TABLE OF CONTENTS

Laboratory evaluation of the pathogenicity of Beauveria bassiana and Metarhizium anisopliae to larvae of the banded sunflower moth, (Lepidoptera: Cochylidae) 
John F. Barker .......................... 101

Pupal and adult parameters as potential indicators of cottonwood leaf beetle (Coleoptera: Chrysomelidae) fecundity and longevity 
David R. Coyle, Joel D. McMillin and Elwood R. Hart .................. 107

Summer Ephemeroptera, Plecoptera, and Trichoptera (EPT) species richness and community structure in the lower Illinois River basin of Illinois 
R. Edward DeWalt, Donald W. Webb and Mitchell A. Harris. .......... 115

Survey of the Reduviidae (Heteroptera) of southern Illinois excluding the Phymatinae, with notes on biology 
A. M. Hagerty and J. E. McPherson .................................. 133

The aphids (Homoptera: Aphididae) associated with bell peppers and surrounding vegetation in southern Illinois 
Godfrey H. Kagezi, David J. Voegtlin and Richard A. Weinzierl .......... 161

First records of Cecidomyia candidipes [Diptera: Cecidomyiidae] in Wisconsin 
Steven J. Krauth ........................................ 175

Distribution of an exotic pest, Agromyza fronfella [Diptera: Agromyzidae], in Manitoba, Canada 
J. G. Lundgren, R. C. Venette, J. Gavloski, W. D. Hutchison and G. E. Heimpel ........ 177

Two new species of Cochylini (Lepidoptera: Tortricidae) from the eastern United States 
Eric H. Metzler ................................ 185

Pitch mass borer, a new clearwing moth record for Ohio [Lepidoptera: Sesiidae] 
Foster Forbes Purrington and David J. Horn .............................. 199

Williamsonia lintneri [Odonata: Corduliidae]—a first Michigan record with additional notes on W. fletcheri 
Stephen Ross and Mark F. O'Brien ................................ 201

Sex ratio and sexual dimorphism in Formica exsectoides, the Allegheny mound ant (Hymenoptera: Formicidae) 
H. C. Rowe and C. M. Bristow .................................... 207

New distribution records for Minnesota Odonata 
Wayne P. Steffens and William A. Smith ................................. 219

Habitat characterization of five rare insects in Michigan [Lepidoptera: Hesperiidae, Riodinidae, Satyridae; Homoptera: Cercopidae] 
Keith Summerville and Christopher A. Clampitt ...................... 225

COVER PHOTO

A male Nannothemis bella [Uhler] (Odonata: Libellulidae) in a typical perch on a sedge. This is the smallest North American dragonfly—about 20 mm in length. Photo by Stephen Ross.
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LABORATORY EVALUATION OF THE PATHOGENICITY OF BEAUVERIA BASSIANA AND METARHIZIUM ANISOPLIAE TO LARVAE OF THE BANDED SUNFLOWER MOTH, COCHYLIS HOSPES (LEPIDOPTERA: COCHYLIDAE).

John F. Barker

ABSTRACT

Laboratory bioassays were conducted to assess the virulence of two entomopathogenic fungi, Beauveria bassiana, and Metarhizium anisopliae to 5th instars of the banded sunflower moth, Cochylis hospes, (Lepidoptera: Cochylidae). Temperature conditions of 20 and 25°C and high humidity, (near saturation) were nearly optimal for development of both fungi. Concentrations of 10^7 to 10^8 conidia/ml produced 100% mortality in 10 days or less and 10^6 conidia/ml produced 90% mortality at 21 to 26 days. Median lethal concentrations of conidia (LC_50) from M. anisopliae were 3.6 x 10^3 at 25°C and 4.1 x 10^3 at 20°C. The LC_50 for B. bassiana was 14.9 x 10^4 conidia/ml at 20°C and 6.7 x 10^3 conidia/ml at 25°C. Although B. bassiana tended to be less virulent at 20°C, these differences were not significant. The high humidities required for germination and growth may reduce the usefulness of these fungi as control agents of C. hospes in the northern Great Plains. Further studies and field evaluations are needed to determine if there are microhabitats in the soil or on the sunflower head where the humidity is high enough for germination and growth of B. bassiana or M. anisopliae. Targeting of C. hospes stages in the soil to avoid contaminating the seed or oil with saprophytic fungal spores may be preferred to targeting the sunflower plant for reasons of preserving seed quality, marketing, and consumption.

Beauveria bassiana (Balsamo) Vuillemin and Metarhizium anisopliae (Metschnikoff) Sorokin (Deuteromycotinia: Hyphomycetes) are entomopathogenic fungi that occur in the soil, have a wide insect host range, and are distributed worldwide (Tanada and Kaya 1993). Virulence to insects varies with the fungal variety or strain, dose, host age, and environmental conditions, particularly temperature and humidity (Miller et al. 1983, Tanada and Kaya 1993). Infection usually takes place through chitinolytic penetration of the integument by fungal hyphae and both genera produce mycotoxins (Tanada and Kaya 1993). Beauveria bassiana and M. anisopliae are are being studied as alternatives to chemical pesticides for the control of a variety of insect species (Tanada and Kaya 1993, Miller et al. 1983) but neither has been significantly explored for microbial control of the banded sunflower moth Cochylis hospes, or other sunflower insect pests. The life cycle of C. hospes begins about the third week in July when eggs are laid on the bracts of sunflower. The larval

1 USDA, ARS, Biosciences Research Laboratory, P. O. Box 5674, State University Station, Fargo, ND 58105.
stages feed on the florets and seeds of the sunflower head. The fifth and ultimate instar leaves the sunflower head in late August and early September to overwinter in the soil, and pupates in late spring (Westdal 1949, Charlet and Gross 1990, Charlet et. al. 1997, Beregovoy and Riemann 1989). The adults emerge about mid-July and begin a new generation. The objective of this study was to assess, in controlled laboratory conditions, the virulence of these fungi to fifth instars and pupae that overwinter in the soil. The latter stages were targeted for control in this study, because application to the sunflower head of large numbers of conidia from saprophytic fungi to control the earlier instars, could reduce the quality or acceptability of the seed or oil by consumers and the sunflower industry. The high humidity needed for fungal growth is more probable in the soil than on the sunflower capitulum where high humidity is incompatible with maintaining seed quality.

MATERIALS AND METHODS

Insects and rearing conditions. Cochylis hospes is routinely reared on insect diet in laboratory environmental chambers maintained at 28 ± 1°C, 50% relative humidity, and a 15:9 L:D cycle (Barker 1988). Fifth instars that had ceased feeding were selected primarily because this stage completes its development in the soil where it was suggested that control be targeted and, secondarily, it circumvented complications that would arise from diet spoilage in the presence of saprophytic fungi. In addition, ingestion of conidia was not required since infection of insects with fungi is primarily through the integument (Tanada and Kaya 1993). Cessation of feeding by the 5th-instar of C. hospes is marked by a change in color about 2 days after the molt to the fifth instar. The insect diet contains Benomyl (Bonide Products Inc. Yorkville, N.Y.) which will inhibit but will not prevent fungal growth, however, contamination of the diet is controlled primarily with the use of a sterile hood, materials, utensils, and control of excess moisture (Barker 1988).

Fungi. M. anisopliae (ATCC # 22099) was obtained from the American Type Culture Collection, Rockville, MD. A strain of B. bassiana, formulated into a commercial microbial insecticide Naturalis-L®, was obtained from Troy Biosciences, Phoenix AZ. Naturalis-L and ATCC 22099 were stock preparations which were sub-cultured on potato dextrose agar plates to produce conidia for bioassay.

