerbated by evaporation due to dry or windy weather, or delays in servicing the traps. Another concern is that the aqueous liquid may not be an effective capture mechanism and that flies entering might escape. A series of tests were conducted by substituting insecticide strips for the liquid as the killing agent. However, these test results were not encouraging. The FAI trap with water captured ten times as many flies per week on average (41.5 ± 6.4) as the dry insecticide version (4.1 ± 2.4). Similarly, the IPM trap with water captured four times as many flies weekly (77.0 ± 43.2) as the dry version IPM trap (19.2 ± 10.7).

Capture Liquid. Another alternative to the preservation and evaporation problem is the use of antifreeze instead of water as the capture liquid. IPM plastic traps with the two component lure and propylene glycol was tested against the standard McPhail trap with torula yeast slurry. The result was a marked improvement. The IPM trap with antifreeze captured nearly twice as many flies per trap: 89 vs. 39 mean flies weekly. Another pair of tests was conducted using all IPM plastic traps and synthetic lures so that the only variable in the design was the capture liquid. In both tests the water based traps captured only half as many flies weekly as did the antifreeze traps. The rate of capture expressed as a percentage of captures and compared by the t-test were found to be significantly different (Table 1).

A series of tests were conducted to determine the best antifreeze concentration. The results were suggestive but inconclusive. A 50% solution was tested against a 10% solution in April and again in May. In the first test the 10% solution was significantly better than the 50% solution (45.1% vs. 35.7% of the flies per week). But, the results reversed in the May test where the 50% solution caught slightly more flies, 40.9% vs. 35.4%, although the difference was not statistically significant. Also, in Texas an 8 week comparison was made between the 10 and 20% concentration against sterile *Anastrepha ludens* with no significant difference in captures (33.2% vs. 26.9%).

IPM vs. FAI Traps. Two pairwise tests were conducted to compare the plastic traps; one with water as the capture liquid and one with antifreeze. The two component lure was used in all traps in both tests. With water as the trap liquid the IPM trap outperformed the FAI trap with a rate of 7 vs. 2 flies per trap-week. With antifreeze as the trap liquid the difference was less dramatic but still significant when the data was converted to percentages with the IPM trap catching 54.4% vs. 45.6% of the flies.

Sticky Traps vs. Liquid Traps. The ChamP traps were tested at Labelle FL against the IPM traps baited with two component lure and 10% propylene glycol as the capture liquid. The ChamP trap was ineffective, capturing an order of magnitude fewer flies, only 18 vs. 228 flies per trap-week over 5 weeks.

Mexico Test

The experiment in Mexico differed from the Florida testing in that all traps were tested simultaneously instead of pairwise, and the targeted insects were native populations of *A. ludens*. Table 2 provides acompilation of the results which were similar to those obtained in Florida with *A. suspensa*. The IPM trap with synthetic lure and antifreeze was the best trap for capturing wild Mexflies by a wide margin. It caught the most flies at all five sites. Moreover, it was the best trap in seven of the ten week test period and was never worse than second best in the other weeks. The next best trap/lure combination was the synthetic lure in the IPM trap with water and borax which caught about half as many flies as the antifreeze version but twice as many as the McPhail-torula trap. The IPM trap with synthetic lure outperformed the McPhail trap in nine out of the ten weeks tested and was the second best trap, after the antifreeze trap, at all five sites. The sticky trap was the least effective trap. It caught the fewest flies at all five sites, catching none at

TABLE 2. MEXICO TRAPPING RESULTS: NUMBER OF *ANASTREPHA LUDENS* CAPTURED AND MEAN WEEKLY PERCENTAGE CAPTURED BY EACH TRAP/LURE COMBINATION. MEANS TESTED PAIRWISE WITH STUDENT'S T-TEST. MAC = MCPHAIL TRAP, IPM = INTERNATIONAL PHEROMONE TRAP, TY = TORULA YEAST, AP = AMMONIUM ACETATE & PUTRESCINE, PG = PROPYLENE GLYCOL.

Trap-Lure	Flies	Mean ± s.d.	t	df	p
IPM-AP-PG	558	47.8 ± 17.4	2.41	18	0.013
IPM-AP-WB	295	29.1 ± 17.2	2.40	18	0.014
MAC-TY-WB	177	14.2 ± 9.5	2.45	18	0.012
IPM-AP-dry	81	6.3 ± 3.7	2.43	18	0.013
ChamP-AP	33	2.6 ± 3.1			

two sites. It was the worst trap in six of the ten weeks and was never better than next to worst in the other weeks. All of these differences in trapping rates were statistically significant (Table 2).

Texas Test

The Texas test was conducted in a commercial grove against aerially released, radiosterilized,*A. ludens*. Temperatures varied sharply during this test such that although an equal number of flies was released weekly, the numbers trapped back also varied sharply. The McPhail trap averaged from 2.2 to 33.2 flies weekly for a mean of 17.0 ± 10.5 flies per trap per week. The IPM traps averaged from 4.4 to 24.8 flies weekly for a mean of 13.7 ± 8.6 flies per trap per week. Because of the variation in weekly captures, these numbers were converted to percentage rates for comparison. Nonetheless, the difference in means, 46.3% (McPhail) vs. 41.3% (IPM), was not statistically significant (t = 0.62, 10 d.f., p = 0.274). Interestingly, the control traps containing only antifreeze succeeded in capturing an average of 5.0 ± 3.9 flies per trap per week. By comparison, Heath et al. (1994) found that traps containing water alone were not attractive to the Mexfly.

During this test three experienced trappers were separately observed and timed with a stopwatch as they serviced the traps. Servicing involved emptying the trap, separating the fruit flies from the other insects and placing them in vials containing preservative, and recharging the trap liquid. The average time required for one person to service the McPhail trap was 150.7 sec (n = 90). The average time required to service the IPM traps was 107.7 sec (n = 90). It was judged that the average difference, 43 sec, was due to the lesser time it took to separate the fruit flies from the IPM trap due to the presence of fewer non-target insects. It should be noted that had these studies been conducted in an urban setting a greater differential might have been found. Trappers have reported incidents wherein house flies have filled McPhail traps requiring up to 15-20 minutes in service time.

We attempted a cost-benefit analysis to compare operating expenses of a program with the plastic traps and synthetic lure versus a program using the traditional McPhail trap with torula yeast. However, because costs vary regionally, especially for labor, and some materials are not universally available, these, cost estimates are relative. As of this writing the plastic traps range about 2-3 times more expensive than the glass McPhail trap. But, because the plastic traps are stackable and light in weight there is a substantial savings in shipment costs over the bulky glass traps. The cost of the commercially available synthetic lure packets is about ten times the cost of three torula yeast pellets. However, whereas the yeast slurry must be renewed every week, the packets need be renewed only once every ten weeks, giving an equivalent cost for lure over the season. The use of 20% propylene glycol incurs an additional cost which would about double the weekly expense in expendable materials, except that this liquid can be recycled and reused three to four times before replacement. The replacement rate varies because it is due mainly to loss in handling (spillage and absorption) rather than deterioration.

Sex Ratio and Reproductive Stage of Trapped Flies

Gender bias is an important concern because surveillance trapping is often combined with SIT suppression programs. Under these conditions there could be an advantage to a female biased trap (Katsoyannos et al. 1999). Trapping *A. suspensa* in Florida, Calkins et al. (1984) reported a strong female bias in McPhail traps baited with protein by a ratio of 2:1 over males. Our Florida results were similar. The*A. suspensa* females outnumbered the males in all trap-lure combinations. In five tests the McPhail trapped flies ranged from 66.4 to 82.9% females with a mean of 75.0 ± 6.2 percent. Captures in the plastic traps baited with ammonium acetate and putrescine with water ranged from 61.6 to 78.7% females for a mean of 75.0 ± 4.4 (n = 8). Traps with the two component lure, but using propylene glycol as the trap fluid, obtained the same result: a range of 62.9 to 85.3% females over six tests for a mean of 77.7 ± 8.02 percent.

However, we obtained very different results with *A. ludens* in Mexico. The McPhail traps caught exactly the same number of males and females. But, the synthetic lure traps were strongly male biased during the ten week study. The flies caught by the plastic traps baited with ammonium acetate and putrescine with water were 71.3% males. The flies caught with the same lure but with propylene glycol were 68.4% males. This result might be explained by the studies of Lopez & Hernandez (1967) with*A. ludens* who found that traps baited with corn protein tended to catch more females, while traps with fermenting bait (sugar and yeast) tended to catch more males. Monitoring populations of*A. ludens* in Belize, Houston (1981) found that sex ratio varied over the season, and from place to place, although the variation was between unity and a skewness in favor of females. Likewise, Robacker (1999) reported gender differences in attraction to the synthetic lures by location and season. Thus, sex ratio of trapped flies is influenced by confounding factors which include changes in the population structure and corresponding changes in the response of the adults to the attractant over the season. Our previous experience with*A. ludens* trapping has been equally ambiguous. Annual surveys for Mexflies in citrus groves in Texas with McPhail traps are consis-

tently female biased at a ratio of 3:1 (1,387 females vs. 411 males from January 1997 through May, 2000). But traps in the chapote mots of Nuevo Leon are generally male biased. From 1995 through 1998 we trapped 3,794 males to 2,711 females, a ratio of approximately 3:2. One explanation is that there may be a stronger influence from lekking behavior in the chapote mots compared to the citrus groves such that male captures are favored in the traps. Robacker (1993) demonstrated experimentally that the male sex pheromone strongly inhibits the attraction of the immature females to the chapote trees with leks.

Using lab bioassays, Robacker & Warfield (1993) found no significant difference between the sexes of *A. ludens* in attraction to torula yeast or to synthetic lure. But, in further refining these tests, Robacker (1999) demonstrated that male response was strongly influenced by age, with older males being significantly more attracted to the synthetic lure. Our data (Table 3) shows the change in reproductive status of the females over the course of the Mexican field test in 1999. The larger numbers captured in the last two weeks of the test was evidently due to an influx of immature flies, indicating a strong local emergence of new adults. The weeks with the largest numbers of flies were also the weeks with the least skew in sex ratio. This suggests that a factor contributing to the bias in sex ratio over most of the test period was a general absence of immature females. Thus, our results indicate that with the two species of *Anastrepha* tested there is a general bias for female captures with the synthetic lure, as there is with the McPhail-torula trap, but that this is subject to local and seasonal variation in population structure and prevailing environmental conditions.

Discussion

The efficacy of a fruit fly trap is influenced by weather (Cunningham et al. 1978, Gazit et al. 1998), by the habitat surrounding the tree with the trap (Aluja et al. 1996), and even the position of the trap within the tree (Hooper & Drew 1979; Robacker et al. 1990). By rotating the traps weekly we hoped to minimize these effects, but because weather conditions also vary from week to week, it was impossible to completely neutralize the influence of the environment. It was also known that different species of tephritids respond differentially to the traps and lures (Aluja et al. 1989). Thus, we deemed it important to apply our studies in different locations, in different habitats, and against different species of fruit flies.

The results of the tests in Florida against *A. suspensa* suggest that the plastic versions of the open-bottom trap can be substituted for the traditional glass McPhail trap without significant loss in effectiveness. Likewise, the artificial lures based on ammonia and putrescine can be used in the plastic traps and catch as many, and often more Caribflies, but with fewer non-target insects, than the McPhail trap. Another advantage of the plastic traps over the McPhail traps is their yellow color. Greany et al. (1977) and Robacker (1992) found that yellow to orange hues are visually attractive to Caribfly and Mexfly respectively. Of the plastic traps tested, the IPM trap outperformed the FAI trap. Tests in Mexico against wild populations of *A. ludens* likewise demonstrated the superiority of the plastic traps with synthetic lures over the traditional glass McPhail with torula yeast. Tests in Texas against sterile flies only demonstrated equivalence between the trap configurations in terms of numbers captured, but a greater selectivity on the part of the synthetic lures, resulting in a reduction of handling time by about one-third.

One might conjecture why there was such large differences among the three configurations of IPM traps and synthetic lure but different preservatives. A concern with the open bottom trap is that flies can exit the trap without getting caught (Aluja et al. 1989). The flies have to fall into the

Table 3. Reproductive age of female *Anastrepha ludens* and sex ratio by Julian week at Santa Rosa Canyon, Nuevo Leon, Mexico (data from wet traps only).

Julian week	Gravid females	Non-gravid females	Males	Percent males
14	15	3	50	73.5
15	29	5	50	59.5
16	32	2	72	67.9
17	25	1	68	72.3
18	65	0	100	60.6
19	14	1	22	59.5
20	14	3	19	52.8
21	8	6	48	77.4
22	6	4	55	84.6
23	7	43	67	59.0
Totals	215	68	551	66.1

liquid and drown to be actually trapped, an essentially passive catch mechanism. The use of a knockdown insecticide or a sticky contact surface might have been expected to solve that problem, yet the two traps with those active trap advantages underperformed all of the liquid traps.

The greater captures by the wet IPM trap compared to the McPhail trap can be explained as resulting from the superior lure in the former. However, it is much more difficult to explain the better catch in the antifreeze trap compared to the water trap, having the same lure and configuration. The capture of flies in traps containing only antifreeze suggests that the antifreeze has an attractance. Inasmuch as propylene glycol itself is unlikely to be attractive to insects there may be an impurity or breakdown product in the commercial formulation which is attractive to flies. For whatever reason, the antifreeze greatly improved captures when used as the trap fluid in combination with the two component lure.

Among the liquid based configurations we cannot make absolute recommendations for one trap over another. Ultimately, program managers must decide which trap is appropriate for their situation, among which, efficacy is but one consideration. In programs where traps are rotated among sites to follow fruit phenology, the portability of the traps may be an overriding factor. Our studies provide information on the characteristics of some of the trap-lure designs now available among those most likely to be useful in fruit fly surveillance programs. For some programs the detection of new infestations is the objective, as opposed to the monitoring of existing populations, and the trapping protocol will vary accordingly. Having uniformity in trapping protocols among programs is a consideration in that it facilitates comparisons across regions. In some cases, for example, where quarantine restrictions are triggered by fly finds, the requisite trap design may be codified (e.g., Nilakhe et al. 1991). Lastly, it might also be noted that the improvement in efficacy of the synthetic lures over the torula yeast is incremental. Until the degree of improvement reaches an order of magnitude, one has to expect that further enhancements will be discovered, and thus, even the best trap-lure designs now available could be outmoded in the near future as research in this area continues.

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HORSEFLIES (DIPTERA: TABANIDAE) FROM PROTECTED AREAS OF THE YUCATAN PENINSULA, MEXICO

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ABSTRACT

Examination of horseflies deposited in the Colección Entomológica Regional of Universidad Autónoma de Yucà Merida, Yucatan, Mexico (CER-UADY) and Instituto Nacional de Diagnóstico y Referencia Epidemiológicos, Mexico City, Mexico (INDRE) collections revealed a significant number of species and new localities from the Peninsula of Yucatan (PY). Previously published information is summarized, and new information about tabanid species reported for PY is presented, with emphasis on the most important protected areas within the biotic province of Yucatan: Celestun, Cuxtal, Dzilam and Ria Lagartos (Yucatan), Calakmul (Campeche), Sian Ka'an and El Eden (Quintana-Roo). Over 5,000 specimens collected by netting, human bait, Malaise traps and light traps were examined. A final list of 29 species, 17 representing state records and three representing PY records, is provided. One species is also reported for the first time from Mexico. Species diversity by state is as follows: Campeche, 19 species, 10 new state records; Quintana Roo, 23 species, 2 new state records; Yucatan, 22 species, 9 new state records. The 29 species reported for the biotic province of Yucatan represents more than 14% of the species known from Mexico. Most of these species have Neotropical or amphitropical affinities. Species showed wide distribution ranges within the biotic province of Yucatan, probably related to climatic and orographic homogeneity, which define the limits of the province.

Key words: Tabanidae, Peninsula of Yucatan, Mexico

RESUMEN

Al revisar los tábanos depositados en las colecciones Colección Entomológica Regional of Universidad Autónoma de Yucà Merida, Yucatan, Mexico (CER-UADY) e Instituto Nacional de Diagnóstico y Referencia Epidemiológicos, Mexico City, Mexico (INDRE), encontramos un número importante de especies y nuevos registros de localidades para la Península de Yucatán (PY). Compilamos y aportamos nueva información de tábanos reportados para la PY, con énfasis en las áreas protegidas más importantes ubicadas en la Provincia Biótica de Yucatán: Celestún, Cuxtal, Dzilam y Ría Lagartos (Yucatán), Calakmul (Campeche), Sian Ka'an y El Edén (Quintana Roo). Se revisaron 5,067 ejemplares recolectados con red entomológica, cebo humano, trampas Malaise y de luz. Incluyendo registros previos y nuevos, obtuvimos un listado final de 29 especies, 17 nuevos registros estatales y tres nuevos registros para la PY. Una especie es nuevo registro para México. La diversidad de especies por estado es la siguiente: Campeche (19 especies, 10 nuevos registros estatales); Quintana Roo (23 especies, 2 nuevos registros estatales); Yucatan (22 especies, 9 nuevos registros estatales). Las 29 especies reportadas para la Provincia biótica de Yucatán representan más del 14% de las especies conocidas para México. La mayoría de las especies tiene afinidad neotropical o anfitropical. Las especies mostraron un amplio rango de distribución dentro de la provincia biótica de Yucatán, probablemente relacionado con la homogeneidad climática y orográfica que define los límites de la provincia.

The family Tabanidae includes approximately 4,290 species worldwide, of which nearly one-third are Neotropical. In the most recent catalogue of Tabanidae south of the USA, 207 species were reported for Mexico, but only 14 species were specifically reported for one or more of the states included within the Peninsula of Yucatan (PY) (Fairchild & Burger 1994). However, it was considered quite possible that some of the 22 species noted as widely distributed in Mexico (e.g*., Diachlorus ferrugatus*) might occur in PY.

Based on an extensive literature review, we recorded 25 species that had been specifically reported for PY from Towsend (1897) to Fairchild & Burger (1994): *Catachlorops fulmineus* var. *ocellatus* Enderlein, *Chlorotabanus mexicanus* (Linnaeus)*, Chrysops auroguttatus* Kröber, *C. flavidus* Wiedemann, *C. pallidefemoratus* Kröber*, C. sca-*

laratus Bellardi, *C. variegatus* (De Geer), *Diachlorus ferrugatus* (Fabricius), *Esenbeckia illota* (Williston), *Leucotabanus canithorax* Fairchild, *L. exaestuans* (Linnaeus), *L. itzarum* (Bequaert), *Scione aurulans* (Wiedemann), *Stenotabanus indotatus* Ibáñez-Bernal, *S. jamaicensis* (Newstead), *S. littoreus* (Hine), *S. pechumani* Philip, *Tabanus campechianus* Towsend, *T. colombensis* Macquart, *T. commixtus* Walker, *T. haemagogus* Williston, *T. occidentalis* var. *dorsovittatus* Macquart, *T. oculus* Walker, *T. vittiger* ssp. *guatemalanus* Hine and *T. yucatanus* Towsend.

Furthermore, Ibáñez-Bernal & Coscarón (2000) reported (without specific names) 9 species for Campeche, 20 for Quintana Roo, and 10 for Yucatan. Our review found 9 species for Campeche, 22 for Quintana Roo, and 13 for Yucatan.

The only previous faunistic studies of the tabanid fauna within PY were a general list of Diptera for Sian Ka'an (Ibáñez-Bernal et al. 1990) and a detailed faunistic work of tabanids for this protected area (Ibáñez-Bernal 1992). These two papers listed 17 species (*Catachlorops fulmineus* var. *ocellatus*, *Chlorotabanus mexicanus*, *Chrysops flavidus*, *C. scalaratus*, *C. variegatus*, *Diachlorus ferrugatus*, *Leucotabanus canithorax*, *L. itzarum*, *Stenotabanus indotatus*, *S. jamaicensis*, *S. littoreus*, *Tabanus campechianus*, *T. colombensis*, *T. commixtus*, *T. occidentalis* var. *dorsovittatus*, *T. oculus* and *T. vittiger* ssp. *guatemalanus*). These 17 species, plus four unconfirmed records by Ibáñez-Bernal (*C. auroguttatus*, *E. illota*, *S. aurulans* and *T. yucatanus*) gives a total of 22 species for Quintana Roo. Only 10 of the species had been previously reported.

Materials and Methods

Study Area

PY is situated in southeast Mexico and has a surface area of 142,523 km^2. PY inland vegetation is tropical, mostly covered by short or medium sized dry deciduous forests, although there are some patches of high perennial forest. Coastal vegetation includes dunes, mangroves, marshes and petenes. The peten includes mangrove, short and medium sized deciduous forests and swamp vegetation elements. A more detailed description of dominant vegetation can be found in Flores & Espejel (1994). An interesting feature is the lack of surface running water, although there are some temporary ponds and cenotes (depressions in the karst landscape filled with groundwater) (Brenner et al. 1995).

PY includes the Mexican states of Campeche, Quintana Roo and Yucatan. PY includes two biotic provinces: biotic province of Yucatan (northern PY) and Peten (southern PY) (Barrera 1962; Alvarez & de Lachica 1991). The present report deals with the biotic province of Yucatan, described as an area including low level carstic soils, without surface running water, situated in the north of PY up river from the mouths of the Champoton and Hondo rivers (Alvarez & de Lachica 1991).

More than 5,000 specimens deposited at CER and INDRE were examined. These specimens were collected by netting, human bait, Malaise traps and light traps. The authors and Adriana Godinez, Herón Huerta, Carmen Martínez, Leticia Miranda, Carlos Navarro, Rafael Paz, Cresencio Pérez, from INDRE and UADY collected the tabanids. Dr. Atilano Contreras and his team from Instituto de Biologia UNAM, also provided specimens from Calakmul, Campeche.

All specimens were collected within seven protected areas (defined as terrestrial areas representing different ecosystems and their biodiversity under special governmental regime of protection conservation, restoration and development; SEMARNAP, 1996), Celestun, Cuxtal, Dzilam and Ria Lagartos (Yucatan), Calakmul (Campeche), Sian Ka'an and El Eden (Quintana-Roo) representing almost 10% of PY land area (Fig. 1). For details about species and collection localities of Sian Ka'an readers are referred to Ibañez-Bernal (1992). There are few records from El Eden, but these were included because of their importance although it is clear that its tabanid diversity is poorly known. Other localities of the states were also included. Even though political borders do not have any biological meaning, they are useful to reference localities where species are recorded. The localities in PY are shown in Fig. 1.

Abbreviations

INDRE = Instituto Nacional de Diagnóstico y Referencia Epidemiológicos; CER-UADY = Colección Entomológica Regional of Universidad Autónoma de Yucatán; CD = Coastal dune; DTF = Deciduous tropical forest; M = Mangrove; P = Peten; PY = Peninsula of Yucatan.

Results

Identification of 5, 067 specimens provided a list of 23 species (Table 1) including 17 state records (see species accounts), and 3 records for PY (*Lepiselaga crassipes*, *Phaeotabanus longiappendiculatus*, *Tabanus pungens*). One species (*Chrysops varians*) is recorded for the first time from Mexico. Seventeen state records were confirmed and six species previously reported for PY (*Catachlorops fulmineus* var. *ocellatus*, *Chrysops auroguttatus*, *Esenbeckia illota*, *Scione aurulans*, *Stenotabanus indotatus* and *S. pechumani*) were not found in this study.

At present, including previous and new records, PY has the following tabanid species:

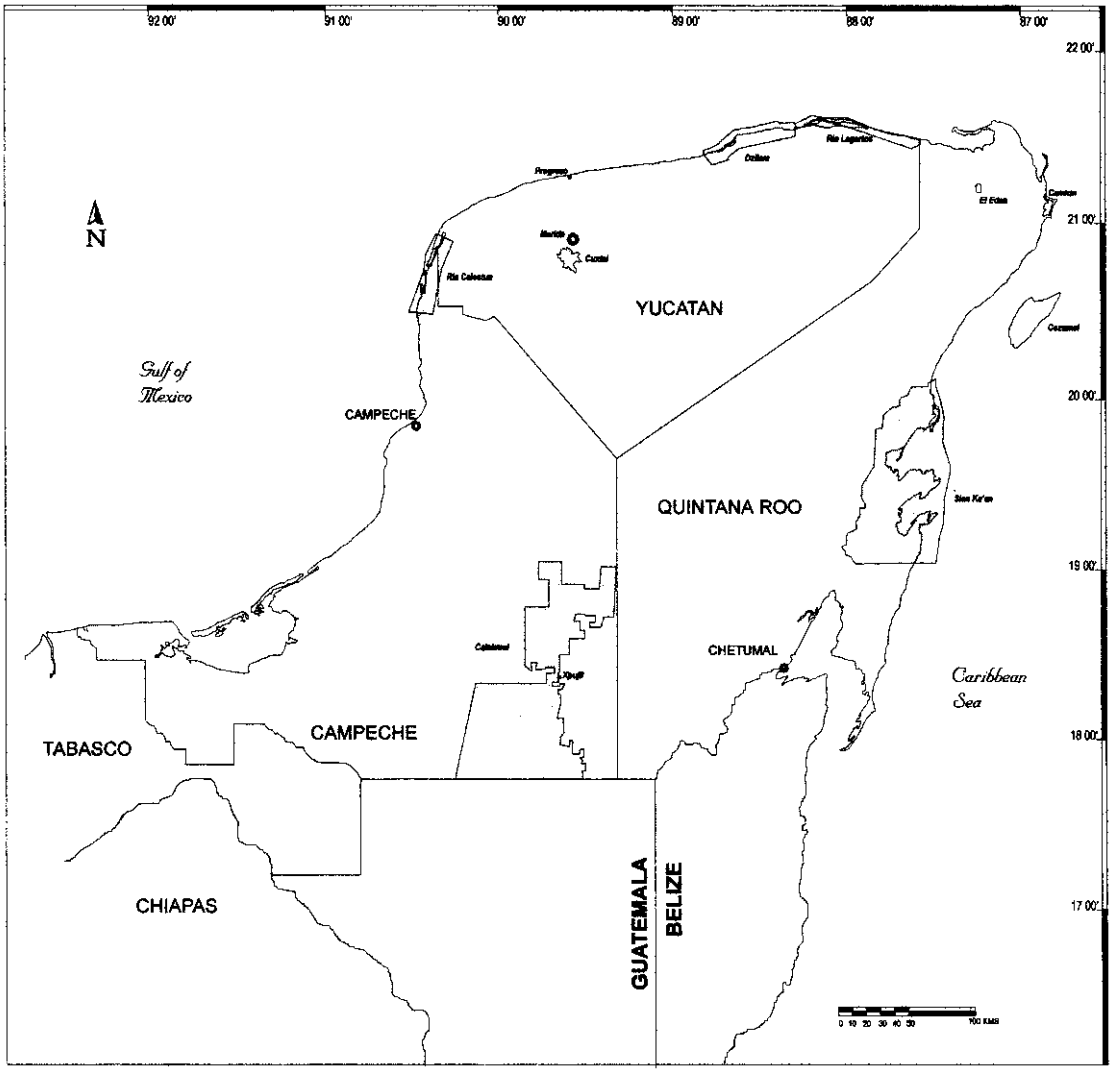

Fig. 1. Protected areas sampled in the Peninsula of Yucatan (redrawn from Bezaury et al. 1995). The map shows the borders of the states of Tabasco and Campeche and with the countries Guatemala and Belize.

Campeche: 19 species, including the following new state records: *Chrysops scalaratus*, *C. varians*, *C. variegatus*, *Lepiselaga crassipes*, *Leucotabanus canithorax*, *L. exaestuans*, *Tabanus colombensis*, *T. commixtus*, *T. occidentalis* var. *dorsovittatus* and *T. oculus*.

Quintana Roo: 23 species, including 2 new state records *(Lepiselaga crassipes* and *Tabanus haemagogus)*.

Yucatan: 22 species, including the following new state records: *Chrysops flavidus, C. scalaratus, C. varians, Lepiselaga crassipes, Phaeotabanus longiappendiculatus, Tabanus campechianus, T. colombensis, T. occidentalis* var. *dorsovittatus* and *T. pungens*.

Annotated List of Tabanidae from Peninsula of Yucatan

Subfamily PANGONIINAE
Tribe Pangoniini
Esenbeckia illota (Williston), 1901

Known Distribution: From Mexico (Chiapas, Campeche, Nuevo Leon, Quintana Roo and Yucatan) to Belize and Honduras (Williston 1901; Bequaert 1931; 1933; Pearse 1945; Philip 1954a, 1978b; Fairchild & Burger 1994). Within PY, Philip (1978b) recorded one female from Campeche. Bequaert (1931) reported one female from Quintana Roo (cited as Territory of Quintana Roo) and Philip (1954a) reported the existence of specimens

TABLE 1. SPECIES OF TABANIDAE RECORDED IN PENINSULA OF YUCATAN, INCLUDING PREVIOUS AND NEW RECORDS FROM PROTECTED AREAS AND OTHER LOCALITIES. SIMBOLS: CA = CALAKMUL RESERVE; CE = CELESTUN RESERVE; CU = CUXTAL RESERVE; ED = EL EDEN RESERVE; DZ = DZILAM RESERVE; RL = RÍA LAGARTOS RESERVE; SK = SIAN KA'AN RESERVE; + = PRESENCE; (*) = REPORTED BY IBÁÑEZ-BERNAL (1992).

	Campeche		Quintana Roo			Yucatan				
Species	CA	Others	ED	SK (*)	Others	CE	CU	DZ	RL	Others
Catachlorops fulmineus var. *ocellatus*				+						
Chlorotabanus mexicanus	+	+		+						
Chrysops auroguttatus					+					
C. flavidus				+		+		+	+	
C. pallidefemoratus	+	+		+	+		+		+	+
C. scalaratus	+			+		+			+	
C. varians	+								+	
C. variegatus	+			+		+		+	+	+
Diachlorus ferrugatus	+	+		+	+	+	+	+	+	+
Esenbeckia illota		+			+					+
Lepiselaga crassipes	+				+					+
Leucotabanus canithorax	+			+						
L. exaestuans	+					+				+
L. itzarum		+		+	+	+	+			+
Phaeotabanus longiappendiculatus						+				
Scione aurulans					+					
Stenotabanus indotatus				+						
S. jamaicensis				+					+	+
S. littoreus				+	+	+		+	+	+
S. pechumani		+								
Tabanus campechianus		+		+	+	+			+	+
T. colombensis		+		+		+	+	+	+	
T. commixtus	+		+	+	+	+	+	+	+	+
T. haemagogus			+			+	+		+	+
T. occidentalis var. *dorsovittatus*	+			+		+	+	+	+	
T. oculus	+	+		+	+	+	+		+	+
T. pungens						+			+	
T. vittiger ssp. *guatemalanus*		+		+		+		+	+	+
T. yucatanus		+			+	+				+

from Yucatan, without more detailed information. None of the reports for Campeche and Yucatan mentioned the collection date.

Tribe Scionini
Scione aurulans (Wiedemann), 1830

Known Distribution: From Mexico (Chiapas, Oaxaca, Tabasco and Veracruz) to Guatemala, Belize, Honduras, Costa Rica and Colombia (Philip 1954a, 1978a; Fairchild & Burger 1994). This species was reported from PY (Bequaert 1931, 1933; Pearse 1945) for Quintana Roo (cited as Territory of Quintana Roo).

Subfamily CHRYSOPSINAE
Tribe Chrysopsinae
Chrysops auroguttatus Kröber, 1930

Known Distribution: From Mexico (Veracruz), to Costa Rica, Panama, northern Colombia and Trinidad (Fairchild 1986; Fairchild & Burger 1994). Within PY this species was reported from an unknown locality in Quintana Roo (cited as southeast of Peto) by Bequaert (1931) (as *Chrysops incisa* Macquart, 1845). However, it was not found in our collections, nor was it collected by Ibáñez-Bernal (1992) in Quintana Roo. This species is very similar to *C. pallidefemoratus* and it is possible that the previous records were misidentifications.

Chrysops flavidus Wiedemann, 1821

This species is widely distributed from the southern USA to Mexico, as well in Cuba and Bahamas (Cruz & Garcia 1974; Fairchild & Burger 1994). It has been reported from the Mexican states of Hidalgo, Tabasco, Veracruz (Fairchild & Burger 1994) and Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992). It is reported here for the first time in Yucatan, mainly from coastal areas

within coastal dune and mangrove, but also from a deciduous tropical forest close to the coast and petens.

Material Examined: YUCATAN, Celestun Reserve, 11 Celestun (CD), 4-XII-1995, 1 ♀ Ecoparaiso (CD), 10-IV-1997, 3 ♀ Rancho Loma Bonita (P), 7-IX-1995, 14 ♀ *Ibid.* 8-XII-1995, 1 ♀ Rancho Loma Bonita (DTF), 19-VII-1996, 2 ♀ *Ibid.* 5-IX-1995, 1 ♀ *Ibid.* 23-X-1996, 23 ♀ *Ibid.* 5-XII-1995; Dzilam Reserve, 2 ♀ Dzilam, 20-I-1993, net, 1 ♀ 2-II-1993, net; Ria Lagartos Reserve, 2 ♀ Rio Lagartos, 6-III-1994, Malaise trap, 1 ♀ El Cuyo, 23-V-1995, net, 1 ♀ EL Cuyo (M), 18-VII-1996, 1 ♀ *Ibid.* 28-XI-1997, 3 ♀ *Ibid.* 29-XI-1995, 13 ♀ Ojo de Agua (P), 8-VII-1996, 5 ♀ Peten Tucha, 31-XI-1995, 3 ♀ *Ibid.* 1-XII-1995, 4 ♀ Entrada a Sac-Bo (DTF), 9-VII-1996.

Chrysops pallidefemoratus Kröber, 1930

Known Distribution: From Trinidad, Belize and the three states of PY (Bequaert 1931, 1944; Fairchild 1942a; Fairchild 1971; Fairchild 1986; Ibáñez-Bernal 1992; Fairchild & Burger 1994).

Material examined: CAMPECHE, Calakmul Reserve, 3 Ejido Nuevo Becan, El Chorro, 30-V-1997, Malaise trap, 7 El Refugio, 2-I-1993, net. YUCATAN, Cuxtal Reserve, 9 Xmatkuil (DTF), 28-31-I-1994, Malaise trap, 3 Xmatlkuil, 24-28-II-1994, Malaise trap; Ria Lagartos Reserve, 2 El Cuyo, 23-V-1995, net; Ria Lagartos Reserve, 1 Peten Tucha, 8-VII-1996, 1 La Darcena (CD), 10-VII-1997, 1 *Ibid.* 28-VIII-1995.

Chrysops scalaratus Bellardi, 1859

The type locality is Mexico. Known distribution from Panama to southern Mexico including the states of Chiapas, Quintana Roo (Sian Ka'an) and Veracruz (Ibáñez-Bernal 1992; Fairchild & Burger 1994). It is reported here for the first time for Campeche and Yucatan.

Material Examined: CAMPECHE, Calakmul Reserve, 1 archaeologic zone, 3-V-1997, Malaise trap, 1 ♀ Ejido Nuevo Becan, El Chorro, 30-V-1997, Malaise trap. YUCATAN, Celestun Reserve, 9 ♀ Celestun (CD), 4-IX-1995, 58 ♀ Rancho Loma Bonita (P), 7-IX-1995, 10 ♀ 1 ♂ Rancho Loma Bonita (DTF), 20-I-1997, 233 ♀ *Ibid.* 5-IX-1995, 9 ♀ *Ibid.* 23-X-1996, 9 ♀ *Ibid.* 5-XII-1995; Ria Lagartos Reserve, 4 ♀ El Cuyo (CD) 23-V-1995 net, 4 ♀ *Ibid.* 5-V-1994 Malaise trap, 1 ♀ La Darcena, 13-I-1997, 1 ♀ Rio Lagartos, 6-III-1994, Malaise trap, 4 ♀ El Cuyo (M), 29-XI-1995, 1 ♀ San Felipe, 26-V-1995, Malaise trap, 2 ♀ Rio Lagartos (P), 4-IV-1997, Malaise trap, 1 ♀ Ojo de Agua (P), 27 ♀ 1 ♂ *Ibid.* 8-VII-1996, 1 ♀ *Ibid.* 31-VIII-1995, 17♀ 1 ♂ *Ibid.* 14-X-1996, 8 ♀ *Ibid.* 1-XII-1995, 17 ♀ Entrada a Sac-Bo (DTF), 21-I-1997, 2 ♀ *Ibid.* 1-IV-1997, 5 ♀ *Ibid.* 9-VII-1996, 1 ♀ *Ibid.* 9-VII-1997, 1 ♀ *Ibid.* 29-VIII-1995, 7 ♀ Peten Tucha, 7-VII-1997, 2 ♀ *Ibid.* 31-VIII-1995, 1 ♀ 1 ♂ *Ibid.* 1-IX-1995, 6 ♀ *Ibid.* 30-XI-1995.

Chrysops varians Weidemann, 1828

Known Distribution: Costa Rica, Panama, Colombia Venezuela, Guyana, Brazil, Ecuador, Peru, Paraguay, Argentina and Trinidad (Fairchild & Burger 1994). This is the first time that *C. varians* is reported for Mexico.

Material Examined: 8 ♀ MEXICO, YUCATAN, Ria Lagartos Reserve, El Cuyo, 23-V-1995, P. Manrique coll., net; 2 ♀ CAMPECHE, Calakmul Reserve, archaeologic zone, 3-V-1997, Contreras, González, Ibarra and Martínez colls., Malaise trap.

Chrysops variegatus (De Geer), 1776

Known Distribution: Includes most of the Neotropics from Mexico to Argentina, as well as Cuba and the West Indies (Fairchild 1971, 1986; Cruz & Garcia 1974; Fairchild & Burger 1994). In Mexico, it has been reported from Jalisco, Tabasco, Quintana Roo (Sian Ka'an), Veracruz and Yucatan (Chichen Itza) (Bequaert 1931, 1933; Pearse 1945; Ibáñez-Bernal et al. 1990; Ibáñez-Bernal 1992). It is reported here for the first time for Campeche.

Material Examined: CAMPECHE, Calakmul Reserve, 10 ♀ archaeologic zone, 3-V-1997, Malaise trap, 2 ♀ Ejido Nuevo Becan, El Chorro, 30-V-1997, Malaise trap, 2 ♀ El Refugio, 2-I-1993, net. YUCATAN, Celestun Reserve, 1 ♀ Rancho Loma Bonita (P), 26-III-1996, 2 ♀ *Ibid.* 8-VII-1996, 1 ♀ *Ibid.* 4-XII-1995, 1 ♀ Rancho Loma Bonita (DTF), 1 ♀ *Ibid.* 28-XI-1995, 1 ♀ *Ibid.* 5-XII-1995, Dzilam Reserve, 7 ♀ Dzilam, 2-2-1993, net; Ria Lagartos Reserve, 1 ♀ San Felipe, 26-5-1995, net, 2 ♀ Rio Lagartos, 6-III-1994, Malaise trap, 4 ♀ Ojo de Agua (P), 8-VII-1996, 1 ♀ Peten Tucha, 2-IX-1995, ♀ 1 *Ibid.* 15-X-1996, 1 ♀ *Ibid.* 30-XI-1995, 1 ♀ Entrada a Sac-Bo (DTF), 19-III-1996, 2 ♀ *Ibid.* 9-VII-1996, 2 ♀ *Ibid.* 9-VII-1997.

Subfamily TABANINAE
Tribe Diachlorini

Stenotabanus indotatus Ibáñez-Bernal, 1992

Described by Ibáñez-Bernal (1991) and reported (Ibáñez-Bernal 1992) for Quintana Roo (Sian Ka'an), Mexico. It is apparently confined to that area (Ibáñez-Bernal 1992; Fairchild & Burger 1994).

Stenotabanus jamaicensis (Newstead), 1909

Known Distribution: Jamaica, Cuba, Hispaniola, Puerto Rico, Cayman Islands and the Bahamas (Bequaert 1940; Philip 1958; Cruz & Garcia 1974). Its continental distribution is restricted to Mexico and Belize (Fairchild & Burger 1994).

Within PY it has been reported for Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992) and Yucatan (Fairchild & Burger 1994).

Material Examined: YUCATAN, Ria Lagartos Reserve, 2 ♀ Rio Lagartos (CD), net.

Stenotabanus littoreus (Hine), 1907

Known Distribution: From Mexico to Panama (Fairchild 1953, 1971; 1986; Fairchild & Burger 1994). It has been previously reported in Mexico for Quintana Roo (Colonia Santa Maria and Sian Ka'an) (Bequaert 1931; Pearse 1945; Ibáñez-Bernal 1992) and Yucatan (Puerto Progreso) (Philip 1978a). Pearse (1945) erroneously cited Colonia Santa Maria, which is near to Puerto Morelos, as Puerto Morelos. The species is widely distributed along the coast of Quintana Roo and Yucatan.

Material Examined: YUCATAN, Celestun Reserve, 59 ♀ Celestun (CD), 4-IX-1995, 1 ♀ Dumac (M), 3-VII-1997, 7 ♀ *Ibid.* 6-IX-1995, 1 ♀ Rancho Loma Bonita (M), 8-VII-1996, 1 ♀ *Ibid.* 7-IX-1995, 2 ♀ Rancho Loma Bonita (DTF), 15-VII-1996, 1 ♀ *Ibid.* 5-IX-1995; Dzilam Reserve, 14 ♀ Dzilam, 15-VIII-1993, Malaise trap; Ria Lagartos Reserve, 1 ♀ El Cuyo (M), 8-VII-1997, 1 ♀ *Ibid.* 23-V-1995, 3 ♀ *Ibid.* 11-VII-1996, 2 ♀ La Darcena (DC), 10-VII-1997, 4 ♀ *Ibid.* 28-VIII-1995, 1♀ *Ibid.* 17-X-1996; 1 ♀ Ojo de Agua (P), 31-VIII-1995, 3 ♀ Peten Tucha, 8-VII-1996.

Stenotabanus pechumani Philip, 1966

Known Distribution: From Texas, USA to Mexico in the states of Veracruz and Campeche (Philip 1966; Fairchild & Burger 1994). We could not confirm its presence in PY.

Catachlorops fulmineus var. *ocellatus* Enderlein, 1925

Known Distribution: From Mexico to Colombia (Fairchild & Burger 1994). In Mexico, it has been collected in Chiapas, Tabasco and Veracruz (Fairchild 1940). Only one specimen has been collected in Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992).

Diachlorus ferrugatus (Fabricius), 1805

Known Distribution: From the southern USA, Bahamas, Mexico and Central America as far south as Costa Rica (Fairchild 1971). In Mexico, it has been found in Tabasco and PY, in Campeche, Yucatan (Puerto Progreso) (Bequaert 1931; Pearse 1945) and Quintana Roo (Sian Ka'an and Cancun) (Ibáñez-Bernal 1992). This species is distributed around the Gulf of Mexico.

Material Examined: CAMPECHE, Calakmul Reserve, 14 ♀ archaeologic zone, 3-V-1997, Malaise trap, 5 ♀ El Refugio, 2-I-1993, Malaise trap. QUINTANA ROO, 1 ♀ Vallehermoso, Rancho 3, 19-VII-1993, Malaise trap, 15 ♀ Vallehermoso, 24-VII-1993, Malaise trap. YUCATAN, Celestun Reserve, 1 ♀ Celestun (CD), 15-I-1997, Malaise trap, 19 ♀ Peten, 8-9-IV-1997, Malaise trap, 6 ♀ Peten, 1-VII-1997, Malaise trap; 1 ♀ Celestun (CD), 3-VII-1997, 1 ♀ *Ibid.* 4-IX-1995, 2 ♀ *Ibid.* 8-XII-1995, 3 ♀ Dumac (M), 28-III-1996, 3 ♀ *Ibid.* 4-VII-1997, 4 *Ibid.* 6-IX-1995, 1♀ 1 ♂ *Ibid.* 16-X-1996, 96 ♀ 6 ♂ Ecoparaiso (CD), 21-I-1997, 4♀ *Ibid.* 10-IV-1997, 15 ♀ *Ibid.* 17-VII-1996, 3 ♀ Peten 2, 20-I-1997, 16 ♀ *Ibid.* 8-IV-1997, 53 ♀ *Ibid.* 30-VI-1997, 234 ♀ 6 ♂ Rancho Loma Bonita (P), 25-III-1996, 16 ♀ *Ibid.* 16-VII-1996, 67 ♀ *Ibid.* 7-IX-1995, 13 ♀ *Ibid.* 24-X-1996, 23 ♀ *Ibid.* 4-XII-1995, 163 ♀ Rancho Loma Bonita (DTF), 26-III-1996, 71 ♀ *Ibid.* 1-IV-1997, 162 ♀ *Ibid.* 16-VII-1996, 22 ♀ *Ibid.* 5-IX-1995, 28 ♀ 1 ♂ *Ibid.* 23-X-1996, 47 ♀ *Ibid.* 5-XII-1995; Cuxtal Reserve, 1 ♀ Dzununcan (DTF), 8-IV-1993, net, 5 ♀ Xmatkuil (DTF), 17-I-1996, net; Dzilam Reserve, 5 ♀ Dzilam, 5-V-1993, net; Ria Lagartos Reserve, 74 ♀ Rio Lagartos, Peten 4, 7-VII-1997, Malaise trap, 1 ♀ El Cuyo, 5-V-1994, Malaise trap, 1 ♀ El Cuyo, 23-V-1995, Malaise trap, 2 ♀ San Felipe, 26-V-1995, net, 7 ♀ Ojo de Agua (P), 21-III-1996, 39 ♀ *Ibid.* 8-IV-1997, 2 ♀ *Ibid.* 30-VI-1997, 348 ♀ 4 ♂ *Ibid.* 8-VII-1996, 2 ♀ 3 ♂ *Ibid.* 31-VIII-1995, 5 ♀ *Ibid.* 14-X-1996, 4 ♀ *Ibid.* 30-XI-1995, 1 ♀ *Ibid.* 1-XII-1995, 111 ♀ Peten Tucha, 16-I-1997, 32 ♀ *Ibid.* 4-IV-1997, 179 ♀ *Ibid.* 8-VII-1996, 4 ♀ 1 ♂ *Ibid.* 1-IX-1995, 12 ♀ *Ibid.* 30-XI-1995, 25 ♀ *Ibid.* 1-XII-1995, 7 ♀ Camino a Nuevo Tekal (DTF), 9-VII-1997, 1 ♀ Entrada a Sac-Bo (DTF), 13-I-1997, 3 ♀ *Ibid.* 19-III-1996, 94 ♀ *Ibid.* 1-IV-1997, 32 ♀ 1 ♂ *Ibid.* 9-VII-1996, 1 ♀ *Ibid.* 29-VIII-1995, 1 ♀ *Ibid.* 5-IX-1995, 1 ♀ *Ibid.* 15-X-1996, 2 ♀ *Ibid.* 28-XI-1995, 1 ♀ La Darcena (CD), 13-I-1997.

Chlorotabanus mexicanus (Linnaeus),1758

Known Distribution: From southern Mexico to northern Brazil (Fairchild and Burger 1994). According to Fairchild (1986) and Ibáñez-Bernal (1992), it has been found in Campeche, Chiapas, Quintana Roo (Sian Ka'an) and Veracruz. This species has been reported from rain forest areas, which probably restricts its distribution in PY to a few southern areas.

Material Examined: CAMPECHE, Calakmul Reserve, 9 ♀ archaeologic zone, 3-V-1997, Malaise trap, 1 ♀ El Refugio, 2-I-1993, light trap.

Phaeotabanus longiappendiculatus Macquart, 1855

Known Distribution: From Mexico to Panama. The first report for Mexico was Bellardi (1859) (as *Tabanus luteoflavus* Bellardi 1859) and the last was Towsend (1897) (as *Tabanus limonus* var. *mexicanus* Towsend 1897). It is reported here for the first time for PY and Yucatan State.

Material Examined: YUCATAN, Celestun Reserve, 1 ♀ Rancho Loma Bonita (P), 7-IX-1995,

Malaise trap, 2 Entrada a Sac-Bo (DTF), 9-VII-1996, Malaise trap, 4 *Ibid.* 15-X-1996.

Catachlorops fulmineus var. *ocellatus* Enderlein, 1925

Known Distribution: From Mexico to Colombia (Fairchild & Burger 1994). In Mexico, has been collected in Chiapas, Tabasco and Veracruz (Fairchild 1940). Only one specimen has been collected from PY in Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992).

Leucotabanus canithorax Fairchild, 1941

This species has been reported from Colombia, Trinidad, Guyana, Panama and Belize (Fairchild 1985; Fairchild and Burger 1994). In Mexico, it has been reported from Chiapas (Fairchild 1985) and Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992; Fairchild & Burger 1994). It is reported here for the first time for Campeche.

Material Examined: CAMPECHE, Calakmul Reserve, 1 ♀ archaeologic zone, 3-V-1997, Malaise trap.

Leucotabanus exaestuans (Linnaeus), 1758

According to Fairchild (1986) and Fairchild & Burger (1994), the range of this species appears to cover the entire Neotropics, from Mexico to Argentina, and Trinidad. This species was reported from Yucatan (Chichen Itza) by Bequert (Bequaert 1931, 1933; Pearse 1945) (as *Tabanus leucaspis* Wiedemann, 1928). It is reported here for the first time for Campeche.

Material Examined: CAMPECHE, Calakmul Reserve, 1 ♀ El Refugio, 2-IX-1993, Malaise trap. YUCATAN, Reserva de Celestun, 1 ♀ Celestun (P), 30-VI-1997, Malaise trap.

Leucotabanus itzarum (Bequaert), 1831

This is apparently an endemic species for Mexico, specifically PY (Fairchild and Burger 1994). The species has been reported in all the states of PY (Bequaert 1931, 1933; Pearse 1945; Fairchild 1971; Fairchild 1985; Ibáñez-Bernal 1992; Fairchild & Burger 1994). It seems to be restricted to deciduous tropical forests.

Material Examined: YUCATAN, Celestun Reserve, 1 ♀ Rancho Loma Bonita (DTF), 15-VII-1996; Cuxtal Reserve, 1 ♀ Tunkas, 19-I-1996, net, 11 ♀ Xmatkuil (DTF), 8-10-VI-1994, Malaise trap, Xmatkuil (DTF), 1 ♀ 10-17-III-1997, Malaise trap, 7 ♀ *Ibid.* 6-12-V-1997, 11 ♀ *Ibid.* 13-20-V-1997, 5 ♀ *Ibid.* 20-28-V-1997, 4 ♀ *Ibid.* 18-22-VI-1996, 7 ♀ *Ibid.* 28-V-2-VI-1997, 43 ♀ *Ibid.* 4-8-VI-1996, 6 ♀ *Ibid.* 10-VI-1997, 15 ♀ *Ibid.* 16-VI-1996, 46 ♀ *Ibid.* 18-28-VI-1996, 1 ♀ *Ibid.* 18-VI-5-VII-1996, 3 ♀ *Ibid.* 24-VI-1-VII-1997, 1 ♀ *Ibid.* 26-VI-5-VII-1996, 9 ♀ *Ibid.* 1-24-VII-1997, 1 ♀ *Ibid.* 5-16-VII-1996, 2 ♀ *Ibid.* 29-VII-1996, 1 ♀ *Ibid.* 29-IX-4-X-1996, 1 ♀ *Ibid.* 28-X-4-XI-1996.