Bioassay. Conidia from sub-cultures of Naturalis-L or ATCC 22099 stock were suspended in 10mM phosphoric acid buffered saline, pH = 7.0, prepared with 0.5 % Tween 80 to reduce clumping of the conidia and counted with a hemocytometer. Serial dilutions were prepared with the following concentrations of conidia/ml: 10^8, 10^7, 10^6, 10^5, 10^4, 10^3, 10^2, or 0 (controls). This method of assay has a limitation in that it does not define precisely what dosage each larva received, but it does define the concentration of conidia to which each larva was exposed. A 1 and a 10µl sample of each concentration was streaked on potato dextrose agar plates to check for viability. Thirty, 5th-instar larvae were transferred to each of the tubes containing conidia and gently shaken for 5–10 sec. by inverting the tube. Longer periods of immersion were avoided because of detrimental effects on larval development and survival that were not related to infection. The 30 larvae were confined individually in 1 ml vented microfuge tubes with a piece of moist potting foam provided for pupation. Moisture was added to the potting foam and replenished as necessary to facilitate survival of pupae and their successful emergence as adults and to facilitate growth of the fungi. Tubes were vented by punching a hole (diameter 4mm) into the cap of the tube and covered with
Nitex (Tetko, Briarcliff Manor, NY) 2-ply polyester (70 threads per cm). The larvae were held at 20±1°C or 25±1°C in environmental chambers maintained on a 15:9 L:D cycle and 60–70% relative humidity. The humidity within the microfuge tubes, with the moist potting foam, was near saturation. Observations for mortality began on the second day after treatment and every other day thereafter for 21 or 26 d at 25 and 20°C, respectively, until the controls and treated insects that survived had pupated and emerged as adults. The LC₅₀ of the treated larvae was determined at 21d (25°C) and 26 d (20°C). Cadavers that did not show obvious mycelial growth were macerated with a forceps and the debris streaked on potato dextrose agar and observed for mycelial growth. The bioassay was replicated eight times and an overall average response for each concentration was obtained by averaging the data from the eight replicates.

**Statistical methods.** POLO-PC (LeOra Software 1987, Berkeley, CA) was used to estimate the LC₅₀s and determine the Chi square goodness of fit. Jandel SigmaPlot (version 5, 1992 and version 2, 1995, San Rafael, CA) and Finney (1947) were used to plot probit regression equations.

**RESULTS AND DISCUSSION**

**Mortality in relation to concentration of conidia and temperature.** Mortality that resulted from treatment of *C. hospes* 5th instars with conidia from *B. bassiana* and *M. anisopliae* was 100% in 10 d or less after treatment with 10⁸ and 10⁷ conidia/ml at both temperatures. Fifth instars begin to pupate about 13 days after becoming fifth instars at 25°C (Barker 1994) but none of the fifths treated with 10⁸ or 10⁷ conidia survived to the pupal stage at 20 or 25°C. Mortality after treatment with 10⁶ conidia of both fungi was approximately 90% at both temperatures over a period of 21 to 26 d (Table 1) while the controls and survivors completed development to the adult stage. The majority of fifths treated with 10⁶ conidia per ml died as fifth instars because development of infected larvae to the pupal stage was retarded relative to the controls, although some pupated and then died. Diapause was not induced in the fifths held at 20°C in this study because the

<table>
<thead>
<tr>
<th>Conc</th>
<th>20°C % mortality</th>
<th>25°C % mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26 d</td>
<td>21 d</td>
</tr>
<tr>
<td><em>M. anisopliae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10⁶</td>
<td>95.8 ± 2.5</td>
<td>92.0 ± 8.5</td>
</tr>
<tr>
<td>10⁵</td>
<td>93.3 ± 1.9</td>
<td>83.3 ± 7.7</td>
</tr>
<tr>
<td>10⁴</td>
<td>68.0 ± 9.0</td>
<td>63.3 ± 18.4</td>
</tr>
<tr>
<td>10³</td>
<td>30.0 ± 8.7</td>
<td>37.5 ± 8.8</td>
</tr>
<tr>
<td>10²</td>
<td>11.1 ± 6.2</td>
<td>16.7 ± 10.9</td>
</tr>
<tr>
<td>0</td>
<td>6.7 ± 2.2</td>
<td>3.3 ± 2.7</td>
</tr>
<tr>
<td><em>B. bassiana</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10⁶</td>
<td>88.7 ± 5.9</td>
<td>91.7 ± 3.3</td>
</tr>
<tr>
<td>10⁵</td>
<td>68.4 ± 8.4</td>
<td>73.3 ± 16.3</td>
</tr>
<tr>
<td>10⁴</td>
<td>48.9 ± 8.8</td>
<td>54.0 ± 12.7</td>
</tr>
<tr>
<td>10³</td>
<td>32.2 ± 5.1</td>
<td>35.3 ± 4.8</td>
</tr>
<tr>
<td>10²</td>
<td>10.7 ± 0.7</td>
<td>13.3 ± 6.9</td>
</tr>
<tr>
<td>0</td>
<td>5.6 ± 4.3</td>
<td>1.3 ± 1.0</td>
</tr>
</tbody>
</table>
Table 2. Estimated median lethal concentrations of conidia for C. hospes 5th instars.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Temp.</th>
<th>LC50 Conidia/ml</th>
<th>Lower limit</th>
<th>Upper limit</th>
<th>Slope ± S. E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. anisopliae</td>
<td>20°C</td>
<td>4,122</td>
<td>2,531</td>
<td>6,269</td>
<td>1.042 ± 0.114</td>
</tr>
<tr>
<td>M. anisopliae</td>
<td>25°C</td>
<td>3,651</td>
<td>2,111</td>
<td>6,184</td>
<td>0.662 ± 0.071</td>
</tr>
<tr>
<td>B. bassiana</td>
<td>20°C</td>
<td>14,956</td>
<td>8,122</td>
<td>26,389</td>
<td>0.621 ± 0.060</td>
</tr>
<tr>
<td>B. bassiana</td>
<td>25°C</td>
<td>8,160</td>
<td>5,268</td>
<td>12,486</td>
<td>0.592 ± 0.051</td>
</tr>
</tbody>
</table>

Larvae were reared to the fifth instar under non-diapause inducing conditions (Barker 1994) and then placed at 20°C as control or test insects. Mortality trended lower for both fungi, at both temperatures, in response to exposure to lower concentrations of conidia. The estimated LC50 values of M. anisopliae conidia at 20 and 25°C were 4.1 x 10^3 and 3.6 x 10^3 conidia/ml at 26 d and 21 d, respectively (Table 2). The estimated LC50 values for larvae treated with B. bassiana at 20 and 25°C were 14.9 x 10^4 and 8.1 x 10^3 conidia/ml respectively (Table 2).

**LC50 values and slopes in relation to temperature.** Optimum temperatures for development, pathogenicity, and survival of fungi generally fall between 20 to 30°C (McCoy et al. 1988). The optimal growth temperatures for Beauveria are 23-25°C and 27-28°C for Metarhizium (Ferron 1981). Generally, there is a decline in virulence of entomopathogenic fungi with declining temperature (Deacon 1983, Rath et al. 1995) outside the optimal temperature range. The LC50 values at 20 and 25°C overlapped for both fungi indicating that the change of temperature from 25 to 20°C did not significantly affect mortality. The overlapping regression lines for M. anisopliae did not clearly demonstrate a trend toward lower virulence at 20°C. B. bassiana showed a trend toward reduced virulence at the lower temperature (Fig. 1). The slopes of the regression lines for B. bassiana at 20°C and 25°C are not significantly different since the lines are nearly parallel but the lines reflect a lower virulence at 20°C than at 25°C. Chi-square heterogeneity < 1 indicated a good fit of the regression equations to the data in each case and P≤0.05 in the Chi-square goodness of fit test.