Lepiselaga crassipes (Fabricius), 1805

Widely distributed south American species that occurs from southern Mexico to northern Argentina and Cuba, Jamaica, Hispaniola, Puerto Rico (Fairchild 1942b; 1986; Cruz and Garcia 1974; Fairchild and Burger 1994). It was collected in Campeche, Quintana Roo and Yucatan, the first specific record for PY, and its three states. All localities are disturbed areas.

Material Examined: CAMPECHE, Calakmul Reserve, 1 ♀ El Refugio, 2-IX-1993, Malaise trap. QUINTANA ROO, 4 ♀ Vallehermoso, 24-VII-1993, Malaise trap. YUCATAN, 1 ♀ Rancho Hobonil, 10-V-1995, Malaise trap.

Tribe Tabanini

Tabanus campechianus Townsend, 1897

Known Distribution: Mexico to Belize (Fairchild & Burger 1994). In Mexico it has been reported from Campeche (as between Campeche and Esperanza, 48 mi. N Puerto Real and Campeche) (Townsend 1897; Bequaert 1931; Pearse 1945; Fairchild 1978) and Quintana Roo (Cancun and Sian Ka'an) (Fairchild 1978; Ibáñez-Bernal 1992). It is reported here for the first time for Yucatan. It seems to be widely distributed in the coastal areas of PY, although at very low densities.

Material Examined: YUCATAN, Celestun Reserve, 1 ♀ Ecoparaiso (M), 16-X-1996, Malaise trap, 1 ♀ Rancho Loma Bonita (P), 25-III-1996, 1 ♀ Rancho Loma Bonita (DTF), 23-X-1996; Ria Lagartos Reserve, 15 ♀ Ojo de Agua (P), 31-VIII-1995, Malaise trap, 1 ♀ Rio Lagartos, Peten Tucha, 28-XI-1995, Malaise trap, 1 ♀ El Cuyo (M), 1 ♀ *Ibid.* 5-V-1994, Malaise trap, 11-VII-1996, Malaise trap, 6 ♀ *Ibid.* 30-VIII-1995, 2 ♀ *idem* 16-X-1996, 1 ♀ *Ibid.* 28-XI-1995, 5 ♀ San Felipe, 26-V-1995, net; 1 ♀ Chuburna Puerto (CD), 15-V-1995, net, 1 ♀ *Ibid.* 15-IV-1995.

Tabanus colombensis Macquart, 1846

Known Distribution: Texas, USA to Brazil and Trinidad (Fairchild & Burger 1994). In Mexico it has been reported for Veracruz (Misantla) (Williston 1901) and for PY only in Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992). It is reported here for the first time for Campeche and Yucatan.

Material Examined: CAMPECHE, 1 ♀ La Libertad, 24-VI-1993, net. YUCATAN, Celestun Reserve, 1 ♀ Celestun (CD), 23-I-1997, 6 ♀ *Ibid.* 27-III-1996, 6 ♀ *Ibid.* 4-IX-1995, 2 ♀ *Ibid.* 4-XII-1995, 4 ♀ Dumac (M), 28-III-1996, 1 ♀ *Ibid.* 3-VII-1997, 3 ♀ Ecoparaiso (CD), 21-I-1997, 2 ♀ *Ibid.* 17-VII-1996, 6 ♀ *Ibid.* 26-X-1996, 1 ♀ *Ibid.* 7-XII-1995, 1 ♀ Ecoparaiso (M), 9-IV-1997, 6 ♀

Ibid. 18-VII-1996, 1 ♀ Celestun (P), 20-I-1997, 2 ♀ *Ibid.* 30-VI-1997, 16 ♀ Rancho Loma Bonita (P), 23-VI-1996, 11 ♀ *Ibid.* 7-IX-1995, 9 ♀ Rancho Loma Bonita (DTF), 26-III-1996, 1 ♀ *Ibid.* 7-IV-1997, 18 ♀ *Ibid.* 16-VII-1996, 4 ♀ *Ibid.* 5-IX-1995, 2 *Ibid.* 23-X-1996, 10 ♀ *Ibid.* 5-XII-1995; Cuxtal Reserve, 1 ♀ Xmatkuil, 24-28-II-1994, Malaise trap; Dzilam Reserve, 1 ♀ Dzilam, 5-V-1993, net; Ria Lagartos Reserve, 2 ♀ Ojo de Agua (P), 16-I-1997, 1 ♀ *Ibid.* 21-III-1996, 3 ♀ *Ibid.* 7-VII-1997, 20 ♀ *Ibid.* 31-VIII-1995, 1 ♀ *Ibid.* 4-IX-1995, 2 ♀ *Ibid.* 14-X-1996, 1 ♀ *Ibid.* 30-XI-1995, 3 ♀ *Ibid.* 1-XII-1995, 3 ♀ Peten Tucha, 4-IV-1997, 3 ♀ *Ibid.* 8-VII-1996, 2 ♀ *Ibid.* 1-IX-1995, 1 ♀ El Cuyo (M), 14-I-1997, 2 ♀ *Ibid.* 20-III-1996, 2 ♀ *Ibid.* 11-VII-1997, 3 ♀ *Ibid.* 16-X-1996, 1 ♀ *Ibid.* 28-XI-1995, 1 ♀ Entrada a Sac-Bo (DTF), 19-III-1996, 2 ♀ *Ibid.* 9-VII-1997, 1 ♀ *Ibid.* 29-VIII-1995, 2 ♀ *Ibid.* 15-X-1996, 2 ♀ La Darcena (DC), 18-III-1996, ♀ 1 *Ibid.* 28-VIII-1995, 3 ♀ *Ibid.* 17-X-1996.

Tabanus commixtus Walker, 1860

Known Distribution: southern Mexico to Venezuela, Hispaniola, Trinidad and Martinique (Fairchild 1983; Fairchild & Burger 1994). This species has been reported for PY in Yucatan (Chichen Itza) (as *T. maya* Bequaert 1931) (Bequaert 1931, 1933; Pearse 1945) and for Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992). It is reported here for the first time for Campeche.

Material Examined: CAMPECHE, Calakmul Reserve, 1 ♀ archaeologic zone, 3-V-1997, Malaise trap, 1340 ♀ *Ibid.* 3-V-1997, 6 ♀ Ejido Nuevo Becan, El Chorro, 30-IV-1997, Malaise trap, 1 ♀ El Refugio, 2-I-1993, Malaise trap; 3 ♀ La Libertad, 24-VI-1993. QUINTANA ROO, El Eden Reserve, 1 ♀ El Eden, 18-III-1996, net; 2 ♀ Vallehermoso, 21-24-VII-1993, Malaise trap. YUCATAN, Celestun Reserve, 16 ♀ Celestun (CD), 27-III-1996, 3 ♀ *Ibid.* 4-IX-1995, 59 ♀ *Ibid.* 7-XII-1995, 3 ♀ Dumac (M), 22-I-1997, 24 ♀ *Ibid.* 28-III-1996, 1 ♀ *Ibid.* 6-IX-1995, 19 ♀ *Ibid.* 6-XII-1995, 2 ♀ Ecoparaiso (CD), 21-I-1997, 2 ♀ *Ibid.* 26-X-1996, 13 ♀ Rancho Loma Bonita (P), 25-III-1996, 12 ♀ *Ibid.* 7-IX-1995, 4 ♀ *Ibid.* 4-XII-1995, 38 ♀ Rancho Loma Bonita (DTF), 26-III-1996, 12 ♀ *Ibid.* 16-VII-1996, 8 ♀ *Ibid.* 5-IX-1995, 1 ♀ *Ibid.* 23-X-1996, 102 ♀ *Ibid.* 5-XII-1995; Dzilam Reserve, 2 ♀ Dzilam, 20-I-1993, 1 ♀ *Ibid.* 2-II-1993, 14 ♀ *Ibid.* 5-V-1993; Cuxtal Reserve, 1 ♀ Xmatkuil (DTF), 4-10-III-1997, Malaise trap, 1 *Ibid.* 10-17-III-1997, 2 ♀ *Ibid.* 24-31-III-1997, 6 ♀ *Ibid.* 6-12-V-1997, 3 ♀ *Ibid.* 13-20-V-1996, 4 ♀ *Ibid.* 20-28-V-1997, 1 ♀ *Ibid.* 28-V-2-VI-1997, 12 ♀ *Ibid.* 4-8-VI-1996, 4 ♀ *Ibid.* 8-10-VI-1994, 9 ♀ *Ibid.* 18-22-VI-1996, 1 ♀ *Ibid.* 18-28-VI-1996; 6 ♀ Mococha, 4-11-XI-1993, Malaise trap; 2 ♀ Muna, 27-IV-1995, net; Ria Lagartos Reserve, 3 ♀ El Cuyo (M), 5-V-1994, Malaise trap, 3 ♀ *Ibid.* 5-VI-1994, 1 ♀ *Ibid.* 11-VII-1996, 10 ♀ 1 ♂ *Ibid.* 29-XI-1995, 8 ♀ Entrada a Sac-Bo (DTF), 19-III-1996, 1 ♀ *Ibid.* 15-X-1996, 6 ♀ *Ibid.* 28-XI-1995, 1 ♀ La Darcena (CD), 23-I-1997, 4 ♀ *Ibid.* 18-III-1996, 1 ♀ *Ibid.* 27-XI-1995, 1 ♀ Ojo de Agua (P), 31-VIII-1995, 2 ♀ *Ibid.* 30-XI-1995, 3 ♀ *Ibid.* 1-XII-1995, 4 ♀ Peten Tucha (P), 21-III-1996, 4 ♀ *Ibid.* 11-VII-1996, 25 ♀ 2 ♂ Rio Lagartos, 6-III-1994, net; 39 ♀ Tzucacab, 10-V-1995, Malaise trap.

Tabanus haemagogus Williston, 1901

The type locality of this species is Temax, Yucatan. Known distribution Mexico (Tabasco) to Guatemala (Fairchild 1971; Fairchild & Burger 1994). Within PY, it has been reported for Yucatan (Chichen Itza, Izamal, Merida, Temax and Tohil) (as *T. filiolus* Williston 1901) (Williston 1901; Bequaert 1931, 1933; Pearse 1938, 1945). It is reported here for the first time for Quintana Roo. It probably also occurs in Campeche.

Material Examined: QUINTANA ROO, El Eden Reserve, 2 ♀ El Eden, 18-III-1996. YUCATAN, Celestun Reserve, 7 ♀ Rancho Loma Bonita (P), 16-VII-1996, 2 ♀ *Ibid.* 7-IX-1995, 4 Rancho Loma Bonita (DTF), 16-VII-1996; Cuxtal Reserve, 2 ♀ Xmatkuil (DTF), 10-17-III-1997, Malaise trap, 5 ♀ *Ibid.* 4-8-V-1996, 1 ♀ *Ibid.* 16-V-1997, 2 28-V-2-VI-1997, 1 ♀ *Ibid.* 1-24-VI-1997, 2 ♀ *Ibid.* 4-8-VI-1996, 2 ♀ *Ibid.* 5-15-VI-1996, 2 ♀ *Ibid.* 5-16-VI-1996, 4 ♀ *Ibid.* 10-VI-1997, 7 ♀ *Ibid.* 17-VI-1997, 20 ♀ 1 ♂ *Ibid.* 18-22-VI-1996, 2 ♀ *Ibid.* 18-24-VI-1997, 38 ♀ 4 ♂ *Ibid.* 18-22-VI-1996, 11 ♀ 2 ♂ *Ibid.* 18-28-VI-1996, 1 ♀ *Ibid.* 28-VI-5-VII-1996, 4 ♀ *Ibid.* 18-VI-5-VII-1996, 1 ♀ 1 ♂ *Ibid.* 1-15-VII-1997, 1 ♀ *Ibid.* 5-15-VII-1996, 1 ♀ *Ibid.* 14-VII-1993, 2 ♀ *Ibid.* 1-24-VII-1997, 1 ♀ 1 ♂ *Ibid.* 24-VII-4-VIII-1996, net, 44 ♀ *Ibid.* 24-VII-4-VIII-1996, 3 ♀ 4 ♂ *Ibid.* 29-VII-4-VIII-1996, net, 3 ♀ *Ibid.* 29-VII-1996, 30 ♀ 2 ♂ 1-VIII-29-IX-1996, 1 ♀ *Ibid.* 2-IX-1992, net, 7 ♀ *Ibid.* 17-25-IX-1996, 4 ♀ *Ibid.* 29-VIII-4-IX-1996, 3 ♀ *Ibid.* 17-25-IX-1996, 2 ♀ *Ibid.* 7-14-X-1996, 5 ♀ *Ibid.* 9-16-X-1996, 1 ♀ *Ibid.* 10-X-1992, 2 ♀ *Ibid.* 11-18-X-1996, 1 ♀ 14-21-X-1996, 1 ♀ *Ibid.* 21-28-X-1996, 1 ♀ 26-30-X-1996, 6 ♀ 3 ♂ *Ibid.* 28-X-4-XI-1996, 1 ♀ *Ibid.* 24-28-XI-1994, 1 ♀ *Ibid.* 26-30-XI-1996; Ria Lagartos Reserve, 1 ♀ Ojo de Agua (P), 1-XII-1995, 3 ♀ Peten Tucha, 11-VII-1996, 3 ♀ Entrada a Sac-Bo (DTF), 9-VII-1996; 15 ♀ Tzucacab, 23-IX-1994, net.

Tabanus occidentalis var. *dorsovittatus* Macquart, 1855

Known Distribution: Mexico to Argentina and Trinidad (Fairchild 1971; Fairchild & Burger 1994). Within PY it has been reported only for Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992). It is here reported for the first time for Campeche and Yucatan.

Material Examined: CAMPECHE, Calakmul Reserve, 2 ♀ archaeologic zone, 3-V-1997, Malaise trap, 4 ♀ El Refugio, 2-I-1993, Malaise trap. YUCATAN, 2 ♀ Celestun (CD), 23-I-1997, 5 ♀

Ibid. 27-III-1996, 1 ♀ *Ibid.* 4-IX-1995, 6 ♀ *Ibid.* 7-XII-1995, 1 ♀ Dumac (M), 22-I-1997, 1 ♀ *Ibid.* 28-III-1996, 1 ♀ *Ibid.* 3-VII-1997, 1 ♀ *Ibid.* 6-IX-1996, 1 ♀ *Ibid.* 6-XII-1995, 35 ♀ Ecoparaiso (CD), 21-I-1997, 2 ♀ *Ibid.* 17-VII-1996, 3 ♀ *Ibid.* 26-X-1996, 2 ♀ Ecoparaiso (M), 18-VII-1996, 2 ♀ Peten 2, 20-I-1997, 2 ♀ *Ibid.* 8-IV-1997, 123 ♀ Rancho Loma Bonita (P), 25-III-1996, 1 ♀ *Ibid.* 8-IV-1997, 51 ♀ *Ibid.* 7-IX-1995, 3 ♀ *Ibid.* 4-XII-1995, 60 ♀ Rancho Loma Bonita (DTF), 20-III-1996, 5 ♀ *Ibid.* 7-IV-1997, 168 ♀ *Ibid.* 16-VII-1996, 33 ♀ *Ibid.* 5-IX-1995, 22 ♀ *Ibid.* 23-X-1996, 38 ♀ *Ibid.* 5-XII-1995; Cuxtal Reserve, 1 ♀ Xmatkuil, 24-VII-4-VIII-1996, net; Dzilam Reserve, 1 ♀ Dzilam, 2-I-1993, 1 ♀ *Ibid.* 20-1-1993; Ria Lagartos Reserve, 4 ♀ Ojo de Agua (P), 16-I-1997, 1 ♀ *Ibid.* 21-III-1996, 10 ♀ *Ibid.* 8-IV-1997, 41 ♀ *Ibid.* 7-VII-1997, 5 ♀ *Ibid.* 31-VIII-1995, 23 ♀ *Ibid.* 14-X-1996, 13 ♀ *Ibid.* 30-XI-1995, 26 ♀ *Ibid.* 1-XII-1995, 1 ♀ Peten Tucha, 21-III-1996, 4 ♀ *Ibid.* 4-IV-1997, 45 ♀ *Ibid.* 8-VII-1996, 4 ♀ *Ibid.* 1-IX-1995, 1 *Ibid.* 1 -XII-1995, 17 El Cuyo (M), 11-VII-1996, 12 *Ibid.* 16-X-1996, 22 ♀ *Ibid.* 29-XI-1995, 3 ♀ Entrada a Sac-Bo (DTF), 19-III-1996, 1 ♀ La Darcena (CD), 18-III-1996, 2 ♀ *Ibid.* 12-VII-1996, 15 ♀ *Ibid.* 17-X-1996.

Tabanus oculus Walker, 1848

Known Distribution: Northern Mexico (Tampico, Tamaulipas) to Panama (Fairchild 1971; Fairchild & Burger 1994). Within PY, it has been reported from Yucatan (Chichen Itza) (Bequaert 1931, 1933; Pearse 1945) and Quintana Roo (Colonia Santa Maria, Sian Ka'an and southeast of Peto) (Bequaert 1931; Pearse 1945; Ibáñez-Bernal 1992). Pearse (1945) erroneously cited Colonia Santa Maria, which is near to Puerto Morelos, as Puerto Morelos. It is reported here for the first time for Campeche.

Material Examined: CAMPECHE, 17 ♀ La Libertad, 24-VI-1993, net; Calakmul Reserve, 5 ♀ El Refugio, 2-IX-1993, Malaise trap, 16 ♀ *Ibid.* 11-IX-1993, 24 ♀ archaeologic area, 3-V-1997, Malaise trap. QUINTANA ROO, 13 ♀ Vallehermoso, 21-VII-1993. YUCATAN, Celestun Reserve, 2 ♀ Rancho Loma Bonita (P), 26-III-1996, 2 ♀ *Ibid.* 7-IX-1995, 1♀ *Ibid.* 4-XII-1995, 2 ♀ Rancho Loma Bonita (DTF), 23-III-1996, 1 ♀ *Ibid.* 16-VII-1996, 2 ♀ *Ibid.* 5-IX-1995, 5 ♀ *Ibid.* 23-X-1996, 4 ♀ *Ibid.* 5-XII-1995; Cuxtal Reserve, 1 ♀ Xmatkuil (DTF), 8-10-VI-1994, Malaise trap, 1 ♀ *Ibid.* 8-28-VI-1996; Ria Lagartos Reserve, 1♀ Ojo de Agua (P), 7-VII-1997, 2 ♀ *Ibid.* 16-X-1996, 6 ♀ *Ibid.* 1-XII-1995, 1 ♀ Peten Tucha (P), 7-VII-1997.

Tabanus pungens Wiedemann, 1828

Known Distribution: Texas to northern Argentina, Trinidad, but not West Indies nor Chile (Coscarón 1979; Fairchild 1986; Fairchild & Burger 1994). This species was erroneously described from Mexico by Bellardi (as *T. sallei* Bellardi 1859 and *T. propinquus* Bellardi 1859). No specific data about its locality were given. It is reported here for the first time for PY (Yucatan).

Material Examined: YUCATAN, Celestun Reserve, 2 ♀ Rancho Loma Bonita (DTF), 1-VII-1997; Ria Lagartos Reserve, 3 ♀ Ojo de Agua (P), 31-VIII-1995, 1 ♀ Peten Tucha, 21-III-1996, 1 ♀ *Ibid.* 8-VII-1996, 1 ♀ *Ibid.* 1-IX-1995, 1 ♀ *Ibid.* 31-XI-1995, 1 ♀ Rio Lagartos (DTF), 13-I-1997, Malaise trap.

Tabanus vittiger ssp. *guatemalanus* Hine, 1906

Known Distribution: USA (Florida) to Brazil, Bahamas, Cuba, Cayman Islands, Jamaica, Puerto Rico and Galapagos Islands (Cruz & Garcia 1974; Fairchild 1978; Fairchild & Burger 1994). In Mexico, its known distribution is apparently restricted to the southeast. Within PY, it had been reported for Campeche (Philip 1954b) and Quintana Roo (Sian Ka'an) (Ibáñez-Bernal 1992). In 1983, Fairchild wrote that this species occurs at least to Yucatan and Campeche, without specific records. It is reported here, probably for the first time for Yucatan.

Material Examined: YUCATAN, Celestun Reserve, 49 ♀ Celestun (CD), 22-I-1997, 27 ♀ *Ibid.* 27-III-1996, 75 ♀ 1 ♂ *Ibid.* 4-IX-1995, 57 ♀ *Ibid.* 7-XII-1995, 29 ♀ Dumac (M), 23-I-1997, 7 ♀ *Ibid.* 28-III-1996, 1 ♀ *Ibid.* 19-VII-1996, 11 ♀ *Ibid.* 6-IX-1995, 14 ♀ *Ibid.* 6-XII-1995, 2 ♀ Celestun (P), 30-VI-1997; 1 ♀ Ecoparaiso (CD), 21-I-1997, 8 ♀ *Ibid.* 17-VII-1996, 22 ♀ *Ibid.* 26-X-1996, 5 ♀ Ecoparaiso (M), 9-IV-1997, 30 ♀ *Ibid.* 18-VII-1996, 10 ♀ *Ibid.* 25-X-1996, 8 ♀ Rancho Loma Bonita (P), 26-III-1996, 23 ♀ *Ibid.* 7-IX-1995, 1 ♀ *Ibid.* 24-X-1996, 2 ♀ *Ibid.* 4-XII-1995, 2 ♀ Rancho Loma Bonita (DTF), 21-I-1997, 4♀ *Ibid.* 26-III-1996, 4 ♀ *Ibid.* 7-IV-1997, 37 ♀ *Ibid.* 17-VII-1996, 19 ♀ 1 ♂ *Ibid.* 4-5-IX-1995, 1 ♀ *Ibid.* 23-X-1996, 4♀ *Ibid.* 5-XII-1995; 3 ♀ Chuburna Puerto, 15-IV-1995, Malaise trap; Dzilam Reserve, 2 ♀ Dzilam, 2-II-1993, net; Ria Lagartos Reserve, 1 ♀ Ojo de Agua (P), 16-I-1997, 4 ♀ *Ibid.* 7-VII-1997, 71 ♀ *Ibid.* 31-VIII-1995, 11 ♀ *Ibid.* 4-IX-1995, 3 ♀ *Ibid.* 14-X-1996, 4 ♀ *Ibid.* 30-XI-1995, 7 ♀ *Ibid.* 4-IV-1997, 3 ♀ El Cuyo (M), 14-I-1997, 9 ♀ *Ibid.* 11-VII-1996, 2 ♀ *Ibid.* 30-VIII-1995, 18 ♀ *Ibid.* 16-X-1996, 1 ♀ *Ibid.* 28-XI-1995, 16 ♀ *Ibid.* 29-XI-1995, 1 ♀ Entrada a Sac-Bo (DTF), 13-I-1997, 3 ♀ *Ibid.* 19-III-1996, 2 ♀ *Ibid.* 9-VII-1997, 1 ♀ *Ibid.* 29-VIII-1995, 1 ♀ *Ibid.* 15-X-1996, 11 ♀ La Darcena (CD), 11-IV-1997, 1 ♀ *Ibid.* 10-VII-1996, 1 ♀ *Ibid.* 28-VIII-1995, 5 ♀ *Ibid.* 17-X-1996, 1 ♀ *Ibid.* 27-XI-1995, 1 ♀ Peten Tucha, 21 ♀ *Ibid.* 8-VII-1996, 6 ♀ *Ibid.* 1-IX-1995, 6 ♀ Rio Lagartos, 6-III-1994, Malaise trap and net.

Tabanus yucatanus Townsend, 1897

The type locality is in the Cenote of Xcolak, 10 mi. SE of Izamal, Yucatan (Towsend 1897).

Known Distribution: Southeast Mexico to Guatemala, Honduras, El Salvador, Costa Rica and Nicaragua. In Mexico the distribution is confined to Chiapas and PY (Fairchild 1971; Fairchild & Burger 1994). Within PY it has been collected in Campeche (Fairchild & Burger 1994), Quintana Roo (Colonia Santa Maria) and Yucatan (Chichen Itza and Merida) (Bequaert 1931; Pearse 1945).

Material Examined: YUCATAN, Celestun Reserve, 1 ♀ Rancho Loma Bonita (DTF), 5-IX-1995.

Discussion

The tabanid fauna of the biotic province of Yucatan includes a little more than 14% of the species known for Mexico. Because collecting has been scattered, knowledge of the tabanid fauna of PY and Mexico is incomplete. However, we consider that species diversity recorded to date is similar to the actual species diversity from this province. The records of most species show wide distribution within the biotic province of Yucatan, probably related to homogeneous physiography (climate, surface, geology and hydrology) which characterizes the province (Barrera 1962; Alvarez & de Lachica 1991).

Thus, according to information provided by Fairchild (1969) and current known distribution of species, we can consider that most of the tabanid fauna of the biotic province of Yucatan is mainly composed of Neotropical elements. Some species found are widely distributed in the Antilles (i.e*., D. ferrugatus*, *L. crassipes and S. jamaicensis*), thus suggesting an important input of the Antillean component to the tabanid fauna of the biotic province of Yucatan.

The best represented genera, *Chrysops* and *Tabanus*, have a worldwide distribution, and do not seem to show affinity to any specific biogeographic pattern. However, 11 of the 15 species of *Chrysops* and *Tabanus* reported show an exclusively Neotropical distribution (amphitropical). In contrast, *C. flavidus*, *T. colombensis*, *T. pungens* and *T. vittiger* have Neotropical distributions but extend to the southern Nearctic Region.

A comparison of the fauna of both biotic provinces in PY is difficult. The biotic province of Peten is a larger area and ecologically more diverse than the biotic province of Yucatan. It includes southern PY, the Mexican states of Tabasco and Chiapas (north), Belize and the Peten of Guatemala (Alvarez and de Lachica 1991). In contrast to the biotic province of Yucatan, it includes rivers and higher lands (600-1500 meters).

The biotic province of Peten has a higher species diversity. According to the catalogue of Fairchild & Burger (1994), 85 species have been reported from this province. At least 23 of the collected species within the biotic province of Yucatan also have been recorded in the biotic province of Peten. In addition, we expect that *C. auroguttatus*, *C. flavidus*, *L. itzarum*, *T. colombensis* and *T. commixtus* could also be distributed within this province. Because of the few records of *S. pechumani*, we cannot speculate about its probable distribution. We consider that the number of species reported for Peten is conservative, since the Mexican states of Tabasco, southern Campeche and northern Chiapas have been poorly sampled. At present, because of the general distribution of the predominantly Neotropical elements of the tabanid fauna of both biotic provinces, it is not possible to use the tabanid fauna to sustain or reinforce the criteria defining the biotic provinces of Yucatan and Peten. However, a complete characterization of tabanid fauna of the Peten Province, including information on the unique northern distribution limits of the species could help to confirm or redefine the limits of these biotic provinces.

Thus, to obtain a complete characterization of PY (including the biotic provinces of Yucatan and Peten), it is necessary to intensify sampling in non-collected areas (i.e*.,* those with different habitats such as cenotes, rivers, medium and high tropical forests), and southern PY included in the northern part of the biotic province of Peten (Alvarez & de Lachica 1991).

The tabanid fauna of some protected and non-protected areas of wetlands, cenotes, medium and high tropical forests remains unknown. For Campeche and Quintana Roo, most of the records are from Calakmul and Sian Ka'an, both undersampled. It would be desirable to have more systematic sampling within the southern parts of both reserves, especially for Calakmul, which is adjacent to a very important biogeographic Mesoamerican corridor that penetrates southern Mexico. Also special efforts should be made in coastal areas such as the Area de Protección de Flora y Fauna de Laguna de Términos (Campeche), Yum Balam-El Eden and islands such as Cozumel and Isla Contoy (Quintana Roo).

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EFFECT OF SEX, REPRODUCTIVE MATURITY STAGE AND TRAP PLACEMENT, ON ATTRACTION OF THE BLUEBERRY MAGGOT FLY (DIPTERA: TEPHRITIDAE) TO SPHERE AND PHEROCON AM TRAPS

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ABSTRACT

We compared the performance of 9 cm diameter green spheres and red spheres and Pherocon AM traps, all baited with the same mixture of ammonium acetate and protein hydrolysate, in attracting blueberry maggot flies, *Rhagoletis mendax* Curran, of different reproductive maturity stages and sex. We also evaluated the effect of trap placement in relation to bush canopy (within the top 15 cm of the canopy, or near the base of the bush, 25 cm above ground, within a row) on attraction to these classes of flies. Results of this study showed that captures of flies on red or green spheres were better than on Pherocon AM traps, irrespective of maturity status or sex. Captures of flies were similar among traps placed in the top or the base of the bush, in the case of small bushes (1.2 m high). Traps placed within the top of the canopy captured more flies than those at the base, in the case of larger bushes (1.5-2.0 m high). At both positions, capture patterns were also not dependent on reproductive maturity or sex. Regression analysis between capture ratio of mature females on Pherocon AM/ Spheres and time revealed a significant inverse relationship, which might have been caused by differential aging of these traps. These data show that sphere traps capture more immature flies than Pherocon AM traps, and therefore can be deployed early in the season, when most flies present are immature females. The combination of more effective sphere traps and correct placement strategy depending on bush characteristics can further optimize blueberry maggot monitoring programs.

Key Words: *Rhagoletis mendax*, ovarian development, traps, highbush blueberry

RESUMEN

Comparamos el desempeño de esferas verdes y esferas rojas de 9 cm de diámetro y trampas Pherocon AM, todas cebadas con la misma mezcla de acetato de amonio y proteína "hydrolysate", en atraer moscas de arándano, *Rhagoletis mendaz* Curran, de diferentes etapas de madurez reproductiva y sexo. También evaluamos el efecto de colocación de trampas en relación al dosel del arbusto (dentro de los 15 cm superiores del dosel, o cerca de la base del arbusto, 25 cm sobre el suelo, dentro de la hilera) en atracción a estas clases de moscas. Los resultados de este estudio demostraron que las capturas de moscas en esferas rojas o verdes fueron mejores que en las trampas Pherocon AM, sin respecto del estado de madurez o sexo. Capturas de moscas en esferas rojas o verdes fueron similares entre trampas colocadas en el tope o la base del arbusto, en caso de arbustos pequeños (1.2 m de altura). Trampas colocadas dentro del tope del dosel capturaron mas moscas que aquellas en la base, en casos de arbustos mas grandes (1.5-2.0 m de altura). En ambas posiciones, patrones de captura también fueron independientes de madurez reproductiva o sexo. Análisis de regresión entre promedio de captura de hembras maduras en Pherocon AM /esferas y tiempo revelaron una relación inversa significativa, la cual pudo ser causada por la vejez diferencial de estas trampas. Estos datos demuestran que trampas esféricas capturan mas moscas inmaduras que trampas Pherocon AM, y por lo tanto pueden ser utilizadas temprano en la temporada, cuando la mayoría de las moscas presentes son hembras inmaduras. La combinación de trampas esféricas mas efectivas y una estrategia de colocamiento correcto dependiendo de las características del arbusto pueden optimizar aun más los programas de control y seguimiento de gusanos de arándano.

The blueberry maggot fly, *Rhagoletis mendax* Curran, (Diptera: Tephritidae), is considered the most important pest of commercially grown low and highbush blueberries, *Vaccinium angustifolium* Aiton and *V. corymbosum* L., respectively, in the eastern and midwestern United States and Atlantic provinces of Canada (Prokopy & Coli 1978; Guibord et al. 1985; Vincent & Lareau 1989; Gaul et al. 1995; Teixeira & Polavarapu 2001). Quarantine regulations are in place to prevent blueberry maggot introduction from infested areas in the U.S. and Canada east of the Rocky Mountains. The Blueberry Maggot Certification Program requires growers who want to export

fruit from infested areas to non-infested areas in Canada to choose either an IPM-based blueberry maggot management program or a calendar-based spray program (Canadian Food Inspection Agency 1999). Growers involved in an IPM program are required to monitor the presence of adults using baited Pherocon AM traps, deployed at least 2 weeks before the earliest expected emergence. Growers following a calendar spray program are required to start insecticide applications beginning 10 d after the first adult capture in the Pherocon AM traps in the area.

The choice of appropriate trap type is an important factor that can affect the reliability of first detection of adults. The model for most of the research on the roles of visual and olfactory stimuli affecting attraction of *Rhagoletis* flies has been the sibling species apple maggot fly, *R. pomonella* (Walsh). Flies are attracted to yellow panels because of their hue and reflectance, and to dark ~7.5 cm diameter spheres because of their shape and intensity contrast with background light (Prokopy 1968; 1972). Fly visual preferences were attributed to the similarity of the reflectance spectrum of yellow panels with that of foliage, and of the shape and contrast of spheres to those of host fruit (Prokopy 1968). Although the original host of the apple maggot is the hawthorn (*Crataegus* L. spp.), flies show a preference for 7.5 cm diameter spheres, as do other *Rhagoletis* species with smaller host fruits (Prokopy 1977).

Blueberry maggot flies found in the field early in the season are predominantly immature females (Lathrop & Nickels 1932). Therefore, the trap deployed for detecting the onset of adult emergence is required to be very attractive to immature females. Immature females spend more time on foliage, looking for food sources, and mature females on fruit, the site for mating and oviposition (Smith & Prokopy 1981; 1982). To the extent that trap captures reflect fly behavior, it has been suggested that foliage type traps (Pherocon AM) should be more attractive to immature females, and fruit-type traps (spheres) to mature females (Prokopy 1968; Neilson et al. 1984). Recently, Liburd et al. (1998) showed that sphere traps, baited with ammonium acetate and protein hydrolysate, were more attractive to the blueberry maggot than Pherocon AM traps, with an equal amount of bait. However, there are no studies that compare the attraction of baited spheres and Pherocon AM traps to different reproductive maturity stages and sex of blueberry maggot flies.

Captures of *Rhagoletis* flies are greatly increased if traps are placed in locations where the range of visual and odor components includes areas preferred by the insects (Reissig 1975; Drummond et al. 1984; Liburd et al. 2000). Site characteristics, like wind exposure and distance to berries, were found to influence blueberry maggot fly captures in lowbush blueberries (Gaul et al. 1995). In highbush blueberries, Liburd et al. (2000) showed that placing traps 15 cm within the top of the canopy increased captures over the usual placement of 15 cm above the canopy. Immature females, depending on food or fruit abundance, may be present for longer periods or be more active in different locations of the plant canopy than mature females. These factors, together with trap characteristics, should be taken into account when deploying traps to capture immature *R. mendax* females, by placing traps in locations where flies spend more time or are more active.

The objective of this study was to determine the trap type and placement more attractive to immature blueberry maggot females. We evaluated the reproductive maturity of female flies captured on baited Pherocon AM and 9 cm diameter green spheres and red spheres. These traps were placed either 15 cm within the top of the canopy, or near the base of the bush, 25 cm above ground, on bushes of different sizes.

Materials and Methods

Research was conducted during 1999 at 2 highbush blueberry fields, Whitesbog and Chatsworth, located in Burlington County, N.J. The Whitesbog site consisted of a 0.5-ha planting of the cultivar 'Elizabeth'. The Chatsworth site was a 1-ha field planted with the cultivar 'Bluecrop'. Neither field was sprayed or pruned for several years. In Chatsworth, bush height was uniformly about 1.2 m. Bush height in Whitesbog was more variable, ranging from 1.5 to 2.0 m. Bushes in Whitesbog were also larger, with dead wood in the lower portion of the bush.

Traps were hung from metal poles. Two trap placement strategies relative to bush canopy were evaluated. Traps were positioned either within the top 15 cm of the canopy, at a height dependent on bush height, or near the base of the bush, 25 cm above ground (from here on, high and low traps, respectively). In the case of high traps, branches were pruned so that they did not contact the trap. We used Pherocon AM yellow boards (Trécé, Salinas, CA), 9 cm diameter plastic green spheres and red spheres (Great Lakes IPM, Vestaburg, MI). Pherocon AM traps were already baited with ammonium acetate and protein hydrolysate, premixed in the adhesive. Spheres were manually coated with the same average amount of baited adhesive (13 g) as in Pherocon AM traps (Liburd et al. 1998), obtained from the same source. Pherocon AM traps (23 × 28 cm) were hung folded in an ~65° angle, with a V shaped cross-section and the sticky yellow surface facing out.

At both locations, all 3 types of traps were arranged in a randomized complete block design. Main factors were trap type (Pherocon AM, red spheres, green spheres) and placement (high, low). Each of the 6 treatments (3 trap types × 2

placements) was replicated 4 times, yielding 24 traps per experiment. Rows were used for blocks, and traps were 6 m apart. In Whitesbog, blocks were separated by 10 to 30 m to take advantage of more homogenous areas. In Chatsworth, blocks were 8 m apart.

Traps were checked twice weekly, and re-randomized after each inspection. Sampling took place throughout the blueberry maggot fly active season, starting when the first flies appeared in early June, until late July, when the population began to decline. Traps were changed once, 3 weeks after the beginning of the experiment. Captured flies were cleaned with Histoclear (National Diagnostics, Atlanta, GA) and stored in glass vials, in 70% ethanol. Flies were sexed, and females were dissected to determine the degree of ovarian maturation. We categorized females as immature if there was no visible development of ooblasts in the ovarioles. In the apple maggot fly, this was shown to correspond to females of less than 7-8 days of age (Dean 1935; Duan & Prokopy 1994). Previously, females have been classified as mature or immature based on the presence of at least 1 fully developed egg (Neilson et al. 1984; Reynolds & Prokopy 1997). We used a more conservative criterion because we wanted to document differences in trap attraction among recently emerged and older females.

Capture data were square-root transformed ($x + 0.5$) and analyzed by 2-way analysis of variance using PROC ANOVA (SAS Institute 1989) with trap type and placement as main factors. Total trap captures, immature and mature female, and male captures were analyzed separately. Means were separated using Tukey Studentized Range test (SAS Institute 1989). Differences were considered significant at the $P = 0.05$ level.

We calculated the ratios of captures of immature and mature females, on Pherocon AM/Sphere traps (mean captures on Pherocon AM/mean captures on both types of spheres), and on High/Low traps (pooled mean captures on high traps/low traps), for each location. Ratios of captures of immature and mature females at each location were plotted to compare relative trends over time. The relationship between capture ratios within each maturity class and days after first sampling was determined using PROC REG (SAS Institute 1989).

Results

Trap type was a significant factor in captures of all classes of flies in both locations ($P < 0.05$), with the single exception of immature flies in Whitesbog (Table 1). Trap placement was a significant factor for all classes of flies in Whitesbog ($P < 0.05$), but not significant in Chatsworth (Table 1). There was one significant interaction between trap type and placement (Whitesbog) where mature females were captured in relatively lower numbers in low placed Pherocon AM traps than in high placed ones ($P = 0.016$). However, because captures in different trap types and placement follow the same general pattern, we did not perform a separate 1-way analysis of variance. Therefore, for all fly categories we present capture data pooled by either trap type (Table 2) or placement (Table 3). Throughout the sampling period, a total of 17,603 flies were captured in Chatsworth (2,154 immature; 8,765 mature; 6,684 male), and in Whitesbog, 7,169 flies were captured (457 immature; 4,048 mature; 2,664 male).

Green and red spheres attracted 2-3 fold more flies than Pherocon AM traps, in Chatsworth (Table 2), irrespective of sex or female maturity. In Whitesbog, both types of spheres captured more flies in each class, but differences in captures were not significant ($P = 0.077$) for immature females. There were no differences in captures of flies of any class between green and red spheres at either location (Table 2).

With respect to trap placement, in Chatsworth, flies did not show a preference for traps at different positions, irrespective of sex or female maturity (Table 3). In Whitesbog, flies were cap-

Table 1. Results of 2-way ANOVA (F and P- value) for comparisons of captures of adult *R. mendax* (immature and mature females, males, and total captures) on different trap type and placement, from 17 June to 29 July 1999 in Chatsworth and Whitesbog, Burlington County, New Jersey.

Location Effect	df	Immature		Mature		Male		Total	
		F	P	F	P	F	P	F	P
Chatsworth									
Type	2,15	9.85	0.0019	55.59	0.0001	91.39	0.0001	66.00	0.0001
Placement	1,15	1.34	0.26	3.32	0.089	3.86	0.068	0.11	0.74
Type × Placement	2,15	0.95	0.41	1.13	0.35	2.91	0.086	0.73	0.50
Whitesbog									
Type	2,15	3.06	0.077	52.35	0.0001	36.74	0.0001	69.00	0.0001
Placement	1,15	9.68	0.0071	61.48	0.0001	147.39	0.0001	146.36	0.0001
Type × Placement	2,15	1.53	0.25	6.10	0.016	0.44	0.65	1.65	0.23

TABLE 2. EFFECT OF TRAP TYPE ON CAPTURES OF ADULT *R. MENDAX* (IMMATURE AND MATURE FEMALES, MALES, AND TOTAL CAPTURES) FROM 17 JUNE TO 29 JULY 1999 IN CHATSWORTH AND WHITESBOG, BURLINGTON COUNTY, NEW JERSEY.

Location Type	Mean ± SEM no. flies per trap			
	Immature	Mature	Male	Total
Chatsworth				
Red Sphere	111.6 ± 8.6 a	453.3 ± 47.3 a	395.0 ± 59.5 a	959.4 ± 119.6 a
Green Sphere	100.4 ± 14.9 a	448.0 ± 45.9 a	330.0 ± 33.4 a	878.9 ± 88.9 a
Pherocon AM	57.3 ± 23.3 b	194.4 ± 19.0 b	110.5 ± 10.8 b	362.1 ± 32.0 b
Whitesbog				
Red Sphere	19.6 ± 3.9 a	206.5 ± 20.1 a	136.5 ± 29.5 a	362.6 ± 49.9 a
Green Sphere	21.5 ± 4.8 a	203.3 ± 25.0 a	138.0 ± 32.5 a	362.8 ± 59.5 a
Pherocon AM	16.0 ± 5.1 a	96.3 ± 22.4 b	58.5 ± 15.2 b	170.8 ± 39.8 b

Means in the same column followed by the same letter (at each location) are not significantly different ($P = 0.05$, Tukey Studentized Range Test).

tured in larger numbers in traps placed in the top of the canopy (Table 3). At this location, high traps captured 44% more immature females, 2-fold more mature females, and 3-fold more males.

The ratios of captures of immature females between Pherocon AM/Spheres and High/Low traps generally follow a similar trend to those of mature flies, in the sampling dates where both classes were captured (Fig. 1). Ratios of captures in Whitesbog are much more variable than in Chatsworth, possibly reflecting increased heterogeneity in bush size. However, ratios of captures of immature and mature females still follow a similar pattern. Regression analysis revealed that, in Chatsworth, for mature flies, there was a significant inverse relationship (Table 4) between Pherocon AM/Sphere trap capture ratio and time ($P = 0.031$). There was also a significant inverse relationship between the High/Low trap capture ratio and time in the case of immature females in Whitesbog ($P = 0.047$). No significant relationships ($P < 0.05$) were found in Whitesbog.

DISCUSSION

Results of this study show that baited red or green spheres were better than Pherocon AM traps in attracting blueberry maggot adults, irrespective of sex or female maturity. These results support the use of baited sphere traps early in the season, when most flies found in the field are immature females. Trap placement in relation to bush canopy was also found to influence fly captures. In case of small bushes (1.2 m), traps placed 15 cm within the top of the canopy were as attractive as those placed near the base of the bush, 25 cm above ground. Where bushes are larger (1.5 to 2.0 m), with fruit and leaves mostly on the top of the canopy, flies were captured in larger numbers on high traps. Liburd et al. (2000) have shown that total captures of flies on traps placed within the top 15 cm of the canopy were equal to or better than traps placed 45 cm above ground for bushes of size comparable to the large ones in this study (1.5 to 1.8 m). These data provide information on

TABLE 3. EFFECT OF TRAP HEIGHT ON CAPTURES OF ADULT *R. MENDAX* (IMMATURE AND MATURE FEMALES, MALES, AND TOTAL CAPTURES) FROM 17 JUNE TO 29 JULY 1999 IN CHATSWORTH AND WHITESBOG, BURLINGTON COUNTY, NEW JERSEY.

Location Height	Mean ± SEM no. flies per trap			
	Immature	Mature	Male	Total
Chatsworth				
High	81.3 ± 9.1 a	341.0 ± 41.5 a	301.3 ± 53.6 a	723.5 ± 100.5 a
Low	98.3 ± 19.0 a	389.4 ± 53.2 a	255.8 ± 41.9 a	743.4 ± 111.6 a
Whitesbog				
High	22.5 ± 3.9 a	208.2 ± 17.1 a	166.3 ± 22.9 a	396.9 ± 42.3 a
Low	15.6 ± 3.3 b	129.2 ± 23.4 b	55.8 ± 9.4 b	200.5 ± 34.3 b

Means in the same column followed by the same letter (at each location) are not significantly different ($P = 0.05$, Tukey Studentized Range Test).

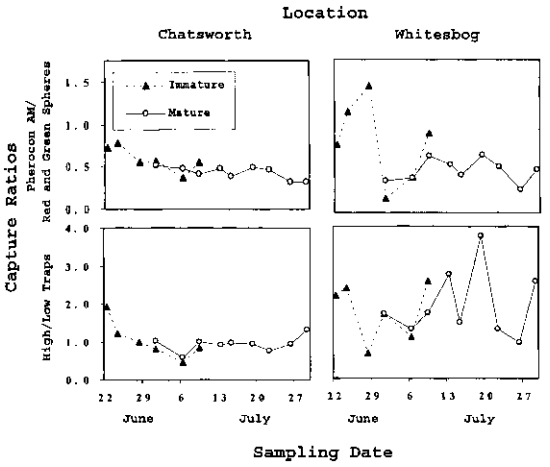

Fig. 1. Ratios of captures of immature and mature blueberry maggot fly females between Pherocon AM/Sphere traps, and High/Low traps, throughout the sampling period.

the best placement of traps with respect to bush physical characteristics, for optimizing captures of immature flies early in the season.

Contrary to previous expectations (Prokopy 1968; Neilson et al. 1984), baited spheres captured significantly more immature females than Pherocon AM traps. The different behavioral preferences exhibited by the blueberry maggot fly for foliage and fruit (Smith & Prokopy 1981; 1982), may not translate into higher trap captures of immature females on baited Pherocon AM traps than on sphere traps. Our study suggests that immature females, like mature females, are receptive to the ammonia stimulus emanating from the bait, and the shape and intensity contrast stimulus from the spheres. There are few studies focusing on relative trap attraction to *Rhagoletis* flies regarding sex and reproductive maturity. Prokopy (1968) evaluated the maturity of female apple maggot flies captured on unbaited yellow boards and red spheres. The percentage of immature females was larger in yellow boards, but the absolute numbers captured were very similar. Neilson et al. (1984) captured slightly more blueberry maggot immature females on baited Pherocon AM traps than on 8.5 cm diameter unbaited red spheres. This is the first study that compares the attraction of baited sphere and Pherocon AM traps to different reproductive maturity stages and sex of blueberry maggot flies.

In this study we found no differences between the performance of red and green spheres for each fly category. Liburd et al. (1998) also had found little difference between red, green, yellow, and blue spheres. These results seem to indicate that the blueberry maggot fly has a response to colored spheres similar to the apple maggot fly, using shape and intensity contrast to detect traps (Owens & Prokopy 1986). Differences in background in relation to red and green spheres were shown to have a complex influence on apple maggot fly captures (Prokopy 1986). Here, differences in background (sky and foliage for traps placed in the canopy, foliage and ground for those near the base of the bush) do not seem to be the major influence on trap captures.

Physical characteristics of the bush were an important factor in captures of all classes of flies. In the case of large bushes, the results are clearly in favor of placement of traps 15 cm within the top of the canopy. Low traps placed near tall bushes were close to dead or non-bearing branches. These areas are probably not very attractive for flies looking for either food sources or fruit for oviposition. Shade from large bushes might have also contributed to the poor performance of low traps. Low Pherocon AM performed poorly when compared to high Pherocon AM traps, possibly because they require flies to go lower to come into visual contact with the yellow surface (facing down), in contrast to spheres, which are visible from all angles. Even though traps placed 25 cm

TABLE 4. REGRESSION ANALYSIS (PARAMETERS, R^2 AND P VALUE) BETWEEN CAPTURE RATIOS OF ADULT *R. MENDAX* (IMMATURE AND MATURE FEMALES) ON PHEROCON AM/SPHERE TRAPS AND HIGH/LOW TRAPS, AND DAYS AFTER FIRST SAMPLING, IN CHATSWORTH AND WHITESBOG, BURLINGTON COUNTY, NEW JERSEY. RATIOS INCLUDE CAPTURES OF IMMATURE FEMALES FROM 17 JUNE TO 9 JULY 1999, AND MATURE FEMALES FROM 1 JULY TO 29 JULY 1999.

Location / Ratio	Immature				Mature			
	a	b	R^2	P	a	b	R^2	P
Chatsworth								
Pherocon AM/Sphere	0.75	-0.017	0.60	0.07	0.57	-0.006	0.51	0.03
High/Low	1.59	-0.061	0.67	0.05	0.73	0.008	0.15	0.30
Whitesbog								
Pherocon AM/Sphere	1.02	-0.024	0.11	0.52	0.47	0.000	0.00	0.98
High/Low	1.82	-0.008	0.00	0.90	1.61	0.013	0.02	0.73

above the ground were somewhat hidden, a large number of flies were still captured in these traps, probably because of a strong effect of the ammonia bait. Aluja & Prokopy (1993) found that if the visual stimulus is strong, odor did not increase the probability of flies finding a fruit, but flies do increasingly rely on odor to find fruit when the visual stimulus becomes weaker.

In smaller bushes (1.2 m), capture patterns were very similar at both 15 cm within the top of the canopy, or 25 cm above ground. Flies of all categories were captured in similar numbers at either trap placement. Gaul et al. (1995) found that placing traps close to fruit increased captures in lowbush blueberries. Behavioral observations have shown that both male and mature females tend to visit and spend more time on fruit, the site for mating and oviposition (Smith & Prokopy 1981; 1982). Lack of preference for high or low traps seems to indicate that if fruit and foliage is more evenly distributed, as on smaller bushes, flies do not restrict their search for food sources or mating and oviposition sites to any particular area of the canopy. Sheltered Pherocon AM traps captured more flies than those exposed to wind (Gaul et al. 1995). This suggests that factors like wind speed at different heights of the canopy, light intensity, temperature, and humidity might also control fly movement and influence captures on low traps.

The significant inverse relationship between captures of mature females on Pherocon AM/Sphere traps and time might be caused by several factors. First, we classified flies as mature if there was any visible developing ooblasts in the ovarioles. It is possible that flies might experience a shift in preference towards spheres after reaching the maturity threshold we established in this study. Given the synchronized pattern of emergence and maturity of the population in the field, the slight trend we observed is not what would be expected if preference were dependent on fly maturity. Second, Pherocon AM and sphere traps may have different ammonia release rates, because of differences in surface area causing slower bait depletion on spheres compared to Pherocon AM traps. In a previous study, Liburd et al. (2000) showed that Pherocon AM and sphere traps experienced a drop in captures at 11 and 40 d, respectively. Finally, attraction to Pherocon AM traps is strongly dependent on yellow hue and reflectance (Prokopy 1972). It is possible that decreased transparence of the adhesive, accumulation of detritus, or pigment decay may affect captures. Spheres, on the other hand, are attractive because of shape and light intensity contrast, which does not change with time. There was also a significant inverse relationship between captures of immature females on High/Low with time, in Chatsworth. Given the few data points we could use in the regression, the reasons for the week relationship ($P = 0.047$) are not clear. In Whitesbog, variability on trap captures between sampling dates, caused by increased heterogeneity in bush size, might have obscured any patterns.

Results of this study indicate that the use of red or green 9 cm diameter plastic sphere traps, baited with ammonium acetate and protein hydrolysate, can significantly increase captures of adult blueberry maggot flies, including immature females, over Pherocon AM traps. In the case of small bushes, captures of flies on traps placed 15 cm within the top of the canopy are equivalent to captures on traps placed 25 cm above ground, for all categories of flies. Smaller bushes are the norm in commercial blueberry plantings. One advantage of low placement is that it does not require pruning of the bush. In case of larger bushes, placement within the top of the canopy is better than near the base of the bush. Blueberry maggot certification programs, either IPM- or calendar-based, that require monitoring of adult presence can benefit from the increased accuracy of spray recommendations as a result of using more effective trap type and placement appropriate to given bush size.

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HOST STATUS OF MAMEY SAPOTE TO CARIBBEAN FRUIT FLY (DIPTERA: TEPHRITIDAE)

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ABSTRACT

Field trapping of *Anastrepha suspensa* (Loew) in groves of mamey sapote, *Pouteria sapota* (Jacq.), showed that fly populations were present in high numbers in all of the groves used for the experiments. Fly populations were highest at the beginning and end of the sampling period. More than 646 fruit of mamey sapote weighing a total of 459.9 kg were exposed to Caribbean fruit flies either in the laboratory or under natural conditions. In one test in the laboratory, 9 Caribbean fruit fly larvae were recovered from mamey sapote fruit. All of the control guava fruit had infestations, some as high as 70 larvae per fruit. In the field tests, no mamey sapote had infestations of Caribbean fruit flies, either naturally occurring or from caged infestation tests. Pressure measurements showed that mamey sapotes averaged -80 to -130 Newtons which is much harder than guavas which averaged -30 Newtons. Magaña and Pantin mamey sapote collected in the field in Florida were not found to be hosts to the Caribbean fruit fly, but laboratory infestation was found to occur.

Key Words: *Pouteria sapota*, *Anastrepha suspensa*, host status, quarantine

RESUMEN

La captura en el campo de *Anastrepha suspensa* (Loew) en arboledas de mamey zapote, *Pouteria sapota* (Jacq.), demostraron que populaciones estaban presentes el altas cantidades en todas las arboledas usadas para los experimentos. Populaciones de mosca fueron mas altas al comienzo y al terminar del periodo de muestreo. Mas de 646 frutas de mamey zapote pesando 459.9 Kg. fueron expuestas a la mosca de fruta del Caribe ya sea en el laboratorio o bajo condiciones naturales. En una prueba en el laboratorio, pocas cantidades de larvas de mosca del Caribe fueron recuperadas de frutas de mamey zapote. Todas las frutas control de guayaba tuvieron infestaciones, algunas tan altas como 70 larvas por fruta. En pruebas de campo, no hubo infestaciones de mosca del Caribe en mamey zapote, ya sea en condiciones naturales o en pruebas de infestación en jaula. Medidas de presión demostraron que mamey sapotes son mucho mas duros que guayabas. Las variedades de mamey zapote Magaña y Pantin, criadas comercialmente en la Florida, no son hospedantes de la mosca de fruta del Caribe.

The mamey or mamey sapote, *Pouteria sapota* (Jacq.), is a fruit tree in the family Sapotaceae native to Central and South America (Morton 1987). The fruit are large, up to several kg, with a salmon pink, orange, to deep red flesh and a large central seed. The dark brown skin or rind is very tough and resistant to puncture or damage, particularly in unripe fruit. The mamey sapote is grown commercially on a small acreage (108 ha) in South Florida with an estimated annual value of $1.5 million (Balerdi et al. 1996; Lamberts & Crane 1990).

The Caribbean fruit fly, *Anastrepha suspensa* (Loew), has a wide host range of over 80 species of fruits (Swanson & Baranowski 1972), but has not been reported to attack mamey sapote. There are records of *Anastrepha ludens* (Loew), *Anastrepha obliqua* (Macquart) and *Anastrepha serpentina* (Wiedemann) attacking mamey sapote in Central America (Emmart 1933; Norrbom & Kim 1988). While there are no records of *A. suspensa* attacking *P. sapota*, *A. suspensa* does attack *Pouteria campechiana* Baehni (the eggfruit or canistel), however these fruit have very thin rinds, and are soft, compared with *P. sapota*. Some of the data on these host lists are from laboratory studies, and the hosts are rarely attacked in the field (Norrbom & Foote 1989).

In summary, there is evidence that the Caribbean fruit fly attacks close relatives of the mamey sapote and close relatives of the Caribbean fruit fly attack the mamey sapote. The purpose of this research was to determine if the Caribbean fruit fly will attack the mamey sapote and infest it under field and laboratory conditions, and the relative severity of any infestations.

MATERIALS AND METHODS

Experiment 1, laboratory cage trials

In 1997 laboratory studies were conducted with several mamey sapote cultivars, Mangaña,

Pantin (Key West), Pace and Maya (Mayapan). Fruit were purchased or collected from groves of each cultivar in Dade County, Florida from April 10 through July 17, 1997. The fruit from each grove on each date were divided randomly into 3 groups with equal numbers of fruit in each group. One group of fruit was held without treatment to determine if any natural infestations were present. The other 2 groups of fruit were placed in cages ($1 \times 1 \times 1$ m) with 10 female and 10 male 10-day-old Caribbean fruit flies. The fruit in 1 of the treatments were punctured (25 pinholes 2-3 cm into the fruit) before placement into the fly cage to allow easier access for ovipositing fruit flies. In addition to these treatments, for each date that fruit were collected, 1 cage was prepared with 5 heat-disinfested guavas (35 minutes immersion in 46°C water) exposed to 10 female and 10 male 10-day-old fruit flies as a positive control.

After exposure to fruit flies for 24 h (under a photoperiod of 14:10 L:D) the fruit were removed from the cages and held 3 to 4 weeks at about 25°C. Any emerging larvae or pupae were collected and counted. At the end of the holding period, each fruit was opened and the pulp inspected for presence of larvae or pupae before disposal.

Experiment 2, field cage trials

In 1998 field tests were conducted with mamey sapote cultivars Magaña and Pantin. Three cooperators were selected for each cultivar and groves were visited every 2 weeks from April to September. Five mamey sapote fruit were individually bagged on the tree with 5 mated female fruit flies for 24 h. A control group of 4 guavas was individually bagged on the mamey sapote tree with 5 female fruit flies for 24 h to ensure that the flies were capable of laying eggs.

The fruit were enclosed in a 45×45 cm plastic bag with many small air holes (Delnet pollination bag, Applied Extrusion Technologies, Inc., Middletown, DE) supplied with water-soaked cotton and a sugar cube. The bag was secured to the tree and fruit with wire twist ties and rubber bands. A 23 cm diameter opaque plastic plate was placed above each bag to shield the fruit from rain and direct sun.

One group of 5 mamey sapote was collected and held without treatment to determine if a field infestation existed. Samples of fruit lying on the ground were also collected if available (some groves did not have any fallen fruit) and held to determine if they were infested. All fruit were then taken to the laboratory where size, weight, inner peel color and firmness were recorded.

Four glass McPhail traps were placed in each grove (1 on each side of the grove) at ¾ tree height in the exterior part of the tree canopy and baited with 10 g of torula yeast plus 300 ml of water. The traps were monitored for the presence of adult flies each week that the grove was sampled for fruit.

Results

Experiment 1, laboratory cage trials

A total of 396 mamey weighing a total of 237.6 kg were used in this experiment. Mean cultivar weights were Magaña 1,019.9 ± 36.3 g, Pantin 718.8 ± 28.0 g, Maya 603.4 ± 39.1 g, and Pace 468.7 ± 13.3 g. Mamey sapote fruit are very firm; pressure tests showed that while fruit firmness declined as the season progressed, it remained higher than -80 Newtons (the force required to push a 12 mm diameter cylinder into the fruit 3 mm; larger negative number = harder fruit) (Fig. 1). Guavas, which are primary hosts for Caribbean fruit flies, average about -30 Newtons when mature. Mamey sapotes, even at the end of the test period, were twice as firm as guavas.

No insects were recovered from any of the fruit held without treatment, therefore there was no natural infestation. The control guavas in every replicate had fruit fly larvae present. Only 1 of the treated replicates had fruit fly larvae in mamey sapote fruit. In the replication from 29 May 1997, 8 larvae were found from unpunctured Magaña mamey sapotes (3 fruit) exposed to female fruit flies, and 1 larva was recovered from punctured Magaña mamey sapotes (3 fruit) exposed to female fruit flies. The guava control (5 fruit) for that replication had 223 larvae, which was much higher than the larvae from control fruit in other replications (Table 1). The fruit from the 29 May 1997 test date showed no physical differences from fruit used on any of the other test dates.

Experiment 2, field cage trials

A total of 250 mamey sapotes weighing a total of 173 kg was used in this experiment. Magaña and Pantin were the two cultivars tested (weighing 882 ± 210 g and 617 ± 93 g, respectively). The fruit were firm, averaging harder than -100 Newtons throughout the season (Magaña -119 ± 17, Pantin -120 ± 11) (Fig. 2). The fruit collected from the ground (3.6 kg Magaña, 46.3 kg Pantin) were usually too soft to measure firmness, and were often split open with the pulp exposed. The number of fallen fruit varied greatly because some growers harvested all fruit or cleaned up fallen fruit. Other growers allowed fallen fruit to rot on the ground under trees.

No larvae were recovered from any of the mamey sapotes tested. No field infestation was found in either fruit on the trees or fruit recovered from the ground. No larvae were recovered from any mamey sapote bagged with female fruit flies. Almost all of the guava control fruit became infested, with larval numbers ranging up to 325 larvae recovered from 4 guavas (Table 2). Caribbean fruit fly adults were present in all of the groves used for the experiments. Fly populations

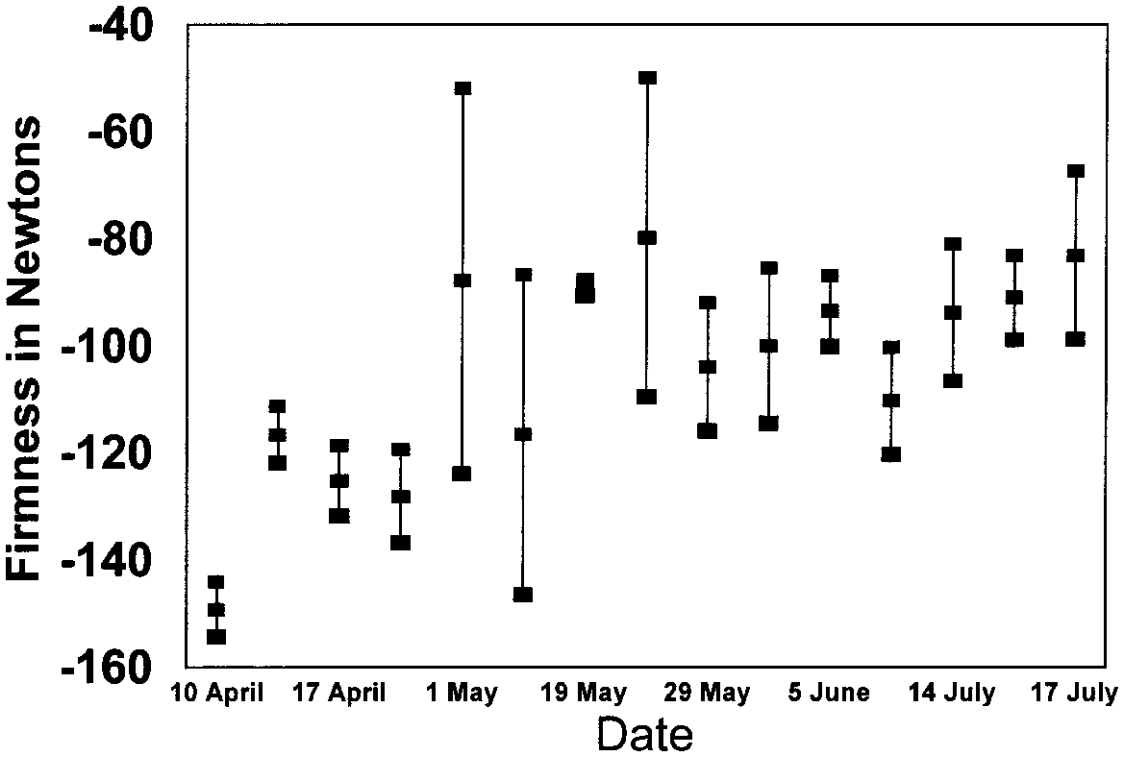

Fig. 1. Firmness of mamey sapote used in laboratory infestation tests in 1997 (the force in Newtons required to push a 12 mm diameter cylinder into the fruit 3 mm).

TABLE 1. NUMBERS OF MAMEY EXPOSED AND LARVAE RECOVERED, LABORATORY TEST 1997.

Date	Cultivar (number exposed)	Number of larvae found			
		Fruit exposed to flies in lab			
		Guavas	Intact mamey	Pinholed mamey	Control mamey
10 April	Maya (9)	1	0	0	0
	Pantin (9)	1	0	0	0
17 April[1]	Magaña (2)	—	—	—	0
	Pace (2)	—	—	—	0
	Pantin (3)	—	—	—	0
17 April	Magaña (9)	16	0	0	0
	Pace (15)	16	0	0	0
1 May	Magaña (9)	5	0	0	0
	Pace (15)	5	0	0	0
19 May	Magaña (9)	5	0	0	0
	Pace (15)	5	0	0	0
29 May	Magaña (9)	223	8	1	0
	Pace (15)	223	0	0	0
5 June	Pantin (90)	11	0	0	0
18 June	Pantin (12)	6	0	0	0
14 July	Pantin (12)	14	0	0	0
	Maya (12)	14	0	0	0
17 July[1]	Maya (150)	—	—	—	0

[1]Fruit held to determine if a natural infestation exists, not exposed to caged flies.

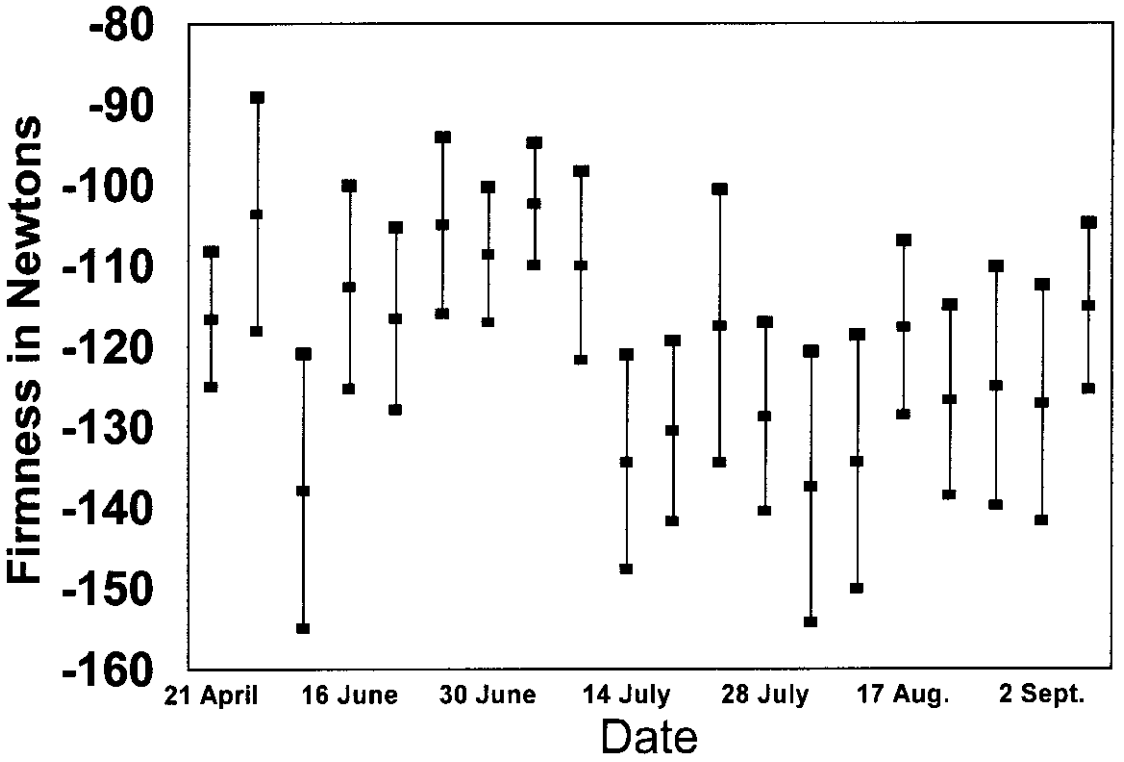

Fig. 2. Firmness of mamey sapote used in field infestation tests in 1998 (the force in Newtons required to push a 12 mm diameter cylinder into the fruit 3 mm).

were highest at the beginning and end of the sampling period (Fig. 3).

Discussion

The collection of fruit for the laboratory tests (1997) covered the commercial season for Magaña and the first half of the season for Pantin which make up 95-98% of the commercial acreage (Balerdi et al. 1996). Most of these fruit ripen during the period April through August. Often a few fruit are available at other times, however Caribbean fruit fly populations are also highest in the early summer (Hennessey 1994). In the laboratory study 9 larvae were recovered from mamey sapotes in 1 of the replications. The control infestations were highest at this time in the experiment (223 larvae). There were no physical differences found between the fruit that were infested and those that were not infested. The high oviposition

Table 2. Numbers of mamey exposed and larvae recovered, field test 1998.

Cultivar	Replication and dates	Number of larvae found (Mean ± SEM)		
		Guava (4 fruit)	Bagged mamey sapote (5 fruit)	Untreated control mamey sapote (5 fruit)
Magaña	R1, 21 Apr.-1 May	30.0 ± 15.3	0	0
	R2, 7 May-13 May	49.3 ± 32.3	0	0
	R3, 19 May-1 June	9.0 ± 9.0	0	0
Pantin	R1, 16 June	19.7 ± 4.8	0	0
	R2, 30 June	279.0 ± 46.0	0	0
	R3, 14-15 July	218.7 ± 45.9	0	0
	R4, 28-30 July	170.7 ± 11.7	0	0
	R5, 17 Aug.	66.3 ± 15.9	0	0
	R6, 2 Sept.	49.5 ± 8.5	0	0

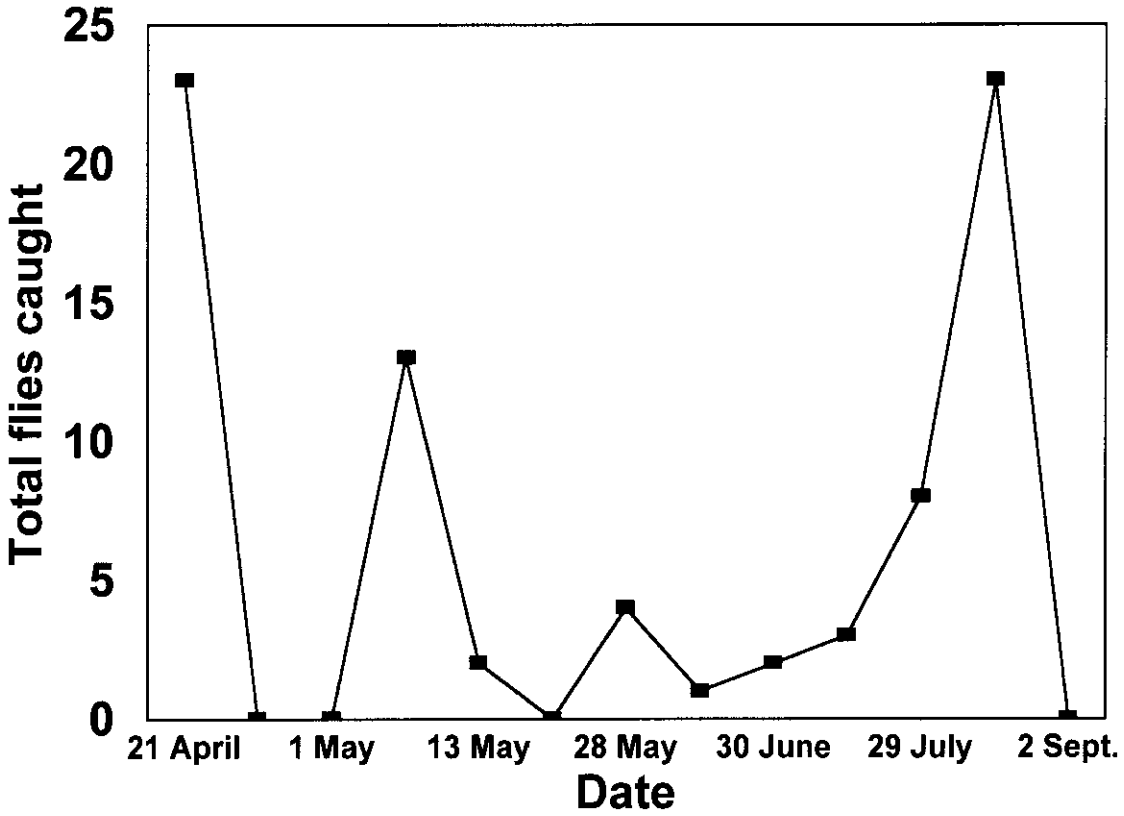

Fig. 3. Total numbers of adult Caribbean fruit flies trapped in field tests, 1998. Four McPhail traps per grove collected weekly.

pressure in this case may have overwhelmed the natural barriers to oviposition. The low number of larvae resulting indicates that the mamey sapote is a poor host under forced infestation.

The collection of fruit and tests done in the field (1998) covered the main harvest season for both varieties tested (Magaña and Pantin). Fruit fly populations were present in the fields, and the flies in the field cage tests produced thousands of larvae in the control guavas. No larvae were found in any of the field-collected fruit samples in either 1997 or 1998, and the cage tests did not produce any infestations in mamey sapotes. In addition none of the fruit which were collected from the ground, and which were often overripe and broken open, produced any fruit fly larvae.

Several fruit have been shown to be non-hosts for the Caribbean fruit fly. Based on Hennessey et al. (1992) and Nguyen & Fraser (1989), limes are not hosts to the Caribbean fruit fly. Limes and other citrus have biochemical defenses which cause mortality of eggs and small larvae (Greany et al. 1983). In this study we found that unripe mamey sapote had a distinct chemical odor and white latex juice present when cut. This suggests that chemical defenses to fruit fly infestation could be present in mamey sapote. Eggs and larvae placed on unripe mamey sapote slices had a high mortality rate (author unpublished data).

Using very high numbers of ovipositing fruit flies increases the likelihood of declaring a non-host a host, since many species of fruit may be infested under the pressure of hundreds of ovipositing females in a confined setting. Under field conditions it is likely that there are fewer than 5 flies visiting any given fruit.

'Forcing' larvae into ripe fruit under artificial conditions does not fairly represent field conditions. Therefore, under the protocol of Cowley et al. (1992), mamey sapote were tested to see whether they would be infested under caged conditions in the field, as well as collecting fruit for evidence of a natural infestation.

In the laboratory and field forced infestation tests, 5 female flies were used. This is probably much higher than the fly population any given fruit is naturally exposed to in the field, and it is more realistic than using hundreds of flies in a small cage. The only infestation that occurred was in a single replication in the laboratory and at a very low rate compared to the control fruit (9 larvae vs. 223 control larvae).

In this two year study, a balanced approach was used which included field and laboratory tests with as large a sample size as was realistic. The protocol of finding host status as proposed by Cowley et al. (1992) was used as a guide. Gould et al. (1999) found that lychees and longans were not hosts to Caribbean fruit flies using similar field and laboratory studies.

A total of more than 646 fruit of Magaña, Pantin, Pace, and Maya mamey sapote weighing in total more than 410 kg were exposed to Caribbean fruit flies either in the laboratory or under forced or natural field conditions. No Caribbean fruit fly larvae were recovered from any fruit collected in the field or exposed to caged flies in the field. In addition, no larvae were recovered from 50 kg of fruit (approximately 100 fruit) which was collected from the ground in the field, and which would be the most likely to have larvae if an infestation were present in mamey sapote.

Mamey sapote are very firm, normally being harvested when the fruit is harder than -80 Newtons. Guavas, one of the best hosts for Caribbean fruit fly, are much softer averaging -41.2 ± 7.1 Newtons (n = 10) when mature green. Guavas have a very strong odor while unripe mamey sapotes are almost odorless. Some fruit odors have been found to be powerful attractants for fruit flies (Robacker et al. 1990; Nigg et al. 1994). In addition there was evidence of chemical defenses to fruit fly infestation in unripe mamey sapotes.

Based on the protocol put forth by Cowley et al. (1992) and extensive laboratory and field tests, Magaña and Pantin mamey sapotes are not hosts to the Caribbean fruit fly in commercial mamey sapote groves and present no risk of transporting *A. suspensa* from Florida to other locations.

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MOSQUITO HOSTS OF ARBOVIRUSES FROM INDIAN RIVER COUNTY, FLORIDA, DURING 1998

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ABSTRACT

Adult mosquitoes were collected for virus isolation from two sites in Indian River County, FL, from May 5 through August 13, 1998 using dry ice-baited CDC light traps (81 trap-nights) and CDC gravid traps (254 trap-nights). A total of 46,150 female mosquitoes (923 mosquito-pools, 50 females/pool) were processed for virus isolation. These females represented 18 species of mosquitoes, with *Culex nigripalpus* comprising 77.4% of all mosquitoes collected, followed by *Aedes infirmatus* (4.9%), *Ae. vexans* (4.0%) and *Cx. erraticus* (2.4%). No St. Louis encephalitis (SLE) and eastern equine encephalitis (EEE) virus isolates were obtained. Keystone (KEY) and Tensaw (TEN) viruses were isolated from *Ae. albopictus* (one isolate of KEY); *Anopheles crucians* (two isolates of TEN); *Cx. nigripalpus* (one isolate of TEN and 2 isolates of KEY); *Coquilletidia perturbans* (two isolates of TEN); and *Wyeomyia vanduzeei* (one isolate of TEN). All isolates were obtained from mosquitoes collected in CDC light traps, except for the KEY virus isolate from *Ae. albopictus*, which was collected in a CDC gravid trap. The isolation of TEN virus from *Wy. vanduzeei* is a first record for Florida.

Key Words: Arbovirues, Tensaw, Keystone, mosquitoes, *Culex nigripalpus*, *Aedes albopictus*, *Coquilletidia perturbans*, *Anopheles crucians*, *Wyeomyia vanduzeei*

RESUMEN

Mosquitos adultos fueron colectados para aislamiento de virus de dos sitios en el Condado de Indian River, FL, desde mayo 5 hasta agosto 13, 1998, usando trampas de luz CDC cebadas con hielo seco (81 noches de trampa) y trampas CDC grávidas (254 noches de trampas). Un total de 46,150 mosquitas (923 grupos de mosquitos, 50 hembras/grupo) fueron procesadas para aislamiento de virus. Estas hembras representaron 18 especies de mosquitos, con *Culex nigripalpus* componiendo 77.4% del total, seguido por *Aedes infirmatus* (4.9%), *Ae. vexann* (4.0%). y *Cx. erraticus* (2.4%). No se obtuvieron virus aislados de encefalitis St. Louis (SLE) o encefalitis oriental equina (EEE). Los virus Keystone (KEY) y Tensaw (TEN), fueron aislados de *Ae. albopictus*, (un aislado de virus KEY); de *Anopheles crucians* (dos aislados de virus TEN); de *Cx. nigripalpus* (un aislado de TEN y dos aislados de KEY); de *Coquillletidia perturbans* (dos aislados de TEN); y de *Wyeomyia vanduzeei* (un aislado de TEN). Todos los aislados fueron obtenidos de mosquitos colectados en trampas de luz CDC, excepto por el aislado del virus KEY de *Ae. albopictus*, el cual fue colectado en una trampa CDC grávida. El aislamiento de virus TEN de *Wy. vanduzeei* es una primera constancia para Florida.

Mosquitoes are vectors and/or hosts of several arboviruses in Florida. These arboviruses include, St. Louis encephalitis (SLE), eastern equine encephalitis (EEE), trivittatus (TVT), Flanders (FLA), Sawgrass (SAW), Tamiami (TAM), Everglades (EVE), Shark River (SR), Jamestown Canyon (JC), Highlands (HJ), Tensaw (TEN), and Keystone (KEY) (Chamberlain et al. 1964; Dow et al. 1964; Wellings et al. 1972; Shroyer 1991; Mitchell et al. 1996). Most of these arboviruses, have been isolated from counties in Florida other than Indian River. Only SLE virus was isolated from mosquitoes in Indian River County in 1990 (Shroyer, 1991). Recently, Mitchell et al. (1996) isolated EEE, EVE, KEY, TEN, TVT, SR, and FLA from mosquitoes associated with waste-tire piles in counties in central and north Florida. In 1997, an above average amount of SLE virus activity in sentinel chickens occurred in Indian River County, Florida, although no human cases were documented there (Day & Stark 2000) with continued SLE virus activity in sentinel chickens in February 1998. There were no virus isolates from the *Culex nigripalpus* Theobald (a proven vector of SLE virus) collected and tested for SLE virus during 1997 in Indian River County (Day & Stark 2000). The purpose of the present study was to isolate and identify arthropod-borne viruses from mosquitoes collected in two different locations in Indian River County during the late spring and early summer of 1998.

Materials and Methods

Mosquito collection sites: Mosquitoes were collected from 2 sites in Indian River County. Site 1 was pine woods with scattered cabbage palm, palmetto, and oak, 25 Km north of the Florida Medical Entomology Laboratory (FMEL), Vero Beach; at this site a sentinel chicken flock was maintained by the Indian River Mosquito Control District as part of its SLE virus surveillance program. The traps were set more than 50 m from the sentinel chicken flock. Site 2 was an oak hammock on the FMEL grounds.

Mosquito collection and handling methods: Mosquitoes were collected twice a week from May 5 through August 13, 1998, in 5 CDC gravid mosquito traps (Reiter 1983) and 1 or 2 dry ice-baited CDC miniature light traps. Mosquitoes from the traps were transported in ice-coolers to the FMEL, where they were separated on a chill table and identified to species; 50 females were then pooled in 2-ml screw-cap cryovials. The cryovials were labeled and frozen at -80%C until they were shipped overnight on dry ice to the CDC laboratory in Fort Collins, Colorado, for virus isolation and identification.

Virus Isolations and *Virus Identification*:

Mosquito pools were triturated in 2 ml of BA-1 diluent by using cold mortars and pestles. BA-1 diluent containing 1× M199 medium with Hanks balanced salt solution (HBSS), 0.05 M Tris pH 7.6, 1% bovine serum albumin, 0.35 gm/L sodium bicarbonate, 100 units/ml penicillin, 100 g/ml streptomycin, 1 g/ml fungizone, and 10 mg/liter phenol red. Suspensions were centrifuged in Eppendorf tubes at 14,000 rpm for 2 min. Supernatants were poured into 1-dram screw-cap vials and stored at -70°C until tested.

Specimens were tested for virus in Vero cell culture grown in 6-well plates. Specimens were inoculated in 0.1-ml quantities in 2 wells each and adsorbed for 1 hr at 37°C; the cells were then overlayed with the first of two nutrient -0.5% agarose overlays. Cell cultures were incubated at 37°C and 3 days later a second agarose overlay containing 1:50,000 neutral red was applied. Cell cultures were returned to the incubator and examined daily thereafter for plaques through day 10 postinoculation.

Virus-positive cell cultures were harvested in 2 ml of BA-1 and frozen at -70°C until they were passed into fluid cultures of Vero cells in 25-cm^2 flasks. When early cytopathic effects (CPE) were noted, infected cells were scraped or trypsinized from the surface of the flask and resuspended in phosphate-buffered saline (PBS), pH 7.4, containing 5% Fetal Bovine Serum (FBS). Twelve-well spot slides were prepared, air-dried, and fixed in cold acetone. These were tested in an indirect fluorescent antibody (IFA) assay (Wulff and Lange 1975) against a battery of hyperimmune grouping ascitic fluids obtained from NIH and CDC. Usually, viral type-specific monoclonal antibodies against common or suspected viruses also were included in the test to definitively identify isolates at this stage.

Virus-positive cell cultures were also characterized by the reverse transcriptase-PCR (RT-PCR) by using flavivirus-consensus, SLE-specific, and bunyavirus serogroup-specific primers (Chang et al. 1994; Kuno et al. 1996). RT-PCR-positive specimens generated by BCS82C and BCS332V primers were genetically sequenced by using an ABI Prism 377 DNA Sequencer (Perkin-Elmer/Applied Biosystems, Foster City, CA) (Kuno et al. 1996). Both strands of the cDNA, located between nucleotide position of 77 to 273 in the small (S) RNA segment, were sequenced and compared with the GenBank data base by using the BLAST search program (http://www.ncbi.nlm.nih.gov/BLAST/). Otherwise, antigenically grouped viral isolates were typed by neutralization (N) assay in Vero cell cultures against reference polyclonal immune reagents prepared against specific members of the antigenic group. Homologous N titers were predetermined for reference reagents used in the identifying N tests.

Results

Totals of 54 light trap and 52 gravid trap were used to collect 81 light and 254 gravid, trap nights, respectively, at the two sites. A total of 94.9% of the female mosquitoes that were tested for viruses were captured in light traps while only 5.1% of the female mosquitoes were collected in gravid traps (Table 1). Mosquitoes in light trap collections were 80.1% *Cx. nigripalpus* with other species comprising less than 5% of the total (Table 1). The main mosquito species in gravid traps were *Aedes albopictus* (Skuse), *Cx. nigripalpus*, *Wyeomyia vanduzeei* Dyar and Knab, and *Wy. mitchellii* (Theobald). All of the *Cx. quinquefasciatus* were collected in gravid traps. (Table 1).

No SLE and EEE virus isolates were obtained from mosquito collected from May 5 through August 13,1998, at the 2 sites. Five species of mosquitoes yielded 9 isolates of arboviruses belonging to 2 antigenic groups, Keystone (KEY) virus of the California antigenic group and Tensaw (TEN) virus of the Bunyamwera antigenic group (Table 2). Four species of mosquitoes yielded 6 isolates of TEN virus: *An. crucians* (two isolates); *Cx. nigripalpus* (one isolate); *Cq. perturbans* (two isolates); and *Wy. vanduzeei* (one isolate). Two species of mosquitoes yielded 3 KEY virus isolates, *Ae. albopictus* (one isolate) and *Cx. nigripalpus* (two isolates). All isolates were obtained from mosquitoes collected in CDC light traps, except for 1 KEY virus isolate, which was recovered from

TABLE 1. MOSQUITOES TESTED FOR THE PRESENCE OF ARBOVIRUSES THAT WERE COLLECTED AT TWO SITES IN INDIAN RIVER COUNTY, FLORIDA, FROM MAY 5 THROUGH AUGUST 13, 1998.

Species	Total tested	Site 1		Site 2		Percentage by species
		Light trap	Gravid trap	Light trap	Gravid trap	
Ae. albopictus	1,000		50	250	700	2.1
Ae. atlanticus	100			100		0.2
Ae. infirmatus	2,250	100		2,150		4.9
Ae. taeniorhynchus	650	150		500		1.4
Ae. vexans	1,850	1,800		50		4.0
An. crucians	750	500		250		1.6
An. quadrimaculatus	50	50				0.1
Cq. perturbans	550	450		100		1.2
Cx. erraticus	1,100	1,100				2.4
Cx. iolambdis	100			100		0.2
Cx. nigripalpus	35,700	26,450	350	8,650	250	77.4
Cx. quinquefasciatus	900		450		450	2.0
Cx. salinarius	400	350			50	0.9
De. cancer	200				200	0.4
Ma. titillans	50	50				0.1
Ps. ferox	50				50	0.1
Wy. mitchellii	100			50	50	0.2
Wy. vanduzeei	350			300	50	0.8
Total	46,150	31,000	850	12,800	1,500	100.0
Percentage by trap and site		67.2	1.8	27.7	3.3	100.0

Ae. albopictus specimens collected in a CDC gravid trap.

The RT-PCR independently confirmed the serological identification that 9 isolates of arboviruses were not SLE or EEE viruses. Nucleotide sequences were obtained from 6 TEN virus isolates and 1 KEY virus isolate. All TEN virus isolates had an identical nucleotide sequence in the S-gene region sequenced. The BLAST search by using GenBank data base indicated that TEN virus isolates shared 95.4%, 95.4% and 93.4% nucleotide identity with Northway, Cache Valley, and Bunyawera viruses, respectively (Table 3). Keystone virus isolate FL-1290 shared 99.5%, 93.4%, and 92.3% nucleotide sequence identity with 1 other KEY virus isolate, Jamestown Canyon and Jerry Slough viruses, respectively.

DISCUSSION

St. Louis encephalitis virus was not isolated from any species of mosquito collected in this study. Similarly, Mitchell, et al. (1996) failed to isolate SLE virus from mosquitoes collected from 36 sites in central and north Florida from April to September, 1993. In 1990, SLE virus was isolated

TABLE 2. VIRUS ISOLATIONS FROM INDIAN RIVER COUNTY, FLORIDA, MOSQUITOES FROM MAY 5 THROUGH AUGUST 13, 1998, AND MINIMUM INFECTION RATES (MIR) BY SITE COLLECTION.

Species	Virus	Site	Isolate number	MIR[1]
Ae. albopictus	KEY	2	FL98-1290	1.0
An. crucians	TEN	2	FL98-1199	2.6
	TEN	2	FL98-1198	2.6
Cx. nigripalpus	TEN	1	FL98-760	0.03
	KEY	1	FL98-5240	0.06
	KEY	1	FL98-5241	0.06
Cq. perturbans	TEN	1	FL98-874	3.6
	TEN	1	FL98-875	3.6
Wy. vanduzeei	TEN	2	FL98-1207	2.9

[1]MIR = Minimum infection rate per 1,000 females tested.

TABLE 3. GENETIC IDENTIFICATION OF VIRUS ISOLATIONS FROM INDIAN RIVER COUNTY, FLORIDA, MOSQUITOES FROM MAY 5 THROUGH AUGUST 13, 1998, BY A BLAST SEARCH OF THE GENBANK DATA BASE.

	Top three scores by the BLAST search (Accession No.; species)		
Strain (FL98-)	X73470; Northway	X73465; Cache Valley	D00353; Bunyamwera
760, 874, 875, 1198, 1199, 1207	95.4 U12801; Keystone	95.4 U12796; Jamestown Canyon	93.4 U12798; Jerry Slough
1290	99.5	93.4	92.3

from *Cx. nigripalpus* in Indian River County during late summer and fall (Shroyer 1991). Interestingly, in the almost 50-year history of the presence of SLE virus in Florida, the virus has only been recovered from *Cx. nigripalpus* during epidemics years (Chamberlain et al. 1964; Dow et al. 1964; Monath and Tsai 1987; Shroyer 1991; Wellings et al. 1972). This could be because mosquitoes were generally collected for virus isolation only during years when epidemics occurred. Furthermore, the minimum infection rates of SLE virus in *Cx. nigripalpus* were low even during epidemics, and ranged from 0.6 to 1.1 per 1000 (Chamberlain et al. 1964; Dow et al. 1964; Shroyer 1991).

Two viruses, KEY and TEN, were isolated from five species of mosquitoes. KEY virus was recovered from *Ae. albopictus* and *Cx. nigripalpus*, and TEN virus from *An. crucians*, *Cx. nigripalpus*, *Cq. perturbans,* and *Wy. vanduzeei*. These two viruses occur in abundance in Florida from April to September each year and have been isolated from several species of mosquitoes, including those collected in our study (Taylor et al. 1971; Wellings et al. 1972; Calisher et al. 1986; Mitchell et al. 1996). Only exception being a (first time) TEN virus isolate from *Wy. vanduzeei*. KEY and TEN viruses also have been isolated from small mammals in Florida. KEY virus was isolated from cotton rats and TEN virus from cotton rats, marsh rabbits, swamp rabbits, and various other small mammals (Taylor et al. 1971; Wellings et al. 1972; Calisher et al. 1986). KEY and TEN viruses are of no public health or veterinary importance.

RT-PCR, followed by nucleotide sequencing of positive specimens, and a GenBank similarity search by using the BLAST search program proved to be effective methods of identifying virus species. By these methods none of the tissue culture- positive specimens contained a detectable level of SLE viral RNA. These results also correlated with serological identification and confirmed that the specimens contained KEY and TEN nucleic acids.

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RESIDUAL CHEMICAL CONTROL FOR *MELANOPLUS DIFFERENTIALIS* (ORTHOPTERA: ACRIDIDAE) IN URBAN LANDSCAPES

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ABSTRACT

Melanoplus differentialis (Thomas) (Orthoptera: Acrididae) and several other species of grasshoppers invade urban/suburban landscapes and retail/wholesale nurseries during the hot, dry summers in the southern United States to consume the foliage of many species of landscape plants and turfgrass. Two experiments were conducted to determine which insecticides could be used to safely provide residual control for the continual daily migration of grasshoppers in urban landscapes and nurseries. Leaves from treated *Hibiscus moscheutos* were harvested sequentially in time at 1-, 5-, and 11-days posttreatment and adult differential grasshoppers were confined on them for 24-, 48- and 72-hr exposures. Treatments with two synthetic pyrethroids, bifenthrin 0.66F (0.782 ml/liter) and lambda-cyhalothrin 9.52 WP (0.748 g/liter), provided 94 and 83%, mortality respectively, with 24-hr exposure to the 1-day-old treated leaves. Both chemicals provided 100% control of the grasshoppers during 72-hr exposure. The half rate (0.391 ml/liter) of bifenthrin also provided 89% control within the 72-hr evaluation. Treatments with diazinon AG600 (4.25 ml/liter) also provided 80-85% control with 72-hr exposure on the 1-day-old treated leaves. Acephate 75% S (0.803 g/liter) provided 33-39% control on the 1-day-old residues. Lambda-cyhalothrin provided 84% control with 72-hr exposure to the 5-day-old treated leaves. Residual control was also provided at 5 days by bifenthrin and acephate (53% and 46-50%, respectively). Most materials evaluated failed to provide any protection at all and none of the treatments provided residual control when grasshoppers were exposed to 11-day-old residues. No phytotoxicity to hibiscus was observed due to any of the treatments.

Key Words: differential grasshopper, bioassays, bifenthrin, lambda-cyhalothrin, diazinon, acephate, landscape pest, nursery pest

RESUMEN

Melanoplus differentialis (Thomas) (Orthoptera: Acrididae) y varias otras especies de saltamontes invaden paisajes urbanos / suburbanos y viveros de venta al por menor / por mayor durante los veranos calientes y secos al sur de los Estados Unidos para consumir el follaje de muchas especies de plantas paisajistas y grama de césped. Dos experimentos fueron llevados a cabo para determinar cuales insecticidas pudieran ser usados para proveer control residual con seguridad para la continua migración diaria de saltamontes en viveros y paisajes urbanos. Hojas de *Hibiscus moscheutos* tratadas fueron cosechadas en secuencia de tiempo a 1, 5, y 11 días después de tratamiento y saltamontes adultos diferenciales fueron confinados con ellas por exposición de 24, 46 y 72 horas. Tratamientos con dos piretroides sintéticos, bifenthrin 0.55F (0.782 ml/litro) y lambda-cyhalothrin 9.52 WP (0.78 g/litro), proveyeron mortalidad de 94 y 83%, respectivamente, con exposición de 24 hr. a las hojas tratadas de 1 día. Ambos químicos proveyeron 100% de control de los saltamontes durante exposición por 72 hr. La media dosis (0.391 ml/litro) de bifenthrin también proveyó 89% de control dentro de la evaluación de 72 hr. Tratamientos con diazinon AG600 (4.25 ml/litro) también proveyó 80-85% de control con exposición de 72 hr. en las hojas tratadas de 1 día. Acephate 75% S (0.803 g/litro) proveyó 33-39% de control en los residuos de 1 día. Lambda-cyhalothrin proveyó 84% de control con exposición por 72 hr. a las hojas tratadas por 5 días. Control de residuos fue tambien proveido a los 5 días por bifenthrin y acephate (53% y 46-50%, respectivamente). La mayoría de los materiales evaluados fracasaron en proveer alguna protección del todo y ninguno de los tratamientos proveyeron control residual cuando los saltamontes fueron expuestos a los residuos de 11 dias. No fitotoxicidad a los hibiscos fue observada debido a alguno de los tratamientos.

Several species of grasshoppers invade urban/suburban landscapes and retail/wholesale nurseries during the hot, dry summers in the southern United States to consume the foliage of many species of landscape plants and turfgrass. The feeding behavior of several species of *Melanoplus* grasshoppers has been studied (Feaver 1985, Fielding and Brusven 1992, Harvey and Thompson 1993, Hinks et al. 1990). Based upon limited surveys during the summer and fall of 1998 and 1999 and the summer of 2000, the differential grasshopper, *Melanoplus differentialis* (Thomas)

(Orthoptera: Acrididae), is the species most frequently encountered in damaging numbers in the Texas landscape. Additionally, the two-striped grasshopper, *M. bivitattus* (Say), and migratory grasshopper, *M. sanguinipes* (Fabricius), migrate into the urban environs to cause significant damage to the landscape.

Cooperative extension reports from Kansas (Bauernfeind 1992) and Texas (Patrick 1998) also report these species as the primary grasshopper pests of gardens and urban landscapes. Nymphs are usually not a problem in urban plantings as they normally develop in pasture and field-crop settings. Only after they molt to the adult stage do we see the migration into urban landscapes. However, in rural landscapes, severe damage may result from both nymphs and adults that readily move by walking from adjacent fields and roadsides. A mature grasshopper feeding on a small shrub or bedding plant can soon disfigure it and several feeding adults can ruin the aesthetic value of plants around a home within a short time. The economic impact to a retail or wholesale nursery can be very high. Plants are sold for their aesthetic value and even limited grasshopper feeding can soon render the plants unsaleable.

Outbreaks are usually preceded by several years with hot, dry summers and warm autumns (Patrick 1998). Also, the dry weather increases survival of both nymphs and adults. The extremely hot and dry summer of 1998 created ideal conditions for extensive outbreaks of grasshoppers across much of the southern United States. Populations the following years (1999 and 2000) were also high and caused extensive damage. As pastures, field crops and uncultivated areas were either harvested or desiccated from the drought conditions, mature grasshoppers readily dispersed into plant nurseries and the urban landscape in search of food. As a result, extensive damage was common, especially in Texas, on lawns and many species of landscape plants. Control strategies were needed to manage the invasion within the urban scape and in plant nurseries. The purpose of these experiments was to determine which insecticides could be used to safely control grasshoppers on landscape plants and in nursery culture and also, to determine if any of the treatments could provide residual control for the continual daily migration of the adults.

Materials and Methods

Two experiments were conducted to evaluate insecticides for residual control. Chemicals and rates evaluated are given in Tables 1 and 2. For each experiment, 'Disco Rose Red' Hibiscus, *Hibiscus moscheutos*, plants [ca. 30 to 40 cm high grown in 15-cm diam. (1 gal) pots] were obtained from a local nursery. Plants were sprayed to runoff with the respective treatments. Silwet, an organosilicon wetting agent, was added to each treatment at a rate of 1 ml/liter of water. Two plants were treated with each insecticide in each replicate to ensure adequate treated foliage would be available for sequential residual evaluations. Plants were maintained in full sun to allow maximum bio-degradation of the treatment chemicals. Leaves were clipped at 1- and 5-days posttreatment (DAT) in Experiment 1 and at 1-, 5-, and 11-DAT in the second experiment, bagged, placed in a cooled ice chest and taken to the laboratory. Two to three treated leaves were caged with each individual adult grasshopper in 9-cm diam. $\times$ 20 mm plastic growth chambers and the individuals were observed every 24 hr for up to five days. Each feeding chamber was first provided with two 7-cm filter paper discs, saturated with distilled water, to maintain foliage turgidity. For both experiments, 5 reps each with 4 adults were evaluated for the respective days after treatment. For each evaluation period, mortality ratings were made at 24-, 48-, 72-, 96- and 120-hr after grasshoppers were caged on the clipped, treated plant material.

For these studies, field populations of adult differential grasshoppers were collected from stands of Johnsongrass, *Sorghum halepense* (L.) Pers., growing in railroad or highway rights-of-way at sites in either Denton or Collin Co., TX. Adults were individually collected with a sweep net, transferred to stems and leaves of Johnsongrass in plastic shoe boxes that had been modified with screen lids, and stored in cooled ice chests for immediate transport to the laboratory. Only grasshoppers that appeared healthy the next day were used to initiate the residue studies. Either males only or females only were used within each replicate, to ensure that any differences in susceptibility due to sex would be accounted for statistically as replication error.

Data were adjusted (Abbott 1925) in Experiment 1 (Table 1) since mortality in the untreated check approached 10% at both 72-hr evaluations. No adjustment was needed in Experiment 2, since no grasshoppers died in the untreated check during the study. All data were analyzed using Analysis of Variance and General Linear Model Procedures. Treatment means were separated by Waller-Duncan k-ratio t test ($k = 100$) ($P = 0.05$) (SAS Institute 1990). Percent mortality data was transformed by arcsines before analysis. Untransformed means are presented.

Results and Discussion

Treatments with two synthetic pyrethroids, bifenthrin 0.66F (Talstar) (0.782 ml/liter) and lambda-cyhalothrin 9.52 WP (Simitar) (0.748 g/liter), provided 94 and 83% mortality, respectively, with 24-hr exposure to the 1-DAT hibiscus leaves (Table 2). Furthermore, both chemicals provided

TABLE 1. CONTROL OF DIFFERENTIAL GRASSHOPPERS (*MELANOPLUS DIFFERENTIALIS*) WITH INSECTICIDES. TREATMENTS IN EXPERIMENT 1 APPLIED ON 10 SEPT. 1998 (5 REPS, EACH WITH 4 ADULT GRASSHOPPERS).