The results of this study show that B. bassiana and M. anisopliae are pathogenic to C. hospes larvae in laboratory conditions where the temperature and humidity are controlled. The humidity level (around 90%) required by these fungi for optimal germination and infection (Deacon 1983) may limit their use as control agents to periods of high humidity. Studies of microhabitats in the sunflower head or the soil may indicate that in those environments the humidity levels are high enough for the development of these fungi. High humidity needed for fungal growth is more probable in the soil than on the sunflower capitulum where it is undesirable because it is incompatible with maintaining seed quality. Application to the sunflower head of large numbers of conidia from saprophytic fungi should be avoided since it could reduce the quality or acceptability of the seed or oil. Humidity levels in the soil are probably 90% under some climatic conditions, but targeting control to C. hospes stages in the soil can only be directed to the 5th instar which enters the soil to overwinter, or to the pupal stage which develops in the soil. Application of conidia to the soil in the fall or in the spring and early summer to control overwintering larval and pupal stages of the next generation of C. hospes is a possibility that circumvents objections to treatment of the sunflower capitulum. Infectivity of the fungus in the soil, however, could be slowed due to suboptimal temperatures that prevail in the fall and spring months. The total mortality from infection with these fungi may be unaf-
Figure 1. Probit regression lines for the mortality of *C. hospes* fifth instars treated with conidia from *M. anisopliae* and *B. bassiana* at 20 and 25°C.
fected at suboptimal temperatures except that it occurs over extended periods of time (Ferron 1978, Rath et al. 1995). Isolation or development of fungal strains that germinate and develop at lower temperature and humidity is another alternative.

ACKNOWLEDGMENTS

The author thanks Sharon Grugel for insect rearing and diet preparation. This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or recommendation by the USDA for its use.

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PUPAL AND ADULT PARAMETERS AS POTENTIAL INDICATORS OF COTTONWOOD LEAF BEETLE (COLEOPTERA: CHRYSOMELIDAE) FECUNDITY AND LONGEVITY

David R. Coyle, Joel D. McMillin and Elwood R. Hart

ABSTRACT

Cottonwood leaf beetle, *Chrysomela scripta*, pupae from a laboratory colony were weighed and monitored through adult emergence, oviposition, and mortality to determine if correlations existed between various pupal or adult parameters and fecundity or longevity. Forty-three female cottonwood leaf beetles were monitored. Pupal weight was not a good indicator of fecundity, total oviposition events, number of eggs/beetle/day, or adult longevity. In addition, adult weight showed very low correlation with fecundity, adult longevity, total oviposition events, or number of eggs/beetle/day. However, adult weight was a marginal indicator of the number of eggs/beetle/day, and correlated well with adult body length. Adult longevity could be used to predict fecundity.

Adult insect performance can be measured in various ways, including survival, pupal weight (Augustin et al. 1997), adult emergence, or fecundity (Miller and Ware 1997). Positive correlations have been determined to exist between pupal weight and adult fecundity in Lepidoptera (Miller 1957, Bessin and Reagan 1990, Spurgeon et al. 1995), Diptera (Hawley 1985, Kainacker et al. 1989), and Hymenoptera (Zhang and Wagner 1991, McMillin and Wagner 1995, Elason and McCullough 1997). Few studies have explored this relationship within Coleoptera.

To our knowledge, either immediate postpupal or sexually mature pupal or adult weights have not been correlated with cottonwood leaf beetle, *Chrysomela scripta* F. (Coleoptera: Chrysomelidae), fecundity or longevity despite this estimate being used and reported previously (Augustin et al. 1997). The objectives of this laboratory study were to determine if size parameters could be used as predictors of fecundity (defined as total eggs per female [Ameen and Story 1997]) and longevity in adult female cottonwood leaf beetles.

MATERIALS AND METHODS

A laboratory colony was established in September 1997 from larvae collected from a hybrid poplar plantation near the Ames Municipal Water Pollution Control Facility near Ames, Iowa. Beetles were reared in plastic crisper
boxes (27 x 19 x 10 cm) under a constant 16L:8D photoperiod and 24:18°C temperature regime. Beetles were fed greenhouse-grown *Populus × eurameri­can* var. 'Eugenei' foliage, LPI 1–8 (Larson and Isebrands 1971, Bingaman and Hart 1992).

More than 700 pupae were selected systematically from this colony and weighed to the nearest 10^{-4} g at 1 day postpupation using a Mettler AE 100 Analytical Balance (Mettler Instrument Corporation, Hightstown, NJ) in February 1998. Plastic disposable petri dishes (100 x 15 mm) were divided into four sections by using two strips of paper that were cut and placed together to divide the area of the dish into quarters. One piece of moistened Whatman #1 filter paper was placed in each dish to prevent desiccation. One pupa was placed in each of these sections immediately after weighing. Pupae were held under the aforementioned controlled conditions until adult emergence.

Upon emergence, pupal duration, adult weight, and total body length were recorded for each adult beetle. Body weight was measured using a Met­tler AE 100 Analytical Balance and body length was measured from the anterior point of the head to the posterior point of the elytra. Cottonwood leaf beetles are sexually dimorphic; therefore, visual estimation of body size was used as an indicator of sex. We assumed that larger beetles were females and smaller beetles were males. Two large and two small adults were placed into small plastic containers (9.5 x 7 x 2 cm) in hopes of obtaining mating pairs. Many *C. scripta* were sorted and paired unsuccessfully; the only beetles used in this study were those that mated. Waterproof paint was used to paint one, two, three, or four identification dots on the elytra of the beetles within their respective containers. The dots did not cause any behavioral changes or me­chanical damage to the beetles (unpublished data). From these containers, 43 mated pairs were selected for observation. Individual pairs were then placed in separate small plastic containers (9.5 x 7 x 2 cm).

Beetle pairs were monitored daily. Fecundity, total oviposition events, and longevity (from emergence to mortality) were recorded for each mated fe­male. Data were analyzed using a correlation and regression analysis (SAS Institute 1985).

**RESULTS**

Pupal weights averaged 0.0335 g (± 0.0048 SE) and ranged from 0.0242 to 0.0442 g. Adult weights at emergence ranged from 0.0195 to 0.0371 g, and averaged 0.0263 g (± 0.0041). Adult females lived up to 34 days postemer­gence, with an average adult life span of 22.47 days (± 7.56). All 43 pairs of beetles monitored mated successfully. Total fecundity ranged from 63 to 1003 eggs/female with an average of 484.5 (± 251.3) eggs. Adult females laid 63.2 (±9.69) eggs/day.

Our study showed poor correlation between pupal weight and adult fecun­dity ($r^2 = 0.08$, $n = 43$, $F = 3.62$, $P = 0.064$), total oviposition events ($r^2 = 0.05$, $n = 43$, $F = 2.06$, $P = 0.159$), the number of eggs/beetle/day ($r^2 = 0.12$, $n = 43$, $F = 5.76$, $P = 0.021$), or female adult longevity ($r^2 = 2.5 \times 10^{-3}$, $n = 43$, $F = 0.14$, $P = 0.715$). Adult weight correlated poorly with fecundity ($r^2 = 0.10$, $n = 43$, $F = 4.64$, $P = 0.037$), total ovipositional events ($r^2 = 0.07$, $n = 43$, $F = 3.21$, $P = 0.081$), and longevity ($r^2 = 0.01$, $n = 43$, $F = 0.56$, $P = 0.456$). Adult length did correlate well with adult weight ($r^2 = 0.55$, $n = 43$, $F = 50.66$, $P < 0.001$) (Fig. 1). Adult weight showed marginal correlation with the number of eggs/female/day ($r^2 = 0.19$, $n = 43$, $F = 9.78$, $P = 0.003$) (Fig. 2). Fecundity correlated well with adult longevity ($r^2 = 0.67$, $n = 43$, $F = 82.4$, $P < 0.001$) (Fig. 3).
Figure 1. Relationship between adult female *C. scripta* weight and length (within 24 h postemergence).

Figure 2. Relationship between adult female *C. scripta* weight and the number of eggs/beetle/day over the entire duration of ovipositional activity.
In most insect orders, healthy larvae are often the largest larvae (and subsequently pupae), and emerge into the largest adults (Kamata and Igarashi 1995). For insects that do not feed as adults and lay only one clutch of eggs, larger larval size would allow the potential for more eggs to develop during pupation. However, this hypothesis would not necessarily hold true for insects such as the cottonwood leaf beetle that feed as adults, experience multiple matings, and lay multiple clutches of eggs. The capacity to mate and oviposit multiple times reduces the need for greater size, which also reduces the probability that size would correlate with fecundity. We found this relationship to be true with *C. scripta*.