Treatment[a]	Rate (ml or g product/liter)	Exposed 1-DAT[b]			Exposed 5-DAT[b]		
		24hr	48hr	72hr	24hr	48hr	72hr
Diazinon AG600 + Abamectin 0.15 EC	4.25 ml/l + 0.31 ml/l	40 a[cd]	53 a	83 a	—	—	—
Diazinon AG600	4.25 ml/l	20 b	58 a	78 a	0 b	0 b	0 b
Acephate 75WP	0.8 g/l	5 bc	21 b	33 b	25 a	35 a	50 a
CGA293,343 25 WG + Emamectin Benzoate 5 SG +	0.16 ml/l 0.23 ml/l	0 c	0 c	22 bc	—	—	—
CGA293,343 25 WG	0.32 ml/l	0 c	5 bc	17 bcd	—	—	—
Pymetrozine 50 WG	0.19 g/l	5 bc	5 bc	5 cd	—	—	—
Abamectin 0.15 EC	0.31 ml/l	5 bc	5 bc	5 cd	—	—	—
Emamectin Benzoate 5 SG	0.23 ml/l	0 c	0 bc	0 cd	—	—	—
Pymetrozine 50 WG + Abamectin 0.15 EC	0.19 g/l + 0.31 ml/l	0 c	0 c	0 cd	—	—	—
Pymetrozine 50 WG + Emamectin Benzoate 5 SG	0.19 g/l + 0.23 ml/l	0 c	0 c	0 d	—	—	—
CGA293,343 25 WG + Abamectin 0.15 EC	0.16 ml/l + 0.31 ml/l	0 c	5 bc	0 cd	—	—	—
Untreated Check	0	0 c	0 bc	0 cd	0 b	0 b	0 b

[a]Silwet, an organosilicon wetting agent was added to all treatments at a rate of 1ml/liter of water.

[b]Leaves were harvested from plants with the respective treatments at 1- and 5-days-after-treatment and caged with individual grasshopper adults. Mortality of the grasshoppers was assayed after 24-, 48- and 72-hr exposure and feeding on the treated leaves.

[c]Analysis was made on arcsine transformation of the percent mortality data: percent mortality is presented.

[d]Means in a column not followed by the same letter are significantly different by Waller-Duncan k-ratio t-test (k = 100) (P = 0.05).

TABLE 2. CONTROL OF DIFFERENTIAL GRASSHOPPERS (*MELANOPLUS DIFFERENTIALIS*) WITH INSECTICIDES. TREATMENTS IN EXPERIMENT 2 APPLIED ON 24 SEPT. 1998 (5 REPS, EACH WITH 4 ADULT GRASSHOPPERS).

Treatment[a]	Rate (ml or g product/liter)	Exposed 1-DAT[b]			Exposed 5-DAT[b]			Exposed 11-DAT[b]		
		24hr	48hr	72hr	24hr	48hr	72hr	24hr	48hr	72hr
Bifenthrin 0.66F	0.782 ml/l	94.4 a[cd]	94.4 ab	100 a	40.0 ab	45.5 b	52.6 b	0 [nss]	0 [ns]	0 [ns]
Lambda-cyhalothrin 9.52WP	0.748 g/l	83.3 a	100 a	100 a	55.0 a	68.4 a	84.2 a	0	0	0
Bifenthrin 0.66F	0.391 ml/l	50.0 b	83.3 b	88.9 b	15.0 bc	15.0 c	26.3 cd	—	—	—
Acephate 75%S	0.803 g/l	33.3 bc	38.9 c	38.9 c	40.0 ab	45.5 b	45.5 bc	0	0	0
Deltamethrin 50SC	1.564 ml/l	16.7 cd	16.7 cd	16.7 d	5.0 c	10.5 c	26.3 cd	—	—	—
Deltamethrin 50SC	0.391 ml/l	0 d	0 d	0 d	0 c	10.5 c	26.3 cd	—	—	—
Carbaryl 4 SL	2.50 ml/l	0 d	0 d	0 d	0 c	0 c	5.3 d	—	—	—
Imadocropid 75WP	0.038 g/l	0 d	0 d	0 d	0 c	0 c	5.3 d	—	—	—
Untreated Check	0	0 d	0 d	0 d	0 c	0 c	0 d	0	0	0

[a]Silwet, an organosilicon wetting agent was added to all treatments at a rate of 1 ml/liter of water.

[b]Silwet, an organosilicon wetting agent was added to all treatments at a rate of 1 ml/liter of water. Leaves were harvested from plants with the respective treatments after 1-, 5-, and 11-days-after-treatment and caged with individual grasshopper adults. Mortality of the grasshoppers was assayed at 24-, 48- and 72-hr exposure and feeding on the treated leaves.

[c]Analysis was made on arcsine transformation of the percent mortality data: percent mortality is presented.

[d]Means in a column not followed by the same letter are significantly different by Waller-Duncan k-ratio t-test (k = 100) (P = 0.05).

100% control of the grasshoppers with 72 hr exposure. The half rate of bifenthrin (0.391 ml/liter) also provided 89% control with 72 hr exposure. Treatments with either diazinon AG600 (4.25 ml/liter) or diazinon AG600 (4.25 ml/liter) + abamectin 0.15 EC (Avid) (0.31 ml/liter) also provided 78-83% control with 72 hr exposure to the 1-DAT leaves (Table 1). Acephate 75% S (Orthene TTO) (0.803 g/liter) provided limited initial control (33-39%) (Table 2). Other treatments evaluated did not provide more than 22% control for the 1-day residue evaluation. Mortality at 96- and 120-hr was not significantly greater than for the 72-hr evaluation.

To determine residual control, leaves that had been treated 5 and 11 days earlier were also harvested and grasshoppers were caged on them. Lambda-cyhalothrin provided 84% control within 72 hr on the 5-DAT leaves. Both bifenthrin and acephate also provided residual control (53 and 46-50%, respectively) at 5 days. The increase in residual control for acephate, from 33- 39% at 1 day to 46-50% at 5 days could probably be attributed to its systemic action. None of the treatments provided any residual control when grasshoppers were exposed to 11-DAT leaves. No phytotoxicity to hibiscus was observed due to any of the treatments.

A higher level of control might have been achieved with these treatments if they were applied directly to the feeding grasshoppers or if the grasshoppers were immediately exposed to the treated foliage. Also, a higher level of control would be anticipated if the treatments were applied to the immature stages. It was the main purpose of these experiments, however, to evaluate the effect of these toxicants on grasshoppers that were migrating onto the treated plants. Only a limited percentage of the grasshopper population will actually be sprayed when the treatment is applied.

These experiments provide important management information for the nursery and landscape industries. These experiments show bifenthrin and lambda-cyhalothrin (both synthetic pyrethroids) and diazinon, each provide significant control of grasshoppers, even when they migrate onto the treated foliage a day after treatments are applied. This level of control may increase if the grasshoppers are directly contacted with the spray treatments. Bifenthrin, lambda-cyhalothrin and acephate also provided at least 5-day residual control for the differential grasshopper. By choosing one of the more residual chemicals, repeat applications should only be necessary every 5 days or even weekly to protect landscape plants. Each of the effective insecticides is labeled for grasshoppers and available for homeowner or commercial treatment of landscape plants.

This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or recommendation by the Texas A&M University Agriculture Program.

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POPULATION DYNAMICS OF THE RED WIDOW SPIDER (ARANEAE: THERIDIIDAE)

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ABSTRACT

Populations of the red widow spider, *Latrodectus bishopi*, in native Florida scrub at the Archbold Biological Station were monitored annually on ten ~0.5 ha transects in late winter from 1987 to 2000. Of 398 *L. bishopi* detected in the study, all but three had their silken retreats built in palmetto leaves. *L. bishopi* at rest in retreats in saw palmetto (*Serenoa repens*) were higher above the ground (~0.5 m) than spiders in scrub palmetto (*Sabal etonia*) (~0.3 m). From a peak of 31 spiders/ha in 1989, the average *L. bishopi* density declined exponentially to only 0.3 spiders/ha in 1997, after which *L. bishopi* densities began to recover. Burning of scrubby transects in spring or summer appeared to have no affect on subsequent *L. bishopi* populations. There were no significant correlations between *L. bishopi* population density and local temperature or precipitation data. These results suggest that undescribed biotic factors may regulate populations of the red widow spider in a density-dependent fashion.

Key Words: *Latrodectus*, Florida scrub, ecology, populations, dynamics, fire

RESUMEN

En diez transectos de ~0.5 ha, determinamos cada invierno de 1987-2000 las poblaciones de la araña *Latrodectus bishopi* en matorral nativo de Florida en la Estación Biológica Archbold. De las 398 *L. bishopi* que encontramos, todos menos tres habían construido sus retiros sedosus entre las ojas de palmitos. Las *L. bishopi* que reposan en el palmito *Serenoa repens* estan más alto (~0.5 m) que ellos que reposan en el palmito *Sabal etonia* (~0.3 m). El promedio densidad de *L. bishopi* disminuyó exponencialmente desde 31 arañas/ha en 1989 a 0.3 arañas/ha en 1997, despues de que las densidades de *L. bishopi* empezaban a recuperar. Quemando el matorral en la primavera o verano no afectó las poblaciones subsiguientes de *L. bishopi*. No había correlaciones significativas entre la densidad de *L. bishopi* y la temperatura o precipitación local. Los resultos sugieren que hay factores biológicos no describido que regular poblaciones de *L. bishopi* en una manera densidad-dependiente.

The red widow spider, *Latrodectus bishopi* Kaston 1938, is endemic to xeric, upland ecosystems found in Central and Southeastern Florida (Levi & Levi 1990; Edwards 1994). It is restricted to sand pine scrub and scrubby flatwoods in several counties that depend on periodic burning to maintain species diversity (McCrone & Levi 1964; McCrone & Stone 1965; Kaston 1970; Levi & Levi 1990; Abrahamson et al. 1984). Little is known about this rare spider. In large part this stems from the fact that it is difficult to find, even when it is locally abundant. Although *L. bishopi* builds a large tangled web on palmetto shrubs (McCrone & Levi 1964; Edwards 1994; Sierwald & Fenzl 1999), the very fine silk is not highly visible in bright sunlight. Furthermore, its funnel-shaped, silken retreat usually is hidden within a folded palmetto leaf (McCrone & Levi 1964; Sierwald & Fenzl 1999). Field biologists studying vertebrates at the Archbold Biological Station in Highlands County, Florida, have noticed that local populations of the *L. bishopi* seem to erupt every 10-20 years. Early reports suggested mild winters and periods of drought subsequently result in an increased abundance of spiders of the genus *Latrodectus* in many regions of the world (Chamberlain & Ivie 1935).

This study was undertaken in order to gain basic knowledge about the interannual population dynamics of *L. bishopi*. Specifically, I censused web-sites of subadult and adult female *L. bishopi* in ten replicate tracts of native scrub annually for twelve out of fourteen years in a row at the Archbold Biological Station to ascertain long-term changes in population density. I identified the plant species used for a retreat and twice during the study I measured the height of each spider's retreat above the ground as an indication of website preference by *L. bishopi*. In addition, I used a null model to test the short-term affect of fire on the density of *L. bishopi*. Finally, using weather data obtained from Archbold records, I tested whether density of *L. bishopi* is correlated in a simple way with temperature or precipitation.

MATERIALS AND METHODS

Study Area

The Archbold Biological Station is located near the southern terminus of the Lake Wales Ridge in Highlands County, Florida (27°11'N lat., 81°21'W long.), 12 km south of the town of Lake Placid.

The elevation of the study area ranges from approximately 38 to 46 m above mean sea level. The predominant vegetative associations in the study area are scrubby flatwoods, which are dominated by low shrubby oaks (*Quercus inopina*, *Q. chapmanii, Q. geminata*) and palmettos (*Serenoa repens* and *Sabal etonia*). Interspersed among the scrubby flatwoods to varying degrees are two other vegetative associations: sand pine scrub, with widely scattered stands of sand pine (*Pinus clausa*) and an understory of xerophytic shrubs, and flatwoods, with open stands of south Florida slash pine (*P. elliottii* var. *densa*) and an understory and ground cover of mesic grasses, herbs, saw palmetto (*Serenoa repens*), and assorted shrubs (Abrahamson et al. 1984).

Spider Censuses

In 1987 Mary Haskins, Zhaofen Yang, and I discovered that *L. bishopi* webs are easily seen and reliably identified from a distance of many meters at dawn on very foggy mornings because the dew-laden cobweb is highly reflective. Using this knowledge, I devised a drive-by method to census *L. bishopi* in scrub on the side of primitive, sandy roads that pass through the scrub. I established a total of ten permanent, roadside transects in scrub that had been burned in 1984 or 1985. Each transect extended 10 m from the road into the scrub and ranged in length from 375 to 730 m. The average area (±SE) of each transect was 0.55 ± 0.03 ha. At dawn on foggy mornings in late winter (February-early March), I drove slowly (1-3 km/h) in a light truck along the edge of each transect, looking from a height of ~2 m into the scrub for *L. bishopi* webs. Upon sighting a web, I stopped the truck, walked to the web, located the spider in its retreat, and marked the web-site with surveyor tape tied 1-2 m high on nearby vegetation. After repeating each drive-by survey three or four times within a 2 week period, I ceased to find additional webs. Subsequently during the daytime I revisited each *L. bishopi* web-site, carefully opened the retreat, noted whether it was occupied by an adult or an immature female, and recorded the species of plant used by a spider for its retreat. In 1989 and 1999 I also measured the height of *L. bishopi* retreats in the two species of palmettos.

To verify the efficacy of the drive-by method for detecting *L. bishopi* webs, in the second year of the study (1989) I walked through each transect during daytime (0900-1600 h) looking for *L. bishopi* webs several days before I began the drive-by censuses. I visually inspected the leaves of every palmetto within a transect at close range (< 1 m). If I found a *L. bishopi* web, I marked its location cryptically by burying a piece of surveyor tape in the sand near it in such a fashion that the tape was not visible from the nearby road. I spent a total of 30 h searching on foot and 20 h driving slowly looking for webs. After the drive-by survey was completed, I compared the number of *L. bishopi* webs detected by the two methods.

Representative specimens of *L. bishopi* were preserved in the collection of arthropods at Archbold. Statistical analyses were performed using SYSTAT (Wilkinson 1989).

Fire Affects on *L. bishopi* Populations

A record of the date, area, and location of fires on the main property at Archbold is kept as part of the fire management plan (Main & Menges 1997). In addition to burns in 1984 or 1985, eight of my transects were burned once and two transects were burned twice during the course of my study. To test the short-term affects of fire on local *L. bishopi* populations, I developed a null model against which to test the observed data. The null model posited that fire in late spring or summer would have no significant affect on *L. bishopi* spider densities determined several months later in winter. Hence, one would expect an equal proportion of transects (1/3) to show an increase, a decrease, or no change in density in winter after the burn event relative to the winter before the burn. The Fisher exact test was used to test the difference between observed and expected outcomes (Zar 1974).

Weather Affects on *L. bishopi* Populations

I conducted my censuses for twelve years (1987-2000, except for 1988 and 1991) late in winter when many of the native shrubs and trees began to flower or produce new foliage. I obtained weather records starting from the official weather center at Archbold, which has been in operation continuously since 1952. As an indicator of long-term climatic conditions that prevail at Archbold, I calculated the 30-year mean value (data for 1952-1981) and the 95% confidence interval (95% C.I.) for four weather parameters: mean daily temperature in winter (Jan., Feb., & Mar.), minimum winter temperature, total annual precipitation, and mean monthly precipitation in winter. Subsequently I compared the same four parameters for each year starting 1985 with the 30-year means to determine whether there were significant annual deviations during my study.

RESULTS

Comparison of Sampling Methods for *L. bishopi*

As summarized in Table 1, searching on foot during the daytime for *L. bishopi* web-sites in the scrub was very inefficient compared to the drive-by method conducted at dawn on foggy mornings. When I searched on foot in 1989, I found a total of

TABLE 1. COMPARISON OF TWO METHODS FOR FINDING WEB-SITES OF RED WIDOW SPIDERS (*LATRODECTUS BISHOPI*) (N = 168) IN 1989. INITIALLY ALL TEN TRANSECTS WERE SEARCHED ON FOOT DURING DAYTIME AND WEB-SITES WERE CRYPTICALLY MARKED. SUBSEQUENTLY THEY WERE CENSUSED AGAIN AT DAWN AND DEW-LADEN WEB-SITES WERE MARKED.

Transect number	Number of web-sites detected			
	On-foot search only	Drive-by search only	By both search methods	Total
1	4	22	28	54
2	1	2	10	13
3	0	0	0	0
4	2	3	5	10
5	1	7	3	11
6	1	8	4	13
7	0	4	0	4
8	1	13	2	16
9	3	14	4	21
10	4	10	12	26
Sum	17	83	68	168
Percent	10.1	49.4	40.5	100.0

85 L. *bishopi* on the ten transects, 68 of which I subsequently detected in the drive-by survey. On the other hand, I detected a total of 151 webs using the drive-by method, 68 of which I had previously found in my laborious searches on foot of the many palmettos in the transects. Hence, searching on foot was only about 50% effective whereas the drive-by method was about 90% effective for finding *L. bishopi*. The webs I missed using the drive-by method often were located low to the ground and on the side of a palmetto plant facing away from the road. Because the drive-by method seemed to be a reasonably accurate way of censusing *L. bishopi* populations, I adopted it throughout the remainder of the study.

Plants Used by *L. bishopi* for Web-sites

Of 398 *L. bishopi* detected in this study, 395 (99.2%) had their retreats located in leaves of palmettos. Two *L. bishopi* had retreats hidden beneath leaves of staggerbush, *Lyonia fruticosa* (Michx.) Torr. [Ericaceae] and a third spider was resting in a retreat spun under leaves of sand live oak, *Quercus geminata* Small [Fagaceae]; both plants are evergreen shrubs.

L. bishopi used saw palmettos (*Serenoa repens*) as web-sites much more often than scrub palmettos (*Sabal etonia*). As indicated in Table 2, 75-80% of *L. bishopi* webs in 1989 and 1999 were in saw palmettos and 20-25% were in scrub palmettos. Analysis of variance revealed that the height of a *L. bishopi* retreat off the ground was highly dependant on the palmetto species ($F = 21.36$, $P < 0.0001$), but not the year of sampling or the species*year interaction. On average *L. bishopi* retreats in saw palmettos were about 0.5 m above ground, whereas those in scrub palmettos were only 0.3 m above the sandy soil. Because the distance from a *L. bishopi* retreat to the top of a typical palmetto leaf was about 0.3-0.4 m (J. Carrel, unpublished data), this means that the maximal height of palmettos harboring *L. bishopi* generally was below 1.0 m.

TABLE 2. HEIGHT ABOVE GROUND (M) OF FEMALE RED WIDOW SPIDERS (*LATRODECTUS BISHOPI*) RESTING IN SILKEN RETREATS AS A FUNCTION OF THE PALMETTO SPECIES SELECTED FOR WEB CONSTRUCTION.[A]

Year	Saw palmetto (*Serenoa repens*)	Scrub palmetto (*Sabal etonia*)
1989	0.51 ± 0.02 [a]	0.32 ± 0.03 [b]
1999	0.47 ± 0.03 [a]	0.33 ± 0.04 [b]

[A] Means ± standard errors followed by the same letter are not significantly different by ANOVA followed by Tukey HSD test ($P \geq 0.05$).

Annual Changes in Density of *L. bishopi*

The density of *L. bishopi* declined one hundredfold from 1989 until 1998, but thereafter it began to increase (Fig. 1). The highest mean density (±SE), achieved in 1989, was 30.7 ± 8.1 *L. bishopi*/ha and the lowest mean density, achieved in 1997, was 0.27 ± 0.27 *L. bishopi*/ha. The decade-long decline in mean *L. bishopi* density was highly exponential. If Y = mean *L. bishopi* density

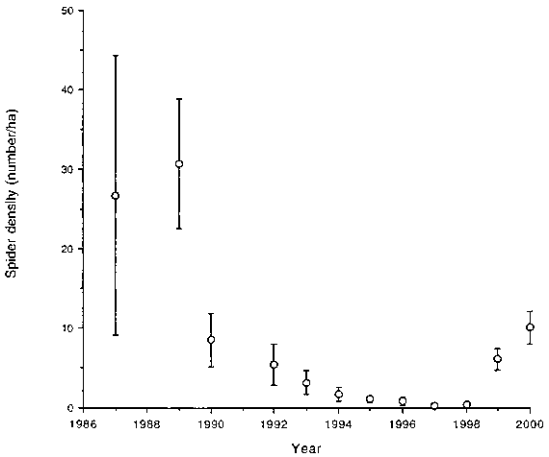

Fig. 1. Annual variation in density of red widow spiders (*Latrodectus bishopi*) at the Archbold Biological Station, Lake Placid, FL. Means ± standard errors are indicated (N = 10 permanent transects).

in year X, and X = 1 for the year 1989 and X = 10 in 1998, then the best fit regression equation is: $Y = 30.827\ (10^{-0.2332X})$ and the correlation coefficient is highly significant ($R = 0.977$, $df = 8$, $P < 0.0001$).

The steady increase in *L. bishopi* densities that occurred from 1998 to 2000 suggests that local spider populations may erupt in the near future. If this were to happen, then in 2003-2005 *L. bishopi* populations would resemble those found in 1987-1989.

Affect of Burning on *L. bishopi* Density

Burning of the scrub in late spring or summer had no affect on subsequent *L. bishopi* spider populations. The observed changes in *L. bishopi* density on any transect were identical to the expected values based on the null model. Of the 12 burn events on transects that happened in the course of this study, four corresponded with increases in *L. bishopi* density, 4 with decreases in *L. bishopi* density, and four with no change in *L. bishopi* density. These results are not very surprising considering the long period of time (~6-10 months) between the occurrence of a fire and my field measurements of spider densities. For example, the palmettos and some other shrubs had fully regenerated many new leaves by the time I conducted my censuses in winter.

Affect of Weather on *L. bishopi* Density

In 1987 and 1989 when *L. bishopi* densities were highest, temperatures were unusually cold (Fig. 2) and precipitation was normal in winter but relatively low during the remainder of the year (Fig. 3). However, in 1990 when *L. bishopi* densities fell greatly compared to the year before, conditions were unusually warm and somewhat dry. In fact, the minimum daily temperature in winter 1990 never dipped below 3.3°C, making this winter the least extreme on record at Archbold.

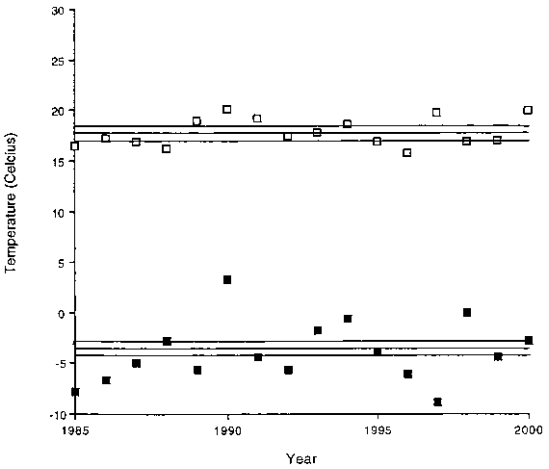

Fig. 2. Mean daily temperature in winter (open squares) and minimum temperature in winter (solid squares) from 1985 to 2000 at the Archbold Biological Station, Lake Placid, FL. Each set of three horizontal lines indicates the 30-year mean ± the 95% confidence interval for both types of data.

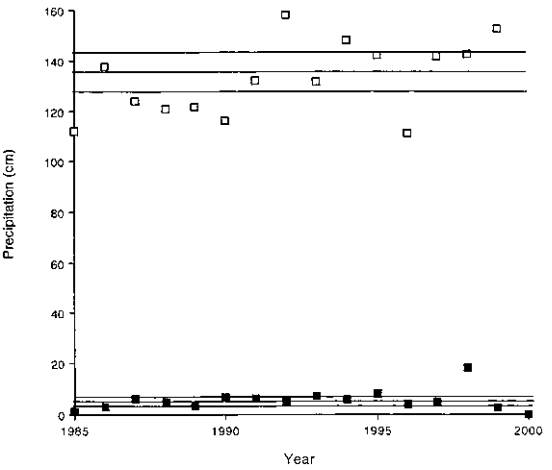

Fig. 3. Total annual precipitation (open squares) and mean monthly precipitation in winter (solid squares) from 1985 to 2000 at the Archbold Biological Station, Lake Placid, FL. Each set of three horizontal lines indicates the 30-year mean ± the 95% confidence interval for both types of data.

Annual *L. bishopi* density was not correlated ($r < 0.45$, $P > 0.05$, $df = 9$ or 10) with any of the temperature or precipitation indices I used (see Methods section). Hence, there was no evidence that weather limits *L. bishopi* populations in a straightforward fashion.

Discussion

Regulation of Spider Populations

Interannual variation in the density of spiders, like those of other animals, can be caused both by abiotic and by biotic factors (Price 1975;Watson & Ollason 1982; Askew & Yalden 1985; Gaston & McArdle 1993; Wise 1993). The lack of a significant correlation between *L. bishopi* density and temperature, precipitation, or fire events during my long-term, highly replicated study suggests that abiotic factors probably did not determine the pattern of change observed in *L. bishopi* populations. On the other hand, the exponential decline in spider densities from 1989 to 1998 implies that a density dependent mechanism might regulate *L. bishopi* populations.

Although there seem to be no long-term studies of population dynamics for any other *Latrodectus* species, there is good evidence that natural enemies commonly limit spider population densi-

ties (Wise 1993 and references therein). Candidate species that effectively prey in a density-sensitive fashion on immature and adult *L. bishopi* are the sphecid wasps *Chalybion californicum* and *Sceliphron caementarium* and the Florida scrub-jay *Aphelocoma coerulescens.* These three species are known to eat *L. bishopi* at Archbold (M. Deyrup and G. Woolfenden, unpublished observations) and, more generally, they are known to modify their feeding habits in response to changes in the relative abundance of prey (Coville 1987; Woolfenden & Fitzpatrick 1984). In addition, theridiid spiders of the genus *Argyrodes* living in *L. bishopi* webs may do more than act as kleptoparasites stealing the host's prey; these small spiders may prey on their hosts (Sierwald & Fenzl 1999). Finally, scelionid wasps of the genus *Idris* may contribute significantly to regulation of *L. bishopi* populations since these tiny animals could easily exhibit both functional and numerical responses as their food base changes. *Idris* is the largest genus of insects at Archbold, consisting of many undescribed species about which little is known except that they specialize in feeding on insect and spider eggs (M. Deyrup, unpublished results).

Site Selection by Widow Spiders

Results presented here indicate that *L. bishopi* strongly prefers saw palmetto (*Serenoa repens*) more than all other shrubs for web-sites. The cause of this preference is not clear. Whether chance or necessity determines habitat selection in web-building spiders has been investigated to a limited extent (Lubin et al. 1993; Wise 1993; Foelix 1996). Considering that palmettos comprise the dominant shrub type in burned scrub at Archbold and saw palmetto is much more common than scrub palmetto (*Sabal etonia*) (Abrahamson 1995), a fully probabilistic model for site selection might generate the observed *L. bishopi* web-site data.

Alternatively, a deterministic process of site selection by *L. bishopi* might involve two aspects of palmetto architecture. First, there is a major difference in the patterns of growth between the two palmetto species. The central axes of saw palmetto leaves originate in expanded basal sheaths extending upward from terminal tufts on horizontal stems just above or at the soil surface, whereas scrub palmetto leaves arise on axes extending up from subterranean stems. *L. bishopi* females occasionally use the tubular spaces in leaf bases of saw palmettos for their retreats, which they cannot do with scrub palmettos. Perhaps young *L. bishopi*, as they disperse from their natal web and actively search for protected sites near the soil surface, preferentially select the terminal tufts on saw palmettos and then tend to remain there as they grow and mature.

Second, saw palmettos consistently have more leaves packed densely in narrower crowns than scrub palmettos. Consequently, saw palmetto leaves often overlap and self-shade (Abrahamson 1995). This suggests that the arrangement of saw palmetto leaves may offer *L. bishopi* more protection from enemies and from thermal extremes than scrub palmetto leaves. Lubin et al. (1993) reported comparable evidence for the desert widow spider, *L. revivensis*: selection of larger shrubs in the Negev desert improves spider survival, growth, and reproductive success. But the cost of moving to new web-sites for desert widow spiders is high (40%) mortality. Experiments designed to determine mechanisms and the cost/benefit ratio of web-site selection by *L. bishopi* in Florida scrub are in progress.

Implications for Conservation of Rare Spiders

The *L. bishopi* is restricted to scrub habitats that are remnants of ancient islands in peninsular Florida, now recognized collectively as a major site of biotic endemism (Deyrup & Eisner 1993). But Florida scrub is threatened by loss of habitat resulting from rapid development and by fragmentation that limits gene flow and heightens the probability of extinction in local populations. Recently Skerl (1999) recommended that spiders which are naturally rare because they have highly restricted ranges might be listed nationally as "species of conservation concern," even if they are locally abundant. In addition, Skerl and Gillespie (1999) advocated targeting for conservation action spiders with narrow habitat requirements, limited dispersal abilities, restricted ranges, and immediate threats. *L. bishopi* seems to meet all of their criteria. Hence, I suggest that *L. bishopi* be listed as a species of conservation concern and that its populations be surveyed in peninsular Florida in order to determine the limits of its distribution.

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COMPARATIVE RESIDUAL TOXICITIES OF PESTICIDES TO THE PREDATOR *EUSEIUS MESEMBRINUS* (ACARI: PHYTOSEIIDAE) ON CITRUS IN FLORIDA

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ABSTRACT

Residual toxicities of registered and selected experimental pesticides used on citrus against *Euseius mesembrinus* (Dean) (Acari: Phytoseiidae) were compared. A tractor-drawn airblast sprayer calibrated to deliver 2,338 liters/ha was used to apply pesticides at one or more recommended rates on mature 'Ruby Red' grapefruit trees. Pesticides rated as highly toxic were: azinphos-methyl 50WP at 4.48 kg/ha, dicofol 4EC at 7.01 liters/ha, formetanate 92SP at 5.84 kg/ha, dimethoate 4EC at 5.85 liters/ha, malathion 57EC at 5.85 liters/ha, propargite 6.55EC at 3.51 liters/ha, benomyl 50WP at 1.68 kg/ha + ferbam 76GF at 5.60 kg/ha, ferbam 76GF at 16.81 kg/ha, carbaryl XLR plus at 18.7 liters/ha + FC435-66 petroleum oil at 46.8 liters/ha, pyridaben 75WP at 462 g/ha + FC435-66 petroleum oil at 46.8 liters/ha, carbaryl 80S at 11.21 kg/ha, ethion 4EC at 7.01 liters/ha + FC435-66 petroleum oil at 46.8 liters/ha, benomyl 50WP at 3.36 kg/ha, chlorfenapyr 2SC at 1.46 liters/ha, and pyridaben 75WP at 462 g/ha. Pesticides that were moderately to slightly toxic were: sulfur 80DF at 16.81 kg/ha, abamectin 0.15EC at 731 ml/ha + FC435-66 petroleum oil at 46.8 liters/ha, chlorfenapyr 2SC at 971 ml/ha + FC435-66 petroleum oil at 46.8 liters/ha, FC435-66 petroleum oil at 93.5 liters/ha, and chlorpyrifos 4EC at 5.85 liters/ha. Pesticides that were considered non-toxic were: FC435-66 petroleum oil at 46.8 liters/ha, carbaryl 80S at 4.48 kg/ha, chlorfenapyr 2SC at 971 ml/ha, chlorpyrifos 4EC at 5.85 liters/ha, fenbuconazole 2F at 292 ml/ha + FC435-66 petroleum oil at 46.8 liters/ha, copper hydroxide 77WP at 4.48 kg metallic/ha, benomyl 50WP at 3.36 kg/ha, and fenbuconazole 2F at 584 ml/ha. Ferbam 76GF at 16.81 kg/ha, benomyl 50WP + ferbam 76GF, carbaryl 80S at 11.21 kg/ha, carbaryl XLR Plus + FC435-66 petroleum oil, and benomyl 50WP at 3.36 kg/ha had significantly higher numbers of missing females from treated leaf surfaces suggesting these products were repellent, irritating, and/or excitatory to the gravid females.

Key Words: Acaricides, fungicides, insecticides, integrated pest and disease management, toxicity, non-target arthropods

RESUMEN

Toxicidad residual de pesticidas registrados y experimentales selectos usados en cítricos contra Euseius mesembrinus (Dean) (Acari: Phytoseiidae) fueron comparados. Una asperjadora de aire a presión y halada por un tractor, calibrada para entregar 2,338 litros/ha fue usado para aplicar pesticidas a una o mas dosis recomendadas en árboles de toronja 'Ruby Red'. Pesticidas clasificados como altamente tóxicos fueron: azinphos-methyl 50WP a 4.48 kg/ha, dicofol 4EC a 7.01 litros/ha, formetanate 92SP a 5.84 kg/ha, dimethoate 4EC a 5.85 litros/ha, malathion 57EC a 5.85 litros/ha, propargite 6.55EC a 3.51 litros/ha, benomyl sowr a 1.68 kg/ha + ferbam 76GF a 5.60 kg/ha, ferbam 76GF a 16.81 kg/ha, carbaryl XLR plus a 18.7 litros/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, pyridaben 75WP a 462 g/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, carbaryl 80S a 11.21 kg/ha, ethion 4EC a 7.01 litros/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, benomyl 50 WP a 3.36 kg/ha, chlorfenapyr 2SC a 1.46 litros/ha, y pyridaben 75WP a 462 g/ha. Pesticidas que fueron moderadamente o levemente tóxicos eran: azufre 80DF a 16.81 kg/ha, abamectin 0.15EC a 731 ml/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, chlorfenapyr 2SC a 971 ml/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, FC435-66 aceite de petróleo a 93.5 litros/ha, y chlorpyrifos 4EC a 5.85 litros/ha. Pesticidas considerados no tóxicos fueron: FC435-66 aceite de petróleo a 46.8 litros/ha, carbaryl 80S a 4.48 kg/ha, chlorfenapyr 2SC a 971 ml/ha, chlorpyrifos 4EC a 5.85 litros/ha, fenbuconazole 2F a 292 ml/ha + FC435-66 aceite de petróleo a 46.8 litros/ha, hidróxido de cobre 77WP a 4.48 kg metalico/ha, benomyl 50WP a 3.36 kg/ha, y fenbuconazole 2F a 584 ml/ha. Ferbam 76GF a 16.81 kg/ha, benomyl 50WP + ferbam 76GF, carbaryl 80S a 11.21 kg/ha, carbaryl XLR Plus + FC435-66 aceite de petróleo, y benomyl 50WP a 3.36 kg/ha tuvieron números significativamente mas altos de hembras ausentes de superficies de hojas tratadas sugiriendo que estos productos fueron repelentes, irritantes, y/o excitatorio a las hembras grávidas.

Citrus is a multi-billion dollar agricultural business in Florida that annually provides 70-80% of the total United States production (Anonymous 1996). Of this, 85% of the Florida crop is used in processing (i.e., juice, sections, pulp) with the balance for fresh market. The pest mite complex on Florida citrus is diverse and includes species in four acarine families: Eriophyidae, Tetranychidae, Tarsonemidae, and Tenuipalpidae (Childers 1994). The citrus rust mite *Phyllocoptruta oleivora* (Ashmead), the pink citrus rust mite *Aculops pelekassi* (Keifer) (Eriophyidae), and several spider mite species, primarily the Texas citrus mite, *Eutetranychus banksi* (McGregor) are important. Approximately 171 million dollars are spent annually by farmers in Florida for chemical control of these mites including the combined costs of chemicals and application equipment, based on estimates for Central, East Coast and Southwest Florida (Muraro & Hebb 1997, Muraro et al. 1997a, Muraro et al. 1997b). Historically, this has been one of the largest commodity markets for acaricide usage within the United States with 2-3 applications per hectare per year on 346,823 hectares of trees (Childers 1994). Citrus rust mites and the fungal pathogen greasy spot, *Mycosphaerella citri* Whiteside, are recognized as key fruit and foliar pests on Florida citrus, respectively. Control recommendations currently rely solely on pesticides for both key pests (Childers et al. 2000a, Roberts & Timmer 2000). Increasing urbanization, the public's concern over pesticide use on food products, increased application and chemical costs, sustaining competitive food exports to foreign markets and compliance with the Food Quality Protection Act of 1996 dictate the need for alternative control strategies.

Because of climatic conditions that exist in Florida, the fungal pathogens: e. g., greasy spot, melanose, *Diaporthe citri* Wolf, citrus scab, *Elsinoe fawcettii* Bitancourt and Jenkins, alternaria brown spot, *Alternaria* sp. and postbloom fruit drop disease, *Colletotrichum acutatum* J. H. Simmonds, are important disease problems for many citrus growers. Current fungicides recommended for these diseases are limited to ferbam, benomyl, ferbam + benomyl, copper formulations applied alone or in combination with petroleum oil, or petroleum oil applied alone (Roberts & Timmer 2000, Timmer 2000a,b,c, McMillan et al. 2000).

Arthropod predators and parasitoids are the most important naturally occurring biological control agents of arthropods in most agroecosystems (Croft 1990). Predacious mites are recognized as highly important in regulating phytophagous mites on citrus worldwide (Keetch 1972, Ferragut et al. 1987, Papacek & Smith 1992, McMurtry & Croft 1997) and Florida citrus has a rich fauna of both predacious and other beneficial mites (Muma 1975). On-going research has identified species within several mite families that have potential in suppressing citrus rust mites and spider mites (Childers 1994, Childers & Abou-Setta 1999; C. C. C., unpublished data). However, little information on comparative toxicities of registered or experimental pesticides to predacious mites on Florida citrus has been available. Such information is essential in developing an effective integrated pest and disease management program.

This study was initiated to assess direct and indirect residual toxicities of different pesticides either registered for use on Florida citrus or being developed for registration as insecticides, acaricides or fungicides. The pesticides were applied and weathered in the field against the predacious mite, *Euseius mesembrinus* (Dean), a prevalent phytoseiid species that feeds on spider mites and other mite species on Florida and Texas citrus (Abou-Setta et al. 1991; C. C. C., unpublished data). Different pesticides were applied and weathered in the field to assess their impact on gravid females, oviposition, and survival of eclosing larvae.

Materials and Methods

Field Application

Four series of field applications were completed between August and September 1997 in a 4 hectare block of 'Ruby red' grapefruit located at the Citrus Research and Education Center in Lake Alfred, Florida. The treatment trees were healthy, vigorous and measured 3.2 to 3.9 m tall and 3.9 to 5.2 m in diameter. Trees were spaced 7.47 m within the row and 8.11 m between rows (= 187 trees/ha). Different trees were selected for each of the series of pesticide treatments with a minimum of four trees separating single tree treatments within the row and with two buffer rows between treatment rows.

Treatments were applied using a tractor-drawn FMC 352 airblast sprayer beginning each morning after the citrus leaves had dried. The sprayer was calibrated to deliver 2,338 liters of spray/ha. Each single tree treatment was sprayed while traveling at 2.4 km/h. Tractor speed was properly adjusted several tree spacings ahead of the sample tree before engaging the sprayer on either side within the rows. The pesticides, application dates, water pH, formulations, and rates per hectare are shown in Table 1. FC435-66 represents a medium, narrow-range petroleum oil with a mid-distillation temperature of 224°C (= 435°F) that meets the designated Florida citrus standards established by Simanton & Trammel (1966). T-Mulz (Harcros Chemicals, Inc., Kansas City, KS), a non-ionic surfactant, was mixed at 10 ml per liter of petroleum oil as the emulsifier. Pesticides tested are registered for use on Florida

TABLE 1. SERIES OF PESTICIDES, APPLICATION DATES, WATER PH, FORMULATIONS, AND RATES PER HECTARE.

Series	Date of application and water pH	Pesticide common name and use[a]		Manufacturer	Pesticide trade name	Formulation[b]	Rate used in 2.34 k liters/ha
I	11 August—pH 7.5	1. Copper hydroxide	F	Griffin Corp. Valdosta, GA	Kocide 101	77WP (50% metallic)	4.48 kg metallic
		2. Copper sulfate	F	Cuproquim Corp. Memphis, TN	Copper 53	98% (53% metallic)	4.48 kg metallic
		3. Fenbuconazole (RH-7592)	F	Rohm and Haas Co. Philadelphia, PA	Enable	2F	584 ml
		4. Fenbuconazole (RH-7592) + petroleum oil	F F, A, I	 Exxon Co., Houston, TX	Enable Orchex 796	2F FC435-66	292 ml 46.8 liters
		5. Benomyl	F	E. I. DuPont de Nemours Wilmington, DE	Benlate	50WP	3.36 kg
		6. Ferbam	F	UCB Chemical Smyrna, GA	Ferbam	76GF	16.81 kg
		7. Benomyl + ferbam	F F		Benlate + Ferbam	50WP 76GF	1.68 kg 5.60 kg
		8. Chlorpyrifos	I	Dow Elanco Indianapolis, IN	Lorsban	4EC	5.85 liters
		9. Sulfur	A	BASF Research Triangle Park, NC	Kumulus	80DF	16.81 kg
		10. Untreated		—	—	—	—
II	18 August—pH 7.3	1. Pyridaben	A	BASF	Nexter	75WP	462 g
		2. Pyridaben + petroleum oil	A F, A, I		Nexter + Orchex 796	75WP FC435-66	462 g 46.8 liters
		3. Abamectin + petroleum oil	A, I F, A, I	Novartis Greensboro, NC	Agri-mek + Orchex 796	0.15EC FC435-66	731 ml 46.8 liters
		4. Chlorfenapyr	A,I	American Cyanamid Co. Princeton, NJ	Alert	2SC	971 ml
		5. Chlorfenapyr + petroleum oil	A,I F, A, I		Alert + Orchex 796	2SC FC435-66	971 ml 46.8 liters
		6. Petroleum oil	F, A, I		Orchex 796	FC435-66	46.8 liters
		7. Petroleum oil	F, A, I		Orchex 796	FC435-66	93.5 liters
		8. Untreated	—	—	—	—	—
III	19 August—pH 7.5	1. Carbaryl	I	Rhone Poulenc Research Triangle Park, NC	Sevin	80S	4.48 kg

[a]A = acaricide, F = fungicide, I = insecticide.
[b]WP = wettable powder, F = flowable, GF = granular flowable, EC = emulsifiable concentrate, SC = soluble concentrate, S, SP = soluble powder, FC 435-66 = Florida citrus 435 oil (Simanton and Trammel 1966), DF = dispersible flowable.

TABLE 1. (CONTINUED) SERIES OF PESTICIDES, APPLICATION DATES, WATER PH, FORMULATIONS, AND RATES PER HECTARE.

Series	Date of application and water pH	Pesticide common name and use[a]		Manufacturer	Pesticide trade name	Formulation[b]	Rate used in 2.34 k liters/ha
		2. Carbaryl	I		Sevin	80S	11.21 kg
		3. Azinphos-methyl	I	Bayer Corp. Kansas City, MO	Guthion	50WP	4.48 kg
		4. Formetanate	A, I	Agro Evo, Wilmington, DE	Carzol	92SP	1.12 kg
		5. Carbaryl	I	Rhone Poulenc	Sevin	XLR Plus 41.2%	18.7 liters
		+ petroleum oil	F, A, I		+ Orchex 796	AI FC435-66	46.8 liters
		6. Dimethoate	I	Platte Chemical Co. Fremont, NE	Dimethoate	400	5.85 liters
		7. Malathion	I	Platte Chemical Co. Fremont, NE	Malathion	57EC	5.85 liters
		8. Dicofol	A	Platte Chemical Co. Fremont, NE	Dicofol	4EC	7.01 liters
		9. Propargite	A	Uniroyal Chemical Co., Middlebury, CT	Comite	6.55EC	3.51 liters
		10. Untreated	—	—	—	—	—
IV	8 September — pH N/A	1. Benomyl	F		Benlate	50WP	3.36 kg
		2. Ferbam	F		Ferbam	76GF	16.81 kg
		3. Chlorpyrifos	I		Lorsban	4EC	5.85 liters
		4. Ethion	A, I	FMC Corp. Philadelphia, PA	Ethion	4EC	7.01 liters
		+ petroleum oil					
		5. Chlorfenapyr	A, I		Alert	2SC	1.46 liters
		6. Chlorfenapyr	A, I		Alert	2SC	971 ml
		+ petroleum oil	F, A, I		+ Orchex 796	FC435-66	46.8 liters
		7. Formetanate	A, I		Carzol	92SP	1.12 kg
		8. Dicofol	A	Platte Chemical Co. Freemont, NE	Dicofol	4EC	7.01 liters
		9. Untreated	—		—	—	—

[a]A = acaricide, F = fungicide, I = insecticide.
[b]WP = wettable powder, F = flowable, GF = granular flowable, EC = emulsifiable concentrate, SC = soluble concentrate, S, SP = soluble powder, FC 435-66 = Florida citrus 435 oil (Simanton and Trammel 1966), DF = dispersible flowable.

citrus except chlorfenapyr (4-Bromo-2-(4-chlorphenyl)-1(ethoxymethyl)-5-(trifluoromethyl) pyrrole-3-carbonitrile), an experimental acaricide of American Cyanamid Co., Princeton, NJ and fenbuconazole (RH-7592), alpha [2-(4-chlorophenyl) ethyl]-alpha-phenyl-1H-1,2,4-triazole-1-propanenitrile, an experimental fungicide of Rohm and Haas Co., Philadelphia, PA. The acaricides, insecticides, or fungicides are used to control one or more arthropod or fungal disease pests included in the Florida Pest Management Guide (Childers et al. 2000a, b; Browning et al. 2000; Roberts & Timmer 2000). Daily maximum-minimum air temperatures and rainfall data during the test intervals between application and completion of leaf sampling for each series of pesticides are listed in Table 2.

Field Sampling

Sixteen or more hardened spring flush leaves were collected at random from the outer exposed canopy around each sample tree at waist to chest height (1.2 to 1.6 m) one and 4 days after each series of pesticide treatments was applied during 1997. Leaves were always collected first from the unsprayed check trees for each treatment series. Disposable rubber gloves were changed between treatments both in the field and laboratory to avoid potential contamination. Individual dry leaves were collected into a paper bag by picking the leaf at the base of the petiole without touching the leaf surface. Each paper bag was then placed on the floor of the air conditioned vehicle out of direct sunlight. Sampling in the field and travel time required less than 1 h before returning to the laboratory for processing.

TABLE 2. MAXIMUM-MINIMUM AIR TEMPERATURES AND RAINFALL DURING THE TEST INTERVALS IN 1997.

Series	Date	Temperature °C		Rainfall (mm)
		Max	Min	
I	11 August	34	22	35
	12	34	22	
	13	36	24	
	14	37	23	6
	15	34	23	
	16	35	22	25
	17	34	22	
II	18	36	22	
III	19	36	23	
	20	36	26	
	21	35	24	
	22	36	22	6
	23	34	19	
	24	34	21	
	25	36	20	
IV	8 September	33	17	
	9	33	17	
	10	34	20	
	11	34	20	3
	12	33	21	
	13	34	19	
	14	36	20	

Laboratory Preparation

Untreated check leaves were always processed first. Leaves from each treatment were removed from a paper bag and briefly placed on a clean paper surface. Leaves for that treatment were then individually selected and prepared for single whole leaf arenas. Contact with treated leaf surfaces was avoided as much as possible. Six leaves (= 6 treatment replicates) were selected per treatment based on size, vigor and minimal leaf blemishes. Individual leaf arenas were prepared with the lower leaf surface facing up based on established methods for rearing phytoseiid mites (Abou-Setta & Childers 1987a). An aluminum foil sheet was placed beneath the foam padding to prevent contact of water with the plastic container and to avoid potential contamination. A filter paper was placed over the foam pad and the leaf arena was then placed over the filter paper. The sides and petiole areas of each whole leaf were covered with absorbent cotton stripping to keep the leaf in position and provide a non-toxic wet barrier to minimize escape of the gravid females. Treated leaf arenas were maintained in the laboratory between 26 and 28°C and held in open boxes to assure adequate ventilation.

Mite Cultures

Euseius mesembrinus was collected from Central Florida citrus groves in the Winter-Spring of 1997, maintained in culture on leaf arenas and fed ice plant, *Malephora crocea* (Jacquin) pollen (Abou-Setta & Childers 1987b).

Large numbers of both *E. mesembrinus* males and females were transferred to several new untreated rearing leaf arenas and held for 24 h to deposit a cohort of eggs ± 12 h old. The following day, all motile mites were removed from the leaf arenas and the eggs were allowed to develop. Gravid *E. mesembrinus* females were then collected from the arenas after 9-10 days (Abou-Setta & Childers 1987b). Cotton fibers were placed on the surface of each leaf for use as an oviposition substrate along with a piece of black construction paper about 4 mm wide by 8-10 mm long that served as a refuge for aggregation. A total of 10 gravid females were transferred individually using a 5-0 sable brush directly onto the black construction paper of each replicated arena to avoid contaminating the brush with pesticides.

The mites were checked to ensure that they were not injured during transfer and any that appeared injured were immediately replaced.

Laboratory Assessment

Each arena was examined 72 h after infestation to determine mortality of gravid females. Three categories were recorded for adults: dead, alive, or missing. A mite was considered dead if it was unable to move forward. In addition, number of live eggs per arena was recorded after 72 h. Eggs were recorded as live when their size, opaque color and oblong-oval shape were consistent. Live larvae or protonymphs per arena were recorded after 72 h.

Statistical Analysis

All data on surviving or missing adults, oviposition and surviving immatures were analyzed in each experiment by analysis of variance (ANOVA) and means were separated using LSD (GLM procedures, SAS Institute 1991). Means and standard errors reported here were calculated using non-transformed data.

Results and Discussion

Maximum air temperatures in the field during the 1997 experiment ranged from 33 to 37°C and two significant rains of 35 and 25 mm occurred on 11 and 16 August, respectively, during evaluation of series I pesticides (Table 2). The 11 August rain occurred about 2 h after the last treatment applications (treatments 3 and 4 in series I).

Gravid Females

Pesticides that resulted in less than 30% survival of gravid female *E. mesembrinus* included: azinphos-methyl, dicofol, malathion, propargite, formetanate, dimethoate, propargite, benomyl + ferbam, ferbam, carbaryl XLR + petroleum oil, pyridaben + petroleum oil, cabaryl 80S at 11.21 kg/ha, ethion + petroleum oil, benomyl, chlorfenapyr and pyridaben (Table 3). Pesticides that remained highly toxic to gravid females when exposed to 4-day-old field treated leaves were: azinphos-methyl, dicofol, formetanate, ferbam and pyridaben + petroleum oil. Use of formetanate in three different treatment regimes in a field experiment on 'Tahiti' limes significantly reduced populations of *Typhlodromalus peregrinus* (Muma) (Acari: Phytoseiidae) for over 2 months following the last applications (Childers & Abou-Setta 1999). Subsequent feeding injury from elevated populations of citrus red mite, *Panonychus citri* (McGregor) in this experiment resulted in economic loss to the grower. Most of the same pesticides were shown to be toxic to *Euseius hibisci* (Chant) in California by Jeppson et al. (1975).

Pesticides listed in Table 4 had significantly higher numbers of missing *E. mesembrinus* females from treated leaf surfaces compared to the untreated checks and other treatments tested. Mites could not be found on the treated leaf arenas, cotton pad strips surrounding each treated leaf surface or on the water saturated sponge beneath the leaf. The gravid females were presumed to have escaped the arena since no visible cadavers or injured mites remained. We suspect that these products were repellent, irritating, and/or excitatory to gravid females.

Fecundity

Pesticides that were not toxic to gravid females but resulted in a 50% or greater reduction in egg production after one day post treatment included: sulfur and benomyl (Table 3). The untreated check from series I had low numbers of eggs produced in the 4 day post spray evaluation. Egg production was significantly lower compared to several other treatments in that series except copper hydroxide, chlorpyrifos, or copper sulfate. None of these treatments had significantly lower egg production in the 1 day postspray series (Table 3).

Larval Survival

Pesticides that were not toxic to gravid females but resulted in a 50% or less reduction in larvae included: abamectin + FC435-66 petroleum oil after one day and benomyl or chlorfenapyr + FC435-66 petroleum oil after 4 days compared with the untreated checks.

Comparative Toxicities

Our data often showed differential toxicity to various life stages of *E. mesembrinus*. Therefore, a simple method to compare toxicities between pesticides was used where ($\bar{x}$ number of surviving gravid females) × ($\bar{x}$ number of live eggs produced/arena) × ($\bar{x}$ number of live larvae) were multiplied. The lower the value obtained the more toxic was the pesticide. Based on these criteria, pesticides evaluated in this study were determined to be highly toxic with values below 200, moderately toxic with values between 200 and 400 and slightly to non-toxic with values greater than 400 (Table 5).

Phytoseiid mites in the genus *Euseius* are recognized as facultative pollen feeders (McMurtry 1992). However, *E. hibisci* (Chant) was shown to feed on avocado leaf sap but not on lemon using radioactive phosphoric acid (Porres et al. 1975). Subsequent studies failed to indicate whether this feeding was restricted to the larval stage or all motile stages of the mite. Abou-Setta & Childers (1987b) reported that *E. mesembrinus*

TABLE 3. *EUSEIUS MESEMBRINUS* GRAVID FEMALE SURVIVAL, EGG PRODUCTION AND LIVE IMMATURES ($\bar{X}$ ± SE) 72 H AFTER INFESTATION ON LEAVES 1 AND 4 DAYS FOLLOWING SPRAY APPLICATION.

Series	Pesticide formulation	Rate per ha	1 day			4 days		
			Surviving ♀♀	Live eggs	Live immatures	Surviving ♀♀	Live eggs	Live immatures
I	1. Copper hydroxide 77WP	4.48 kg metallic	9.6 ± 0.2 a	12.3 ± 1.9 bc	6.3 ± 0.9 abcd	7.5 ± 0.6 ab	2.3 ± 1.0 d	4.0 ± 0.3 bc
	2. Copper sulfate 98%	4.48 kg metallic	9.1 ± 0.4 a	13.5 ± 0.9 bc	6.9 ± 0.7 ab	7.9 ± 1.7 a	3.4 ± 1.6 cd	3.5 ± 0.6 bc
	3. Fenbuconazole 2F	584 ml	8.8 ± 0.4 a	21.3 ± 2.4 a	7.1 ± 0.5 a	9.0 ± 0.5 a	13.8 ± 2.9 a	7.4 ± 1.0 a
	4. Fenbuconazole 2F + petroleum oil FC435-66	292 ml 46.8 liters	8.9 ± 0.4 a	14.8 ± 1.0 abc	5.5 ± 1.2 abcde	8.6 ± 0.7 a	13.8 ± 1.9 a	3.4 ± 0.9 bc
	5. Benomyl 50WP	3.36 kg	9.6 ± 0.2 a	10.6 ± 2.3 c	7.6 ± 1.0 a	9.8 ± 0.2 a	2.0 ± 1.1 d	4.8 ± 0.8 b
	6. Ferbam 76GF	16.81 kg	2.6 ± 1.3 b	2.8 ± 1.7 e	3.8 ± 0.9 e	2.4 ± 1.1 c	1.5 ± 0.8 d	2.9 ± 0.9 c
	7. Benomyl 50WP + ferbam 76GF	1.68 kg 5.60 kg	2.9 ± 1.2 b	1.9 ± 1.0 e	3.9 ± 0.9 de	5.9 ± 1.4 b	4.3 ± 2.0 cd	4.4 ± 0.4 bc
	8. Chlorpyrifos 4EC	5.85 liters	9.4 ± 0.3 a	15.4 ± 2.5 abc	4.4 ± 0.7 bcde	8.1 ± 0.5 a	7.4 ± 1.9 bc	3.8 ± 0.8 bc
	9. Sulfur 80DF	16.81 kg	8.5 ± 0.6 a	5.9 ± 2.0 d	4.1 ± 0.8 cde	9.5 ± 0.3 a	11.4 ± 1.3 ab	5.0 ± 0.7 ab
	10. Untreated	—	9.0 ± 0.5 a	15.8 ± 1.1 ab	6.9 ± 1.2 abc	8.1 ± 0.4 a	3.6 ± 1.3 cd	3.9 ± 0.7 bc
II	1. Pyridaben 75WP	462 g	7.1 ± 0.9 ab	6.4 ± 1.8 bc	3.6 ± 0.7 ab	9.3 ± 0.3 a	3.0 ± 0.7 bc	6.4 ± 1.1 d
	2. Pyridaben 75WP + petroleum oil FC435-66	462 g 46.8 liters	5.4 ± 1.5 b	4.8 ± 1.7 c	1.3 ± 0.6 c	8.4 ± 0.5 a	0.4 ± 0.4 d	7.6 ± 0.8 cd
	3. Abamectin 0.15EC + petroleum oil FC435-66	731 ml 46.8 liters	8.8 ± 0.3 a	11.1 ± 1.8 ab	2.5 ± 0.6 bc	9.5 ± 0.2 a	3.8 ± 0.6 ab	6.4 ± 0.8 d
	4. Chlorfenapyr 2SC	971 ml	8.3 ± 0.8 a	14.6 ± 2.5 a	4.9 ± 1.1 ab	9.1 ± 0.5 a	6.0 ± 0.7 a	12.3 ± 1.0 ab
	5. Chlorfenapyr 2SC + petroleum oil FC435-66	971 ml 46.8 liters	7.0 ± 1.4 ab	11.0 ± 2.3 ab	4.0 ± 1.3 b	9.0 ± 0.2 a	3.0 ± 0.7 bc	10.1 ± 0.7 abc
	6. Petroleum oil FC435-66	46.8 liters	8.5 ± 0.9 a	17.1 ± 2.9 a	3.4 ± 0.8 b	8.9 ± 0.3 a	4.6 ± 0.8 ab	7.9 ± 0.6 cd
	7. Petroleum oil FC435-66	93.5 liters	8.9 ± 0.4 a	12.4 ± 2.2 a	3.4 ± 1.0 b	9.5 ± 0.2 a	4.9 ± 1.0 ab	9.5 ± 1.0 bc
	8. Untreated	—	9.1 ± 0.2 a	12.6 ± 1.1 a	6.3 ± 0.6 a	9.6 ± 0.2 a	4.4 ± 0.7 ab	3.9 ± 0.8 e
III	1. Carbaryl 80S	4.48 kg	9.3 ± 0.4 a	10.0 ± 1.7 a	6.0 ± 0.8 a	8.8 ± 0.3 a	13.0 ± 1.9 a	4.9 ± 0.4 bc
	2. Carbaryl 80S	11.21 kg	4.5 ± 0.8 b	2.1 ± 1.1 b	4.9 ± 0.7 a	8.0 ± 0.6 ab	7.0 ± 1.5 a	4.1 ± 0.6 c
	3. Azinphos-methyl 50WP	4.48 kg	0 ± 0 d	0 ± 0 c	0 ± 0 c	0 ± 0 d	0 ± 0 d	0 ± 0 e
	4. Formetanate 92SP	1.12 kg	0 ± 0 d	0 ± 0 c	0 ± 0 c	0 ± 0 d	0 ± 0 d	0 ± 0 e
	5. Carbaryl-XLR plus 41.2% ai + petroleum oil FC435-66	18.7 liters 46.8 liters	3.8 ± 0.8 b	2.9 ± 0.9 b	2.8 ± 0.8 b	9.3 ± 0.3 a	13.8 ± 1.6 a	4.9 ± 0.4 bc

Means within each column within each series followed by the same letter are not significantly different ($P \geq 0.05$).

TABLE 3. (CONTINUED) *EUSEIUS MESEMBRINUS* GRAVID FEMALE SURVIVAL, EGG PRODUCTION AND LIVE IMMATURES ($\bar{X}$ ± SE) 72 H AFTER INFESTATION ON LEAVES 1 AND 4 DAYS FOLLOWING SPRAY APPLICATION.

			1 day			4 days		
Series	Pesticide formulation	Rate per ha	Surviving ♀♀	Live eggs	Live immatures	Surviving ♀♀	Live eggs	Live immatures
	6. Dimethoate 400	5.85 liters	0 ± 0 d	0 ± 0.1 c	0.6 ± 0.6 c	9.0 ± 0.3 a	12.5 ± 0.6 a	7.1 ± 1.0 ab
	7. Malathion 57EC	5.85 liters	2.3 ± 1.1 c	0 ± 0 c	0 ± 0 c	9.8 ± 0.2 a	17.8 ± 1.0 a	7.5 ± 0.7 a
	8. Dicofol 4EC	7.01 liters	1.0 ± 0.7 cd	0.1 ± 0.1 c	0.5 ± 0.5 c	2.6 ± 1.5 c	2.9 ± 1.9 cd	2.1 ± 1.1 d
	9. Propargite 6.55EC	3.51 liters	0 ± 0 d	0 ± 0 c	0.5 ± 0.4 c	6.3 ± 1.3 b	6.6 ± 1.9 b	6.0 ± 0.6 abc
	10. Untreated	—	9.5 ± 0.3 a	12.5 ± 2.0 a	4.9 ± 0.9 a	9.5 ± 0.3 a	17.3 ± 0.8 a	5.6 ± 0.5 abc
IV	1. Benomyl 50WP	3.36 kg	6.3 ± 1.0 bcd	5.9 ± 2.9 e	3.9 ± 1.2 ab	9.4 ± 0.3 ab	11.8 ± 2.6 cd	4.3 ± 0.6 bc
	2. Ferbam 76GF	16.81 kg	5.8 ± 0.9 cd	7.3 ± 1.9 cde	4.3 ± 0.4 a	3.6 ± 0.9 d	6.3 ± 2.3 e	5.4 ± 0.9 b
	3. Chlorpyrifos 4EC	5.85 liters	7.8 ± 0.4 abc	12.5 ± 1.5 abc	4.1 ± 0.8 ab	8.9 ± 0.2 ab	16.3 ± 1.1 bc	4.8 ± 0.8 b
	4. Ethion 4EC + petroleum oil FC435-66	7.01 liters 46.8 liters	5.4 ± 1.3 cd	6.8 ± 3.0 de	2.4 ± 0.7 b	7.1 ± 1.1 bc	7.9 ± 2.2 de	2.3 ± 0.8 d
	5. Chlorfenapyr 2SC	1.46 liters	5.3 ± 1.5 d	9.3 ± 3.4 cde	3.1 ± 0.9 ab	6.0 ± 1.6 cd	7.5 ± 1.9 de	4.1 ± 1.0 bcd
	6. Chlorfenapyr 2SC + petroleum oil FC435-66	971 ml 46.8 liters	7.8 ± 1.2 abc	11.1 ± 2.4 bcd	3.3 ± 0.8 ab	8.9 ± 0.4 ab	11.0 ± 1.2 cd	2.8 ± 1.2 cd
	7. Formetanate 92SP	1.12 kg	0 ± 0 e	0 ± 0 f	0 ± 0 c	0 ± 0 e	0 ± 0 f	0 ± 0 e
	8. Dicofol 4EC	7.01 liters	0 ± 0 e	0 ± 0 f	0 ± 0 c	0 ± 0 e	0 ± 0 f	0 ± 0 e
	9. Untreated	—	9.0 ± 0.3 ab	15.9 ± 1.7 ab	4.8 ± 0.6 a	9.9 ± 0.1 a	23.8 ± 2.5 a	10.8 ± 0.9 a

Means within each column within each series followed by the same letter are not significantly different ($P \geq 0.05$).

TABLE 4. PESTICIDES WITH SIGNIFICANTLY GREATER NUMBERS OF MISSING *EUSEIUS MESEMBRINUS* GRAVID FEMALES ($\bar{X}$ ± SE) AFTER 72 H EXPOSURE ON TREATED LEAF SURFACES 1 AND 4 DAYS AFTER SPRAY APPLICATION 1997.

Series	Pesticide	Formulation	Rate per ha	Missing females	
				1 day post spray	4 days post spray
I	Ferbam	76WP	16.81 kg	6.3 ± 1.2 a	4.5 ± 1.1 a
	Benomyl	50WP	1.68 kg		3.3 ± 1.2 a
	+ ferbam	76WP	5.60 kg	5.1 ± 1.2 a	
	Untreated	—	—	0.9 ± 0.5 b	0.5 ± 0.2 b
III	Carbaryl	80S	11.21 kg	1.4 ± 0.6 a	0.4 ± 0.2 a
	Carbaryl	XLR Plus	18.7 liters		
	+ petroleum oil	FC435-66	46.8 liters	2.3 ± 0.9 a	0 ± 0 a
	Untreated	—	—	0.3 ± 0.3 b	0.3 ± 0.2 a
IV	Benomyl	50WP	3.36 kg	1.4 ± 0.4 a	0.5 ± 0.3 bc
	Ferbam	76WP	16.81 kg	1.3 ± 0.6 ab	4.4 ± 0.9 a
	Chlorpyrifos	4EC	5.85 liters	0.8 ± 0.4 abc	1.0 ± 0.3 b
	Untreated	—		0.4 ± 0.2 bc	0.1 ± 0.1 c

Means within each column within each series followed by the same letter are not significantly different ($P \geq 0.05$).

was able to develop to the protonymph stage when no food sources were available except the citrus leaf substrate. In this study, chlorfenapyr + FC435-66 oil, abamectin + FC435-66 oil, or FC435-66 oil applied alone at 46.8 or 93.5 liters/ha had lower larval survival rates compared with the other treatments (Table 3). These data suggest that reduced larval survival was caused by either interference with larval feeding attempts through the petroleum oil film covering the leaf surface or by direct or indirect toxicity of the pesticides or combinations with acaricides. It is known that penetration of abamectin into the wax layers of both citrus leaves and fruit increases considerably when combined with petroleum oil under field conditions (Dybas 1990). The use of petroleum oil provided substantial extension of residual activity of abamectin versus abamectin applied alone in controlling citrus rust mite (C. C. C., unpublished data).

Understanding the toxic effects of field weathered pesticides against key predacious mite species is important for all commodities. Climatic conditions in Florida are characterized by warm temperatures, high humidity, and moderate to high annual rainfall. During the summer (i.e., May through October), humidity conditions at night approach 100% and result in long hours of leaf and fruit wetness that often extend into early to mid-morning. In addition, afternoon rain showers frequently occur, especially between May and October. Because of these conditions, accelerated degradation of many pesticides has been shown (Nigg et al. 1983). For example, organophosphate pesticide residues on citrus degrade much more quickly on Florida citrus compared with residues in California (Nigg et al. 1977, Thompson et al. 1979, Nigg & Stamper 1981). Despite such harsh environmental conditions, several of the pesticides evaluated in this study maintained relatively long-termed residual toxicities to *E. mesembrinus* either directly by reducing female survival or indirectly by impacting fecundity rates or larval survival as shown in this study. This study showed the potentially disruptive effects of using ferbam and benomyl on Florida citrus by adversely affecting the predacious mite *Euseius mesembrinus*.

The results of this study provide a comparison of direct and indirect toxic effects by various pesticides to *E. mesembrinus* under field conditions. This information is step one in a process of identifying the possible disruptive impact of specific pesticides used on Florida Citrus. Previous studies have shown that toxicity of certain pesticides to populations of predacious mites and consequent reductions in their effectiveness against phytophagous mite pests (Childers & Enns 1975; Childers & Abou-Setta 1999). Longer term field studies are in progress to identify possible subtle or delayed negative effects of one or more pesticides used in citrus for arthropod and fungal disease control.

ENDNOTE

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TABLE 5. HIGHEST TO LOWEST COMPARATIVE TOXICITIES OF VARIOUS PESTICIDES AND UNTREATED CHECKS TO EUSEIUS MESEMBRINUS ON 24 H POST-TREATED PESTICIDE LEAVES.

Treatment	Series	Calculated ratings	Toxicity rating
Azinphos-methyl	III	0	Highly toxic
Dicofol	IV	0	Highly toxic
Formetanate	III	0	Highly toxic
Formetanate	IV		Highly toxic
Dimethoate	III	0	Highly toxic
Malathion	III	0	Highly toxic
Propargite	III	0	Highly toxic
Dicofol	III	0.05	Highly toxic
Benomyl + ferbam	I	21	Highly toxic
Ferbam	I	28	Highly toxic
Carbaryl XLR + petroleum oil	III	31	Highly toxic
Pyridaben + petroleum oil	II	34	Highly toxic
Carbaryl (11.21 kg)	III	46	Highly toxic
Ethion + petroleum oil	IV	88	Highly toxic
Benomyl	IV	145	Highly toxic
Chlorfenapyr	IV	153	Highly toxic
Pyridaben	II	164	Highly toxic
Ferbam	IV	182	Highly toxic
Sulfur	I	206	Moderately to slightly toxic
Abamectin + petroleum oil	II	244	Moderately to slightly toxic
Chlorfenapyr + petroleum oil	IV	286	Moderately to slightly toxic
Chlorfenapyr + petroleum oil	II	308	Moderately to slightly toxic
Petroleum oil (93.5L)	II	375	Moderately to slightly toxic
Chlorpyrifos	IV	400	Moderately to slightly toxic
Petroleum oil (46.8L)	II	494	Non-toxic
Carbaryl (4.48 kg)	III	558	Non-toxic
Untreated (III)	III	582	Non-toxic
Chlorfenapyr	II	594	Non-toxic
Chlorpyrifos	I	637	Non-toxic
Untreated (IV)	IV	687	Non-toxic
Untreated (II)	II	722	Non-toxic
Fenbuconazole + petroleum oil	I	724	Non-toxic
Copper hydroxide	I	744	Non-toxic
Benomyl	I	773	Non-toxic
Copper sulfate	I	848	Non-toxic
Untreated (I)	I	981	Non-toxic
Fenbuconazole	I	1331	Non-toxic

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FIRST RECORDS OF THE SUGAR CANE AND FORAGE GRASS PEST, *PROSAPIA SIMULANS* (HOMOPTERA: CERCOPIDAE), FROM SOUTH AMERICA

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ABSTRACT

The genus *Prosapia* Fennah and *P. simulans* (Walker) are reported for the first time in South America, based on recent field collections in Colombia and museum specimens from Venezuela. *Prosapia simulans* was found on *Axonopus micay* García-Barr., *Brachiaria decumbens* Stapf, *B. dictyoneura* (Fig. & De Not.) Stapf, *Cynodon plectostachyus* (K. Schum.) Pilger, *Hyparrhenia rufa* (Nees) Stapf and *Saccharum officinarum* L. (Poaceae). Persistent field populations were detected from 1060-1621 m elevation, principally associated with *B. decumbens*, reaching economic levels in one of the observed sites. On two occasions *P. simulans* was found on sugar cane. Evidence suggests that this Central American sugar cane and forage grass pest is a well-established new arrival, thereby representing a new threat to pasture production and potential threat to cane production in Colombia's Cauca Valley. The distribution, bionomics, and pest status of *P. simulans* are summarized, and its mode of introduction and potential pest status are discussed.

Key Words: *Brachiaria decumbens*, Colombia, forage pest, new detection, *Prosapia simulans*, *Saccharum officinarum*, spittlebug

RESUMEN

El género *Prosapia* Fennah y *P. simulans* (Walker) son reportados por primera vez en Suramérica, basado en recolecciones recientes del campo en Colombia y especímenes de museo de Venezuela. *Prosapia simulans* fue encontrado en *Axonopus micay* García-Barr., *Brachiaria decumbens* Stapf, *B. dictyoneura* (Fig. & De Not.) Stapf, *Cynodon plectostachyus* (K. Schum.) Pilger, *Hyparrhenia rufa* (Nees) Stapf y *Saccharum officinarum* L. (Poaceae). Poblaciones persistentes en campo fueron detectadas desde 1060-1621 msnm, principalmente asociada con *B. decumbens*, alcanzando niveles económicos en uno de los sitios observados. En dos ocasiones *P. simulans* fue encontrado sobre caña de azúcar. La evidencia sugiere que esta plaga centroamericana de caña de azúcar y gramíneas forrajeras es una nueva llegada bien establecida, representando así una nueva amenaza para la producción de pastos y una amenaza potencial para la producción de caña en el Valle del Cauca en Colombia. Se resume la distribución, las bionómicas, y el estado de plaga de *P. simulans,* y se discute su modo de introducción y estado de plaga potencial.

Grassland spittlebugs (Homoptera: Cercopidae) are native xylem-feeding insects that are broadly distributed and damaging pests of graminoid crops in the Neotropics. Major hosts include sugar cane (*Saccharum officinarum* L.) and forage grasses, particularly the widely sown and highly susceptible *Brachiaria decumbens* Stapf. This diverse group of spittlebugs, which includes dozens of species from at least 11 genera, poses a major limitation to productivity and persistence of the most extensive agricultural activity in the Neotropics, pastures for the production of forage, milk and beef.

The most widely distributed species in this pest complex is *Prosapia simulans* (Walker), occurring in the lowland tropics from Mexico to Panama (Hamilton 1977). To our knowledge, this species and the genus *Prosapia* Fennah have never been reported in South America. Herein we report the first field detection of *P. simulans* in Colombia, and an additional record from museum specimens collected in Venezuela. Quantitative measures of field abundance were performed to make a preliminary assessment of population density and persistence. We summarize the literature on its geographic distribution, bionomics and pest status; provide diagnostic characters to distinguish it from other grassland spittlebugs in northern South America; and discuss its possible mode of introduction and pest status potential.

FIELD DETECTION

We discovered populations of *P. simulans* on six farms in the Cauca Valley of Colombia in 1999-2000. All specimens were identified using characteristics of the male genitalia and compared with type specimens at the Natural History Museum (BMNH), London.

The first report was obtained 2-VI-1999 when a single female was captured in the course of weekly surveys to document population fluctuations of the common local spittlebug species *Zulia*

carbonaria (Lallemand) in *Brachiaria dictyoneura* (Fig. & De Not.) Stapf (population 1, Hacienda Las Palmas, 3.050°N, 76.498°W) (Table 1, Fig. 1). Additional surveys in surrounding pastures and sugar cane fields, and weekly surveys in the same site over the following year, did not recover more individuals.

On 2-VII-1999 a large population was discovered approximately 94 km northeast in a pasture of *B. decumbens* at 1155 m elev. (population 2, Finca El Mirador del Paraíso, 3.650°N, 76.240°W) (Table 1, Fig. 1). On that visit *P. simulans* was the only spittlebug species present, with abundant adults and nymphs (unmeasured). A follow-up visit to the same pasture on 4-IV-2000 verified a continued presence at greater abundance than the first visit, measured at 46.8 nymphs/m^2 (n = 10 0.25m^2 quadrats) and 190 adults/50 sweeps (n = 4 series of 50 sweeps). In the second and third visits, *Z. carbonaria* and *Zulia pubescens* (F.) were also detected. Although economic thresholds based on quantitative yield loss data have never been established for grassland spittlebugs, these levels are considered highly damaging in forage grasses of Mexico. Padilla and Esquiliano (1966) designate >30 nymphs/m^2 and >25 adults/50 sweeps as "severe" while Velasco & Sifuentes (1970) designate >46 nymphs/m^2 and >150 adults/50 sweeps as "high" infestations.

Subsequent to the detection of this large population, four additional populations were detected between 1100 and 1621 m elevation, ranging from the valley floor to just over the top of the western cordillera of the Andes (Table 1, Fig. 1). These populations were persistent because the insect was detected over a few to several months.

In population 3 (Finca Canadá, 3.849°N, 76.466°W), *P. simulans* were detected along with *Z. carbonaria* and *Z. pubescens* in five upland pastures of *B. decumbens* and *Cynodon plectostachyus* (K. Schum.) Pilger. In the second visit, various *P. simulans* adults were found feeding on sugar cane (*S. officinarum*) but nymphs were absent. In populations 4 (Finca La María, 3.940°N, 76.438°W) and 5 (Finca La Albania, 3.950°N, 76.453°W) the insect was detected along with *Z. carbonaria* and *Z. pubescens* in three upland pastures of *B. decumbens*. Additional hosts in population 5 included *Axonopus micay* García-Barr., *C. plectostachyus* and *Hyparrhenia rufa* (Nees) Stapf. In population 6, *P. simulans* were detected along with *Z. carbonaria* and *Z. pubescens* in four lowland pastures of *B. decumbens* (Hacienda Piedechinche, 3.373°N, 76.142°W). On a separate occasion, a single nymph was observed in a spittle mass at the base of the leaf whorl on sugar cane; at the time only *P. simulans* adults were found on nearby weeds and grass (L.A. Lastra, CENICAÑA, pers. comm.).

Voucher specimens of *P. simulans* from all six populations were deposited in the Cornell University Insect Collection under Lot #1227.

Additional South American Records

A series of *P. simulans* was identified in the insect collection of the Centro Internacional de Agricultural Tropical (CIAT), Cali, Colombia (2 specimens) and BMNH (7 specimens). This material was all collected on 30-V-1980 by Gerardo Pérez Nieto from Venezuela, Bolivar State, La Vergareña, in pasture, calculated to be near 6.783°N, 63.559°W (Fig. 1). No other South American specimens were found in the collections at BMNH, Cornell University, the Universidad Nacional in Palmira or the Universidad del Valle in Cali (Dept. Valle del Cauca).

Distribution, Pest Status and Bionomics

The genus *Prosapia* comprises 14 species and ranges from Ontario, Canada to Panama (Hamilton 1977). Two new species from Costa Rica are being described (V. Thompson, Roosevelt University, pers. comm.). *Prosapia simulans* is widespread in the lowland tropics (Fig. 1). It is reported in nine Mexican states (Chiapas, Guerrero, Nuevo León, Oaxaca, Querétaro, San Luis Potosí, Tabasco, Tamaulipas, Vera Cruz), within 70 miles of the United States border (Fennah 1953; Clark et al. 1976; Agostini et al. 1981), and throughout Central America (Belize, Costa Rica, Guatemala, Honduras, Nicaragua, Panama) (Metcalf 1961; D.P., personal observation of specimens at BMNH). Although Guagliumi (1955) lists *P. simulans* in Colombia, the report is unsubstantiated and is probably in error.

Prosapia simulans attacks many of the major forage grass species in this geographic range, including *Cenchrus ciliaris* L. (Enkerlin & Morales 1979), *Cynodon nlemfuensis* Vanderyst (Peck 1999), *Digitaria decumbens* Stent (Oomen 1975), *Paspalum notatum* Fluggé (V. Thompson, pers. comm.), *S. officinarum* (Box 1953, Oomen 1975), and *Zea mays* L. (Ballou 1936). Four additional host species in greenhouse studies are *Avena sativa* L., *Pennisetum glaucum* (L.) R. Br., *Setaria italica* (L.) P. Beauv. and *Sorghum* sp. (Enkerlin & Schwartz 1979). The only non-graminoid host (adults only) reported is the tree *Ilex haberi* (Aquifoliaceae) (Peck 1998a).

Enkerlin & Morales (1979) also add the following hosts (citing Flores et al. 1965 and Velasco 1968) but do not specify if they are particular to *P. simulans* or the sympatric *Aeneolamia albofasciata* (Lallemand): *Chloris gayana* Kunth, *Cynodon plectostachyus* (K. Schum.) Pilger, *Cynodon dactylon* (L.) Pers., *Echinochloa polystachya* (Kunth) Hitchc., *H. rufa*, *Panicum purpurascens* Raddi, *Panicum maximum* Jacquin, and *Pennisetum purpureum* Schumach.

The current pest status of *P. simulans* in sugar cane of Central America is poorly documented. Although reported as an injurious cane pest in

TABLE 1. POPULATIONS OF *PROSAPIA SIMULANS* DETECTED IN CAUCA VALLEY, COLOMBIA.

New population	Location (vereda, municipality, department)	Elev. (m)	First detection and subsequent visits	
			Date	Estimate of population size
1	Santander de Quilichao, Santander de Quilichao, Cauca	1060	2-VI-1999	1 female
2	Santa Helena (a), El Cerrito, Valle del Cauca	1155	2-VII-1999	Unmeasured
			4-IV-2000	46.8 nymphs/m^2, 190 adults/50 sweeps
			5-V-2000	112 adults/50 sweeps
3	Cordobitas, Yotoco, Valle del Cauca	1535	1-II-2000	Unmeasured
			6-IV-2000	2.3 adults/50 sweeps
			23-V-2000	Unmeasured
4	Diamante la Gaviota, Calima el Darien, Valle del Cauca	1575	12-VI-2000	9.7 adults/50 sweeps
			27-VI-2000	13.8 adults/50 sweeps
5	La Primavera, Calima el Darien, Valle del Cauca	1621	12-VI-2000	4.0 adults/50 sweeps
			27-VI-2000	6.5 adults/50 sweeps
6	Santa Helena (b), El Cerrito, Valle del Cauca	1100	6-VII-2000	23 adults/50 sweeps
			7-X-2000	26.8 adults/50 sweeps
			26-X-2000	Unmeasured

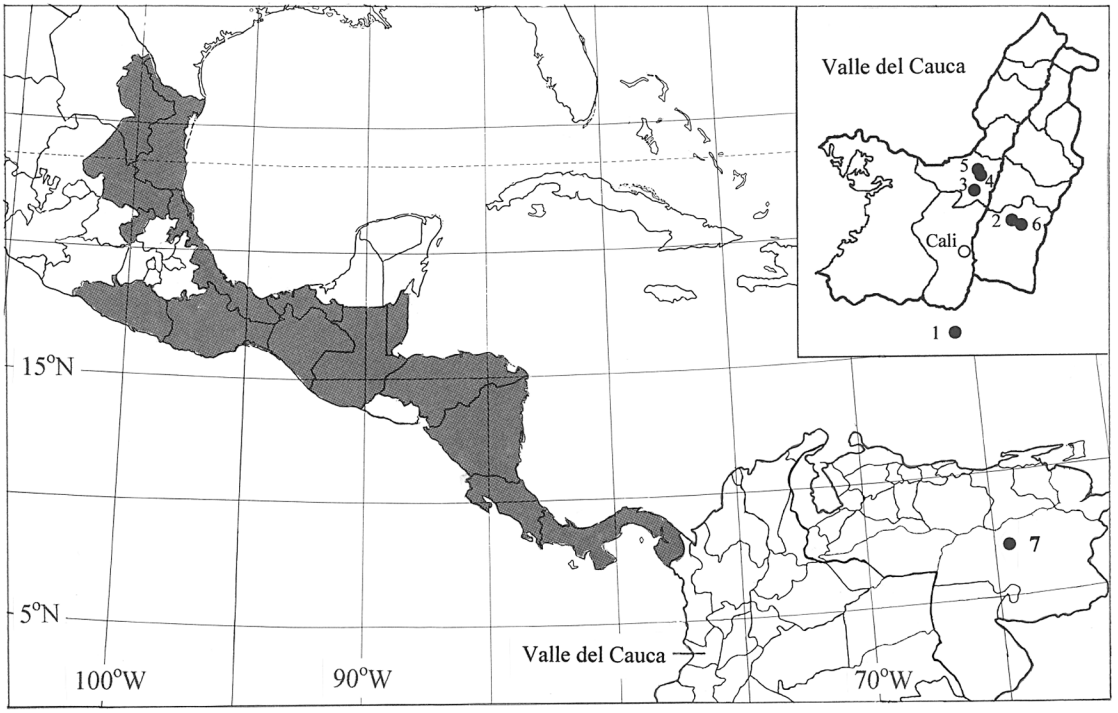

Fig. 1. Known geographic distribution of *Prosapia simulans* in Mexico (by state) and Central America (by country) with new locations (by number) in South America where it was collected in Colombia and Venezuela: 1) Santander de Quilichao 2) El Cerrito (a), 3) Yotoco, 4) Calima el Darien (Diamante la Gaviota), 5) Calima el Darien (La Primavera), 6) El Cerrito (b), and 7) La Vergareña.

Honduras and Nicaragua (J. Gaviria, consultant, pers. comm.), its pest status is probably inferior to the sympatric *Aeneolamia postica* (Walker).

Information on the specific biology and behavior of *P. simulans* is limited because most studies were conducted on a mixed species complex rather than *P. simulans* in particular. Oomen (1975) reported two generations of *P. simulans* annually in *D. decumbens* pastures near the Gulf Coast of Mexico, with preoviposition plus the egg incubation stage requiring 33.5 d, nymphal stage 25.5 d, and total generation time 58 d. Velasco & Sifuentes (1970) reported a preoviposition period of 4 d, egg incubation of 18.7 d, nymphal stage of 22-48 d and total generation time of 58.4 d. Like all other species studied in pastures, nymphs and adults of *P. simulans* occur only during the wet season, while dormant eggs survive the dry season and hatch under wet conditions. The genus *Prosapia* lays eggs in the soil but like other spittlebug species a proportion are attached to the plant stem and litter (Pass & Reed 1965, Peck 1998b). Current studies at CIAT show that *P. simulans* in Colombia primarily oviposits on the surface of the plant stem in preference to the soil or plant litter (CIAT 2000).

In all of the above studies, *P. simulans* was described as sharing pastures with another spittlebug species, such as *A. albofasciata* in northern Mexico, or *A. postica* in Honduras. There are no known published reports of it achieving outbreak status individually. The pest status of grassland cercopids in general has increased in forages of South America over the last decade. Based on reports received by CIAT (D.P., personal observation), increasingly affected areas include northern Argentina, Ecuador, and the Andean hillsides, Caribbean coast, and Amazonian forest margins of Colombia.

Diagnostic Characters

Prosapia simulans can be separated from the other 13 described species of *Prosapia* by the following male genitalic and color pattern characters (Hamilton 1977): two short blunt teeth at tip of aedeagal shaft, preapical gonopore, subgenital plates appressed on inner margins, crown of head lighter than anterior margin of pronotum, one light-colored transverse band across pronotum and two across tegmen, head and tegminal bases red to brown, and mesopleura blotched with black.

Male *P. simulans* can be distinguished from the other 17 species associated with wild and cultivated graminoids in Colombia and Ecuador (Peck 2001) by dorsal color pattern: dark brown to black with one transverse band across the center

of the pronotum and two bands (complete to interrupted) across the tegmen (Fig. 2). These transverse bands are greatly reduced to absent in females. As the only known member of the genus in South America, *P. simulans* is also distinguished by the genus definition of Fennah (1949, 1953) and supporting male genitalia characters discussed by Hamilton (1977).

In Mexico and Central America, there is significant variation in the color and form of the transverse bands of *P. simulans*, ranging from yellow to pink/red to orange, broad to narrow, and distinct to completely obscured, particularly in females (Clark et al. 1976, D.P., personal observation). There is additional variation among Central American populations in color of subgenital plates and patches on ventral edge of abdominal tergites (same color as venter to black). The Colombian populations displayed a particular subset of this color and pattern variation. Of 140 males examined from across the six populations, all had narrow pale yellow tegminal bands with some reduction of the posterior band. The color of the venter was predominantly pink/red (64%), but some individuals were yellowish brown (16%) or intermediate (20%). With very few exceptions, background tegmen color was brown (versus black), subgenital plates were black, and black patches on the abdominal tergites were pronounced. Of 43 females examined, all had both tegminal bands and pronotal band greatly reduced to barely evident on a black background. Female venters were black with red (58%) to yellowish brown (30%) to intermediate (12%) markings. Background tegmen color was usually brown (74%) but sometimes black (26%).

For males (population 1, n = 40), mean (mm) ±SE (range) head capsule width, forewing length and body length (including wings) was 2.04 ± 0.009 (1.93-2.14), 6.84 ± 0.045 (5.93-7.43) and 8.52 ± 0.049 (7.36-9.29), respectively. For females (population 1, n = 40) these measures were 2.31 ± 0.009 (2.21-2.43), 6.80 ± 0.035 (6.36-7.21) and 8.71 ± 0.052 (7.29-9.29), respectively.

Mode of Introduction and Economic Considerations

Although the occurrence of *P. simulans* in Colombia and Venezuela could be attributed to low endemic populations only recently detected, we believe this is unlikely because *P. simulans* is a conspicuous insect that has warning coloration and is present in an agricultural activity vital to the region. Furthermore, the Cauca Valley and Venezuela have been under relatively high surveillance. The CIAT forages program has been active in the Cauca Valley for the last 20 years and extensive fieldwork on grassland spittlebugs was conducted in the 1950's across Venezuela (Guagliumi 1955, 1956a, b, 1957).

Alternatively, *P. simulans* may have arrived through natural or human-mediated dispersal. Natural dispersal is a possibility for the Cauca Valley populations. Given the detection of one high elevation population on the Pacific side of the western cordillera of the Andes, *P. simulans* could have spread from Panama through the Darien Gap, the Chocó region of Colombia, and down the Pacific coast. Testing this mode of introduction will depend on collections from those key intermediate regions.

Human mediated dispersal is a more likely possibility for the Venezuelan population given how remote the Venezuelan site is to Panama and the absence of *P. simulans* in northern Colombia. Spittlebug monitoring programs conducted by the Corporación Colombiana de Investigación Agropecuaria (CORPOICA), the Universidad del Sucre and CIAT over the last four years on the Caribbean coast have not detected this species. The preference of *P. simulans* for oviposition sites on the plant stem versus soil and litter increase the likelihood of entry with infested vegetative material.

Broader surveys should be carried out to identify the extent of *P. simulans* populations and monitor their spread in pastures and cane plantations of the Cauca Valley. At the spittlebug densities detected in one location of this study, milk and beef cattle production will be negatively affected and the persistence of improved *B. decumbens* pastures will be compromised. Spread or introduction of this species to lowland regions of Colombia such as the Caribbean coast or the extensive eastern Llanos would have severe economic implications.

Up to now, *P. simulans* has not been reported on Colombian sugar cane beyond the two observations noted above. Nevertheless, because the evidence suggests that *P. simulans* is a recent arrival, cane producers should consider this species a potential threat. With the notable exception of the Cauca Valley of Colombia, essentially all cane-producing regions of Central and South America have experienced major spittlebug pest problems (Fewkes 1969). For instance, the spittlebug *Aeneolamia varia saccharina* (F.) devastated the cane industry in Trinidad and other Caribbean regions at the turn of the century (Williams 1921). Brazilian cane fields have a long history with a diverse complex of other species (Guagliumi 1972) and in the last decade spittlebug pest status has increased in cane plantations of Ecuador and Central America.

The menace may be heightened now as management shifts from preharvest burning to green production by the year 2005 in the Cauca Valley (Cenicaña 1998). This change in cultural practice is known to influence the status of insect pests, such as the emergence of *Mahanarva fimbriolata* (Stal) in cane fields in São Paolo State, Brazil (P. Botelho, CCA/UFSCar, pers. comm.).

Fig. 2. *Prosapia simulans* showing most common color patterns (dorsal and ventral) of males (left) and females from newly detected populations in Cauca Valley, Colombia. Bar = 2 mm.

Finally, these observations highlight the need for care in transfer of vegetative and soil materials associated with cercopid host plants. There is some other anecdotal evidence for regional introductions of grassland spittlebugs such as *Z. carbonaria* from the Cauca Valley into the Colombian Amazon, and an isolated report of the Central Brazil species *Notozulia entreriana* (Berg) in the Colombian Llanos (Peck 2001). One well-documented case is *Lepyronia coleoptrata* (L.) (Homoptera: Aphrophoridae), a Palearctic spittlebug with immigrant status in the United States (Hoebeke & Hamilton 1983). With the increasing movement of vegetative material throughout the Caribbean Basin and northward insect range expansion due to warming trends, sugar cane and forage grass production in the southern United States, like the Cauca Valley, would be threatened by the arrival of new spittlebug pests. The southeast United States already suffers from the native *Prosapia bicincta* (Say), a damaging pest of forage grass, turf grass and ornamentals (Fagan & Kuitert 1969; Braman & pendley 1993; Braman & Ruter 1997).

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LIFE HISTORY AND LABORATORY REARING OF *EMESAYA B. BREVIPENNIS* (HETEROPTERA: REDUVIIDAE) IN SOUTHERN ILLINOIS

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ABSTRACT

The life history of *Emesaya b. brevipennis* (Say) was studied in southern Illinois from April to December 1998. The bug also was reared in the laboratory on *Drosophila* sp. at 26 ± 3.0°C under a 16:8 (L:D) photoperiod. This bivoltine species apparently overwintered as eggs. First instars were found primarily from early to late May and mid-July to mid-August, second instars from late May to early June and from late July to mid-August, third instars from late May to mid-June and during August, fourth instars primarily from early June to early July and early to late August, fifth instars primarily from mid-June to mid-September, and adults from late June to early December. In the laboratory, the incubation period averaged 33.91 d. The five nymphal stadia averaged 11.27, 7.84, 8.85, 11.14, and 16.75 d, respectively. Total developmental time averaged 89.76 d.

Key Words: Bivoltine, copulation, spider webs

RESUMEN

El historial de vida de *Emesaya b. brevipennis* fue estudiado en el sur de Illinois desde Abril a Diciembre del 1998. El insecto también fue criado en el laboratorio en *Drosophila* esp. a 26 ± 3.0° bajo un fotoperíodo de 16:8 (L:O). Esta especie bivoltina aparentemente sobrevivió el invierno como huevos. Los primeros instares fueron encontrados principalmente del comienzo al final de mayo y mitad de julio a mitad de agosto, los segundos instares de tarde en mayo a temprano en junio y de finales de julio a medio agosto, terceros instares de finales de mayo a mitad de junio y durante agosto, cuarto instares principalmente desde el comienzo de junio al comienzo de julio y todo el mes de agosto, quinto instares principalmente de mediados de junio a mediados de septiembre, y adultos desde el fin de junio al comienzo de diciembre. En el laboratorio, el periodo de incubación fue un promedio de 33.91 d. El tiempo de desarrollo total fue 89.76 d.

Emesaya brevipennis (Say) is one of the emesine reduviids, a cosmopolitan group of bugs characterized by markedly slender bodies and appendages (Wygodzinsky 1966). This New World species is divided into three subspecies, *E. b. australis* McAtee & Malloch, *E. b. occidentalis* McAtee & Malloch, and *E. b. brevipennis* (Say) (Froeschner 1988), all of which occur in America north of Mexico. *E. b. brevipennis*, which is the most widely distributed of the three subspecies, occurs from New York and Massachusetts south to Florida and west to Iowa, Kansas, Texas, and California (Froeschner 1988). It occurs throughout Illinois (JEM, unpublished data).

Emesaya b. brevipennis has received much attention over the years, probably due, in part, to its large size (33.0-37.0 mm [Blatchley 1926]) and wide distribution. Published information on its biology has consisted mainly of scattered notes. It has been collected under bridges (e.g., Gates & Peters 1962); in sheds, barns, and outbuildings (e.g., Banks 1909; Blatchley 1926; Froeschner 1944; Gates & Peters 1962; Howes 1919; Readio 1926, 1927; Torre-Bueno 1923, 1925; Uhler 1884; Wickham 1910); from vegetation (e.g., Banks 1909; Blatchley 1926; Froeschner 1944; Gates & Peters 1962; Torre-Bueno 1923, 1925; Uhler 1884), flood debris, Spanish moss (Elkins 1951), screens (Brown & Lollis 1963); and in association with spider webs (Banks 1909; Brown & Lollis 1963; Howes 1919; Readio 1926, 1927; Usinger 1941; Wickham 1910).

Based on the literature, this subspecies apparently is univoltine (Banks 1909; Readio 1927) and overwinters as eggs (Howes 1919; Readio 1927). Nymphs occur in the spring and much of the summer (Brown & Lollis 1963; Readio 1927; Uhler 1884; Wickham 1910), and adults can be found during the summer and early fall (Brown & Lollis 1963; McAtee & Malloch 1925; McPherson 1992; Readio 1927; Uhler 1884; Wickham 1910). The eggs are oviposited in the summer and early fall (Brown & Lollis 1963; Howes 1919; Readio 1927) and are attached to spider webs (Brown & Lollis 1963; Readio 1926, 1927), rafters of wooden structures (Howes 1919; Readio 1926, 1927), and twigs of bushes and trees (Uhler 1884).

This paper presents information on the field life history and biology of *E. b. brevipennis* in southern Illinois.

Materials and Methods

Field Life History

During summer 1997, a population of *E. b. brevipennis* was discovered near Bluff Lake, Union Co., IL. The numbers observed and accessibility of the site suggested a life history study was possible. Therefore, a study was conducted from April to December 1998, before and after the active season, respectively.

The study site is located in the Jonesboro quadrangle 7.5' topographic (T13S, R2W, NW1/4, NE1/4, Sec. 20), 4 miles east of state highway 3. It consists of a Bailey limestone rock face (Nelson & Devera 1995) covered by vines of *Campsis radicans* (L.) and *Rhus radicans* L. The rock face is approximately 18.5 m high and parallels the east side of township road 235N for 160.9 m. The site is surrounded by a forested area containing *Acer barbatum* Michaux, *Carpinus caroliniana* Walter, *Carya glabra* (Miller), *Carya ovalis* (Wangenheim), *Celtis occidentalis* L., *Fagus grandifolia* Ehrhart, *Quercus rubra* L., and *Ulmus rubra* Muhlenberg. The bugs were observed on webbing of the araneid spider *Anelosimus studiosus* (Hentz), which enclosed the vines on the rock face.

Samples of up to 20 adults and nymphs, and notes on the bugs' activities, were taken weekly from early May to early December. Sampling was by hand picking and confined to an approximately 11.0 m long and 6.0 m high section of the rock face. Nymphs large enough to be identified to instar and adults were not collected. Younger nymphs were preserved in 70% ethanol and taken to the laboratory for closer examination. Plant material, webbing, and the rock face were examined in the field for eggs.

Laboratory Rearing

Eggs were collected at Bluff Lake on 13 February (n = 163) and 6 March (n = 75) 1999, brought to the laboratory, placed on moistened filter paper in the bottoms of petri dishes (approximately 9 cm diam., 2.0 cm deep) and covered with the lids. Approximately 4-6 drops of distilled water were added every 1-2 d to keep the filter paper moist.

The resulting nymphs were placed in 1-pt (approximately 0. 47 liter) Mason jars with a disc of moistened filter paper on the bottom. Each jar was closed with a disc of paper toweling and wire screening and secured with the band of the 2-piece Mason jar lid. A strip of paper toweling,

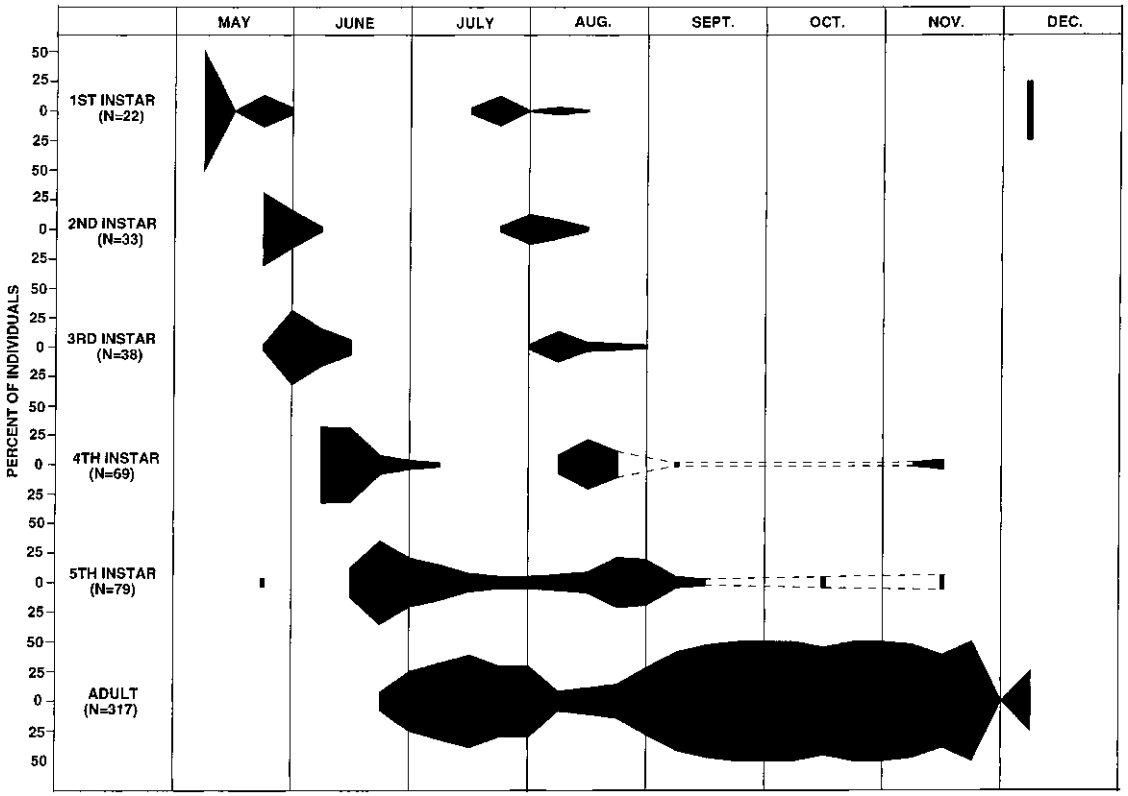

Figure 1. Percent of individuals in each stage per sample of *Emesaya b. brevipennis* collected at Bluff Lake, Union Co., IL, during 1998.