Average fecundity values in our study (484.5 ± 251.3 eggs per female) were similar to those obtained in a laboratory study by Burkot and Benjamin (1979) (510.0 ± 152.9). Furthermore, the average number of eggs per cluster (63.2 ± 9.69) was nearly identical to that of Burkot and Benjamin (1979) (64.3 ± 14.7). Head and Neel (1973) observed egg masses of 50–100 eggs per cluster in outdoor caged studies. Field studies by Lowe (1898) (45 eggs per cluster) and Haugen (1985) (55.6 ± 11.9 eggs per cluster) are slightly less than those obtained in this study; this could be attributed to the more optimal conditions in the laboratory.

Limited food resources and crowding can impact fecundity in chrysomelids (Zvereva et al. 1995). Intraspecific competition among adults for food resources can lead to reduced leaf area consumed per adult, which subsequently can have an impact on beetle health and reproduction (Zvereva et al. 1995). Adult *C. scripta* are only in competition for food in nature during high population levels (E. R. Hart, personal observation); there was no competition for food resources in this study. All adult beetles were fed ample foliage, and no beetles suffered food shortage or crowding during the course of

Figure 3. Relationship between adult female *C. scripta* longevity and fecundity.
this experiment. In a study by Bauer et al. (1990) adult *C. scripta* reared on foliage in petri dishes had a shorter life span (33.0 ± 3.4 days) than did adults reared under colony conditions (55 ± 5.8 days). This may have occurred in our study, although life spans for insects in the larger laboratory colony were not recorded. Adults in this study had slightly shorter life spans (22.47 ± 7.56 days) than did the insects in the study by Bauer et al. (1990).

A linear relationship existed between adult female weight and length. These findings parallel results from other studies (Zhang and Wagner 1991), and result from heavier beetles often being larger beetles; increased size often is expressed through increased body length. Fecundity correlated well with adult longevity. This correlation is evident in other leaf beetles as well (Ameen and Story 1997). Presumably, this relationship results because female beetles with longer lives have more opportunities to mate and oviposit than do beetles with shorter life spans. Multiple mating increases fecundity in other insect species (Lamunyon 1997), and the opportunity longer-lived cottonwood leaf beetles have to mate multiple times may be a factor in the increased fecundity. Although the focus of this study was on body size and fecundity correlations of adult females, we recognize that body size can have important implications for adult males as well (Tammaru et al. 1996). Future studies could examine the relationship between male body size and mating success.

Inbreeding can have negative effects on reproduction (Wildt et al. 1987). This laboratory colony had been sustained since October; experiments took place in February. Some inbreeding may have taken place during this time, as this was the fourth generation of cottonwood leaf beetles in the laboratory. Additional factors such as rearing conditions or possible microbial contamination may have influenced longevity and thus total fecundity (Webber and Ferro 1996, Jackson 1997).

Many *Populus* clonal variations and hybrids are being screened for use in short-rotation woody crop systems. Adult cottonwood leaf beetles may live longer on certain genotypes or selections of *Populus* than others. Planting *Populus* clones and hybrids preferred by cottonwood leaf beetle could result in more egg masses and more larvae and could potentially contribute to outbreak conditions. Many characteristics, including growth, hardiness, and pest preference and performance need to be taken into consideration when choosing *Populus* plant material for advancement in regional trials. The performance and life expectancy of adult cottonwood leaf beetles is one of these characteristics.

For insects that feed as adults and have multiple oviposition events, increased larval, pupal, and adult size may be of little benefit to fecundity, because they will have more than one opportunity to oviposit. Therefore, previous measurements of cottonwood leaf beetle larval performance that used pupal weight (Augustin et al. 1997) may not be entirely relevant, and future studies on larval performance should focus on survival, adult longevity, and actual fecundity.

ACKNOWLEDGMENTS

We thank Valasia Iakovoglou and Christine Hall for technical assistance. Thanks to Rich Faltonson, Iowa State University, for care of foodstock trees and Leah S. Bauer, North Central Forest Experiment Station, USDA Forest Service, East Lansing, MI for supplying cottonwood leaf beetles. Thanks to Julie L. Todd for her helpful review of this manuscript. Funding for this project was supplied in part by the Oak Ridge National Laboratory, operated by
LITERATURE CITED


McMillin, J. D. and M. R. Wagner. 1995. Season and intensity of water stress: Host-


SUMMER EPHEMEROPTERA, PLECOPTERA, AND TRICHOPTERA (EPT) SPECIES RICHNESS AND COMMUNITY STRUCTURE IN THE LOWER ILLINOIS RIVER BASIN OF ILLINOIS

R. Edward DeWalt¹, Donald W. Webb¹, and Mitchell A. Harris²

ABSTRACT

Ephemeroptera, Plecoptera, and Trichoptera (EPT) species richness is useful for monitoring stream health, but no published studies in Illinois quantitatively document EPT richness or assemblage structure. The objectives of this study were to characterize adult EPT richness and structure and relate these to relative water quality at eight stream sites (160–69,300 km² area) in the lower Illinois River basin. Adults were ultra-violet light trapped in June, July, and August 1997. Nutrient enrichment by nitrate and nitrite nitrogen was strongly evident, especially in smaller drainages, while critical loss of stable habitat was observed in larger water bodies. Seventy EPT species were identified from 17,889 specimens. Trichoptera were by far the most speciose (41 species), followed by Ephemeroptera (26), and Plecoptera (3). Caddisflies also dominated species richness across sites, contributing 18.0 of the average 28.9 total EPT species collected. Site EPT richness varied significantly (F = 5.51, p = 0.003, df = 7), with smaller drainages supporting greater richness, generally. Differences were also evident for months (F = 21.7, p = 0.0001, df = 2), with June being lower (11.8 average) than either July (20.6) or August (18.1) values. Hilsenhoff biotic index (HBI) scores did not vary significantly across sites (F = 0.7, p = 0.7, df = 7), but were different across months (F = 5.4, p = 0.02, df = 2). June (4.23) and July (4.53) means were not different, but both were lower (of better quality) than August (5.33) scores. The relationship of EPT to HBI scores was not investigated statistically due to problems of sample size and interdependence of monthly samples, but graphical analysis suggested no consistent relationship. This suggested a decoupling of the HBI from the EPT and implied that the gain in taxonomic resolution achieved by using adults outstripped the resolution of the HBI. Use of the HBI to characterize adult aquatic insect communities is discouraged. New state records and range extensions for Ephemeroptera and Trichoptera are presented and possible loss of sensitive Plecoptera in the drainage is discussed.

Aquatic macroinvertebrates are an effective tool for monitoring stream health (Plafkin et al. 1989). Due to the great efforts necessary in working with entire communities of macroinvertebrates, aquatic scientists have sought subsets of this community that yielded information quickly and with

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less expense (Barbour et al. 1992). One such subset uses the sum of Ephemeroptera + Plecoptera + Trichoptera (mayflies, stoneflies, caddisflies, or combined as EPT) species richness per unit effort. Lenat and Penrose (1996) summarized the history and usefulness of the EPT index, and others (Wallace et al. 1996, Lenat 1988, and Barbour et al. 1992) confirmed its suitability as an index of stream health.

The state of Illinois, through the efforts of Illinois Natural History Survey (INHS) researchers Burks (1953), Frison (1935), and Ross (1944) set the stage to use EPT species as a effective biomonitoring tool. Despite published identification manuals, no published studies exist that document the spatial or temporal variability of EPT species richness or community structure in Illinois streams.