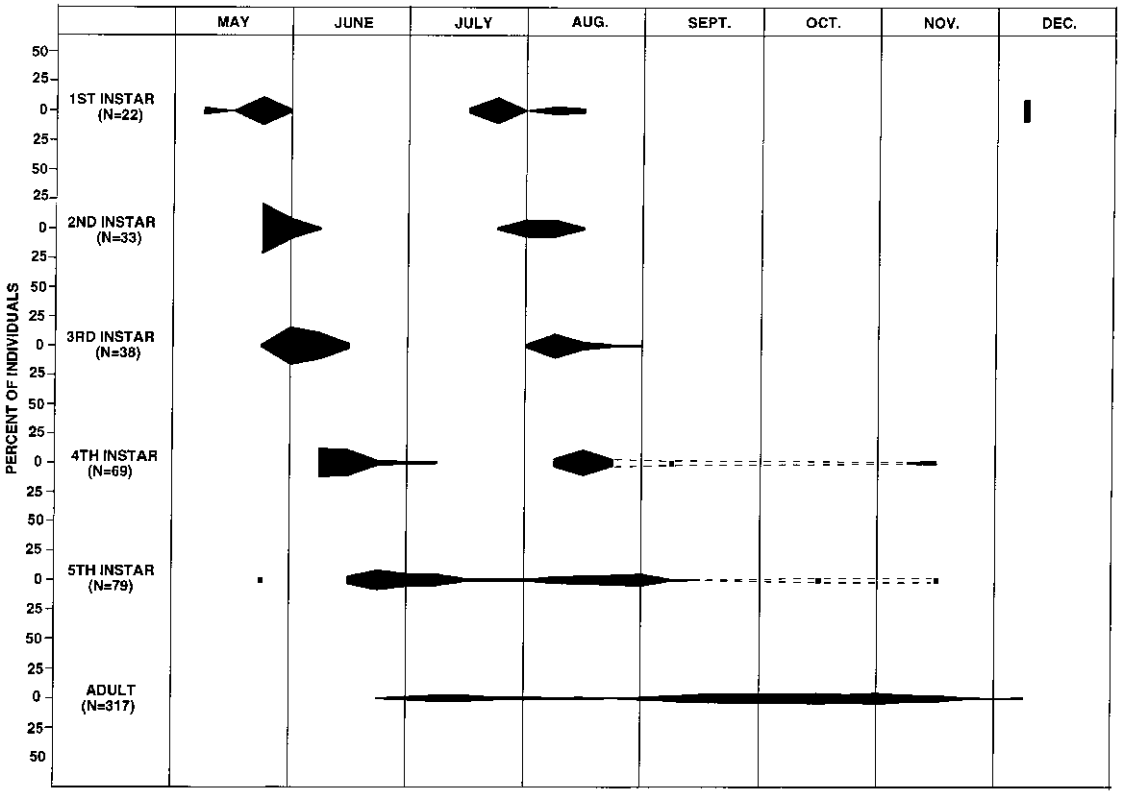

Figure 2. Percent in each sample of total individuals of same stage of *Emesaya b. brevipennis* collected at Bluff Lake, Union Co., IL, during 1998.

folded longitudinally (to prevent the strip from rolling up when damp), was suspended inside the jar from the lid and secured at the upper end between the discs of wire screen and paper toweling. This strip increased surface area for walking and absorption of excrement. The filter paper was moistened with 8-10 drops of distilled water per day. The bugs were fed five *Drosophila* sp. adults per day for this and subsequent instars.

To determine if eggs could develop without an intervening cold period (i.e., without passing through cold winter temperatures), three adult females were collected at Bluff Lake on 22 October 1998, brought to the laboratory, and placed in a 1-qt (approximately 0.95 liter) Mason jar prepared similarly to the 1-pt jars for nymphs. The strip served a third function in addition to those for nymphs, that of an ovipositional site. As with nymphs, the filter paper was moistened with 8-10 drops of distilled water daily, and the bugs were fed five *Drosophila* sp. adults per day. The resulting eggs also provided incubation data, not possible with the 1999 field-collected eggs, which were laid at unknown times.

Eggs were removed, placed on moistened filter paper in the bottoms of petri dishes, and treated similarly to the field-collected eggs discussed above.

The bugs were kept in incubators maintained at 26 ± 3.0°C and a photoperiod of 16:8 (L:D) (approximately 2,800 lux).

Results and Discussion

Field Life History

Emesaya b. brevipennis is bivoltine in southern Illinois (Figs. 1 and 2) based on peaks in abundance of adults and nymphs.

This species apparently overwintered as eggs, which were glued lengthwise to the vines, webs, and rock surface. We could not distinguish fertile eggs in the field because the eggs are dark and durable, even if not fertile. Of the 238 eggs collected in February and March for the laboratory-rearing study, 121 (50.8%) hatched. We assumed all had been oviposited the previous fall.

First instars were found primarily from early to late May and mid-July to mid-August, second instars from late May to early June and from late July to mid-August, third instars from late May to mid-June and during August, fourth instars

TABLE 1. COMPARISON OF MONTHLY TEMPERATURES (°C) FROM 1961 TO 1990WITH THOSE OF 1998.

	Year					
	1961-1990[1]			1998[2]		
Month	Max	Min	Avg	Max	Min	Avg
January	4.8	-5.2	-0.2	7.1	-1.6	2.8
February	7.7	-3.1	4.5	10.7	0.8	5.8
March	13.9	2.4	8.1	12.8	2.7	7.7
April	20.0	7.9	14.0	19.8	7.2	13.5
May	25.0	12.6	18.8	27.0	14.8	20.9
June	29.7	17.2	23.4	29.7	16.7	23.2
July	31.4	19.4	25.4	30.6	18.5	24.6
August	30.5	18.3	24.4	32.8	18.8	25.8
September	26.8	14.6	20.7	30.9	15.7	23.3
October	21.1	8.1	14.6	23.2	8.7	15.9
November	13.9	3.2	8.5	15.7	3.4	9.5
December	7.0	-2.5	2.2	8.9	-0.7	4.1

[1]At Anna, Illinois (COOPID. 110187, Midwestern Regional Climate Center, Champaign, IL).
[2]At Anna, Illinois (COOPID. 110187, National Climatic Data Center, Asheville, NC).

primarily from early June to early July and early to late August, fifth instars primarily from mid-June to mid-September, and adults from late June to early December (Figs. 1 and 2).

A few nymphs were found outside the primary times of occurrence in the field of their respective instars (Figs. 1 and 2), including four firsts (3 December), four fourths (6 September, n = 1; 5-13 November, n = 3), and seven fifths (20 May, n = 1; 11 October, n = 3; 13 November, n = 3). We believe that this was atypical and the result of unusually mild temperatures during the spring and fall (Table 1; note average temperatures for 1961-1990 and 1998).

Copulation was observed in late September (6 pairs) and early October (8 pairs). Interestingly, on 5 November 1998, a male was seen in copulo with an apparently dead female.

Laboratory Rearing

Eggs were glued singly and lengthwise to the paper toweling, screening, filter paper, and sides of the jar. Each egg was dark brown to black with longitudinal rows of thin, toothlike projections and capped by a cephalic operculum with a central tubercle, as described by McAtee & Malloch (1925). The incubation period averaged 33.91 days (Table 2).

The first instar emerged through the cephalic end of the egg, pushing aside the operculum. It was whitish, almost transparent, but became more visible after feeding.

The first through fifth stadia averaged 11.27, 7.84, 8.85, 11.14, and 16.75 d, respectively (Table 2). The total developmental period averaged 89.76 d. Most nymphs died during the fifth stadium, which resulted from incomplete ecdysis.

TABLE 2. DURATION (IN DAYS) OF EACH IMMATURE STAGE OF *EMESAYA B. BREVIPENNIS* UNDER LABORATORY CONDITIONS.

	No. Completing			
Stage	Stadium	Range	Mean ± SE	Cumulative mean age (d)
Egg[1]	34	30-38	33.91 ± 0.39	33.91
Nymph[2]				
1st instar	52	7-19	11.27 ± 0.30	45.18
2nd instar	49	6-14	7.84 ± 0.20	53.02
3rd instar	47	6-16	8.85 ± 0.30	61.87
4th instar	43	7-20	11.14 ± 0.41	73.01
5th instar	20	14-22	16.75 ± 0.53	89.76

[1]35 eggs, all of which laid in laboratory, used for incubation determination.
[2]Nymphs hatched from field-collected eggs.

Brown & Lollis (1962) suggested that females have a sixth instar; however, none was found.

In conclusion, *E. b. brevipennis* is bivoltine, at least in southern Illinois, and overwinters as eggs. It will feed on *Drosophila* adults in captivity. Interestingly, this apparently is not true of *Emesaya brevicoxa* (Banks). Several specimens of this reduviid found in cobwebs beneath the eaves of a cabin were kept alive in a "breeding cage" for 5 months on various species of spiders. Although supplied miscellaneous insects, they never were observed to feed on them (Usinger 1941).

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IONIZING IRRADIATION QUARANTINE TREATMENT AGAINST SWEETPOTATO WEEVIL (COLEOPTERA: CURCULIONIDAE).

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ABSTRACT

An ionizing irradiation quarantine treatment of 165 Gy was approved by the California Department of Agriculture against sweetpotato weevil, *Cylas formicarius elegantulus* (Summers), infesting sweetpotatoes from Florida. The first commercial shipment was made in May, 2000. At ≥400 Gy, 'Picadito' white-fleshed sweetpotatoes sometimes showed noticeable discoloration of cooked flesh. Therefore, there is not a large margin between the minimum absorbed dose required for quarantine security (165 Gy) and the minimum dose which might cause objectionable loss to commodity quality (about 400 Gy); it can be expected that the absorbed dose range absorbed by sweetpotatoes irradiated on a full pallet when the minimum target dose is 165 Gy will be 165-500 Gy. To be safe, sweetpotatoes should be irradiated in smaller units than pallet loads, which could result in higher processing costs compared with irradiation on standard pallets. This is the first instance of an irradiation quarantine treatment being approved and used against a non-fruit fly where live adults can be found by inspectors and indicates a significant advance in the transfer of this promising quarantine treatment technology.
Sweetpotato weevil adults irradiated with a target absorbed dose of 150 Gy (maximum absorbed dose was 165 Gy) lived for 32 days, while at 32 days unirradiated weevils had suffered 57% mortality.

Key Words: *Cylas formicarius elegantulus*, boniato, disinfestation, gamma

RESUMEN

Un tratamiento cuarentena de irradiación ionizante de 165 Gy fue aprobado por el Departamento de Agricultura de California contra el picudo de batata, *Cylas formicarius elegantulus* (Summers), infestando batatas de Florida. El primer envío comercial fue hecho en mayo del 2000. A ≥400 Gy, batatas con carne blanca 'Picadito' a veces demostraron decoloración evidente de carne cocida. Por lo tanto, no hay un margen amplio entre la dosis mínima absorbida requerida para seguridad de cuarentena (165 Gy) y la mínima dosis que pueda causar perdida objecionable a la calidad del producto (alrededor de 400 Gy); es de esperarse que la gama de dosis absorbida por las batatas irradiadas en una paleta cuando la dosis objetivo mínima debe ser 165 Gy será 165-500 Gy. Para estar seguros, las batatas deberían ser irradiadas en unidades más pequeñas que en cargas de paleta, lo cual puede resultar en costos de procesamiento mayores comparado con irradiación en paletas estándar. Esta es la primera instancia que un tratamiento cuarentena de irradiación es aprobado y usado contra una mosca no frutal donde adultos vivos pueden ser encontrados por inspectores e indica un avance significativo en la transferencia de esta prometedora tecnología de tratamiento cuarentena.
Adultos del picudo de batata irradiados con una dosis objetivo de absorber 150 Gy (dosis máxima absorbida fue 165 Gy) vivieron por 32 días, mientras que en el día 32 picudos sin irradiar sufrieron una mortalidad de 57%.

The sweetpotato weevil, *Cylas formicarius elegantulus* (Summers), is considered the most serious pest of both orange-fleshed and white-fleshed (boniato) sweetpotatoes, *Ipomea batatas* (L.) Lam., in much of the crop's growing range (tropics and subtropics) including the southeastern United States, Hawaii, and Puerto Rico. It was first noted in the United States in Louisiana in 1875. Female weevils oviposit in sweetpotatoes by chewing a small cavity in the root or stem, depositing an egg, and sealing the hole with frass. In the field they tend to oviposit near the juncture of the stem and tuber. In storage sweetpotato weevils infest all over the roots until they are completely destroyed. The complete life cycle requires about 35 days in the warm sweetpotato-growing regions of the world. Larvae usually pupate in the roots, and the female has about a 7 day preoviposition period. Sweetpotato-growing areas which do not have the weevil, such as the southwestern United States and the Mediterranean region, prohibit the importation of sweetpotatoes without a treatment that ensures that all weevil stages present are dead. Killing the weevils without harming the roots is difficult (Hallman & Chalot 1993); a feasible treatment has not been available.

Ionizing irradiation has proven to be a viable quarantine treatment against fruit flies (Diptera: Tephritidae) because much research with these insects has been conducted and doses required to

control fruit flies are relatively low (Hallman 1999). The only commercial uses of irradiation as a quarantine treatment have been against fruit flies. An unfavorable property of irradiation quarantine treatments which sets it apart from all other treatments that have been commercially implemented is the fact that irradiation does not provide acute mortality at the doses used on fresh commodities. Inspectors may find live insects and be unable to distinguish them from unirradiated insects. The measure of efficacy of irradiation quarantine treatments against fruit flies is prevention of adult emergence from irradiated eggs and larvae. Thus, inspectors will find no adult fruit flies in imported fruits. Even though live larvae may be found, a treatment which prevents the presence of adults is easier to accept than one which allows for the presence of live adults in properly treated produce. All stages of the sweetpotato weevil may be found in marketed roots. The adult is invariably the stage of insects which requires the highest radiation dose to control (Hallman 2000). This has been substantiated for sweetpotato weevil by Dawes et al. (1987), who observed little reproduction after 30 pairs of 7 day-old adults were irradiated with 100 Gy. At 150 Gy, no reproduction occurred (n = 30).

Materials and Methods

After obtaining permission from the U.S. Dept. Agric., Animal and Plant Health Inspection Service, Plant Protection and Quarantine and the Texas Dept. Agric., sweetpotato weevils were collected from a 'boniato' sweetpotato field near Homestead, Florida in the spring of 1999. They were shipped to our laboratory and reared on orange-fleshed sweetpotato roots purchased from the local market and 'boniato' (larger, white-fleshed) sweetpotato roots shipped from Homestead. Rearing conditions were about 25°C, 75%RH, and a photoperiod of 16:8 (L:D).

Gamma radiation was applied with a ^{137}Cs self-contained, dry-storage irradiator (Husman Model 521A, Isomedix, Inc., Whippany, NJ) which was delivering a centerline absorbed dose rate of about 40 Gy·min^{-1} during the time of this research. Reference standard dosimetry was done in 1997 using the Fricke system. Routine dosimetry during our research was done with radiochromic film (Gafchromic MD-55, ISP Technologies, Inc., Wayne, NJ), and absorbance at the 510 nm wavelength was read with a spectrophotometer (Milton Roy Spectronic 401, Ivyland, PA) using the Fricke centerline determination as the standard.

Adult sweetpotato weevils up to 3 weeks old were placed with pieces of sweetpotato root in clear plastic cylinders (29 cm × 4 cm diameter) in the center of perforated stainless steel mesh cylinders (11.4 cm inside diameter, 50 cm long) which were placed in the irradiator for sufficient time to achieve the target dose of 125 Gy. Routine dosimetry readings yielded the absorbed dose range. Irradiated weevils and unirradiated controls were placed with sweetpotato roots, which were changed every 3-4 days, until all irradiated weevils were dead. Data recorded were death of weevils and the number of new insects found in sweetpotato roots exposed to both irradiated and unirradiated weevils. Eight replicates of 200-600 weevils (sex ratio of about 1:1) with a total of 3,250 weevils were irradiated with 125 Gy. All irradiated insects within each replicate were held together to maximize the probability that fertile adults would mate. Subsequently 14 replicates with 1,000-3,950 adult weevils per replicate (total 30,655) were treated with a target dose of 150 Gy and counts of mortality and reproduction were made as before.

To be viable a quarantine treatment must not only ensure near 100% efficacy but it must also not lessen fruit quality excessively. McGuire & Sharp (1995) found darkening of cooked sweetpotato tubers at 400 Gy but not at 200 Gy; there were no other negative consequences (concerning appearance, rot, shelf life, weight, or organoleptic qualities) from irradiation up to 1 kGy. Therefore, sweetpotato quality research was only focused on color of cooked roots; organoleptic preference tests were conducted because color can influence an organoleptic rating. 'Boniato' (cv Picadito) tubers grown in Homestead, Florida and shipped to Weslaco, Texas were irradiated with 0 (control), 200, 300, 400, and 500 Gy, held at about 24°C, and cooked 4 days after irradiation using the following recipe: Roots were washed, peeled, cut into slices about 2.5 cm thick, and placed in about 2 liters of about 24°C water with about 2 ml of lemon juice for about 10 minutes while the cooking pot was prepared. In the cooking pot the root chunks were placed in about 2 liters of 100°C water with about 4 g of salt and kept in the boiling water until they were tender upon which they were removed from the water and kept in a covered dish. Qualitative observations on color of cooked roots were made and an informal panel was assembled from laboratory personnel (7-10 persons) and asked to rate organoleptic qualities of sweetpotato pieces by marking on a 9 cm-long line with 'extremely dislike' written on the left end and 'extremely like' written on the right end of the line. Data were recorded as distance (cm) from the left end of the line to the mark. There were 4 replicates done on different dates. These data were not analyzed statistically because they are qualitative and may not be normally distributed, but are reported as mean and SEM of the 4 replicates.

Results

Weevils irradiated with 125 and 150 Gy died at a faster rate than unirradiated weevils (Table 1). This

TABLE 1. NUMBER OF ADULT PROGENY AND LONGEVITY OF IRRADIATED AND UNIRRADIATED SWEETPOTATO WEEVILS.

Irradiation dose (Gy)	Mean ± SEM adult progeny/female		Mean ± SEM days until 100%mortality	Mean % ± SEM control still alive
	Irradiated	Control[1]		
125	0.014 ± 0.0078	41.8 ± 7.4	32.6 ± 3.4	53.0 ± 7.3
150	0 -	33.3 ± 5.9	31.5 ± 1.6	57.2 ± 8.3

[1]Control terminated when all irradiated weevils in same replicate died. Therefore, adult progeny/female in control expected to be greater.

is usually, but not always, the case for insects irradiated near the minimum doses that provide sterility (Hallman 2000). Complete mortality of irradiated weevils occurred at a mean of 32.6 days at 125 Gy and 31.5 days at 150 Gy. During the research done at 125 and 150 Gy, respectively, 53 and 57% of unirradiated weevils were still alive the day the last irradiated weevils died. Reproduction, based on the number of F_1 adult weevils found in sweetpotatoes offered to irradiated weevils averaged 0.014 and 0 per female at 125 and 150 Gy, respectively.

The upper range of dosimetry readings when the target dose was set at 150 Gy was 165 Gy; therefore, 165 Gy should be used as the recommended dose for quarantine security of sweetpotato weevil adults.

Even the unirradiated control sweetpotato tubers showed some mottling 10 minutes after the roots were removed from the hot water. However, the roots irradiated with 500 Gy and then cooked showed consistent and dark mottling. Cooked tubers that had been irradiated with 300 Gy were no more discolored than the control. In 2 of the replicates at 400 Gy considerable discoloration, more than in the control, occurred while in the other 2 replicates at 400 Gy the degree of discoloration after cooking was not greater than in the control. The informal organoleptic panel found no differences among the cooked roots, even considering that those exposed to 500 Gy did not look as pleasing as the others. Mean (±SEM) organoleptic values were 5.8 (0.2), 5.7 (0.3), 5.6 (0.3), 5.5 (0.3), and 5.6 (0.2) for 0 (control), 200, 300, 400, and 500 Gy, respectively.

DISCUSSION

The information from this study was submitted via the Florida Department of Plant Industry to the California Department of Agriculture to enable an irradiation quarantine treatment to be applied to Florida sweetpotatoes, including 'boniatos' for shipment to California. It was approved effective April 1, 2000, and the first shipments occurred in late May. Although 30,655 adults were eventually irradiated with a target dose of 150 Gy, authorities in California accepted the treatment after research with only 18,800 of the adults had been completed. California stipulated that sweetpotatoes be packed in cardboard boxes without holes before irradiation to reduce the chance of post-treatment re-infestation.

Because sweetpotatoes irradiated with ≥400 Gy sometimes showed mottling after cooking, there is not a comfortable margin between the minimum dose required for quarantine security (165 Gy) and the maximum which should be allowed to prevent possible detrimental affects to commodity quality. If sweetpotatoes were irradiated in standard pallet-loads, some tubers in the interior of the load would probably receive at least 500 Gy and risk objectionable post-cooking coloration. Sweetpotatoes will probably need to be irradiated in narrower units than the standard pallet, increasing the cost of treatment because of the extra manipulation required to break down and re-stack pallets.

This case is the first acceptance of an ionizing irradiation quarantine treatment involving adult insects and advances the transfer of this promising technology significantly because it sets a precedence for dealing with live adults found in properly irradiated commodities. Acceptance of live, but sterile, adults by inspectors shows a great deal of confidence in irradiation and this research.

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SOME EFFECTS OF GROUP SIZE ON THE OUTPUT OF BEGINNING NESTS OF *MISCHOCYTTARUS MEXICANUS* (HYMENOPTERA: VESPIDAE)

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ABSTRACT

It is not known how pleometrosis (nest initiation in groups) and haplometrosis (nest initiation alone) are both maintained in the paper wasp *Mischocyttarus mexicanus* (Saussure). To answer this question, reliable measurements of the reproductive success of each tactic are needed. It is shown here that females that begin nests alone are more likely to raise a few daughters in rapid succession rather than many daughters at the same time. Females in small groups or alone also tend to have smaller first daughters than those females working in large groups. This difference in resource allocation between small and large groups causes measurements of per capita rates of production to correlate differently with group size depending on whether the number of cells, number of offspring, or weight of offspring added per day is measured. These data are consistent with the observation that haplometrotic females receive more predator and conspecific attacks than pleometrotic females, and thus produce their first daughters quickly to guard the nest. In addition the chronic mystery of a negative correlation between per capita productivity and group size in social insects is shown to be an expected outcome and not necessarily an indication that efficiency decreases with an increase in group size.

Key Words: *Mischocyttarus mexicanus*, paper wasps, efficiency, social behavior, Polistinae, per capita productivity

RESUMEN

No se sabe como pleometrosis (iniciación de nido en grupos) y haplometrosis (iniciación de nido solo) son mantenidos en la avispa de papel *Mischocyttarus mexicanus* (Saussure). Para contestar esta pregunta, se necesitan medidas confiables del éxito reproductivo de cada táctica. Se demuestra aquí que hembras que comienzan nidos solos son mas propensas a criar unas pocas hijas muy rápidamente en vez de muchas hijas al mismo tiempo. Hembras en grupos pequeños o solas también tienden a hacer sus primeras hijas más pequeñas que aquellas hembras trabajando en grupos grandes. Esta diferencia en asignación de recursos entre grupos pequeños y grandes causa que evaluaciones de producción promedio per capita sean correlacionadas diferentemente con el tamaño del grupo dependiendo en que el numero de células, numero de crías, o el peso de la cría sumado por día sea evaluado. Estos datos apoyan la noción que hembras haplometroticas reciben mas ataques de predadores y conespecificos que hembras pleometroticas, y por lo tanto producen su primera hija rápidamente para proteger el nido. Adicionalmente, el misterio crónico de una correlación negativa entre productividad per capita y tamaño del grupo en insectos sociales es demostrado ser un resultado esperado y no una debilitación de la hipótesis que grupos mayores son más eficientes.

When females of *Mischocyttarus mexicanus* (Saussure) (a Polistine paper wasp) begin nests, they can be found doing this alone or in groups of sisters (Litte 1977). The existence of solitary nest-founding (haplometrosis) together with group nest-founding (pleometrosis) is common in paper wasps (West-Eberhard 1967; Litte 1981; Strassmann 1983; Reeve 1991; Gadagkar 1996) and some other hymenopterans (Michener 1964; Mintzer 1979; Tschinkel and Howard 1983; Mintzer & Vinso 1985; Rissing & Pollock 1987, 1988; Stark 1992). Since haplometrotic and pleometrotic sisters can often be found working near one another, it is compelling to hypothesize that these two modes of nest initiation are the result of decisions made by females: they must decide whether to join a sister, and sisters must decide whether to accept help (Strassmann 1996; Clouse 1997). How these two tactics are maintained in the population is an exciting topic for those who study the selective advantages of social and solitary behavior.

It has become increasingly clear that for many Polistines, nests require guarding to survive, and this may be a driving force behind the evolution and maintenance of pleometrosis. We know already that nests of *M. mexicanus* and other paper wasps suffer continuous intrusions by conspecifics which prey on larvae and/or usurp the current foundress, and we know that lone females suffer more from these attacks (Gamboa 1978; Makino &

Sayama 1991; Kasuya et al. 1980; Kasuya 1982; Klahn 1988; Gamboa et al. 1992; Clouse 1995; Katada & Iwahashi 1996) as well as attacks by ants, birds, and other predators and parasites (Yamane 1996). This is because lone females cannot both guard their nests and forage, so their nests are left vulnerable for part of every day. Moreover, since initial attacks on haplometrotic nests are more successful than those against pleometrotic nests, haplometrotic nests probably receive a higher rate of return attacks than pleometrotic ones. However, haplometrotic females seem to compensate by making numerous and brief foraging trips, and, at least in some populations, haplometrotic females are larger than even the highest-ranking pleometrotic females (Clouse 1997).

The observation that *M. mexicanus* nests suffer regular intrusions is consistent with the finding that adult females on a nest are significantly less related than full sisters (Strassmann et al. 1995). Strassmann et al. (1995) also asserted that *M. mexicanus* females mate only once, and Litte (1977) observed that nests had only a single egg-layer, so queen replacement—whether by daughters, co-foundresses, or outside usurpers—is the most probable explanation for low relatedness. Since hymenopteran sisters who share both parents are more related to each other than to their own offspring, low relatedness between hymenopteran females of any species disqualifies perhaps the most elegant explanation for their cooperation.

Even if pleometrotic females are raising relatively unrelated nieces, if they are producing many more of them than they would alone, low relatedness may not matter; Strassmann et al. (1995) suggest that Litte's (1977) data on nest sizes, survivorship, and production rates support this hypothesis. Indeed, many studies of social insects (including *M. mexicanus* (Litte 1977)) have focused on comparing the productivity of pleometrotic and haplometrotic nests (Table 3). Investigators divided some measure of reproductive output (cells, eggs, larvae, etc.) by the number of foundreses, obtaining a per capita productivity statistic for each female that could be compared across groups of various sizes (Gadagkar 1996). However, the results of such studies were almost always that females could expect to produce fewer offspring if they worked in larger groups (Brian 1953, 1956; Michener 1964; West-Eberhard 1967; Gibo 1974; Hermann & Dirks 1975; Gibo 1978, Noonan 1981; Strassmann 1981; Itô 1987, Klahn 1988; Queller & Strassmann 1988; Wenzel & Pickering 1991; Tschinkel 1993). Not only have these results thwarted another hypothesis for the evolution of social behavior in insects, but they have also been interpreted as running counter to the intuitive and theoretically defensible (Queller 1996) notion that the costs of working in groups are offset by gains in efficiency. Thus, per capita productivity data in social insects have become a serious snag in our understanding of the evolution of social behavior in general.

Recognizing that there were fundamental problems with the measures of per capita productivity to date, I did this study to obtain improved measures of per capita productivity for a social insect. First, previous measures rest on the assumption that all females have the same intrinsic reproductive potential, an assumption that is probably not true and not testable (Clouse 1997); so I attempted manipulating nests such that females could not control the size of the group to which they belonged. Second, by discounting failed nests, previous studies did not count the output (albeit, zero) for many foundresses, so I kept a record of nest surviorship and presumed causes of mortality. Third, the types of output measures chosen by previous studies were subject to different biases if females altered the way they allocated resources in small versus large groups. It has been shown already that colonies of the fire ant *Solenopsis invicta* Buren produce smaller daughters when foundress associations are large (Goodisman & Ross 1996). Thus, I collected different types of output data for the same nests. And finally, previous measures often did not factor in the time required to produce the measured output, so I calculated output for all nests as a daily rate of production. In addition, the interpretation of per capita productivity in the broader study of the evolution of social behavior is revisited in the Discussion.

Materials and Methods

Mischocyttarus mexicanus is well-suited for studying the selective advantage, and accordingly reproductive output, of pleometrosis and haplometrosis in social insects. Like other paper wasps, they make open paper nests that can observed and easily manipulated. Being a resident of the Eastern subtropics, and having evolved from a tropical genus, *M. mexicanus* females start new nests year-round (Litte 1977, Hermann et al. 1985). In addition, all females (even the first daughters) are apparently capable of being the principal egg-layer on the nest. The females are timid relative to other Polistines (Hermann & Chao 1984), and they readily nest around buildings and on outdoor paraphernalia (wind chimes, ladders, etc.).

I conducted all work at Archbold Biological Station, Highlands County, Florida, between 10 May and 31 July, 1993. I used three different sets of nest to measure various parameters of production: Manipulated Pleometrotic and Haplometrotic, Restarted, and Unmanipulated nests. The methods are arranged by nest type, and the results are arranged by production measurement. All data are reported as (mean ± standard error) unless otherwise noted.

Set I. Manipulated Pleometrotic and Haplometrotic Nests

The main goal of studying Set I was to measure different rates of production on nests for which I had manipulated the group size. I wanted nests that were as close to the first day of initiation as possible, and I wanted pleometrotic females to end up in small or large groups with equal probability after manipulation. Nests were found in saw palmetto (*Serenoa repens*) along roadsides and paths, and only those that had only eggs were included. Upon discovery, the initial size and shape of each nest was recorded and drawn. An attempt was made to control for group size by removing foundresses at night. I removed one female from nests that had two females, two or one female alternately from nests that had three females, and the appropriate number of females from larger nests to make nests with four or one female alternately. Females were removed by disturbing them with a pine needle until they walked onto the needle or tried to sting it, whereupon they were placed in a vial and frozen later. Many nests required more than one night to remove the required number of females, since females often dropped off their nests when disturbed. Females already found working alone and whose nests had only eggs were harassed to mimic the disturbance caused by removing foundresses. They were touched with a stick at night for several minutes, often to the point where they left the nest for the rest of the night. The number of females on each nest was recorded every night, and these data were used to calculate an average number of females working on each nest per day.

When the most mature larva spun a cocoon in which to pupate ("cell capping"), I collected the entire nest. The number of cells and offspring added since the nest was first discovered were recorded. Then the offspring were removed, dried at 60°C for five hours, and weighed to the nearest 0.01 mg. Eggs adhered too tightly to the nest paper to be removed and were included with the weight of the nest paper. The nest paper was cut back to the size upon discovery, and the paper added since discovery was dried and weighed. Four rates of daily per capita production were generated from these measurements: number of new cells, number of offspring, total weight of nest product, and weight of offspring per female per day. Only successful nests were used in final calculations, and for one nest, ambiguities over its size at collection forced me to exclude it from measures of cell and offspring addition.

Set II. Restarted Nests

As the study of Set I progressed, it became clear that most would not survive long enough to obtain production data. The goal of studying Set II was to obtain a sample of nests for which I had determined the group size, and that had enough females to survive to first pupation. At night I cut down nests that were large enough to have produced daughters, and on the following night I searched nearby leaves for the restarted nests. For such nests, it is impossible to determine if the foundresses were haplometrotic or pleometrotic, since daughters and subordinate foundresses are indistinguishable. The group sizes were altered to form groups with either (1) four or more females or (2) less than four females. The number of females was recorded each night, and when the first cell capped on a nest, the entire nest was collected. The offspring that capped their cells (prepupae) were removed, dried, and weighed. When a nest had more than one offspring cap its cell, the pre-pupal weights were averaged to produce one weight for each nest. Per capita rates of production were calculated in the same way as for Set I above.

Set III. Unmanipulated Nests

The goal in studying Set III was to obtain a large sample of unmanipulated nests from which to determine how females in different sized groups allocate resources differently among their offspring. I conducted a survey of 51 pre-eclosion nests between 10 May and 15 May 1993. Each nest was censused at night and then collected, whereupon the numbers of eggs, first through fifth instar larvae, and pupae were recorded. Pre-eclosion nests were easy to recognize by the fact that they had their oldest offspring in the center cells (the first cells built), and any cells large enough to contain pupae did not show signs of previous occupation (e.g., meconium).

It was obvious from the initial survey that some foundresses had put their efforts into a few offspring rather than continually adding new ones. For example, a nest with one fifth-instar larva and two eggs had clearly concentrated resources on the one large offspring more than a nest with one third-instar larva, two first and second instars, and three or four eggs. However, it was not possible to immediately compare a nests that had a more scattered array of larval sizes. For example, the degree of concentration of nests that did not have any older larvae, just a few second- or third-instars, was not easily compared to nests that had older larvae and no eggs. Therefore I used data on the size and number of offspring to calculate a single measure of how concentrated resources were in the oldest offspring for each nest. I assigned each offspring to a size class between one and seven (egg = 1, first instar = 2, . . . fifth instar = 6, pupa = 7). I divided the size class value of the oldest offspring on each nest by the quantity of the youngest offspring. For example, if

a nest had six eggs, four second-instars, three fourth-instars, and one pupa, I divided "7" (for the pupa) by "6" (for the number of eggs). This measure I refer to as "concentration," and for this hypothetical nest, the concentration is 1.17. It is not as concentrated as another hypothetical nest that has one pupa and two eggs (concentration = 3.5), but it is more concentrated than a nest that has two fifth-instars, two fourth-instars, and six third-instars (concentration = 6 ÷ 6 = 1).

Results

I. Per capita rates of production

Ninety-nine nests were initially included in Set I. Thirty-six percent were begun by one female, 26% were begun by two females, 21% by three females, nine percent by four females, and eight percent by five to nine females. The removal of foundresses from pleometrotic nests was not effective in assigning females to group sizes without respect to their initial group size: even after the manipulation, the average number of females on nests that originally had four or more females (mean = 3.17, SD = 0.30, N = 17) was significantly higher than the average number of females on nests that originally had three females (1.73 ± 0.58, N = 18; Fisher's PLSD; $P < 0.01$) and those that originally had two females (1.39 ± 0.09, N = 25; Fisher's PLSD; $P < 0.01$). In addition, 80% of nests did not survive for more than 20 days.

There were enough survived pleometrotic nests in Set I to measure productivity; however, different methods for measuring productivity on survived nests gave contradictory results. The number of cells added per female per day did not correlate with the average number of females (Spearman Rank Correlation; N = 10; rs = 0.33; P = 0.32). However, there was a significant positive correlation between the number of offspring added per female per day and the average number of females (Spearman Rank Correlation; N = 10; rs = 0.71; P = 0.03). There was also a significant negative correlation between the average number of females per day and both the total mg of nest product added per female per day (Spearman Rank Correlation; N = 11; rs = -0.70; P = 0.03) and the mg of offspring added per female per day (Spearman Rank Correlation; N = 11; rs = -0.61; P = 0.05).

I was successful in altering the group sizes in restarted nests (Set II) such that the group sizes before and after manipulation did not correlate (Spearman Rank Correlation; n = 23; P = 0.34). Analyzing just survived nests, there was no correlation between the average number of females on the nest per day and any of the four per capita measures of daily production.

Manipulated haplometrotic females from Set I were more productive than both manipulated pleometrotic nests in Set I and restarted nests (Set II) regardless of the production measure used (Mann-Whitney U; $P < 0.02$ for all comparisons) (Table 1).

II. The size of the largest offspring

The average weights of all pre-pupae from Sets I and II combined were positively correlated with the average number of females on their nest of origin (Spearman Rank Correlation; N = 34; rs = 0.63; P = 0.02). The average weight (mg) of the first pre-pupa on restarted nests (Set II) tended to be positively correlated with the average number of females on the nest (Spearman Rank Correlation; N = 13; rs = 0.52; P = 0.07).

Restarted nests (Set II) had larger pre-pupae than manipulated haplometrotic females (1.4 ± 0.06 mg, n = 13 versus 1.3 ± 0.03, n = 12; Mann-Whitney U; P = 0.01), and manipulated pleometrotic females (Set I) (1.1 ± 0.09, n = 10; $P < 0.01$). Manipulated pleometrotic (Set I) and haplometrotic pre-pupae were not significantly different in size (P = 0.16)

III. Concentration

Nests from Set III were more concentrated when being built by fewer females. For collected nests, concentration ratios for one-female, two-female, three-female, and four or more-female nests were significantly different (Table 2; Kruskal-Wallis; $P < 0.025$). From Set I, manipulated haplometrotic nests had higher concentration measures than manipulated pleometrotic nests (4.31

Table 1. Average per capita rates of production (± standard error) for three nest types: those in which the female was originally alone, in which females were originally in groups, and those that were restarted after being cut down.

Measurement	Manipulated Haplometrotic	N	Manipulated Pleometrotic	N	Restarted	N
# cells/female/day	0.28 ± 0.02	12	0.07 ± 0.01	10	0.15 ± 0.01	15
# offspring/female/day	0.25 ± 0.03	12	0.01 ± 0.03	10	0.13 ± 0.01	15
mg offspring/female/day	0.96 ± 0.17	12	0.57 ± 0.10	11	0.52 ± 0.06	15
total mg/female/day	1.44 ± 0.22	12	0.96 ± 0.18	11	0.84 ± 0.08	15

± 0.41, N = 13, versus 2.34 ± 0.50, N = 12; Mann-Whitney U; P < 0.001). From Set II, restarted nests with less than four females (N = 8, concent. = 1.69 ± 0.34) did not have significantly different concentration ratios from restarted nests with more than four females (N = 11, 1.35 ± 0.29; Mann-Whitney U; 0.25 > P > 0.15), although the trend was similar to sets I and III.

IV. Time to cell capping

Restarted nests (the only nests I followed since initiation), took longer to raise a daughter to prepupal stage if there were less than four females on average working on the nest (25.33 ± 1.24 days versus 22 ± 0.45 days; Mann-Whitney U; P < 0.01).

Discussion

The mortality rates of new nests make it clear why measuring the final production of reproductive offspring has not yet been done: the mortality rate for new nests is so high (80% failed within 20 days), one would have to follow several hundred nests to have a few left for analysis in the final stages. Moreover, it indicates that when addressing the question of what a female can expect to produce, the chance of nest failure (producing nothing) must be factored into the calculation.

Among nests that did survive, two processes heavily influence measurements of production during the pre-eclosion stage in *M. mexicanus*. First, small nests seem to rush the production of their first adult daughter. This is supported here by the fact that (1) in Set I the per capita rate of adding new offspring is larger in bigger groups, but these bigger groups have a smaller per capita rate of adding biomass, (2) the "concentration" ratio was higher for nests attended by one female than by several, and (3) smaller restarted groups lagged behind large ones in the time to cell capping by only two to three days. Each of these results is what we would expect if females in small groups, especially haplometrotic females, primarily fed their oldest daughter and laid few additional eggs. The fact that the first daughter on smaller nests tended to be smaller than those from larger associations is also consistent with the idea that small nests rush their first daughter to eclosion; perhaps the first daughter herself decides to pupate early, since her own life is at stake the longer the nest lacks extra guards.

The second factor biasing productivity measures is that surviving haplometrotic females have much higher daily rates of production than pleometrotic females, regardless of what type of output one measures. It can be legitimately argued that not having lost sisters or their original nest, the lone females in this study were not nearly as traumatized as the other females in this study (and thus were more productive). But I disturbed lone females to the point that I thought they might abandon their nests, and they naturally have great demands placed on them daily by the need to procure prey, water, paper, and nectar alone. Nonetheless, even while concentrating efforts on the oldest offspring to a greater extent than any other nests, they added more cells per female per day *and* more biomass per day than any other group. Although the daily per capita rate of cell addition declines as group size decreases in pleometrotic nests (Set I), it rises sharply again for lone females, and thus lone females stand apart from the overall production trends. Lone female production is so much larger than group production in this study, production analyses that assume that the only behavioral difference between haplometrotic and pleometrotic females is their choice in the number of nesting associates should not be accepted.

Since per capita productivity has been used to compare the reproductive output of pleometrotic and haplometrotic females, and productivity has been the axis of discussions about synergy in insect societies, per capita productivity has been equated with "efficiency." Thus, for much of the past forty-five years, productivity measures in social insects have led to discussions of the larger question of why social behavior is apparently inefficient. However, per capita productivity merely measures the marginal productivity of each additional worker, and diminishing marginal returns from adding sisters, or any other factor of production, is quite expected (Krebs & Davies 1987). This is because as one adds additional units of a production input, while holding others constant, the additional units become increasingly redundant. (Interestingly, a few human examples exist of *increasing* marginal returns during the initial stages of production, and some wasp data reflect this phenomenon when foundress group size increases from one to two females (West-Eberhard 1967, Metcalf & Whitt 1977, Litte 1981, Noonan 1981, Strassmann 1981).)

Table 2. Average concentration values for collected nests. "Concentration" was calculated by dividing the stage of the oldest offspring (egg = 1, first instar = 2, . . . fifth instar = 6, pupa = 7) by the number of the youngest offspring.

Number of Foundresses	1 N = 28	2 N = 8	3 N = 7	>3 N = 8
Concentration	2.09 ± 0.35	1.03 ±0.24	0.70 ±0.14	0.35 ±0.16

TABLE 3. PREVIOUS MEASUREMENTS OF PER CAPITA PRODUCTIVITY. THE FACTORS COUNTED TO OBTAIN EACH MEASUREMENT ("MEAS.") ARE AS FOLLOWS: F = NUMBER OF CELLS FULL OF POLLEN AND EGGS OR SMALL LARVAE, E = NUMBER OF EGGS, L = NUMBER OF LARVAE, CC = NUMBER OF CAPPED CELLS, C = NUMBER OF CELLS, O = NUMBER OF OFFSPRING, R = NUMBER OF REPRODUCTIVE OFFSPRING, P = NUMBER OF PUPAE AT FIRST ECLOSION, B = BIOMASS OF OFFSPRING, J = ENERGY EQUIVALENT OF OFFSPRING IN JOULES, I = INCLUSIVE FITNESS BASED ON ESTIMATES OF RELATEDNESS. THE CORRELATION BETWEEN PER CAPITA PRODUCTIVITY AND GROUPS SIZE ("CORR.") COULD BE POSITIVE (+), NEGATIVE (-), OR NOT SIGNIFICANT (N.S.). DATA FROM MICHENER (1964) WERE NOT ANALYZED STATISTICALLY.

Family	Species	meas.	corr.
Halictidae	*Pseudagapostemon divaricatus*[1]	F	–
	Augochloropsis sparsilis[1]	F	–
	Lasioglossum imitatum[1]	F	–
	Lasioglossum rhytidophorum[1]	F	–
Apidae	*Apis mellifera*[1]	CC	–
	Bombus americanum[1]	O	+
Formicidae	*Mymica rubra*[2]	B, L, P	–
	Myrmica rubra macrogyna	L	–
	Solenopsis invicta[3]	O, R, B, J	–
Vespidae	*Polybia bistriata* & *P. bicyttarella*	E	–
	49 nests from 11 Polybine species[1]	E	–
	Polistes fuscatus[4]	C	–
	P. fuscatus[5]	C, O	n.s.
	P. fuscatus[6]	O	–
	P. fuscatus[7]	R	n.s.
	P. annularis[8]	C	–
	P. annularis[9]	I	–
	P. annularis[10]	R	–
	P. metricus[11]	E	n.s.
	P. metricus[12]	R	+
	P. metricus[13]	R	n.s.
	P. chinensis antennalis[14]	E, C	–
	Mischocyttarus mexicanus[15]	C	–
	M. labiatus[16]	C, P	–
	Ropalidia fasciata[17]	C	–
	R. marginata[18]	O	–

[1]Michener (1964)
[2]Brian (1953, 1956)
[3]Tshinkel (1993)
[4]West-Eberhard (1993)
[5]Gibo (1974)
[6]Gibo (1978)
[7]Noonan (1981)
[8]Hermann and Dirks (1975)
[9]Strassmann (1981)
[10]Queller and Strassmann (1988)
[11]Bohm (1977)
[12]Metcalf and Whitt (1977)
[13]Gamboa (1978)
[14]Hoshikawa (1979)
[15]Litte (1977)
[16]Litte (1981)
[17]Itô (1987)
[18]Shakarad and Gadagkar (1993)

True efficiency measurements in social insects await refinement of a system by which total energy input can be accurately measured (such as in Suzuki 1981), because "efficiency" is a ratio of output to input (Brian 1953; Jeanne 1986). Using output measures which encompass total output and are thus free from the resource-allocation biases shown here should provide novel and interesting efficiency data.

Moreover, if productivity, survivorship, and relatedness can be combined to calculate reliable expectations of reproductive success for haplometrotic and pleometrotic foundresses, it could open new doors of research into the maintenance of so-

cial and solitary behavior. One possibility is that these tactics are evolutionarily stable strategies in which mothers deliberately make some large reproductive daughters who can keep the hectic pace of working alone and some small daughters who can work more slowly in groups. The overall payoff could be the same for both types of females if the large females suffer more from attacks and lose more nests, but if they survive, their nests produce more reproductive offspring in the end than pleometrotic ones. Another possibility is that one or the other strategy is more successful but can be adopted only under certain circumstances. Haplometrosis—naturally desirable since the female gets to lay all the eggs—may require a minimal body size and fat store to defend the nest and make numerous foraging trips; pleometrosis—also desirable since foundresses get to produce on a relatively well-guarded nest—may require having and finding certain types of sisters to minimize fighting between foundresses.

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GLYPTOTERMES AMPLUS, A NEW DAMPWOOD TERMITE (ISOPTERA: KALOTERMITIDAE) FROM ST. LUCIA

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ABSTRACT

Glyptotermes amplus n. sp. is described from soldiers and imagos collected on St. Lucia, West Indies. It is the seventh described species of West Indian *Glyptotermes* and is the largest species among its Lesser Antillean congeners.

Key Words: taxonomy, new species, Neotropics, West Indies, Lesser Antilles

RESUMEN

Glyptotermes amplus n. sp. es descrita de soldados e imagos colectados en St. Lucia, Antillas Menores. Es la séptima especie descrita de la especie antillana *Glyptotermes* y la mayor especie entre sus congeneres de las Antillas Menores.

Glyptotermes Froggatt is a tropicopolitan genus that is the second most diverse in the family Kalotermitidae after *Neotermes* Holmgren (Krishna 1961). The soldier caste of *Glyptotermes* is rather variable among species, but most can be distinguished from those of other kalotermitid genera by their rather cylindrical head capsule, steep frons, and short, thickened mandibles. The soldier head capsule of many *Glyptotermes* species is also characterized by a pair of rounded frontal protuberances that are separated by a median depression or cleft. Unlike those of the closely aligned genus *Calcaritermes* Snyder, *Glyptotermes* soldiers do not have an enlarged apical spur on the front tibia. Wing venation of the imago of *Glyptotermes* is similar to that of *Calcaritermes* in which the sclerotized media runs close and parallel to the radial sector to the wing tip. *Glyptotermes* spp. are typically found in wet forests infesting sound or rotting wood or wood scars in live trees.

In the New World, all 25 known species of *Glyptotermes* are Neotropical in distribution of which 6 have been described from the West Indies (Constantino 1998). *Glyptotermes pubescens* Snyder (1923) and *G. liberatus* (Snyder) (1929) were described from Puerto Rico and Jamaica, respectively. *Glyptotermes liberatus* is also known from Puerto Rico (Martorell 1973). *Glyptotermes adamsoni*, *G. parvoculatus*, and *G. tubifer* were described by Krishna & Emerson (1962) from Trinidad and Tobago, Trinidad only, and St. Vincent, respectively. The description of *G. (= Calotermes) posticus* (Hagen) (1858) is based on a single dealated female from St. Thomas U.S.V.I., and according to Snyder (1929), is probably that of a *Cryptotermes* species. Furthermore, Snyder (1929) determined that the soldier described as *Kalotermes posticus* by Banks (1919) was actually that of a new species that Snyder (1929) renamed *Kalotermes liberatus*. Nevertheless, Krishna (1961) included *posticus* in his revised species list of *Glyptotermes*. Two unidentified *Glyptotermes* spp. were reported from Dominica and Martinique (Scheffrahn et al. 1994).

During a 1998 expedition to St. Lucia, a new species of *Glyptotermes* was collected. The descriptions of the soldier and imago of *Glyptotermes amplus* n. sp. are provided herein.

MATERIALS AND METHODS

Morphometrics of specimens preserved in 85:15 ethanol: water were made with a stereomicroscope fitted with a calibrated ocular micrometer. Scanning electron micrograph prints were scanned at 600 dpi, the digital image outline traced using photograph-enhancing software (Photo Magic, Micrografx, Inc., Richardson, TX), the background converted to black, and the scale bar digitally redrawn (Scheffrahn et al. 1999).

Latitude and longitude coordinates were measured at collection sites using a Garmin GPS model 38 global positioning receiver (Garmin International, Olathe, Kansas). Coordinates of collection sites were converted to decimal degrees and mapped (Fig. 3) 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).

The holotype soldier and morphotype imago are deposited in the collection of the American Museum of Natural History, New York [AMNH]. Paratype soldiers and imagos are deposited in the National Museum of Natural History (Smithsonian Institution), Washington, D.C. [USNM]; the

Florida State Collection of Arthropods, Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Gainesville [FSCA]; and the authors' collection at the University of Florida Research and Education Center, Ft. Lauderdale [FTLD].

Glyptotermes amplus, New Species

Imago (Fig. 1A, Table 1).

General color dark castaneus brown except as noted. Frons slightly lighter than remainder of head; epicranial suture indistinct. T-shaped pattern on pronotum midline slightly paler. All ventral surfaces of lighter tint than dorsum; anteclypeus pale yellow. Wing scale venation and sclerotized veins beyond the scale including costa, subcosta, radius, radial sector, and media dark brown; wing membranes brown.

Head capsule with few scattered short or medium bristles; lateral margins of pronotum fringed with more numerous alternating short and long bristles. Bristle patterns on each tergite and sternite consist of about 8 long and a few more short bristles. Antennae with 13-14 articles; relative length formula usually 2 < 3 > 4 = 5. Eyes medium-sized, slightly triangulate with straight margins bordering antennae, ocelli, and posteroventral margins of head. Ocelli prominent, white, and ellipsoid; narrowly separated from eyes. Pronotum about as wide as head; anterior margin broadly concave, posterior margin akin to 3 adjacent octagon sides with the median (most posterior) side slightly emarginate. Fore wings with radius, radial sector, and median veins running closely parallel to tips of wings; connected near tips by 2-3 short, pigmented cross veins; surfaces covered with large, evenly-spaced tubercles. Subcosta extending about 1/6 length of fore wings beyond sutures; cubitus faint. Arolia present.

Soldier (Fig. 1B-D, Table 2).