Aquatic biologists using EPT species as indicators of stream health typically rely on immature stages (Lenat 1988). However, many EPT species are known solely as adults, the immatures often being identifiable only to the generic level. Use of immatures can lead to underestimates of assemblage richness, to an over simplification of community structural characteristics, and to a loss of the ability to associate ecological conditions with species requirements (Resh and Unzicker 1975). Use of adults permits species level identification in most cases. Additionally, recent studies suggest that many adults of EPT species fly only relatively short distances from their parent stream, and that the probability of encountering them greatly diminishes with increasing lateral distance (Griffith et al. 1998, J. Morse pers. comm.). These studies suggest that greater use of adult EPT for assessing stream health is appropriate.

The objectives of this study are to document the temporal and spatial variation in summer adult EPT species richness and assemblage structure for eight sites in the lower Illinois River basin of central Illinois. Additionally, EPT richness will be related to general water quality in the basin using Hilsenhoff's (1987) biotic index (HBI). The HBI has not been used on a subset of the aquatic community and certainly not with the adult stage. This study provides an opportunity to test the HBI's usefulness under both circumstances. The present study complements a basin-wide assessment of water quality currently being conducted by the National Water Quality Assessment Program (NAWQA) of the United States Geological Survey (USGS).

METHODS AND MATERIALS

Physical habitat and water chemistry. Water chemistry investigations followed standardized NAWQA methods as outlined by Shelton (1994). Dissolved oxygen (DO), pH, conductivity, total Kjeldahl nitrogen, nitrogen as dissolved NO$_2^-$ and NO$_3^-$, and total phosphorus were monitored at least monthly at each of eight stream sites from 1 May through 31 August, 1997. Nitrogen-to-phosphorus ratios (N:P) were calculated from the sum of total Kjeldahl nitrogen and NO$_2^-$ and NO$_3^-$ concentrations divided by the total phosphorus concentration for each date. The potential for hypoxic conditions at four of the eight sites was monitored using Hydrolab™ recorders over 48-hr periods during August 1997. Year around water chemistry, discharge, and contaminant data for the 1997 water year are available in United States Geological Survey (1998).

Physical habitat descriptions followed Meador et al. (1993). Habitat parameters were measured at low flow, in September 1996 or 1997 from six transects in each of the eight study reaches. A Geographic Information System
provided general land use and land cover categories at 1:250,000 scale (Anderson et al. 1976, United States Geological Survey 1990).

**EPT sampling.** Adult EPT were collected using a Bioquip™ 12-vt, ultraviolet DC light source. The trap was run for 1 hr immediately after sunset on a single evening in each of June, July, and August 1997. It was placed 1 m above the stream bank, so that an unobstructed viewing arc of at least 90° was maintained across the stream. This was accepted as adequate for attracting local EPT species. A vertical white sheet reflected this light and provided a surface for hand picking of adults. Two 20 cm x 30 cm white trays, filled with 80% ethanol, trapped insects that fell from the sheet. Mayfly subimagines were picked directly from the sheet and allowed to transform before preservation. Stonefly males were also hand picked and prepared for examination according to Stark (1989).

Most specimens, except females of some taxa, were identified to species. Species richness was tallied for each month and as a “total” for each site. Percentages of the top five numerically dominant taxa, tallied across the entire sample period, demonstrated which species were most abundant at each site. Literature records and searches of electronic databases at the INRS provided historical records at or near each sampling location. Specimens of all species have been deposited in the INHS insect collection.

The HBI is a measure of the overall tolerance of the aquatic macroinvertebrate community to organic pollution, but also is sensitive to general watershed disturbance (Hilsenhoff 1998). It has never been applied to an assemblage of adult aquatic insects, nor has it been applied to insects alone. Here it is applied to adult EPT in order to have a second measure of stream health. Both EPT and HBI scores were subjected to a repeated measures analysis of variance (ANOVA) to examine mean differences across months and sites (Cody and Smith 1997). A second iteration of this approach was conducted including total EPT and HBI values as a fourth “month” to facilitate a discussion of which months were most similar to totals. Following the ANOVA, Duncan’s multiple range test (MRT, α = 0.05) defined any significant differences. The relationship of EPT richness to HBI scores was investigated graphically. The potential problem of interdependence of monthly values at a site and the small sample size within months necessitated this approach.

**Lower Illinois River Basin Description**

The lower Illinois River basin drains much of the Grand Prairie Division of Illinois (Schwegman et al. 1973). This region, once an extensive tall-grass prairie, accounts for approximately 30% of the state’s landmass. Few areas of the country have experienced the degree of modification evident in this region. Corn and soybean agriculture now account for >90% land use in all rural counties. Additionally, the tiling of fields for drainage, straightening of channels, and the removal of most natural riparian vegetation has transformed the division’s meandering perennial streams into straight agricultural drainage ditches, often with critically low flows during summer months (Page 1991).

The Illinois River can be divided into upper and lower basins due to an abrupt change in the river profile (United States Army Corps of Engineers 1974) occurring near Starved Rock State Park (site 1 of Fig. 1). The upper basin has the steepest gradient and, concomitantly, the greatest flow rate. The present study focuses on the lower basin that drains a 46,550 km² area of central and western Illinois. Major rivers here include 390 km of the Illinois River mainstem, the Vermilion (3,450 km² drainage area), Mackinaw
Figure 1. EPT collection sites in the lower Illinois River basin, summer 1997. Indicates sample locations. 1 = Illinois River, Starved Rock State Park; 2 = Panther Creek; 3 = Mackinaw River; 4 = Indian Creek; 5 = Sangamon River, Monticello; 6 = Sangamon River, Oakford; 7 = La Moine River; 8 = Illinois River, Florence.

Agriculture averaged 91.1% land use coverage in the basins studied (Table 1). These streams varied widely in basin size, channel width and depth, and in average discharge. The four smallest streams had bottom substrates of fine sand and gravel, abundant bank and snag habitat, and largely
Table 1. Physical characteristics of eight stream sites in the lower Illinois River basin, 1 May through 31 August 1997. Width and depth parameters represent the average of six measures. Discharge n is indicated in that column.

<table>
<thead>
<tr>
<th>Site</th>
<th>Drainage Area (km²)</th>
<th>% Agriculture</th>
<th>Mean Discharge (m³/sec)</th>
<th>Mean Width (m)</th>
<th>Mean Maximum Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois River, Starved Rock</td>
<td>28,750</td>
<td>75.0</td>
<td>290.0 (9)</td>
<td>200.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Panther Creek</td>
<td>240</td>
<td>99.0</td>
<td>1.1 (5)</td>
<td>8.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Mackinaw River</td>
<td>2,750</td>
<td>95.0</td>
<td>12.0 (5)</td>
<td>28.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Indian Creek</td>
<td>160</td>
<td>97.0</td>
<td>1.1 (5)</td>
<td>10.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Sangamon River, Monticello</td>
<td>1,426</td>
<td>96.0</td>
<td>10.6 (18)</td>
<td>20.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Sangamon River, Oakford</td>
<td>13,200</td>
<td>94.0</td>
<td>61.7 (5)</td>
<td>74.0</td>
<td>1.6</td>
</tr>
<tr>
<td>La Moine River</td>
<td>1,700</td>
<td>90.0</td>
<td>12.0 (18)</td>
<td>20.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Illinois River, Florence</td>
<td>69,300</td>
<td>83.0</td>
<td>610.0 (9)</td>
<td>156.0</td>
<td>4.9</td>
</tr>
</tbody>
</table>
shaded stream banks. The Mackinaw, a small river, differed from the other small drainages in having coarse mineral substrates. Two large river sites, the Illinois River at Florence and the Sangamon River at Oakford, had a mostly shifting sand bottom with little available snag habitat. The Illinois River at Starved Rock State Park, another large river site, had abundant bank and snag habitat and varied bottom substrates and current velocities.

RESULTS

Water chemistry. Dissolved oxygen concentrations varied most within streams (Table 2). The Sangamon River at Oakford experienced pronounced super-saturation during daylight hours. The Illinois River at Florence was the only site with relatively low daytime DO concentrations. However, 48-hr continuous monitoring of DO revealed that Panther and Indian Creeks, two of the smaller drainages, declined to near or below 5 mg/l during predawn hours (Fig. 2).