Head capsule, in dorsal and lateral views, grading from pale orange-brown in posterior 1/3

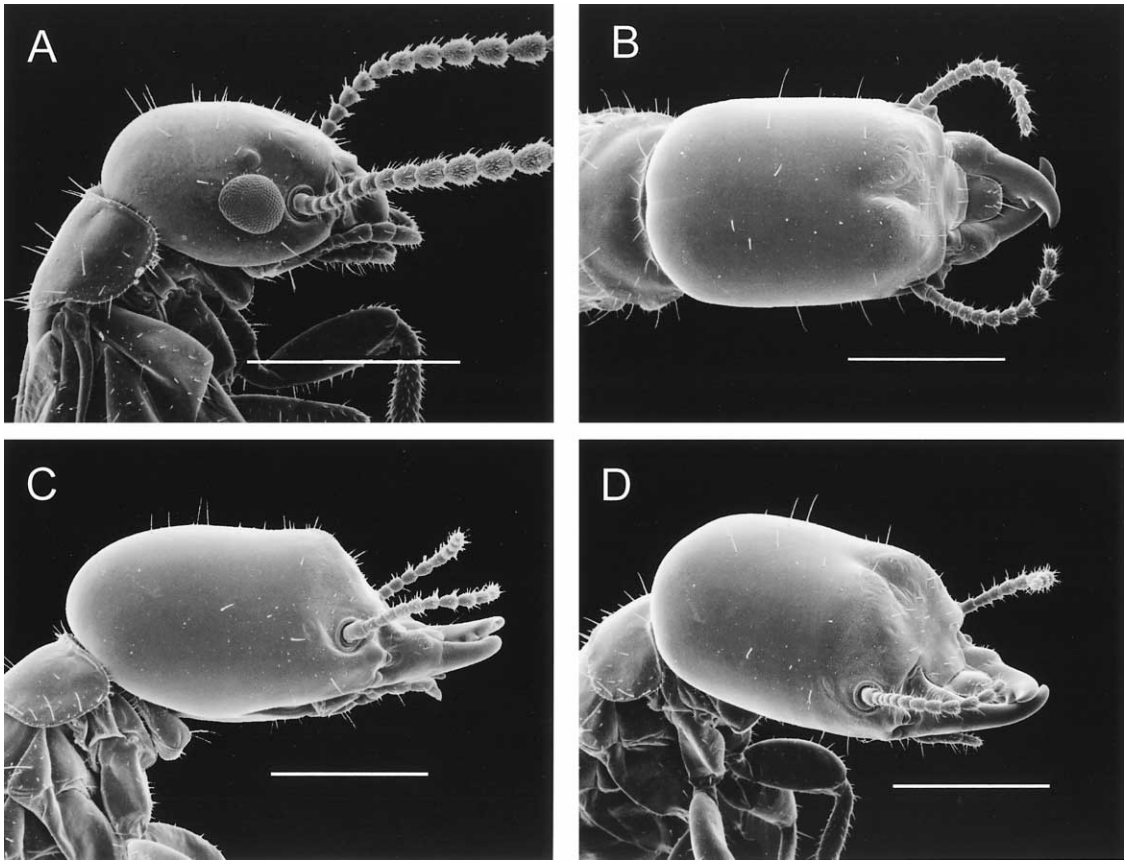

Fig. 1. Lateral view (A) of *Glyptotermes amplus* imago from Barre De L'Ilse rain forest, St. Lucia. Dorsal (B), lateral (C), and oblique (D) views of soldier head capsule of *G. amplus* from Edmond Forest Reserve, St. Lucia. Scale bars equal 1 mm.

TABLE 1. MEASUREMENTS OF *GLYPTOTERMES AMPLUS* IMAGO.

Measurement in mm (n = 5♂, 5♀ from 2 colonies)	Range	Mean ± S.D.	Morphotype
Head length with labrum	1.37-1.47	1.42 ± 0.030	1.42
Head length to postclypeus	1.00-1.11	1.06 ± 0.039	1.03
Head width, maximum at eyes	1.21-1.24	1.22 ± 0.013	1.22
Eye diameter, maximum	0.26-0.30	0.29 ± 0.011	0.29
Eye to head base, minimum	0.15-0.20	0.20 ± 0.020	0.16
Ocellus diameter, maximum	0.11-0.14	0.13 ± 0.008	0.13
Pronotum, maximum length	0.64-0.72	0.69 ± 0.027	0.65
Pronotum, maximum width	1.12-1.24	1.18 ± 0.040	1.17
Total length with wings	8.52-9.51	9.03 ± 0.39	9.23
Total length without wings	5.18-6.39	5.91 ± 0.44	5.96
Fore wing length from suture	6.25-6.67	6.45 ± 0.15	6.32
Fore wing, maximum width	1.45-1.65	1.56 ± 0.057	1.45
Hind tibia length without spurs	0.88-1.01	0.96 ± 0.039	0.93

to orange-brown in middle, to dark orange-brown at frontal protuberances; narrow black band between antennal fossae running along anterior margin of frons and postclypeus. Mandibles nearly black in distal half, grading to dark reddish-brown near bases. Anteclypeus translucent pale yellow. Labrum translucent ferruginous orange. Pronotum pale yellow-brown with hyaline midline and yellow-brown margins. Scattered medium and short bristles on head capsule, nota, tergites, and sternites.

Head capsule subcylindrical. Frontal protuberances rounded in dorsal view. Protuberances separated by median cleft; cleft narrow and deeper at its origin on the vertex, then becoming wider and shallower at mid-frons. Protuberances and cleft covered with faint rugose striations. Frontal plane sloping near 60° from plane of vertex. Labrum lingulate, nearly transparent. Eye spots large, hyaline, and elliptical; margins diffuse with head capsule pigmentation; centers slightly above centers of antennal fossae. Mandibles short, stout; with basal 1/3 consisting of conspicuous humps; humps covered with rugose striations. Mandible points recurvate. Dentition distinct, teeth bluntly conical. Antennae with 11-13 articles; relative length formulae usually $2 > 3 < 4 < 5$ or $2 > 3 = 4 < 5$. Pronotum as wide as head, twice as wide as long. Anterior margin of pronotum weakly concave with minute median incision; posterior margin parallels anterior margin except for narrow weak concavity near middle; lateral margins evenly convex.

Comparisons.

The imago of *G. amplus* is much larger than that of any congener in the Lesser Antilles, including *G. adamsoni*, *G. parvoculatus*, *G. tubifer*, and several undescribed species from Dominica, St. Lucia, and St. Vincent. The imagos of the Greater Antillean *G. liberatus* and *G. pubescens*

TABLE 2. MEASUREMENTS OF *GLYPTOTERMES AMPLUS* SOLDIER.

Measurement in mm (n = 9 from 4 colonies)	Range	Mean ± S.D.	Holotype
Head length to tip of mandibles	2.64-2.97	2.82 ± 0.098	2.87
Head length to median cleft	1.32-1.48	1.39 ± 0.055	1.40
Head length to genal tip	1.93-2.10	2.05 ± 0.054	2.07
Genal tips outside width	1.16-1.28	1.23 ± 0.041	1.24
Frontal protuberances outside width	0.95-1.03	1.00 ± 0.028	1.01
Head width, maximum	1.34-1.54	1.44 ± 0.055	1.47
Head height, excluding postmentum	1.11-1.31	1.23 ± 0.059	1.26
Pronotum, maximum width	1.23-1.47	1.35 ± 0.072	1.47
Pronotum, maximum length	0.64-0.69	0.66 ± 0.022	0.67
Left mandible length; tip to ventral condyle	1.11-1.21	1.16 ± 0.031	1.16
Total length	4.85-6.63	5.92 ± 0.55	5.94
Hind tibia length without spurs	0.83-0.93	0.89 ± 0.032	0.92
Eye spot, maximum diameter	0.15-0.21	0.18 ± 0.018	0.20

are somewhat smaller (head width 1.06-1.15 and 1.08-1.14 mm, respectively) than *G. amplus*. The imago of *G. liberatus* is nearly as darkly pigmented as *G. amplus*, however, the pronotum of the former is much narrower, the ocelli smaller, and the wing membrane tubercles smaller and denser than in *G. amplus*. The imago of *G. pubescens* is reddish-brown, its compound eyes smaller, and wing membrane tubercles smaller than those of *G. amplus*.

The soldier of *G. amplus* is larger or much larger in all measurements than soldiers of congeners from the Lesser Antilles. Unlike *G. amplus*, the median frontal cleft, frontal protuberances, rugosity, and mandibular humps are absent in the soldier of *G. liberatus* (Fig. 2A). The head capsule of *G. liberatus* is narrower and proportionally longer and the pronotum narrower than in *G. amplus*. The frons plane of *G. liberatus* slopes at a smaller angle to the vertex plane than that of *G. amplus*. The anterior margins of the frontal protuberances of *G. pubescens* soldiers are truncate (Fig. 2B); while in *G. amplus* they are hemispherical. The median frontal cleft of *G. pubescens* is deeper and hardly widens toward the frons while in *G. amplus* the cleft is more shallow and widens broadly toward the frons. The frons plane of *G. pubescens* slopes at a greater angle to the vertex plane than that of *G. amplus*.

Type Material.

Holotype soldier and 3 paratype soldiers (1 for SEM): St. Lucia, Edmond Forest Reserve, 13.838°N 60.996°W, 28.v.1998 (collection reference no. STL195). Morphotype imago, 2 paratype soldiers and 4 paratype imagos [USNM]: St. Lucia, Barre De L'Isle ridge, 13.920°N 60.959°W, 30.v.1998 (STL417). One paratype soldier: same data as STL417, second colony from same location (STL422). Five paratype imagos and two paratype soldiers [FSCA]: St. Lucia, Quilesse Forest Reserve, 13.843°N 60.974°W, 27.v.1998 (STL110). Three paratype soldiers: St. Lucia, Font Hill, 18.047°N 77.947°W, 30.v.1997 (JA641). Additional *G. amplus* material examined: second colony, same data as STL110; one soldier, pseudergates; (STL111). All above material taken collectively by J. A. Chase (JC), J. Krecek (JK), B. Maharajh (BM), J.R. Mangold (JM), and R. H. Scheffrahn (RS).

Etymology.

This species is named "amplus" after the Latin word for large, referring to the large size of imagos and soldiers compared with other West Indian *Glyptotermes* species.

Specimens from other West Indian *Gyptotermes* Examined.

Dominica: *Glyptotermes* sp.: Cabrit Peninsula-Ft. Shirley, 15.58°N 61.48°W,28.v.1994, JC, JK, JM, and RS coll., imagos, soldiers, (DM030); Crompton Point, 15.58°N 61.37°W, 29.v.1994, otherwise same data (DM062); Springfield Station trail to Mount Joy,15.35°N 61.38°W, 30.v.1994, otherwise same data (DM142); **Grenada:** *Glyptotermes parvoculatus*: Concord Falls, 12.12°N 61.73°W, 18.xiii.1997, JC and BM coll., dealates, soldiers (GR054). **Jamaica:** *Glyptotermes liberatus*: Lowe River, 18.250°N 77.505°W, 25.v.1997, JC, JK, BM, JM, Yves Roisin, and Paul Ban, coll., imagos, soldiers (JA145). **Martinique:** *Glyptotermes* nr. *tuberifer*: Conservation Area, Precheur Grand Riviere, 14.84°N 61.22°W,1.vi.1994, JC, JK, JM, and RS coll., imagos, soldiers (MA051). **Puerto Rico:** *Glyptotermes liberatus*: El Yunque Park, Sierra Palm Trail,18.30°N 65.78°W, 31.v.1993, JC, JM, Julian de la Rosa (JR), and RS coll., imagos, soldiers (PR143); Highway 143 between hwys. 139 & 140, 18.18°N 66.48°W, 2.vi.1993, same data (PR224, 225); *Glyptotermes pubescens*: Hwy 787 5 km E. Cidra, 18.17°N

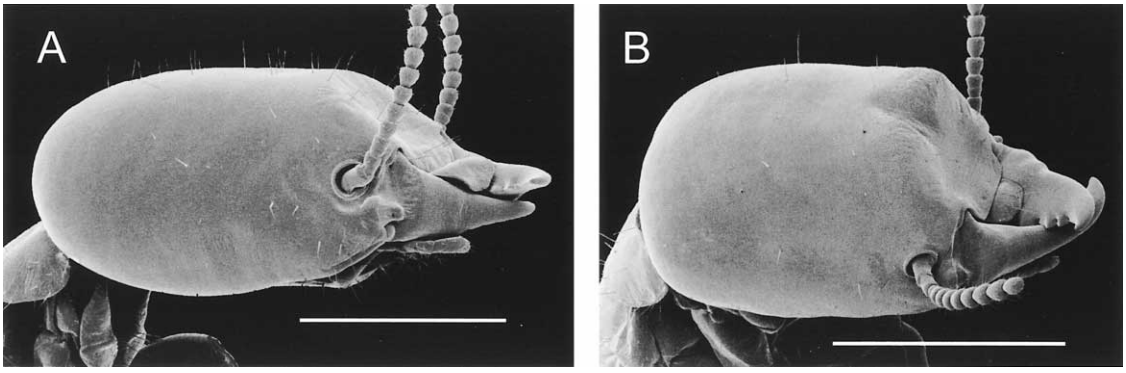

Fig. 2. Frontolateral view (A) of *G. liberatus* soldier head capsule from Highway 143 between Highways 139 and 140, Puerto Rico (PR224). Oblique view (B) of *Glyptotermes pubescens* soldier head capsule from Monte de Estado camp, Puerto Rico (PR246).

66.13°W, 31.v.1993, JC, JM, JR, and RS coll., imagos, soldiers (PR160); Monte de Estado camp on Hwy 366, 18.15°N 66.97°W,2.vi.1993, same data (PR245, 246); Cambalache State Forest,18.43°N 66.60°W, 4.vi.1993, same data (PR312). **St. Lucia:** *Glyptotermes* sp.: Barre De L'Isle, 13.924°N 60.959°W, 27.v.1998, JC, JK, BM, JM, and RS coll., 1 soldier (STL66); Quilesse Forest Reserve, 13.843°N 60.974°W, same data, imagos, dealates, soldiers (STL109); same data, dealates, soldiers (STL112). **St. Vincent:** *Glyptotermes tuberifer*: Fancy (end of the road), 13.380°N 61.171°W, 24.v.1998, JK, BM, and JM coll., imagos (STV50); *Glyptotermes* sp.: Vermont Falls Trail,13.217°N 61.215°W, 25.v.1998, JK, BM, and JM coll., imagos, dealates (STV152).

BIOLOGY

Five colonies of *G. amplus* were collected from 3 of 20 sites (Fig. 3) surveyed for termites in St. Lucia in 1998. Colonies of *G. amplus* were encountered in moist dead limbs of various woody hosts in the type localities, all of which were rainforest habitats (400 meters in elevation. Three colonies contained winged imagos, suggesting that dispersal flights commence in late spring and early summer. Like other Gyptotermes, the foraging galleries of *G. amplus* are often more darkly stained than the surrounding wood suggesting a microbial origin for the stain.

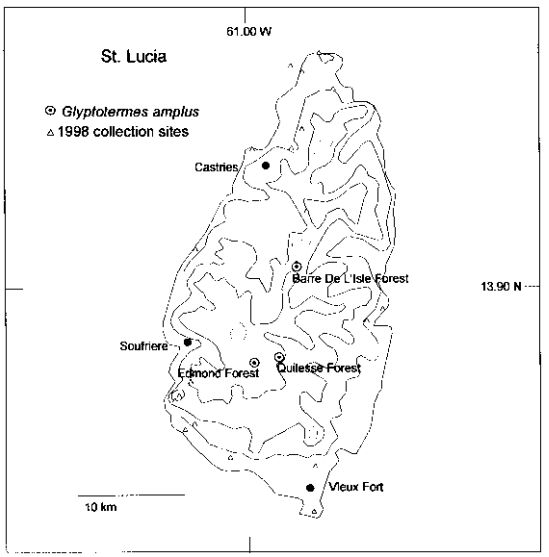

Fig. 3. Localities of *Glyptotermes amplus* and 1998 termite collection sites on St. Lucia, West Indies. Topographic lines are spaced at approximately 200 meter increments.

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COLONY DEFENSE BY WINGPADDED NYMPHS IN *GRYLLOPROCIPHILUS IMBRICATOR* (HEMIPTERA: APHIDIDAE)

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ABSTRACT

Large, wax-covered colonies of the North American aphid *Grylloprociphilus imbricator* (Fitch) are known to last over several months on exposed twigs of American Beech (*Fagus grandifolia* Ehrhart). We hypothesized that the colonies could not persist for such a long period without defense against predators, and found that nymphs of the second generation attacked moth larvae that had been artificially introduced into the aphid colony. Nymphs of all four instars participated in the attack and stung the larvae with their stylets. Of 69 nymphs that attacked the larvae, 36 (52.2%) were 4th instar. Unlike older nymphs of other eriosomatines, wingpadded 4th-instar nymphs of *G. imbricator* were slender in shape with long legs, and actively walked around on the twig. This is the first report that wingpadded nymphs are the main defenders of an aphid colony.

Key Words: Defensive behavior, *Fagus*, soldier aphid, sociality, woolly beech aphid

RESUMEN

Se sabe que colonias grandes y lanudas del afido norteamericano *Grylloprociphilus imbricator* (Fitch) duran varios meses en ramitas expuestas de *Fagus grandifolia* Ehrhart. Formamos la hipótesis que las colonias no podrían durar por tanto tiempo sin defensa contra predadores, y encontramos que ninfas de segunda generación atacaron larvas de polilla que habían sido introducidas artificialmente a la colonia áfida. Ninfas de todos los cuatro instares participaron en el ataque y picaron las larvas con sus estiletes. De 96 ninfas que atacaron las larvas, 36 (52.2%) fueron 4to instar. A diferencia de esos otros eriosomatinos, ninfas de 4to instar "wingpadded" de *G. imbricator* fueron delgadas en forma con patas largas, y caminaron activamente en la ramita. Este es el primer reporte que ninfas "wingpadded" son los principales defendedores entre los áfidos.

Many aphid species of the subfamilies Eriosomatinae (formerly known as Pemphiginae (Blackman & Eastop 2000)) and Hormaphidinae are known to produce sterile or non-sterile defenders that attack predators, particularly in those species that form long-lived galls or large, exposed colonies (e.g., Aoki 1977; see review by Stern & Foster 1996). The defenders, or individuals that play a defensive role, are usually 1st- or 2nd-instar nymphs. Wingpadded 3rd- or 4th-instar nymphs, which are of course larger than younger nymphs but are usually obese, short-legged and sluggish, so far have not been reported to function as defenders. Exceptions are *Epipemphigus niisimae* (Matsumura) (Aoki et al. 1996) and *Dinipponaphis autumna* (Monzen) (Aoki et al. 1999), gall-forming aphids with small colony sizes. Although their wingpadded nymphs attacked artificially introduced insects, they functioned as auxiliary defenders at best (Aoki et al. 1999).

The woolly beech aphid, *Grylloprociphilus imbricator* (Fitch) (Eriosomatinae), forms large colonies on twigs of American Beech (*Fagus grandifolia* Ehrhart), its primary host, in North America (Hottes & Frison 1931; Smith 1974, Blackman & Eastop 1994). Colonies may reach 120-150 cm in length (Smith 1974). The single fundatrices or their offspring were found on beech from April to November in North Carolina (Smith & Denmark 1984). All the second-generation aphids become winged adult females, which migrate to the secondary host, baldcypress (*Taxodium distichum* (L.)), from the middle of June to the latter half of October or perhaps even to the end of November (Smith 1974; Smith & Denmark 1984). We questioned whether the colonies could last for so long without defense against predators, and found that nymphs of *G. imbricator* indeed attacked artificially introduced insects. In this species, nymphs of all four instars played a defensive role, but 4th-instar nymphs were the main defenders, as described below.

MATERIALS AND METHODS

Wax-covered colonies of *G. imbricator* were found on twigs of a few beech trees (*Fagus grandifolia*) in the Nichols Arboretum of the Univer-

sity of Michigan, Ann Arbor, Michigan, USA, on July 13 and 14, 2000. We chose one colony (accession no. 00168) for the experiment to determine whether nymphs might attack predators. Tortricid larvae (approximately 4-11 mm long) were collected from nearby shrubs of *Hamamelis virginiana* L., and individually placed on the colony to test for a defensive response. Although tortricid larvae are not natural predators of *G. imbricator*, in our extensive experience with defensive aphids we have found that moth larvae will readily elicit an attack response by aphids, if the aphids attack actual predators (see, e.g., Aoki 1977; Aoki & Kurosu 1986; Foster & Rhoden 1998). This is fortunate from a practical standpoint, because moth larvae are much more conveniently collected at a field site than are aphid predators such as syrphid or coccinellid larvae.

If an introduced larva fell off the colony due to attack by aphids within three minutes, we caught the larva in a small paper box and deposited the larva and the attached aphids into a vial of 80% ethanol. If a larva did not fall, we picked up the larva three minutes after introduction and deposited the larva and the attached aphids into a vial of 80% ethanol. The experiment was repeated ten times. After all trials, the entire colony was collected and preserved in 80% ethanol. The aphids were later examined and identified in the laboratory. Another entire colony (accession no. 00169) was also preserved in 80% ethanol. We also placed another tortricid larva on a third colony of *G. imbricator* to take photographs of attacking aphids. We did not replicate this experiment across colonies for practical reasons, due to the large size of the colonies (several thousand aphids, see Results). If trials had been replicated across multiple colonies, this would have necessitated collecting, counting, and sorting many thousands of aphids, and would have decimated the aphid population in the arboretum. We are confident that the defensive behavior observed should be consistent across colonies, due to our experience with other defensive aphids, and because the same behavior was elicited in the third colony assayed for photographs.

In the laboratory, all aphids from the two colonies (nos. 00168 & 00169) were detached from twigs, and the total number of aphids and 4th-instar nymphs was counted under a dissecting microscope. Many aphids, including nymphs that had attacked the larvae, were boiled in 10% KOH solution, stained with acid fuchsin or Evans' blue, and mounted in balsam. The slide-mounted specimens were examined under a light microscope to determine the instar of each nymph, and whether any dimorphism occurred within an instar. Because 1st-, 2nd- and 3rd-instar nymphs could be distinguished from each other only in slide-mounted specimens under a compound microscope, we could not categorize the entire colony according to each nymphal instar (as it is impractical to slide-mount thousands of aphids).

Results and Discussion

Colony Structure

The colony (no. 00168) used for the experiment contained a single fundatrix and a total of 4,218 nymphs of the 2nd generation, of which 479 (12.8%) were 4th-instar nymphs. Another colony (no. 00169) contained a single fundatrix, two winged adults, and 7,437 nymphs, of which 1,143 (15.4%) were 4th instar. No wingless adults (except the fundatrix) were found in the samples, which indicates that the individual fundatrices produced thousands of nymphs. The fundatrices were very large (approximately 5-6 mm long) and superficially resembled a termite queen (Fig. 1). Each fundatrix was hidden under a layer of nymphs, which we had to remove to observe her. No winged adults were contained in colony 00168. Because this colony contained cast-off skins of wingpadded 4th-instar nymphs, it is certain that the colony had already produced some winged adults. A number of winged adults were found in other colonies.

No ants were observed visiting the two experimental colonies, or five other colonies that we were able to examine at close range. When we lightly touched a twig on which a colony was formed, some nymphs produced honeydew, but not many droplets of honeydew fell from the colony, contrary to the usual observation of aphids. (Hottes & Frison (1931) mentioned that *G. imbricator* often "produces so much honey-dew that the ground beneath the infestation becomes discolored." Thus, if ants were present, they were not effectively removing the honeydew from the observed colonies.) Put together, these observations strongly suggest that *G. imbricator* does not depend on defense by ants on the primary host.

We found no within-instar dimorphism in the 2nd generation of *G. imbricator*. This indicates that no morphologically distinct soldier caste is produced in the species.

Defensive Behavior

All ten tortricid larvae introduced onto the colony were attacked by nymphs of *G. imbricator* (Fig. 2). Eight were attacked almost immediately after introduction, and the other two were attacked 14 and 39 seconds after introduction. The attacked larvae responded by wriggling, and four fell off the colony within three minutes (27-128 seconds after introduction). A total of 69 nymphs attacked the ten tortricid larvae, and 47 of them did not detach themselves from the larvae even after being deposited in ethanol. We ascertained under a dissecting microscope that many of them, including nymphs

Fig. 1. A fundatrix of *Grylloprociphilus imbricator* with a few nymphs on her body. The fundatrix was removed from the colony and place on a leaf.

Fig. 2. Six 4th-instar nymphs and several younger nymphs of *Grylloprociphilus imbricator* attacking a tortricid larva. The larva was removed from the colony and placed on a leaf.

Fig. 3. Part of a colony of *Grylloprociphilus imbricator* formed on a twig of *Fagus grandifolia*. Some 4th-instar nymphs were excitedly walking around while raising their abdomens covered with wax filaments.

of all four instars, stung the larvae with their stylets. We also confirmed the stinging behavior by placing some aphids on our hands. At least one 4th-instar nymph and one 3rd-instar nymph stung our skin and caused minor irritation.

Wingpadded nymphs, especially 4th-instar nymphs, were very active. When the colony was disturbed, many 4th-instar nymphs raised the tips of their abdomens covered with woolly wax and a few long wax filaments (Fig. 3), and walked around while waving their abdomens back and forth. Stationary (and probably feeding) nymphs also waved the tips of their abdomens in the same way. Unlike other aphids, including *Pseudoregma* (Aoki et al. 1981, Sakata & Ito 1991), they did not lift their hind legs or wave them.

Of the 69 nymphs that attacked the introduced larvae, 36 (52.2%), 4 (5.8%), 3 (4.3%) and 26 (37.7%) were 4th-, 3rd-, 2nd- and 1st-instar nymphs, respectively. These figures indicate that 4th-instar nymphs are more likely to attack introduced larvae than are non-4th-instar nymphs (test of proportions; 36/479 vs. 33/3739, $Z = 10.58$, $P < 0.001$). In eight of the ten trials, at least one 4th-instar nymph attacked the introduced larva. We observed that 4th-instar nymphs of *G. imbricator* have a slender body and long legs (Figs. 2 & 3), which look quite different from those of other eriosomatines, and probably account for their comparatively greater mobility. On the other hand, 4th-instar nymphs of *G. imbricator* become swollen just before molting into winged adults. These nymphs look more similar to 4th-instar nymphs of related species.

Defensive behavior, often exhibited by specialized defensive morphs, has evolved several times and in different generations in aphids (Stern & Foster 1996). This is the first report that wingpadded 4th-instar nymphs are the main defensive morph. As discussed earlier, in almost all aphid species, the main defenders are small 1st- or 2nd-instar nymphs. Some species, such as *Pseudoregma alexanderi* (Takahashi) and *Colophina monstrifica* Aoki, have acquired larger soldiers by enlarging their sterile 1st-instar nymphs (Aoki et al. 1981, Aoki 1983). In contrast, *G. imbricator* has acquired large defenders by modifying the behavior and morphology of its wingpadded 4th-instar nymphs.

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MELANAPHIS SACCHARI (HOMOPTERA: APHIDIDAE), A SUGARCANE PEST NEW TO LOUISIANA

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While inspecting sugarcane (interspecific hybrids of *Saccharum* spp.) varietal trials on the USDA-ARS Ardoyne Research Farm near Houma, LA on 9 September 1999, we noticed an infestation of an aphid unfamiliar in Louisiana sugarcane. Specimens were collected and sent to the USDA-ARS Systematic Entomology Laboratory, Beltsville, MD for identification. Gary L. Miller identified the specimens as the sugarcane aphid, *Melanaphis sacchari* (Zehntner). The collection of this species represents a new distribution record for the continental United States and holdings of the National Aphidoidea Collection, which until now included specimens from Florida and Hawaii.

The sugarcane aphid is a widely distributed insect being reported from 24 countries (Mead 1978). Pemberton (1948) reported the sugarcane aphid in Hawaii as early as 1896. The aphid was first reported in the continental United States during 1977 on sugarcane in Florida (Mead 1978). Hall and Bennett (1994) presented a general review of *M. sacchari* as a pest of Florida sugarcane. The aphid is known to attack grasses including species in the following genera: *Saccharum*, *Sorghum*, *Oryza*, *Echinochloa*, *Panicum*, and *Pennisetum* (Denmark 1988). Its status as an economic pest of sugarcane remains unclear. Yield reductions associated with sooty mold that accompanies severe infestations of the aphid in sugarcane and the possibility that the aphid might vector sugarcane mosaic virus and other diseases are of principal concerns with the invasion of the insect into Louisiana.

Following identification of the aphid, a survey of the Louisiana sugarcane producing area was initiated on 25 October 1999 to assess the geographical range of the infestation. Four sites in each of the parishes growing sugarcane were surveyed, except in St. Charles Parish where only two sites were chosen because it has comparatively less acres of sugarcane in cultivation. Similarly, Calcasieu and Cameron Parishes were combined into a single survey unit because they are contiguous to one another and both having only a few scattered acres of sugarcane in cultivation. Survey sites were cane fields chosen at random and were selected to be a minimum of 9 km distant from each other. The sample scheme was patterned after that of White et al. (1995) such that two sets of ten separate stools of cane in perpendicular directions were examined for the presence of sooty mold and colonizing aphids. Because sooty mold can be associated with other sugarcane homopterans (principally the West Indian canefly, *Saccharosydne saccharivora* Westwood), sooty mold alone could not be used as a means of verifying the occurrence of the aphid in our sample fields.

Sugarcane aphids were found in eight of the 21 parishes surveyed (38%) (Fig. 1). We did not find aphids at all four sample sites in any given parish. Generally, where sugarcane aphids were detected their infestation densities were low. Overall, the survey indicated the aphid has already spread throughout much of the sugarcane growing areas in Louisiana. The low population levels of the aphid observed at each site during our survey may have been related to the time of year our survey was conducted.

Large outbreaks of *M. sacchari* in Florida sugarcane occur most commonly during the summer. The aphid is subjected to biological control in sugarcane in Florida by pathogens (*Verticillium lecanii*), predators including *Diomus terminatus* Say (Coleoptera: Coccinellidae) and *Allograpta exotica* (Wiedemann) (Diptera: Syrphidae), and one parasitoid species (*Lysiphlebus testaceipes* (Cresson) (Hymenoptera: Braconidae) (Hall 1987). The following predators are also thought to attack the sugarcane aphid in Florida: *Chrysoperla externa* (Hagan) (Neuroptera: Chrysopidae), *Micromus subanticus* (Walker) (Neuroptera: Hemerobiidae), *Coleomegilla maculata fuscilabris* (Mulsant), *Cycloneda sanguinea* (L.), *Hippodamia convergens* Guerin, and *Ola v-nigrum* Mulsant (Coleoptera: Coccinellidae) (Hall 1988). Environmental factors may often be largely responsible for the initial decline in aphid levels following a summer outbreak (Hall 1987). Although an assessment of biological control of the aphid in Louisiana has not been conducted, we noted during our survey that the aphid was attacked by *D. terminatus* (specimens identified by M. Thomas, Florida Department of Agriculture & Consumer Services, Division of Plant Industry, Florida State Collection of Arthropods, Gainesville), by an unidentified syrphid fly larvae, and by at least one unidentified species of an internal parasitoid. No information is available on varietal resistance to the aphid.

Thanks are extended to Dr. Chris Carlton and research associates Fred Posey and Vickey Mosely, Louisiana State University Agricultural Center, Baton Rouge, LA for technical support. Voucher specimens of the aphid are located in the

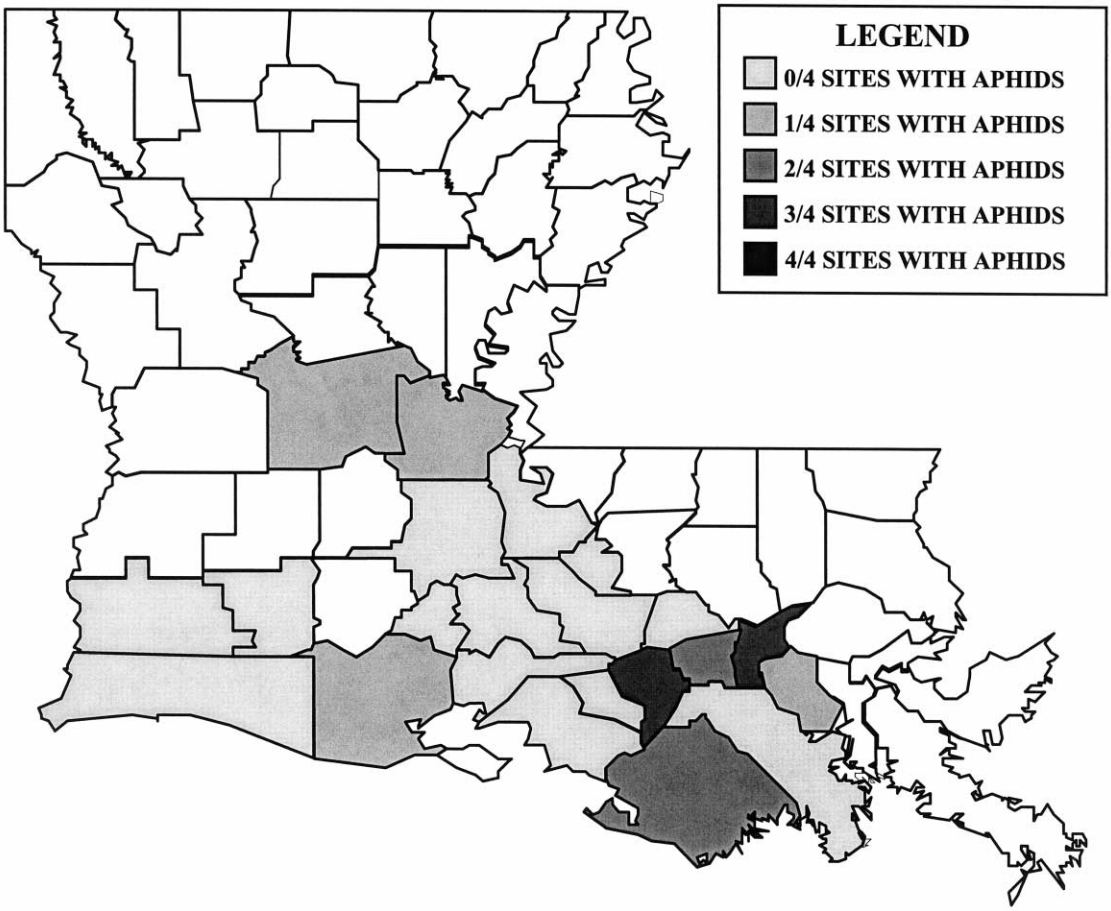

Fig. 1. The distribution of the sugarcane aphid throughout the Louisiana sugarcane growing area during the 1999 growing season. Groupings in legends are based on the total of fields sampled within a parish and those found to be infested by the sugarcane aphid.

Louisiana State University Arthropod Museum in Baton Rouge, LA and the USDA-ARS Systematic Entomology Laboratory, Beltsville, MD.

SUMMARY

The sugarcane aphid, *Melanaphis sacchari* (Zehntner) was found in Louisiana on 9 September 1999 and documented as a new record and potential pest for the state. The aphid was found in 8 of 21 sugarcane growing Parishes that were surveyed in Louisiana, indicating the pest is already widely distributed across Louisiana. The coccinellid *Diomus terminatus* Say was identified as one of several biological control organisms attacking the aphid in Louisiana.

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LABORATORY AND FIELD INFESTATION STUDIES ON MONSTERA TO DETERMINE ITS HOST STATUS IN RELATION TO THE CARIBBEAN FRUIT FLY (DIPTERA: TEPHRITIDAE)

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The monstera or ceriman, *Monstera deliciosa* (Liebm.), is a widely cultivated aroid (Araceae) native to central America (Morton 1987). The fruit are cylindrical stalks 20 to 30 cm long, 5 to 9 cm in diameter with hard green plates covering segments. When ripe, the segments have a juicy pulp with a pineapple flavor (Morton 1987). The fruits have a small gourmet market, and are sometimes shipped from Florida to larger cities around the United States. The Caribbean fruit fly, *Anastrepha suspensa* (Loew), is the main fruit fly of quarantine importance in south Florida where monstera is grown. It has a wide host range (Swanson & Baranowski 1972), but monstera has not been reported as a host.

In 1998 laboratory and field studies were conducted with ripe monstera fruits from a mixed fruit grove in Dade County, Florida. Fruit were collected on July 16, Aug. 18 and Sept. 2, 1998. On each date 15 fruit were brought to the laboratory and divided randomly into 3 groups of 5 fruit. One control group was held without treatment to detect natural infestations. The other 2 groups were placed in cages ($1 \times 1 \times 1$ m) with 5 female and 5 male 10 day old Caribbean fruit flies. One of the treatments had pinholes placed in the fruit to allow flies to attempt to oviposit. For each date five heat-disinfested guavas exposed to an equal number of fruit flies were used as a positive control.

After exposure to fruit flies for 24 h (under conditions of 14/10 h of light/dark conditions) the fruits were removed from the cages and held three to four weeks (at about 25°C). Any emerging larvae or pupae were collected and counted.

Field tests were conducted in the mixed fruit grove on July 16, Aug. 18 and Sept. 2, 1998. Five monstera fruits were bagged on the plant individually with five female fruit flies for 24 h. A control group of four guavas was placed on the monstera plant in bags with five female fruit flies for 24 h to ensure that the flies were capable of laying eggs.

Fruit were placed in perforated plastic bags (45×45 cm) (Delnet pollination bag, Applied Extrusion Technologies, Inc., Middletown, DE) with water soaked cotton and a sugar cube. The bag was secured to the plant with wire ties. All fruit were taken to the laboratory where size and weight were recorded.

Four McPhail traps were placed in the grove and monitored for flies each week that the grove was sampled for fruits.

A total of 44 monstera weighing 23 kg were used. They weighed 523.1 ± 15.8 g and were 26.4 ± 3.3 cm long and 5.9 ± 0.6 cm in diameter.

No insects were recovered from any of the monstera fruits collected, therefore there was no natural infestation in the field. All of the control guavas had fruit fly larvae present (224.3 ± 163.3 larvae per 4 guavas). None of the treated fruit exposed to fruit flies in the laboratory had any fruit fly larvae.

No larvae were recovered from any of the monstera fruits bagged with fruit fly adults in the field. All of the guava control fruits were heavily infested (124.7 ± 46.4 larvae per 4 guavas). Caribbean fruit flies were present in the fruit grove used for the experiments (adults were trapped in McPhail traps), and guavas in the grove were so highly infested that the grower had abandoned commercial production of guavas.

Monstera are harvested in the summer and early fall in South Florida, so the tests in this study covered the fruiting season. Fruit fly populations were high in the grove and the flies in the field tests produced hundreds of larvae in the control guavas.

There are no reports of any fruit flies attacking monstera or any Araceae (Aluja et al. 1987; Norrbom & Kim 1988; White & Elson-Harris 1992). Morton (1987) states that unripe monstera contains oxalic acid, and are considered toxic to humans, causing oral and dermal irritation. Howard & Kenny (1987) found that cultivars of carambola with high levels of oxalic acid were poor hosts to the Caribbean fruit fly.

SUMMARY

Based on the protocol of Cowley et al. (1992) and the tests conducted, I conclude that Monstera is not a host to the Caribbean fruit fly and presents no risk of transporting *A. suspensa* to other states from Florida.

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ARTIFICIAL DIET AND REARING METHODS FOR THE *MELALEUCA QUINQUENERVIA* (MYRTALES: MYRTACEAE) BIOLOGICAL CONTROL AGENT *OXYOPS VITIOSA* (COLEOPTERA: CURCULIONIDAE)

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The mass production of insects for biological control of pests has become a common technique for permanent establishment, periodic colonization, or inundative releases of agents (Etzel and Legner 1999). For biological control of weeds the production of agents for mass release has been modest possibly due to a lack of knowledge of suitable mass-rearing techniques. Numerous artificial diets have been described for phytophagous insects, especially for pest species of the Noctuidae and Curculionidae (Singh 1977). Although artificial diets have been described for a few species of weed biological control agents (Baer and Quimby 1981; Smith and Wilson 1995; Blossey et al., 2000), none are currently available commercially. The purpose of this study was to develop an artificial diet and rearing conditions for the Australian weevil *Oxyops vitiosa* Pascoe (Coleoptera: Curculionidae) introduced in south Florida (Center et al., 2000) for the biological control of the invasive species *Melaleuca quinquenervia* (Cav.) S. T. Blake (Myrtaceae).

Several artificial diet recipes were tested initially (e.g., Vanderzant 1973; Chang and Jensen 1972; Baer and Quimby 1981; Toba et al. 1969), however, a modified Harley and Willson diet (Harley and Willson 1968) resulted in the best larval survival and performance. These recipes frequently include material from the insect's host plant. For the melaleuca herbivore *O. vitiosa*, each diet was formulated with *M. quinquenervia* tip leaves in various concentrations and modifications were based upon insect performance in previous trials. Tip leaves were blended into a slurry with the described amount of water (Table 1). The diets also were modified by omitting antibiotics and formaldehyde. All diets were dispensed into 1 oz cups and each was covered with a plastic cap. Larvae reared on *M. quinquenervia* plants were obtained from our colonies and tested individually on experimental diets. All test insects were reared at 27°C, 90% RH, and under a 14:10 h photoperiod. During the initial diet screening 3rd instars were tested and if the results indicated that larval feeding, growth and development occurred then 1st instars were tested in subsequent trials.

Third instar larvae were reared successfully (50% survival) through to the pupal stage on diet 1 (Table 1). The adults that resulted from the larvae fed this diet had greater weights than those reared on plant material. Males weighed 39.1 ± 0.3 mg and females 48.0 ± 0.5 mg compared to plant-fed males (36.0 ± 0.5 mg) and females (41.8 ± 0.4 mg). However, when neonate larvae were reared on diet 1, none survived to the pupal stage. Several modifications of diet 1 resulted in 10 additional formulations. The concentration of sorbic acid and methylparaben were decreased while maintaining a culture apparently free of contamination. Additionally, increased amounts of *M. quinquenervia* leaf material were added in diets 10 and 11. Although the neonate larvae fed well on several diets, overall larval survival, prepupal weight, and development rate to the pupal stage were greatest when fed diet 11.

Pupation substrates were evaluated which included mixtures of: 1) all purpose sand (400 g; Bonsal Co., Charlotte, NC, USA), peat moss (56.7 g; Scotts Co., Marysville, OH, USA), and deionized water (100 ml, N = 39); 2) crushed floral foam (42.5 g; Smithers-Oasis Co. Kent, OH, USA), sand (400 g) and deionized water (100 ml, N = 49); and 3) crushed floral foam (42.5 g), sand (400 g), and $CuCl_2$ (1% in 100 ml deionized water, N = 114). Each substrate was poured individually into 1 oz cups. Prepupae were collected on live plants from field sites and placed individually on each test substrate. All prepupae were reared as described above and the number of emerging adults was counted.

The results indicated that percent survival of the *O. vitiosa* prepupae to the adult stage was relatively high with little difference among the substrates. Adult emergence on the sand/peat moss mixture was 92.3%, 91.8% on the crushed floral block/sand, and 87.7% on crushed floral block/sand with $CuCl_2$ (1%). These levels of adult emergence are considerably higher than those obtained previously from sand alone (<10%; Wheeler unpublished data) and by others (52%; Purcell and Balciunas 1994) possibly because sand alone was a poor pupation substrate.

SUMMARY

The laboratory colonies of the melaleuca herbivore *O. vitiosa* that were established on plants and those produced on artificial diets yielded a

TABLE 1. ARTIFICIAL DIET INGREDIENTS AND THE RESULTS OF FEEDING NEONATE *O. VITIOSA* LARVAE.

	Diet										
Ingredient	1	2	3	4	5	6	7	8	9	10	11
AlphaCel (g)	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
Sucrose (g)	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Glucose (g)	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Corn Starch (g)	3.38	3.38	3.38	3.38	3.38	2.37	2.37	2.37	2.37	2.37	2.37
Wesson Salts (g)	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775
Cholesterol (g)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Linseed Oil (ml)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lecithin (g)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Casein (g)		6.66	6.66	6.66	6.66	6.66	8.66	8.66	8.66	8.66	8.66
Vanderzant Vitamins (g)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Ascorbic Acid (g)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Sorbic Acid (g)	0.35	0.32	0.26	0.2	0.16	0.12	0.16	0.08	0.16	0.16	0.16
Methyl Paraben (g)	0	0.32	0.26	0.2	0.16	0.12	0.16	0.16	0.25	0.16	0.16
Agar (g)		5.285	5.285	5.285	5.285	5.285	5.285	5.285	5.285	5.285	5.285
Water (ml)		200	200	200	200	200	200	200	200	200	200
Melaleuca leaves (g)	70	70	70	70	70	70	70	70	70	100	130
N		8	12	31	20	20	93	48	45	44	46
Percent survival to:											
pupa		0	0	0	0	33.3	41.9	35.4	35.6	54.6	60.9
Weight of:											
prepupa						44.1a	44.0 a	45.1 a	49.7 a	44.4 a	50.8 a
se						1.4	1.4	1.4	2.1	1.3	2.1
Development time to:[1]											
pupa						27.0 ab	29.4 a	25.5 b	23.7 b	29.2 a	23.9 b
se						0.8	0.9	1.2	1.2	0.7	0.7

[1]Values in a row followed by the same letter are not significantly different according to a Ryan's Q mean comparison test ($P < 0.05$).

surplus of insects that were released at *M. quinquenervia* infested sites throughout south Florida. In the laboratory, we were able to rear *O. vitiosa* from egg hatch through to pupation on artificial diets modified with host plant tissues. The weight gain and development rate of the artificial diet-reared insects was slightly lower but comparable to that of insects fed *M. quinquenervia* leaves (Wheeler unpublished data). For example, about 61% (Table 1) of the diet 11-fed larvae survived to the prepupal stage while 30-90% (N = 20) survived when fed *M. quinquenervia* leaves (Wheeler unpublished data). Mean weight of diet 11-reared prepupae was 50.8 mg (Table 1) whereas leaf-reared prepupae weighed between 59.6 to 66.3 mg. Moreover, the larvae completed development to the pupal stage after 23 to 24 d when fed diet 11 compared with 21 to 23 d when fed leaves. Finally, survival of pupae to adult exceeded 90% when reared in a combination of sand/peat moss and water. Florida Agricultural Experiment Station Journal Series No. R-07918

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GENERIC ASSIGNMENT AND SYNONYMY OF SOME INDO-WEST PACIFIC APHROPHORIDAE (HEMIPTERA: CERCOPOIDEA) IN THE NATURAL HISTORY MUSEUM, LONDON

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The type specimens representing most of the Indo-West Pacific species of Aphrophoridae described by Walker, Distant, China, and Lallemand in the Natural History Museum, London, were examined. As a result, four new generic synonymies, eleven new specific synonymies, thirty-seven new combinations, and one reinstated combination are proposed below.

Abdas minutus (Lallemand), NEW COMBINATION

Peuceptyelus minutus Lallemand, 1927b: 101. S. INDIA.

Abdas Distant, 1916, previously known only from the type species *A. nuncupatus* Distant, 1916, occurs in south India. It is characterized by small size (5.5-6.0 mm), dorsum somewhat smooth and polish and densely and finely punctate, head elongate (slightly shorter than pronotum), and male genital styles broad and strongly forked apically. Examination of the female holotype of *Peuceptyelus minutus* Lallemand shows that it is an *Abdas* species.

Amarusa majuscula (Distant), NEW COMBINATION

Ptyelus majusculus Distant, 1908g: 90.?INDIA.

Amarusa Walker, 1857, is a genus of large aphrophorids with seven species known from northern Borneo, Philippines, Indonesia, New Guinea, Solomon Is., New Hebrides, eastern Australia and south Japan (Okinawa). Members of the genus are diagnosed by their large size (length 12-19 mm), elongate, strongly pubescent, predominantly brown, and somewhat robust habitus; head and rostrum short, tylus small; ocelli closer to eyes than to each other; pronotum strongly convex medially and posteriorly; male genital styles with apex laminatedly forked; and aedeagal shaft with apex expanded, curved posteriorly and usually armed with small teeth on hind edge.

Examination of the female holotype confirms that *majusculus* is a member of *Amarusa*. The holotype of *majusculus*, bearing a locality label 'Assam? Margharata', supposedly from NE India, was apparently mislabeled. Until now, no authentic *Amarusa* species have been recorded from the Indian subcontinent or from continental Southeast Asia.

Clovia affinis (Distant), NEW COMBINATION

Ptyelus affinis Distant, 1908g: 88. INDIA, BURMA.

Ptyelus LePeletier & Serville, 1825, is an Afrotropical genus of large aphrophorids. Unfortunately many Asian *Clovia* species were previously described under *Ptyelus*. Members of *Clovia* can be recognized by their relatively smooth dorsum, elongate head and tylus, head, pronotum and postclypeus lacking median carina, head, pronotum and scutellum usually with longitudinal yellow striae, head and thorax beneath laterally usually decorated with a yellow, inverted V-shaped fascia extending backward from apex of face, and aedeagal shaft usually vertical with spinous processes at apex.

Clovia exclamans (Walker), REINSTATED COMBINATION

Perinoia exclamans Walker, 1857b: 166. BORNEO, SUMATRA.

Originally described in *Perinoia*, *exclamans* was later correctly transferred to *Clovia* by several students (e.g., Kirby 1891a; Lallemand 1932b). Nevertheless, this species was included in *Perinoia* in Metcalf's (1962) world catalogue of the Aphrophoridae. My examination of the female holotype of *exclamans* showed that it belongs to *Clovia*.

Clovia punctifascia (Walker), NEW COMBINATION

Cercopis punctifascia Walker, 1870b: 288. INDONESIA (BATJAN).

Phymatostetha punctifascia (Walker); Butler, 1874b: 266.

Originally described in *Cercopis*, *punctifascia* was transferred to *Phymatostetha* in Cercopidae by Butler (1874b) with no justification. This was accepted by Metcalf (1961) in his world catalogue of Cercopidae. Distant (1900a: 686) and Lallemand & Synave (1961: 9) stated that *punctifascia* belongs to Aphrophorinae (= Aphrophoridae in this paper), but they gave no generic placement. I found that *punctifascia* is a member of the Aphrophoridae and tentatively place the species in the genus *Clovia*.

Clovia sarawakana Lallemand

Clovia sarawakana Lallemand, 1939d: 57. SARAWAK; S CHINA, SE ASIA.

Nagaclovia formosana Matsumura, 1940a: 48, pl. 3, fig. 5. NEW SYNONYMY.

Clovia sulcata (Distant), NEW COMBINATION

Ptyelus sulcatus Distant, 1908g: 90. NEPAL.

Interocrea Walker

Interocrea Walker, 1870b: 328. Type species: *I. nigripes* Walker, 1870b, by monotypy.