Nutrient enrichment was evident in all stream reaches, but dissolved NO$_2^-$ and NO$_3^-$ concentrations were highest in the smallest streams (Table 2). Consequently, N:P ratios were highest and most variable for these streams. Larger rivers showed neither the magnitude, nor the variability, in nutrient parameters found in the smaller drainages.

EPT richness and community structure. A total of 17,889 adult EPT were examined for an average of 2,236 specimens per stream (Table 3). Seventy-two EPT taxa were identified overall. Caddisflies provided 41 (58.6%), mayflies provided 26 (37.1%), and stoneflies added another 5 (6.9%) EPT species identified (Table 3). Caddisflies also dominated species richness across sites, contributing 18.0 of the average 29.1 total EPT species collected. Mayflies contributed 9.8 species, while stoneflies contributed only 1.4.

Total richness separated into three groupings by general stream size (Table 3). Large rivers (Illinois River reaches and the Sangamon River at Oakford) averaged 24.0, small rivers (Mackinaw, La Moine, and Sangamon (Monticello) Rivers) yielded 30.7, and small streams (Panther and Indian Creeks) were the richest at 34.5 EPT species.

Species richness of EPT varied significantly across sites ($F = 5.9$, $p = 0.002$, df = 7). A complex relationship developed from three overlapping groupings of sites. Indian Creek, a small, EPT-rich stream (22.0 average), had a greater richness than all large river sites (11.0 to 15.7 averages) and the La Moine (16.0 average), a small river. None of the other small streams or small rivers (Panther, Mackinaw, Sangamon at Monticello, and La Moine, 16.0 to 20.7 averages) were significantly different from each other. Significant differences were also found for EPT across months ($F = 22.7$, $p = 0.0001$, df = 2). June EPT richness (11.9 average) was significantly lower than that for July (20.9) or August (18.1) values. July and August values were not significantly different from each other. Caddisflies drove this monthly trend, with low June richness that increased dramatically in July (Table 4). Conversely, mayfly richness showed a continuous increase throughout the summer. Stoneflies were of such low diversity that no trend was noticeable for them. When total richness was added as a fourth "month", significant differences strengthened ($F = 53.9$, $p = 0.0001$, df = 3). Total EPT richness formed a third grouping with a mean of 29.1 EPT, but relationships among the other sites were unchanged.

Large river sites (Fig. 3a) concentrated an average of 92.7% of their abundance across the five most dominant taxa. The small rivers (Fig. 3b) supported only 83.4% of their entire catch among the five dominant taxa,
Table 2. Mean, range, and number of measures for water chemistry parameters from the Illinois river basin collected 1 May 1997 through 31 August 1997. All units in mg/l unless otherwise noted.

<table>
<thead>
<tr>
<th>Site</th>
<th>Dissolved Oxygen</th>
<th>pH</th>
<th>Conductivity (uS/cm)</th>
<th>Dissolved NO$_2$/NO$_3$ N</th>
<th>Total Kjeldahl N</th>
<th>Total P</th>
<th>N:P Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois River, Starved Rock</td>
<td>2.2</td>
<td>8.0</td>
<td>652</td>
<td>4.2</td>
<td>(2.3-3.7)</td>
<td>(0.8-1.6)</td>
<td>(0.32-0.51)</td>
</tr>
<tr>
<td>Panther Creek</td>
<td>9.1</td>
<td>8.1</td>
<td>763</td>
<td>7.9</td>
<td>(0.3-16.0)</td>
<td>(0.4-2.2)</td>
<td>(0.01-0.29)</td>
</tr>
<tr>
<td>Mackinaw River</td>
<td>11.4</td>
<td>8.3</td>
<td>629</td>
<td>5.0</td>
<td>(0.3-10.0)</td>
<td>(0.7-1.6)</td>
<td>(0.07-0.28)</td>
</tr>
<tr>
<td>Indian Creek</td>
<td>10.1</td>
<td>8.2</td>
<td>648</td>
<td>6.3</td>
<td>(0.5-1.5)</td>
<td>(0.04-0.42)</td>
<td>(19-236)</td>
</tr>
<tr>
<td>Sangamon River, Monticello</td>
<td>8.0</td>
<td>7.9</td>
<td>614</td>
<td>7.9</td>
<td>(0.6-17.0)</td>
<td>(0.3-1.3)</td>
<td>(0.04-0.47)</td>
</tr>
<tr>
<td>Sangamon River, Oakford</td>
<td>12.0</td>
<td>8.3</td>
<td>672</td>
<td>3.5</td>
<td>(0.1-7.0)</td>
<td>(0.9-1.8)</td>
<td>(0.25-0.68)</td>
</tr>
<tr>
<td>LaMoine River</td>
<td>7.9</td>
<td>7.8</td>
<td>625</td>
<td>5.0</td>
<td>(0.5-9.4)</td>
<td>(0.3-4.4)</td>
<td>(0.06-1.7)</td>
</tr>
<tr>
<td>Illinois River, Florence</td>
<td>6.7</td>
<td>8.0</td>
<td>707</td>
<td>3.8</td>
<td>(1.6-6.7)</td>
<td>(0.5-1.9)</td>
<td>(0.11-0.58)</td>
</tr>
</tbody>
</table>
Figure 2. Mean and standard deviation of dissolved oxygen concentrations (mg/l) measured at four lower Illinois River basin sites. Values represent continuously monitored conditions over 48 hr periods in August 1997.

while small creeks supported only 66.4% of their catch among the five dominants. The latter had a fauna singularly different from either the large or small rivers. The single, most dominant taxon averaged 44.3% (33.4–54.9) of the total catch in large rivers, only 30.0% (26.7–32.1) for small rivers, and 26.6% (26.1–27.1) for small creeks.

Three caddisfly species, Potamyia flavia (Hagen), Hydropsyche bidens Ross, and Cheumatopsyche pettiti (Banks) dominated the three large rivers (Fig. 3a). Only six other taxa were considered dominant, and no overlap existed among them. The three small rivers (Fig. 3b) shared two dominant taxa. These were the caddisflies C. pettiti and Ceraclea tarsipunctata (Vorhies). Small creeks shared the dominant caddisflies Nectopsyche sp. (probably N. diarina Ross) and Ceratopsyche bronta (Ross). They shared few dominant taxa with either the small or large river sites.

Hilsenhoff Biotic Index scores. Monthly HBI scores did not vary significantly across sites ($F = 0.7$, $p = 0.7$, df = 7) (Fig. 4), but were different across months ($F = 5.4$, $p = 0.02$, df = 2). The June (4.23) and July (4.53) means were not different from each other, but both were significantly different from the August (5.33) mean. When total HBI scores (4.78 average) were added to the model, differences in months strengthened ($F = 5.2$, $p = 0.008$, df = 3), and a complex relationship developed between the months. Total HBI occurred in two groupings, with August in one group and June and July in the other.
Table 3. EPT species contributions (%), taxon richness, abundance, and ordinal abundance (%) from eight lower Illinois River basin sites, summer 1997.

<table>
<thead>
<tr>
<th>SPECIES/SITES—&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td><strong>EPHEMEROPTERA</strong></td>
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<tr>
<td>BAETIDAE</td>
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<td></td>
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<tr>
<td>Acentrella ampla</td>
<td>P</td>
<td>P</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Baetis intercalaris</td>
<td>P</td>
<td>0.1</td>
<td></td>
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<tr>
<td>Callibaetis fluctuans</td>
<td></td>
<td>0.1</td>
<td>0.2</td>
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<td>Fallecon quilleri</td>
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<tr>
<td>Labiobaeis propinquus</td>
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<td>P</td>
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<td>Paracleodes minutus</td>
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<td></td>
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<tr>
<td><strong>CAENIDAE</strong></td>
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<tr>
<td>Caenis amica</td>
<td></td>
<td>0.1</td>
<td>5.4</td>
<td>0.4</td>
<td>0.1</td>
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<tr>
<td>Caenis hilaris</td>
<td>3.9</td>
<td>5.5</td>
<td>2.8</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
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<tr>
<td>Caenis latipennis</td>
<td>0.3</td>
<td>1.3</td>
<td>1.5</td>
<td>32.1</td>
<td>0.1</td>
<td>0.5</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td><strong>EPHEMERIDAE</strong></td>
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<td></td>
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<tr>
<td>Hexagenia bilineata</td>
<td>0.5</td>
<td>0.18</td>
<td></td>
<td>*</td>
<td>*</td>
<td>P</td>
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</tr>
<tr>
<td>Hexagenia limbata</td>
<td>0.2</td>
<td>0.9</td>
<td>0.6</td>
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<td></td>
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<tr>
<td>Hexagenia rigida</td>
<td></td>
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<td>*</td>
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<tr>
<td>Pentagenia vittigera</td>
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<tr>
<td><strong>HEPTAGENIIDAE</strong></td>
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<tr>
<td>Heptagenia diabasia</td>
<td>4.3</td>
<td>0.4</td>
<td>0.1</td>
<td>*</td>
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<td></td>
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Table 3. EPT species contributions (%), taxon richness, abundance, and ordinal abundance (%) from eight lower Illinois River basin sites, summer 1997 (Continued).

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| Mayfly species | 11 | 9 | 15 | 10 | 11 | 7 | 8 |
| Stonfly species | 2 | 0 | 0 | 1 | 0 | 4 | 2 | 1 |
| Caddisfly species | 16 | 22 | 16 | 28 | 21 | 10 | 16 | 15 |

| Total EPT | 29 | 31 | 32 | 38 | 36 | 19 | 24 | 24 |

Abundance: 1259 1420 2772 2439 1913 2967 1104 2038
% abundance mayflies: 7.10 23.6 8.96 8.50 36.95 4.99 2.62 1.48
% abundance stoneflies: 0.10 0.00 0.04 0.00 0.10 0.51 0.18 1.32
% abundance caddisflies: 92.80 76.40 91.00 91.50 62.00 94.50 97.20 97.20
* Indicates historical record from literature or INHS databases.

P = present at <0.1%.

1 = Illinois River, Starved Rock
2 = Panther Creek
3 = Mackinaw River
4 = Indian Creek
5 = Sangamon River, Monticello
6 = Sangamon River, Oakford
7 = La Moine River
8 = Illinois River, Florence

Table 4. EPT species richness for June, July, and August from eight lower Illinois River basin sites, summer 1997. MF = mayfly; SF = stonefly, CF = caddisfly, Total = all EPT for month.

<table>
<thead>
<tr>
<th>SITES</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUG</th>
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<tbody>
<tr>
<td></td>
<td>MF</td>
<td>SF</td>
<td>CF</td>
</tr>
<tr>
<td>Illinois R., Starved Rock</td>
<td>1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Panther Cr.</td>
<td>4</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Mackinaw R.</td>
<td>3</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Indian Cr.</td>
<td>4</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Sangamon R., Monticello</td>
<td>3</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Sangamon R., Oakford</td>
<td>2</td>
<td>1</td>
<td>6</td>
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<tr>
<td>La Moine R.</td>
<td>3</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Illinois R., Florence</td>
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<td>8</td>
</tr>
<tr>
<td>Means</td>
<td>2.8</td>
<td>0.5</td>
<td>8.5</td>
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</table>
Figure 3. Percentage contribution of the top five numerically dominant EPT taxa at three large rivers (a) and at five small rivers and creeks in the lower Illinois River basin, summer 1997. Provided are the mean sum and ranges of percentages of all five dominants across sites (n = 8), and the mean sums for combinations of large rivers (n = 3), small rivers (n = 3), and small creeks (n = 2). Bars representing Cheumatopsyche and Nectopsyche spp. are for females, which are not readily identifiable.
DISCUSSION

Streams in the lower Illinois River basin have been drastically modified by agricultural practices (Page 1991). Widespread plowing, fertilizer application, and drainage of fields have aided in nutrient enrichment of streams. However, nutrient enrichment did not seem to impact EPT richness. Stream size and habitat heterogeneity appeared the most important factors influencing EPT richness. For instance, the Sangamon River at Oakford and the Illinois River at Florence were large rivers with shifting sand bottoms and little other stable habitat. They yielded low richness values. Indian and Panther creeks and the Mackinaw and Sangamon (Monticello) rivers had abundant and varied stable substrates and yielded the greatest EPT richness. The La Moine River was an enigma. It was similar in most respects to the Sangamon River (Monticello) site, but supported low EPT species richness.

Species richness was also dependent upon month of collection. June samples were of lowest richness, due in large part to the influence of water temperatures (>3°C cooler than July and August temperatures) on species emergence. Even though July richness was not significantly different from August values, it was numerically greater at five sites, while being equivalent at only two of them (Table 4). If only a single date can be sampled, early July would be preferable since more of the total EPT richness was accounted for by this month than any other.

Streams experiencing degradation often have a less-rich fauna and abundances heavily devoted to a relatively few species (Plafkin et al. 1989). Abundance in large rivers exemplified this trend (Fig. 3a), while smaller drainages (Fig. 3b) displayed more even distributions of abundance. Larger rivers appeared to be, overall, more heavily impacted than small rivers and creeks. The latter were more nutrient enriched than large rivers, but they were also well shaded and had noticeably more stable and heterogeneous habitat available.

Average stream quality, as determined by HBI scores, degraded over the summer months, a trend discussed by Hilsenhoff (1998) for Wisconsin streams. Hilsenhoff’s (1987) quality rating criteria provided some insight into the HBI’s usefulness for adult-based samples. Overall, 50% of the streams were rated as being of “good” quality (Fig. 4). “Very good” or “fair” quality accounted for another 25% each.

However, it appeared that a decoupling of the two indices took place. Extreme examples of this decoupling included the Sangamon River at Oakford (lowest EPT and “very good” quality) and Indian Creek (highest EPT and “fair” or “good” quality) (Table 3 and Fig. 4). If both HBI scores and EPT richness, derived from adult EPT, were good predictors of stream health, the two should have a strong, negative relationship like that found by Barbour et al. (1992) in their comparison of the Environmental Protection Agency’s Rapid Bioassessment metrics for benthic macroinvertebrate communities. This strong, negative relationship has also been found for benthic EPT (R² = 0.54, F = 30.93, p = 0.0001) collected from 26 randomly chosen Illinois stream sites in 1997 (R. DeWalt, unpublished data).

This was not the case during the present study. Although a robust test of this hypothesized relationship cannot be presented due to low sample size and interdependence of monthly EPT and HBI scores, there appears to be little or no relationship derived from adult EPT samples. Graphically, total EPT and total HBI values appeared to be positively related, as did July values, but both June and August values demonstrated no trend whatsoever (Fig. 5). Most probably, this lack of concordance is due to the use of adults. The increased taxonomic resolution obtained by using adults was not
Hilsenhoff Suggested Quality Ratings

- Fairly Poor
- Fair
- Good
- Very Good
- Excellent

<table>
<thead>
<tr>
<th>Large Rivers</th>
<th>Small Rivers</th>
<th>Small Creeks</th>
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<tbody>
<tr>
<td>Illinois R.</td>
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<td>Indian Cr.</td>
</tr>
<tr>
<td>Starved Rock</td>
<td>Mackinaw R.</td>
<td>Panther Cr.</td>
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<tr>
<td>La Moine R.</td>
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Figure 4. Total Hilsenhoff biotic index scores and range (error bars) of monthly scores calculated from EPT adults for eight streams in the lower Illinois River basin, summer 1997. Sites are organized by relative stream size and Hilsenhoff's (1987) quality ratings criteria are provided for comparative purposes.

matched by the availability of HBI tolerance values for species. The caddisfly genera Cheumatopsyche, Oecetis, and Ceraclea were good examples of there being only one tolerance value available for each of three species (Hilsenhoff 1987) found during this study, even though generalized differences in tolerance were demonstrated long ago (Resh and Unzicker 1975).