Pareurycercopis Lallemand & Synave, 1953b: 197. Type species: *P. boharti* Lallemand & Synave, 1953b, by original designation. NEW SYNONYMY.

Species of *Interocrea* occur in the Pacific islands and northeastern Australia and are characterized by their small size, elongate head and tylus, and the pronotum and forewings usually covered with numerous small brown spots. A direct comparison of type material of the type species of *Interocrea* and *Pareurycercopis* shows that the two genera are congeneric.

Interocrea boharti (Lallemand & Synave), NEW COMBINATION

Pareurycercopis boharti Lallemand & Synave, 1953b: 197, figs. 13-15. NEW GUINEA, PHILIPPINES.

Jembra brevistriga (Walker), NEW COMBINATION

Ptyelus brevistriga Walker, 1858: 348. S. CHINA.

Cercopis (Aphrophora) nigronervosa Lallemand, 1924: 296. NEW SYNONYMY.

Jembra pallida Metcalf & Horton, 1934: 408, pl. 39, fig. 45, pl. 43, figs. 136, 140. [Synonymised with *J. nigronervosa* (Lallemand) by Liang, 1999: 343.] NEW SYNONYMY.

The genus *Jembra* was recently revised by Liang (1999). *J. brevistriga* is a common and widespread species in south China.

Liorhina bifasciata (Lallemand), NEW COMBINATION

Clovia bifasciata Lallemand, 1940b: 144. INDONESIA (LARAT IS.).

Liorhina Stål, 1870, is a genus of small to moderately large and somewhat robust aphrophorids, generally brown or blackish brown with yellow striae or markings which are distributed mainly in the Pacific islands. The genus *Clovia* Stål, 1866, has been confused with *Liorhina* and many species have been wrongly assigned to that genus. Externally *Liorhina* is very similar to *Clovia* but can be distinguished from the latter by the head relatively short, vertex and pronotum usually with transverse yellow striae, male pygofer narrow and elongate, and aedeagal shaft directed anterodorsally, usually lacking spinous processes at apex.

Liorhina borneensis (Lallemand), NEW COMBINATION

Clovia borneensis Lallemand, 1932c: 175. N. BORNEO.

Liorhina chinai (Lallemand), NEW COMBINATION

Clovia chinai Lallemand, 1927b: 103. PHILIPPINES (LUZON).

Liorhina concolor (Lallemand), NEW COMBINATION

Clovia vittifrons var. *b* Stål, 1870c: 725. PHILIPPINES.

Clovia vittifrons concolor Lallemand, 1912a: 45. Replacement name for *C. vittifrons* var. *b* Stål.

Clovia concolor Lallemand; Lallemand, 1940b: 138.

Liorhina deflexa (Walker), NEW COMBINATION

Perinoia deflexa Walker, 1870b: 295. MYSOL, NEW GUINEA.

Liorhina divergens (Lallemand), NEW COMBINATION

Clovia divergens Lallemand, 1940b: 145. NEW GUINEA.

Liorhina fakarensis (Lallemand), NEW COMBINATION

Clovia fakarensis Lallemand, 1940b: 146. NEW GUINEA.

Liorhina furcata (Walker), NEW COMBINATION

Perinoia furcata Walker, 1870b: 297. INDONESIA (SULA IS., CERAM).

Liorhina hieroglyphica (Lallemand & Synave), NEW COMBINATION

Clovia hieroglyphica Lallemand & Synave, 1953a: 234, figs. 3a-d. INDONESIA (SUMBA).

Liorhina humboldtiana (Distant), NEW COMBINATION

Clovia humboldtiana Distant, 1909j: 175, pl. 10, figs. 7, 7a. NEW GUINEA.

Liorhina kinana (Lallemand), NEW COMBINATION

Clovia kinana Lallemand, 1932b: 171. BORNEO.

Liorhina laratensis (Lallemand), NEW COMBINATION

Clovia laratensis Lallemand, 1940b: 143. INDONESIA (LARAT IS.).

Liorhina lineolata (Lallemand), NEW COMBINATION

Clovia lineolata Lallemand, 1922a: 273. PHILIPPINES (LUZON).

Liorhina matemana (Lallemand & Synave), NEW COMBINATION

Clovia matemana Lallemand & Synave, 1955b: 4, figs. 4-5. SOLOMON ISLANDS.

Liorhina muiri (Lallemand), NEW COMBINATION

Clovia muiri Lallemand, 1939e: 106. JAVA.

Liorhina nigra (Lallemand & Synave), NEW COMBINATION

Iophosa nigra Lallemand & Synave, 1953b: 196, figs. 10-12. NEW GUINEA, SOLOMON ISLANDS.

Liorhina plena (Walker), NEW COMBINATION

Perinoia plena Walker, 1870b: 298. INDONESIA (SULA IS.).

Liorhina quinquesignata (Lallemand), NEW COMBINATION

Clovia quinquesignata Lallemand, 1924b: 204. NEW GUINEA.

Liorhina rotundata (Lallemand), NEW COMBINATION

Clovia rotundata Lallemand, 1940b: 140. JAVA.

Liorhina scutellata (Lallemand), NEW COMBINATION

Clovia scutellata Lallemand, 1940b: 144. NEW GUINEA.

Liorhina soembana (Lallemand), NEW COMBINATION

Clovia soembana Lallemand, 1940b: 141. INDONESIA (SOEMBA IS.).

Liorhina subfurcata (Walker), NEW COMBINATION

Perinoia subfurcata Walker, 1870b: 298. INDONESIA.

Liorhina subjuncta (Walker), NEW COMBINATION

Perinoia subjuncta Walker, 1870b: 295. NEW GUINEA, INDONESIA, PHILIPPINES.

Clovia geniculata Lallemand, 1924b: 205. NEW SYNONYMY.

Liorhina tenggerana (Lallemand), NEW COMBINATION

Clovia tenggerana Lallemand, 1940b: 139. JAVA.

Liorhina transversa (Walker), NEW COMBINATION

Perinoia transversa Walker, 1870b: 299. NEW GUINEA, INDONESIA.

Peuceptyelus sigillifera (Walker)

*Aphrophora sigillifer*a Walker, 1851b: 700. N. INDIA, S. ASIA.

Jembrana bipartita Distant, 1916a: 192. NEW SYNONYMY.

Jembrana costalis Distant, 1916a: 192. NEW SYNONYMY.

Peuceptyelus wagneri Lallemand & Synave, 1953a: 236, fig. 4. NEW SYNONYMY.

Widespread from India to south China and southeastern Asia, this species is highly variable in color and size.

Philagra Stål

Chalepus Walker, 1851b: 731. Type species: *C. hastatus* Walker, 1851b, by subsequent designation of Distant, 1908g: 107. (preoccupied).

Philagra Stål, 1863c: 593. Type species: *P. douglasi* Stål, 1863c, by subsequent designation of Metcalf & Horton, 1934: 400.

Philagrina Lallemand, 1946a: 193. Type species: *P. espadon* Lallemand, 1946, by original designation. NEW SYNONYMY.

The Indo-Australian *Philagra* is a very distinctive genus and can be easily recognized by its

head conically produced in front of the eyes into a cephalic process as long as or longer than the pronotum and scutellum combined.

Philagra espadon (Lallemand), NEW COMBINATION

Philagrina espadon Lallemand, 1946a: 193. INDONESIA (ROON IS.).

Externally this species is very similar to *P. douglasi* Stål from Indonesia (Batjan, Halmahera).

Philagra recurva (Lallemand), NEW COMBINATION

Philagrina recurva Lallemand, 1946a: 194. NEW BRITAIN.

Externally this species is similar to *P. scotti* Stål from Indonesia (Halmahera, Moluccas).

Poophilus costalis (Walker)

Ptyelus costalis Walker, 1851b: 707. Widespread in AFRICA and ASIA.

Ptyelus jayakari Distant, 1916a: 187. NEW SYNONYMY.

Poophilus Stål, 1866, is an Afro-Asian genus and is diagnosed by hind tarsomeres I and II with long, dense hairs ventrally, and aedeagal shaft usually with broad apical processes. The examination of the holotypes of *Ptyelus costalis*, *P. jayakari*, *P. inconspicuus* and *P. mahei* shows that the former two species are conspecific and that the latter two species are both members of *Poophilus*.

Poophilus inconspicuus (Distant), NEW COMBINATION

Ptyelus inconspicuus Distant, 1908g: 90. S. INDIA.

Poophilus mahei (Distant), NEW COMBINATION

Ptyelus mahei Distant, 1909h: 45, pl. 4, figs. 14, 14a. INDIA (MAHE IS.)

Sinophora Melichar

Sinophora Melichar, 1902c: 113. Type species: *S. maculosa* Melichar, 1902c, by monotypy.

Pentacantha Lallemand, 1922b: 64. Type species: *P. brunnea* Lallemand, 1922b, by original designation. NEW SYNONYMY.

Sinophora species can be recognized most easily by their hind tibiae which are armed with 3-6 lateral spurs and the structures of the male genitalia, especially the very small subgenital plates and the large genital styles. Examination of the holotype of *Pentacantha brunnea* shows that it is clearly a *Sinophora* species.

Yunnana China

Yunnana China, 1925: 482. Type species: *Y. vera* China, 1925, by original designation.

Lepyropsis Metcalf & Horton, 1934: 416. Type species: *L. bipunctata* Metcalf & Horton, 1934, by original designation. NEW SYNONYMY.

The direct comparison of the holotypes of *Y. vera* China and *L. bipunctata* Metcalf & Horton (National Museum of Natural History, Washington, D.C.) shows that the two species are the same, resulting in the generic synonym of *Lepyropsis* with *Yunnana*.

Yunnana carixia (Walker), NEW COMBINATION

Aphrophora carixia Walker, 1851b: 701. SW CHINA. [Incorrectly synonymised with *Peuceptyelus coriaceus* (Fallén) by Stål, 1862b: 493.]

Peuceptyelus dubiosus Melichar, 1902: 111. NEW SYNONYMY.

Yunnana vera China, 1925: 482, figs. 4A-B. NEW SYNONYMY.

Lepyropsis bipunctata Metcalf & Horton, 1934: 417, pl. 37, figs. 2, 4, 11, 12. NEW SYNONYMY.

Known from Yunnan and Sichuan of southwestern China, this species was inadvertently described as new several times by different workers.

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Summary

Taxonomic changes affecting the Oriental Aphrophoridae are proposed to stabilize the nomenclature. Four new generic synonymies, eleven new specific synonymies, thirty-seven new combinations and one reinstated combination are proposed.

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(References prior to 1955 are given in Metcalf's (1960) bibliography).

OBSERVATIONS ON THE SEXUAL CASTES OF THE FIRE ANT PARASITE *SOLENOPSIS DAGUERREI* (HYMENOPTERA: FORMICIDAE)

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Several natural enemies of fire ants, *Solenopsis* spp., have been under study as biological control agents (Briano et al. 1995a and 1995b; Porter et al. 1995a, 1995b and 1997; Orr et al. 1995; Pesquero et al. 1995; Williams et al. 2000). The workerless parasitic ant, *Solenopsis daguerrei* (Santschi 1930) (= *Labauchena daguerrei*), discovered in Argentina in 1930, has been considered a potential candidate for the biological control of the imported fire ants, *Solenopsis invicta* Buren and *Solenopsis richteri* Forel, in the United States since the 1970´s (Lofgren et al. 1975; Jouvenaz et al. 1981; Jouvenaz 1983 and 1990).

The abundance of this parasite and its detrimental effects in the host colony were documented on populations of fire ants in Argentina and other parts of South America (Bruch 1930, Silveira-Guido et al. 1973, Briano et al. 1997, Pesquero et al. 1998, Calcaterra et al. 1999). It was found only parasitizing the *Solenopsis* complex species (Calcaterra et al. 2000). Its presence was low in the areas surveyed (Briano et al. 1997), however, lower fire ant densities were observed in parasitized locations and fewer host queens were found in parasitized compared to nonparasitized colonies (Calcaterra et al. 1999).

Little is known about the mating behavior and dispersal mechanisms of this ectoparasitic ant. Observations made by Silveira-Guido et al. (1973), suggested that copulation is rapid, occurs inside the nest or on the tumulus, and that one male can copulate with several females or more than once with the same female. Thus, the purpose of this study was to determine if *S. daguerrei* females are effectively fertilized in the host nests and to observe them after they fly out of colonies.

Observations were made in two consecutive warm seasons (April to June 1999, and February to May 2000). Fifteen *S. richteri* colonies parasitized with *S. daguerrei* were collected in San Eladio, 60 km W of Buenos Aires, Argentina (59° 10'W, 34° 45'S). The colonies were put in buckets coated with talc, brought to the laboratory, and placed in a walk-in cage (2 by 2 by 2 m) in a plastic greenhouse. When weather conditions (24-33°C, and high RH) and time of day (from 2.30 to 5.30 p.m.) were acceptable, sexuals of *S. daguerrei* flew out of the host nests. Most of the sexuals (n = 756) were captured on the ground with an aspirator, immediately after landing, a couple of meters away from the buckets. Then, they were sexed. Females were kept overnight in small plastic (ventilated) tubes with moist tissue paper to discover if they lost their wings. Preliminary observations had indicated that many females lost their wings immediately after capture when still confined within the aspirator. Also, we assumed that the tendency to dealate would be similar to its fire ant host, whose newly-mated queens lose the wings immediately after landing for colony founding. A sample of the parasitic females (n = 183) was dissected to determine if the spermatheca contained sperm, a confirmation of insemination.

After several weeks, the parasitized colonies in buckets were separated from the soil by flotation (Banks et al. 1981). The remaining *S. daguerrei* sexuals were collected, sexed, and the females kept in tubes, then dissected to confirm insemination.

Almost all the sexuals captured on the ground, 97.6%, were females, and 62.3% of them lost their wings a few minutes after capture (Table 1). However, the tendency to dealate was not consistent; in some colonies, almost 92% of the females lost their wings, while in others, none of the females captured lost their wings (Table 1). The reason for this difference is unknown. Most females collected after flying out of host colonies were inseminated: 84% of wingless females and 76% of winged ones. Because of this, it seems that insemination by itself is not the only condition for dealation.

On the other hand, none of the 120 females collected after flotation lost their wings and only 40% were inseminated. It appears that these mated females remained in the nests waiting for appropriate conditions to fly. No males were found in the host colonies. However, because the ratio of females to males for *S. daguerrei* is usually 3:1 (Calcaterra et al. 1999), we assumed that most males did not leave their host colonies and died within them.

Based on these results, we conclude that most *S. daguerrei* females are fertilized in the host nest and immediately after they fly for dispersal. It seems that males do not abandon their host colony. This agrees with Wilson (1971) who reported that, in inquiline species, nuptial flights are often

TABLE 1. CAPTURE AND DISSECTION OF SEXUALS OF *S. DAGUERREI.*

Date	Temp. (°C)	No. of sexuals captured ♂	No. of sexuals captured ♀	% of females that lost their wings	No. (%) of wingless females Dissected	No. (%) of wingless females Inseminated	No. (%) of winged females Dissected	No. (%) of winged females Inseminated
Sexuals after flying out of the colonies								
20 APR 99	24	1	22	88.9	4	4 (100)	10	8 (80)
21 APR 99	27	1	37	91.3	6	5 (83)	4	4 (100)
22 APR 99	27.5	0	94	74.5	29	26 (90)	18	13 (72)
23 APR 99	32	5	156	75.4	—	—	62	55 (89)
16-23 FEB 00	27-33	7	245	73	36	28 (78)	—	—
24-31 MAR 00	28-32	4	106	—	—	—	—	—
5 APR 00	28	0	13	—	—	—	—	—
13 APR 00	28	0	27	35	—	—	—	—
24 APR 00	33	0	24	0	—	—	—	—
28 APR 00	32	0	14	0	—	—	14	2 (14)
Total or mean	29.2	18	738	62.3	75	63 (84)	108	82 (76)
Sexuals remaining in the colonies								
16 JUN 99	—	0	28	0	—	—	28	9 (32)
20 MAR 00	—	0	34	0	—	—	34	17 (50)
15 MAY 00	—	0	58	0	—	—	58	22 (38)
Total or mean	—	0	120	0	—	—	120	48 (40)

replaced by the mating of nest mates within or near the host nest. He also stated that a probable consequence of this is geographic fragmentation of populations of inquiline species. This seems to be the case with *S. daguerrei,* which has small and localized populations in Argentina (Briano et al. 1997). According to Hölldobler and Wilson (1990) this applies to most permanent parasites.

To determine if mated *S. daguerrei* females could parasitize new host colonies, we took 326 females that flew out of their host colonies (most of them newly-mated queens) and transferred them to 8 *S. richteri* and 3 *S. invicta* nonparasitized colonies, collected in San Eladio and San Justo (Santa Fe Province), respectively. These test colonies were housed in trays according to Banks et al. (1981) and kept in darkness at 15°C to make it easier for establishment of the parasite. After a week, the colonies were put back under light conditions at 30°C to stimulate egg laying of both host and parasite queens.

Survival of the introduced parasites ranged from a few minutes to almost three weeks. Mortality of the parasite queens was 93% between days 1-3, 95.6% by day 7, 99.8% by day 14, and 100% by day 21. Despite the unsuccessful attempts at parasitism, we frequently observed that some queens of *S. daguerrei* found and yoked host queens very rapidly. These parasite queens survived longer in the host colonies, while those that did not yoke to any of the host queens were killed immediately. This lack of successful parasitization is consistent with some field attempts in which no parasitization was obtained.

We speculate that if eggs were laid by parasitic *S. daguerrei* queens before being killed, this F1 generation would be "accepted" by the host colony and thus initiate parasitism. However, further tests are necessary to confirm this hypothesis.

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SUMMARY

When weather conditions were favorable, most females of *S. daguerrei* flew out of their host colonies. The large majority, 76 to 84%, were mated, and 62.3% lost their wings after the flights. Some females remained in their host colonies, 40% of which were inseminated. None of the females remaining in the colony lost their wings. Attempts to initiate parasitism were unsuccessful; however, those parasite queens yoked to host queens survived longer than those that did not.

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A FIRST CONTRIBUTION TO A KNOWLEDGE OF THE CICADA FAUNA OF EL SALVADOR (HOMOPTERA: CICADOIDEA)

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The cicada fauna of Central America has received little study since Distant's *Biologia Centrali-Americana* (Distant 1881, 1883, 1900, 1905). Davis (e.g., 1919, 1928, 1936, 1941, 1944) described new genera and species but worked mainly on the Mexican fauna. More recent work on Central American cicadas has generally focused on the ecology of Costa Rican (e.g. Young 1972, 1976, 1980, 1981) and Panamanian (e.g. Wolda 1984, 1993, Wolda and Ramos 1992) cicadas.

A search of the Cicadoidea bibliographies (Metcalf, 1963a, 1963b, 1963c; Duffels & van der Laan 1985) shows that no Cicadoidea have been reported from El Salvador. I have come across several species in the Florida State Collection of Arthropods (FSCA) and the William R. Enns Entomological Museum (WEEM), University of Missouri and have been given specimens by a student that represent the first cicadas to be described as being collected in El Salvador. Original specimens are housed in the collections above with vouchers in the author's collection.

Family Cicadidae Leach, 1815

Subfamily Tibiceninae Atkinson, 1886

Tribe Tibicenini Distant, 1889

Diceroprocta belizensis (Distant, 1910). Specimens in the FSCA were collected at the Ruinas de San Andres, Dept. La Libertad, 16-VIII-1971. In the WEEM, there are specimens from La Unión, Dept. La Union, 13-V-1964 and Santa Tecla, Dept. La Libertad, 10-IV-1959.

Diceroprocta bicosta (Walker, 1850). Specimens in the WEEM were collected at Puente Cascutlan, Dept. San Salvador, 30-V-1958.

Tribe Fidicinini Distant, 1905

Fidicinoides determinata (Walker, 1858). Specimens in the WEEM were collected in San Salvador, Dept. San Salvador, 1-IV-1959. The species was transferred to *Fidicinoides* from *Fidicina* with the creation of the genus by Boulard and Martinelli (1996).

Fidicinoides pronoe (Walker, 1850). There are specimens in both the FSCA and the WEEM from Santa Tecla, Dept. La Libertad collected 9-III-1935, 2-IV-1957, 1-IV to 29-IV-1971, 19-IV to 6-V-1972, and 20-IV-1977. The species was transferred to *Fidicinoides* from *Fidicina* with the creation of the genus by Boulard and Martinelli (1996).

Pacarina schumanni Distant, 1905. Specimens in the FSCA were collected at the Ruinas de San Andres, Dept. La Libertad, 16-VIII-1971. These specimens represent the first *P. schumanni* to be reported from outside of Mexico (Metcalf, 1963a).

Tribe Hyantiini Distant, 1905

Quesada gigas (Olivier, 1790). Specimens were given to the author by a student from El Salvador. The specimens were collected at San Salvador, Dept. San Salvador on 7 and 8-III-2001. A voucher is deposited in the FSCA.

Family Tibicinidae Buckton, 1889

Subfamily Tibicininae Distant, 1906

Tribe Carinetini Distant, 1905

Herrera ancilla (Stål, 1864). In the FSCA, there are multiple specimens from Santa Tecla, Dept. La Libertad, collected between 29-V and 7-VI-1970 and 24-V and 16-VII-1972. Specimens in the WEEM were collected in San Salvador, Dept. San Salvador between 30-V and 11-VII-1959.

There are probably many other species present in El Salvador that await addition to the cicada fauna. Neighboring Guatemala, Honduras, and Nicaragua have been reported to have another 13 species and 9 genera in addition to the species identified here from El Salvador (Metcalf 1963a, 1963b, 1963c, Duffels and van der Laan 1985).

I wish to thank Julieta Brambila of the Florida State Collection of Arthropods and Robert Sites of the William R. Enns Entomological Museum for their assistance during my visits and Manuela Miranda for collecting specimens in El Salvador.

SUMMARY

This paper identifies the first cicada species to be reported from El Salvador. Seven species from five genera and two families have been identified from museum specimens.

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RECOGNITION OF THE TYPES OF *OKANAGANA OCCIDENTALIS* (HEMIPTERA: CICADOIDEA: TIBICINIDAE): LECTOTYPE DESIGNATION, TYPE LOCALITY AND SPECIES IDENTITY

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Cicadas of the genus *Okanagana* Distant are restricted to North America. Three species, *O. rimosa* (Say), *O. bella* Davis and *O. occidentalis* (Walker) have overlapping geographic ranges and are similar in external appearance. The type of *O. rimosa* has been lost; for *O. occidentalis*, the subject of the present paper, the type series is uncertain. The original description of *O. occidentalis* appears in the appendix of an account by Lord (1866a) of the animals he collected in British Columbia and Vancouver Island. Walker's description Walker (1886) does not list numbers of specimens examined, localities or depository. Although it is unclear which specimens were available to Walker for the species description, we have located specimens in The Natural History Museum (BMNH) collection which we consider to be the types. Information on these specimens is detailed below.

Among a list of specimens from British Columbia, donated by Lord to the BMNH (reg. no. 1864.18), there is reference to a single specimen of *Cicada occidentalis*, Walker's new species (although unpublished at the time). A later entry in the register (1864.33) duplicates this information and additionally states "The new species were described by Mr. Walker". These records call into question whether the Lord Collection contained all the Walker types for the new species that Lord collected or whether Walker had access to other specimens. If the Lord Collection contained all the Walker types, then *O. occidentalis* was described from a single specimen having the BMNH reg. no., 1864.18. However, there is currently no specimen of *O. occidentalis* in the Museum with this registration number. This specimen appears to have been lost or destroyed many years ago. Davis (1923) makes reference to correspondence with a Mr. Blair (in 1921) and a Mr. Bequart (in 1922) in which they state the type could not be found or was lost.

Other evidence suggests that there was more than one specimen available to Walker for his description. In Lord's (1866b) re-description, two general locations (several hundred kilometers apart) are given for where the species was originally collected (see type locality discussion). In addition, the BMNH collection now contains the following four British Columbian specimens (female) of *O. occidentalis* that are contemporary to its original description, and which we believe to have been collected by Lord. The following data labels are associated with these specimens; the numbers refer to entries in the BMNH register.

Specimen (a). Labelled: 'Vancouv / er's. Isl.'; '60 13' on reverse of blue disc.

Specimen (b). Labelled 'Brit/Columb' and '60 / 112' on reverse of blue disc; Brit Columb / Chulukweyuk / Prairie June 59'.

Specimen (c). Labelled '74 / 86' and 'Brit/Columb' on reverse of white disc; 'Brit. Columbia / Chulukweyuk / Trail. Aug. 1859'.

Specimen (d). Labelled '74 / 86' and 'Brit/Columb' on reverse of white disc; 'occidentalis' handwritten label (by Walker?); yellow "cotype" disc put on by Distant (see Davis, 1923).

From the BMNH register the following additional information is given:

1860.13 [specimen (a)]: "Presented by Lieut Col. Hawkins" and added in another handwriting in pencil: "J K Lord for the North Am B...[thereafter unclear].

1860.112 [specimen (b)]: "Collected by Mr. Lord Assistant Naturalist to H.M. Boundary Commission on the North West Coast of America sent by Col. Hawkins to the Foreign Office. Presented by Lord John Russell". An accompanying entry adds that Hawkins was "Her majestys commissioner for defining the Boundary Line between the British & American Territory in Oregon".

1874.86 [specimens (c) and (d)]: "Presented by Mr. F. Walker". It is unclear how Walker acquired these specimens, as it would be expected that specimens collected by Lord would have gone through the Foreign Office before being donated to the BMNH, as in the case of specimen (b).

As noted above, Lord's collection contained various insects, from British Columbia, with Walker's new species names (reg number 1864.18). A few of these, together with a few registered as 1860.112, located in the BMNH during

the course of this study, are labelled as types and also have the "Chulukweyuk" label found on specimens (b) and (c). The above museum register entries can be considered bibliographic evidence that Walker had access to the four specimens of *occidentalis* when describing the species (as per Article 72.4.1. of the Code; ICZN 1999). These entries, together with the specimen labels provide a link between all specimens, further supporting their status as types. They are automatically considered syntypes, since a holotype was not designated and there is currently no lectotype (as per Article 73.2 of the *Code*; ICZN 1999).

We here select specimen (b) as the lectotype and the remaining, slightly smaller, three specimens are considered paralectotypes.

Measurements of the lectotype (per Recommendation 74C of the *Code*; ICZN 1999) are:

body length = 21.5 mm

length to wing tip = 30.5 mm

wing length = 26 mm

maximum width of forewing = 9.2 mm

wingspan (2 × wing length + width of mesothorax) = 62.3 mm

width of mesothorax = 6.9 mm

width of head across eyes = 6.9 mm

These measurements are slightly less than the values of 12 lines (= 25.4 mm) for body length and 32 lines (= 67.7 mm) for "wings" (we assume wing span) given in Walker's (1866a) original description. The lectotype is located in the Natural History Museum collection with the accession number '60 112'. The collection label has the following information: 'Brit Columb Chulukweyuk Prairie June 59'.

Davis (1919) suggested that the type locality of *O. occidentalis* was in the north-eastern portion of the state of Washington in the Colville Valley, where the Boundary Line Commission had its headquarters. However, in determining the type specimens of *O. occidentalis* it became clear that at least some of Lord's specimens (including the lectotype of O. occidentalis, here designated) were collected in "Chulukweyuk", British Columbia.

As noted above, there are examples of other Walker types in the BMNH from the Lord Collection, or reference to them in the BMNH register. There are referred to as either "Chulukweyuk", "Chulukweyuk Prairie", "Chulukweyuk Trail", "Chulukweyuk Lake", or "Chulukweyuk River". Lord (1866a) makes reference to a "Chelukweyuk River" (note the different spelling) in the lizard section of his book. Lord (1866a: 289) also mentions that he received curatorial assistance from a Mr. Smith at the BMNH. The hand writing in the register entries appears to be similar to the "Chulukweyuk" data labels which suggests the labels were added to the specimens by a curator (possibly Mr. Smith). "Chulukweyuk", therefore, may be a transcription error of Chelukweyuk.

The settlements of British Columbia have been spelled many different ways in attempts to anglicize Native American place names. We have been able to trace Chelukweyuk to the modern city of Chilliwack. Chilliwack is a Halkomelem word that was originally pronounced 'ch.ihl-Kway-uhk' (Akrigg & Akrigg 1986) and is located in the Fraser River valley of the southwestern British Columbia mainland along the eastern side of the Cascade Mountains at approximate coordinates 49° 10' N 121° 57' W. This locality may be consistent with Lord's (1866b) re-description which mentions the Cascade Mountains. Chilliwack is consistent with the museum registers and data labels in that there is a lake, river, and other geographical features that share the name. Therefore, the type locality of *O. occidentalis* is considered to be Chilliwack, British Columbia.

Based on the type series of four females in the BMNH collection, *O. occidentalis* can be distinguished from females of similar species by the sinuate hind margin of the pregenital sternite. Other similar sympatric species, i.e. *O. bella* Davis and *O. rimosa* (Say), have a straighter margin.

Summary

Okanagana occidentalis (Walker) was described from specimens collected in British Columbia. As no holotype was designated we identify a syntypic series in the Natural History Museum, London and designate a lectotype to clarify the identity and type locality of the species. Present day Chilliwack, British Columbia is identified as the type location.

We would like to thank Daniele Perez-Venero of Barry University (USA), Dennis Duffy at the Archives of British Columbia (Canada), and Janet Mason, Provincial Toponymist, Geographic Data BC, Ministry of Environment, Lands & Parks, British Columbia (Canada) who helped us to locate Chulukweyuk and Gillian Watson, CABI (BMNH) for her helpful comments on an earlier draft of the manuscript.

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RETENTION OF CODED WIRE TAGS, AND THEIR EFFECT ON MATURATION AND SURVIVAL OF YELLOW MEALWORMS (COLEOPTERA: TENEBRIONIDAE)

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A variety of methods have been used to mark insects for studies of movement or population dynamics (Hagler et al. 1992). Paints, dyes, and other external marks are commonly used, but generally last for only a short period within a single life stage (White 1970; Charlwood et al. 1986; Lutwama and Mukwaya 1994). By incorporating rare earth elements (Akey 1991) or radioisotopes (Baldwin and Cowper 1969, Lafleur et al. 1985) into the diet of insect larvae, marked individuals have been identified through multiple life stages. However, this technique is generally limited to only a few molts before concentrations of the marking agent are reduced to background levels. The binary coded wire tag first reported by Jefferts et al. (1963) is characterized by high tag retention and has little effect on growth or survival of tagged individuals. This tag has been successfully used to mark crustaceans (Prentice and Rensel 1977; Uglem and Grimsen 1995; Isely and Eversole 1998) but has yet to be evaluated for use on insects. The objective of this study was to evaluate the retention across life stages of the coded wire tag in the yellow mealworm, *Tenebrio molitar* (Coleoptera: Tenebrionidae), and to determine the effects of tagging on growth and survival.

Late instar mealworms (n = 207, mean weight = 0.18 g) were obtained from a local pet store. One group (n=155) was tagged with sequentially numbered, standard length, binary-coded wire tags using a Mark IV Tag Injector (Northwest Marine Technologies, Shaw Island, Washington). Each tags measured 1 mm (length) × 0.1 mm (diameter) and was etched with an unique binary code readable under a dissecting microscope. Tags were injected through the exoskeleton parallel to the long axis of the abdomen with a fixed injection needle imbedded beneath the dorsal surface of the second abdominal segment (Fig. 1). One group (n = 52) was not tagged and served as a control. Each mealworm was placed in an individual 50 ml plastic container. Each container was filled with approximately 20 g of rolled oats, which provided nutrition and a substrate. Mealworms were held at 21 C under a 12 h light, 12 h dark photoperiod. Individual mealworms were evaluated every 7 d after tagging for mortality, tag retention, molting, and metamorphosis until they reached adulthood. The presence of tags was verified using a hand-held coded wire tag detector (Northwest Marine Technologies, Shaw Island, Washington). Differences between experimental and control groups in mean time to pupation and adulthood were evaluated using a *t*-test ($P < 0.05$). Differences between experimental and control groups in survival to pupation and adulthood were evaluated by chi-square analysis ($P < 0.05$).

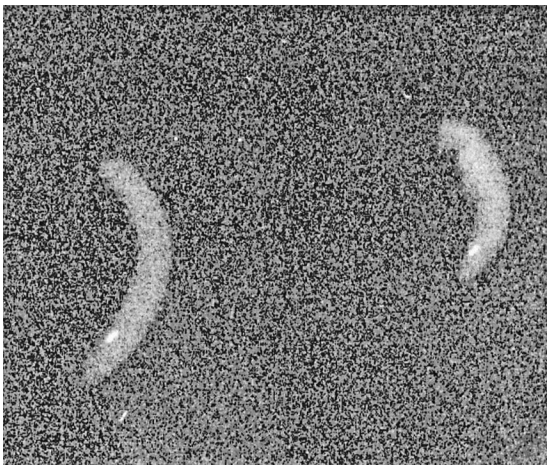

Fig. 1. X-ray of yellow mealworm, *Tenebrio molitar* (Coleoptera: Tenebrionidae), larva and pupa tagged with a 1 mm × 0.1 mm coded wire tag. coded wire tag appear as a white line.

After 70 d, 5 experimental and 1 control individual had not metamorphosed from larva to pupa. These individuals were counted as mortalities for the purpose of the analyses. We found no difference in the mean time to pupation for tagged and untagged mealworms (Table 1). There was also no difference in the mean time to adulthood between tagged or control groups. However, initial (72 h) mortality of tagged individuals was 14%, and mortality of tagged individuals was higher than mortality of control individuals to both the pupa and adult phases (Table 2). Survivorship of tagged mealworms to the pupal stage

TABLE 1. INITIAL NUMBERS AND TIME TO METAMORPHOSIS (MEAN ± S.E.) OF MEALWORMS TAGGED WITH CODED WIRE TAGS AND UNTAGGED CONTROLS.

		Time to metamorphosis (days)	
Treatment	N	Larvae to pupae	Pupae to adult
Tagged	85	12.1 ± 2.69	21.8 ± 3.56
Control	52	12.3 ± 3.58	23.9 ± 3.34

was 82%. Survivorship from pupa to adult was 79%. All mortalities occurred during molting, either within the larval stage, or between larvae and pupae, or pupae and adult. This was likely the result of not imbedding the tag completely through the exoskeleton. Included in this were 12 pupae that only partially metamorphosed. In these individuals, the head and thorax exhibited adult characteristics, while the abdomen retained the appearance of the pupae. It appeared that the presence of the tag may interfere with metamorphosis in some cases. These partially metamorphosed individuals lived approximately one week and were counted as pupae for statistical analysis. This resulted in 65% survival from larvae to adulthood, in contrast to the 98% survivorship exhibited in the control group. This mortality rate is higher than has been reported for other invertebrates tagged with coded wire tags (Uglem and Grimsen 1995; Isely and Eversole 1998) or insects tagged with fluorescent powder (Naranjo 1990), but compares favorably with insects marked with trace elements (Moss and Van Steenwyk 1984; Armes et al. 1989).

Tag retention within surviving larvae was 99% (Table 2), and the proportion of pupae retaining tags was 86%. However, as many pupae which lost tags did not survive to adulthood, the proportion of adults retaining tags was 93%. All tags were lost during metamorphosis and located in shed exoskeletons. Tag retention rates we observed compare favorably with retention rates of coded wire tags in other studies on invertebrates (Brandt and Schreck 1975; Joule 1983; Isely and Eversole 1998). Further, coded wire tags do not degrade with time, as has been noted with pigments (Naranjo 1990) and trace elements (Moss and Van Steenwyk 1984; Armes et al. 1989).

TABLE 2. PROPORTION OF INDIVIDUALS WITHIN LIFE STAGES RETAINING TAGS AND PERCENT SURVIVAL WITHIN LIFE STAGES FOR MEALWORMS TAGGED WITH CODED WIRE TAGS AND UNTAGGED CONTROLS.

Treatment	Life Stage	N	Tag Retention (%)	Survival (%)
Tagged	Larvae	155	99	86
Control	Larvae	52	—	100
Tagged	Pupae	127	86	82
Control	Pupae	51	—	98
Tagged	Adult	100	93	79
Control	Adult	51	—	100

Funding for this study was provided by the South Carolina Cooperative Fish and Wildlife Research Unit. Critical review of this manuscript was provided by J. R. Tomasso and A. G. Eversole. Cooperating Agencies for the South Carolina Cooperative Fish and Wildlife Research Unit are the U. S. Geological Survey, Clemson University, the South Carolina Department of Natural Resources, and the Wildlife Management Institute.

SUMMARY

This study demonstrates that coded wire tags can be used to mark certain insect larvae without adverse effects on maturation, and that tags are retained through the adult phase in high enough proportion for practical application. Coded wire tags also offer the benefit that marked organisms can be identified to the batch or individual level.

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ERRATUM

Effects of Vegetation Control on Parasitoids of the Nantucket Pine Tip Moth (Lepidoptera: Tortricidae). By Kenneth W. McCravy and C. Wayne Berisford. 84(2) 282-287.

The captions for Figs. 2 and 3 (p. 285) were erroneously reversed in the final printing.

BOOK REVIEWS

ARNETT, R. H., JR. 2001. American insects. A handbook of the insects of America north of Mexico. Second edition. CRC Press; Boca Raton. xvii + 1003 p. ISBN 0-8493-0212-9. Paperback. $99.95.

Over the years, Ross Arnett's "American insects" has become a standard reference for professional entomologists. A formidable manual, American insects is the place to go for a quick check on species richness, and a list of all genera found in America north of Mexico. Over 17,000 species reportedly are referenced. For common and pest species, geographic distribution is given. Keys for family level identification also are included.

The author died in 1999 at the age of 80, still vigorous in mind but frail in body. He had essentially completed the task of revising this popular book, but it fell to Mike Thomas and Paul Skelley of the Florida State Collection of Arthropods to fine-tune the manuscript prior to publication. Collectively, they made numerous improvements that make this important manual even more useful.

The second edition is substantially the same as the earlier version in organization, scope, and detail. As before, the contents are arranged taxonomically, though one additional order (Strepsiptera) now occurs, having been elevated from a family of Coleoptera. Some of the orders (e.g., Coleoptera, Lepidoptera, portions of Hemiptera and Homoptera) have been revised with the assistance of specialists, though the changes are principally nomenclatural. The order name "Hemiptera" is conserved, but the order names of diplurans, bristletails, and silverfish have been changed. Extinct orders have been elevated (as judged by font characteristics) to the status of living orders, but they are not numbered (as are living orders) and are not included in the table of contents.

The major benefits to the revision, other than updating the nomenclature, are changes designed to make the handbook more "user friendly." For example, in the first edition the index referenced book sections rather than page number, and I always found it difficult to navigate through this large tome. Also, the figures now have descriptive labels instead of only figure numbers. I found it most annoying to have to search the page (or pages) seeking an identity for the numerous illustrations. These are significant and greatly welcomed improvements.

Not all the changes are improvements, however. The first edition bore an impressive index, which has been markedly reduced in scope. For example, the entries listed under "Y" have been reduced from 63 to 4. The insect common names have been deleted from the index, as have species entries. I think this is unfortunate. Many of the users will be economic entomologists and students, and more familiar with "Mexican bean beetle" than "*Epilachna varivestis*." Some users now will need another book to reference the scientific name is order to assess the contents of "American insects." Similarly, genus designations change much more frequently than species designations, and it now will be difficult to find information on species where such changes have occurred without first knowing the old genus name. I also was surprised to see a slight deterioration in quality of the line drawings. The photograph quality was not significantly affected, but some line drawings now have a fuzzy appearance.

Preparation of this monumental reference was undoubtedly a Herculean task for a single author, so it is not surprising that a number of errors in spelling, and underestimates of geographic range, have crept into the document. Unfortunately, most of these seem to have been preserved in the revision. The author is not solely at fault for this situation. It is difficult to acquire good editing and proofreading; friends quickly become former friends when you ask them to read such an enormous work, and publishers don't care to expend the funds to hire experts. I admit to being aware that the specific designations of several of my "favorite" insects such as asparagus beetle, lubber grasshopper, and eastern lubber grasshopper (common names which you can't look up in the index of the second edition!) were spelled incorrectly in the first edition. I should have notified Ross so corrections could be made in the second edition. Collectively we need to notify the publisher of such errors so as to enhance the future value of this important reference.

Overall, an immensely valuable book has been improved in the second edition. If you don't own a copy, give serious consideration to purchase of this book. If you own the first edition and you use it only occasionally for reference, the changes are not so great that you need to rush out to acquire a new version. If you are like me, however, and can't navigate effectively without page numbers, upgrading to the second edition will make an already useful reference even more handy.

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HOGARTH, P. J. 1999. The biology of mangroves. Oxford Univ. Press; Oxford, UK. ix + 228 p. ISBN 0-19-850222-2. Paperback. $34.95.

Mangrove swamps (mangals) are not the cup of tea of most terrestrial biologists who probably abhor them because they are usually muddy, smelly and buggy. However, they are actually important habitats for many marine organisms, including my favorite insects, the sea-skaters. So, as soon as I received the review copy of this book I looked for *Halobates*, *Asclepios* and *Trochopus* in the index. Alas, none has been included, although they are some of the most prominent marine insects associated with tropical Pacific, Indian and Atlantic mangroves. They are often overlooked. When I visited the marine laboratory of the University of the South Pacific in Fiji some years ago, and asked about sea-skaters, Drs. X and Y, who had worked on mangrove communities for many years, told me that they were definitely absent from the mangroves around the laboratory. However, not wanting to be so easily discouraged, I took a bucket and a plastic scoop, marched off to the nearby mangrove swamp and returned some 15 minutes later with no less than 100 *Halobates*! One just has to know how to look for them.

This attractive book, 5th of a series on the Biology of Habitats has a preface, 8 chapters, a suggested list for further reading, an extensive bibliography (which also includes a list of websites on mangroves), a glossary, and a general index. Each chapter begins with a short general introduction followed by detailed discussions of the subject matter divided into short sections. There are many fine black-and white illustrations (figures, tables, graphs, photographs, and electron micrographs), most, but not all, with scales to indicate sizes of the animals or plants.

Chapter 1 (Mangroves) tells us what a mangrove is, where mangrove forests are found, how they cope with tidal water, salt and nutrients in their environment, and how they propagate. There is a nice discussion on vivipary, common among mangroves but rare in other higher plants.

Chapter 2 (The mangrove ecosystem) reviews the mangrove ecosystem, how it is divided spatially and what determines its general size and shape. Although with only few species compared with tropical forests, they show rather complex species zonations (e.g., Fig. 2.2). Biological features (propagule sorting by size, smaller ones being carried further up the shore) and physical factor (duration of inundation, salinity) as well as changes in the sea-level and sediment accumulation can all affect species zonation. Mangroves tend to trap or create mud, which provides a habitat for larvae of biting midges (Ceratopogonidae: *Culicoides*) and various other invertebrates. Decomposing leaf litter from mangroves is an important source of nutrients and a substrate for bacteria and fungi. As the author aptly says "a mangrove habitat is a great deal more than mud which happens to have trees growing in it".

Chapters 3 and 4 (The mangrove community) discuss respectively the terrestrial and marine components of the mangrove community. The former is largely devoted to terrestrial vertebrates (amphibians, reptiles, birds and mammals), with a short section on insects (herbivores, ants, termites, biting flies and fireflies). [I was disappointed to note that there was no reference to Murphy's 1990 comprehensive review of about 100 insect herbivores on 21 species of mangrove trees in Singapore.] The marine chapter is largely devoted to crabs (Brachyura), the most dominant invertebrates in the mangrove, with detailed information on their biology, physiology, adaptations and behavior (especially that of fiddler crabs). There are also brief discussions on the algae, fauna on mangrove roots, snails, the meiofauna, and a slightly longer section on mudskippers.

Chapter 5 (Measuring and modelling) reviews the mangrove community as a whole and presents a food web or energy flux model (Fig. 5.7), with discussions on each component. Such quantitative approaches are particularly useful in the management of mangrove systems.

Chapter 6 (Comparisons and connections) compares mangroves, which are predominantly tropical, with salt marshes, their equivalents in the temperate region, and how they serve as important nurseries for various marine invertebrates, some of which may be of great economic value.

Chapter 7 (Biodiversity and biogeography) presents an interesting discussion on the biodiversity and origin of the mangroves. There are considerable differences in the distribution of various species, with a much greater abundance in the Indo-West Pacific (57 spp.) than in the Atlantic-Caribbean-East Pacific (15 spp.). South-east Asia, long considered the center of diversity for many tropical marine organisms, has also the greatest diversity of mangroves. Since fortunately we have some fossilized mangrove seeds, we are able to date their origins to sometime in the late Cretaceous or early Paleocene, around 69 myr ago. They then became widespread around the world throughout the entire pan-tropical zone (Fig. 7.6). Their present distribution is quite different and is largely a result of continental drift, leading to local extinction of some species and diversification of others. [For a more recent discussion on the origins of mangroves see Aaron et al. (1999).] Molecular genetics studies on a few genera will help in our understanding of the evolution and genetic diversity of mangroves. The chapter ends with discussions on 2 experimental studies, attempting to relate species richness with habitat area or productivity.

The final chapter (Impact) reviews uses of mangroves by humans as well as animals, and how they could be managed, protected or rehabilitated. Two case studies are presented, one in Malaysia, the other in Pakistan.

Although mangroves serve important functions in the lives of many people in the tropics and are of enormous economic potential, so far little effort has been made worldwide for their protection. This book should help us to appreciate their importance and encourage more sustainable management of these valuable resources.

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KITCHING, R. L. 2000. Food webs and container habitats: The natural history and ecology of phytotelmata. Cambridge Univ. Press; New York. xiii + 431 p. ISBN 0-521-77316-4. Hardback. $100.

A phytotelma is a pool of water impounded by a plant. The plural is phytotelmata, pronounced phyto.**telm**.ata (in keeping with other Greek plurals ending in -ata). The word was coined in the late 1920s from the Greek words meaning plant and pool. The word phytotelm serves both as a noun (a vernacular English equivalent of phytotelma) and an adjective. The best known are the pitchers of Old World (*Nepenthes*) and New World (*Sarracenia*) pitcher plants, flower bracts of many but not all species of *Heliconia* (Heliconiaceae), leaf axils of many but not all species of bromeliads (Bromeliaceae), and treeholes (water-collecting cavities in trunks and buttresses and large branches of hardwood trees). Phytotelmata are natural containers and they have a rich fauna including specialist aquatic organisms that occur nowhere else, non-specialist aquatic opportunists, and riparian organisms (terrestrial organisms that live on the margins of aquatic habitats and may occasionally enter the water).

This is the first single-authored book on phytotelmata in general (apart from one entirely in Japanese). Roger Kitching is one of the few ecologists to have worked intensively on two phytotelm systems: treeholes and the pitchers of *Nepenthes*. Furthermore, his treehole studies were carried out in England, Australia, New Guinea, and the USA, and his *Nepenthes* studies in Sulawesi and Borneo. The disparate study sites and two major systems (colored with some experience of some other systems) allow him singular insight into how these systems function. He also collected together a substantial portion of the literature on these and other phytotelm systems and was able to weave parts of the knowledge of those other authors into this book.

The introduction gives a brief history of studies of phytotelmata, documents the locales of Kitching's own studies, and then broaches the subject that is the core of the book: the construction of food webs. He points out that manipulative experimentation is a key to how food webs work, but it cannot answer all questions. His cut-off point for inclusion of literature was mid-1997—there had to be a cut-off point. For lack of other information, he assumed not unreasonably (p. 306) that aquatic oligochaete worms "must generally reach phytotelmata in run-off and mobile debris"—thanks to Lopez et al. (1999) we know now that at least some oligochaetes and ostracods are able to disperse between bromeliad phytotelmata by phoresy on frogs and snakes.

Chapter 2 gives a brief oversight of phytotelmata formed by bromeliad axils, pitcher plants, treeholes, bamboo internodes, and plant leaf axils (including *Heliconia* flower bracts). This chapter includes tables of key works and of the plant families involved (except for those forming treeholes, because such a list could include almost all hardwood trees). Chapter 3 addresses the subject of feeding guilds within the aquatic fauna (from rotifers through arthropods to vertebrates); it does not deal with bacteria, fungi, or Protozoa, nor does it provide tables assigning taxa to guilds. Chapter 4 delineates the environments occupied by and provided by phytotelmata, physical and chemical.

Chapters 5-14, grouped into 4 sections Methods and theories, Patterns in phytotelm food webs, Processes structuring food webs, and Synthesis, are the core of the book. The study of food webs is a structured method of depiction by diagram and analysis of trophic relationships of organisms: what feeds on what, and how communities (if such occurs) are structured by predation. It covers the facets that other authors have studied under other rubrics: species richness, seasonality, invasion, succession, habitat-partitioning, competition, and population dynamics. Food webs in temperate-region phytotelmata are found to have two levels, but in the tropics may have three or even four levels. These chapters also provide hypotheses and predictions. Kitching finds evidence (p. 267) of the potentially central role of predators in all five principal classes of phytotelmata (treeholes, bromeliads, bamboo internodes, leaf axils of other plants, and pitchers). This, however, is not affirmation that predation is in all instances the central controlling factor, for in some instances in my experience the central role may be taken by rainfall, and rainfall-induced nutrient influx, and then the central role is of scramble competition.

An annex (p. 301-384) is a bestiary. Phylum by phylum, from Platyhelminthes to Chordata, it gives a brief account of each major taxon, for some at the level of phylum, for some arthropods down to the level of family. It provides a classification, down to the level of species, of some of the taxa (Annelida, Crustacea, Odonata, Culicidae, Chironomidae, Ceratopogonidae, Psychodidae, Phoridae, Syrphidae, Coleoptera, Acari, and frogs) in tables. This classification was a brave undertaking because it seems to be the first to attempt a listing for the fauna of all phytotelmata. To satisfy an arthropod systematist it would require two things that were not done: first, provision of author (describer) name(s) for every species; second, not just a listing of the species as reported from phytotelmata, but also integration of all of those species concepts with all of the subsequent taxonomic literature (not just the literature on phytotelmata) on the taxa involved. However, it gives references to the literature and thus provides much of the spadework by which a

much later compiler can complete it. It will of course not be complete for many decades because so much is yet unrecorded.

Would I buy this book? Yes, absolutely. Not just because there is none better at explaining how phytotelm communities interact (and I happen to be interested in phytotelmata). But also because phytotelmata are extraordinarily manipulable little ecosystems that lend themselves to experimentation and are helping to answer broader questions in ecology. And, I find the book to be easy to read: it has very few jargon expressions and very few typographical errors. It is illustrated by numerous black and white figures of adequate quality, and six black and white prints (one of which, in its original color, adorns the front cover) of *Nepenthes* pitcher plants.

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Becker Microbial Products Inc.
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Best Termite & Pest Control Inc.
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Yoder Brothers
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