Application of the HBI to adult EPT and other aquatics cannot be done effectively at this time. However, if species specific tolerance values become available, especially in those speciose genera with widely varying tolerance, the HBI might be appropriate for use with adult collections. Until such time, it appears that adult EPT richness tracks change in habitat degradation in a predictable manner and may be used effectively to monitor stream health.

The use of adults in biomonitoring of streams can be criticized on several fronts. One such criticism is that adults may have originated from a water source of very different water quality than the target source. A recent study by Griffith et al. (1998) demonstrated that caddisflies and stoneflies in small Appalachian drainages had exceedingly low probabilities of moving any more than 60 m laterally from their parent waters. Additionally, J. Morse (pers. comm.) reports that adult caddisflies in Three Runs Creek, South Carolina, had a similar range of lateral movement. In both instances, it is prudent to
Figure 5. Relationship of adult EPT species richness and HBI scores for eight streams in the lower Illinois River basin, summer 1997. Monthly (June, July, and August), total HBI, and hypothesized relationships (line).

assume that a species came from the target water body unless a larger water body is nearby.

Additional criticism of the use of adults is that ultra-violet lights produced a "trap habitat" favorable to a species assemblage far different from the population in the stream. This might explain why stream sites with poor habitat heterogeneity and low EPT richness had higher HBI scores than expected. Comparable benthic collections are necessary to test this assertion, but were unavailable for this study.

Use of adult insects provides the highest level of taxonomic resolution possible. It also increases the likelihood of correct identification and association of environmental conditions or requirements with a species. Meeting this goal provides useful information to other aquatic ecologists and systematists alike (Resh and Unzicker 1975). For this reason alone, species-level identification should be sought for aquatic biomonitoring whenever possible.

Notes on species and historical distributions. Two new state records and range extensions for several baetid mayfly species resulted from this study. No published records of \textit{Acentrella ampla} (Traver) exist for Illinois (Randolph and McCafferty 1998). Records for three locations (Table 3), stretching across central Illinois, now exist. \textit{Paracloeodes minutus} (Daggy) has never been reported from Illinois (Randolph and McCafferty 1998), but is now known from the Mackinaw River. \textit{Baetis intercalaris} McDunnough was known from extreme northern and southern Illinois (Burks 1953, Randolph and McCafferty 1998), but it has now been recorded from central Illinois from
the Mackinaw River drainage (Table 3). Burks (1953) recorded *Fallceon quilleri* (Dodds) (as *Baetis cleptis* Burks) at a single location from extreme west central Illinois. It is now known from north central Illinois at two locations (Table 3).

Small streams were inhabited by populations of two heptageniid mayflies rare to Illinois (Table 3). *Leurocota aphrodite* (McDunnough), primarily an Appalachian species (Randolph and McCafferty 1998), was known only from the state’s eastern border (Burks 1953). It has now been collected from northwestern Illinois. *Nixe inconspicua* (McDunnough) was known from several locations in northern and eastern Illinois (Burks 1953) and is now known from western Illinois.

Stoneflies were not diverse and rarely abundant. Four perlid species were found in the basin, *Perlesta decipiens* (Walsh), *P. golconda DeWalt and Stark, P. lagoi Stark*, and *Perlinella drymo* (Banks). *Perlesta decipiens* occurred in all but the smallest streams. DeWalt and Stark (1998) recently described *P. golconda* from southern Illinois, while *P. lagoi* is a new state record and previously known only from Mississippi (Stark 1989). Both were taken only from the Sangamon River, Monticello site. The perlodid *Isoperla bilineata* (Say) occurred in low abundance in the four largest rivers. Historical records from Frison (1935), and from INHS specimen databases, demonstrated that several perlid stonefly species were once commonly found in the larger drainages of the lower Illinois River basin (Table 3). These species included *Acroneuria abnormis* (Newman), *Agnetina capitata* (Pictet), *Atta-neuria ruralis* (Hagen), and *Neoperla clymene* (Newman). Lenat (1993) and Hilsenhoff (1987) listed these species as intolerant of watershed disturbance and organic enrichment. These intolerant stoneflies have been largely eliminated from the drainage, while *P. decipiens* and *I. bilineata* (listed as moderately tolerant) have persisted.

Ross (1944) recorded no more than five individuals of the caddisfly *Hydroptila perdita* Morton from Illinois. All were taken from the extreme eastern border. The present study reports them from five of the eight streams studied, demonstrating a wide distribution and common abundance throughout central Illinois. Three rarely collected leptocerid caddisflies were taken during the study. Panther Creek yielded a large population of *Triaenodes melacus* Ross. Ross (1944) reported it from low gradient, sandy streams in southern Illinois, but from nowhere else in the state. It is known from spotty records throughout the Midwest (K. Manuel, pers. comm.). *Nectopsyche pavida* (Hagen) was known from only three Illinois locations (Ross 1944). Several females were collected from the Sangamon River (Monticello), confirming a historical record for that location. *Ceraclea punctata* (Banks) was known from only two locations in Illinois, both in the extreme south (Ross 1944). A single specimen was taken from the Sangamon River at Oakford, extending its range into west central Illinois.

**ACKNOWLEDGMENTS**

Several USGS scientists, D. L. Adolphson, D. H. Dupre, K. Gao, R. B. King, and P. J. Terrio, aided in the collection of physico-chemical, habitat, and biological data during the study. L. J. Peraino, formerly of the INHS, and I. Pearse, of Tuscola High School, assisted with light trapping. Several student workers helped sort, label, and database specimens. These included P. Li, M. Lavin, D. Duong, B. Lopez, and L. Hernandez. Moshe Yanai, Department of Statistics, University of Illinois, provided help with the statistical analysis. Two scientists at the INHS, S. J. Taylor and G. A. Levin, provided
valuable comments on drafts of the manuscript. This study was supported by the USGS through contract number 1434-HQ-97-SA-00692.

LITERATURE CITED


Shelton, L. R. 1994. Field guide for collecting and processing stream-water samples for
A survey of the nonphymatine reduviids of southern Illinois was conducted from April 1996 to November 1998. In addition to county distributions, information was collected on times of occurrence of adults and nymphs and associated habitats. These data were supplemented with label information associated with southern Illinois specimens housed in the Southern Illinois University Entomology Collection (SIUEC).

Twenty-five species were collected during this survey. An additional six species housed in the SIUEC were collected previously in southern Illinois but not during the survey. Of the 31 species, nine are state records: Ploiaria hirticornis, Rocconota annulicornis, Sinea complexa, Microtornus purcis, Rasahus hamatus, Saica elkinsi, Oncocephalus geniculatus, Pnirontis languida, and Pnirontis modesta.

The family Reduviidae occurs worldwide and contains approximately 930 genera and 6,500 species (Schuh and Slater 1995); approximately 195 species and subspecies in 49 genera occur in America north of Mexico (Froeschner 1988).

In the older literature, the Reduviidae (assassin bugs) and Phymatidae (ambush bugs) were treated as separate families (e.g., Slater and Baranowski 1978, Froeschner 1988, Maldonado Capriles 1990). However, the families now have been combined, and the phymatids currently are treated as a subfamily of equal status to the other reduviid subfamilies. Of the 23 subfamilies currently recognized worldwide, 10 occur in America north of Mexico (Schuh and Slater 1995). For the purposes of this paper, only the nonphymatine reduviids will be considered. The Phymata spp. still are in need of major taxonomic revision.

Reduviids are characterized by a bilobed, cone-shaped head; a three-segmented beak, with the tip resting in a stridulatory groove on the prosternum; and usually four-segmented antennae (Blatchley 1926). In Illinois, species range in length from approximately 7 mm (Oncerotrachelus) to 40 mm (Emesaya, Arilus) and vary in body shape from ovoid (e.g., Harpactorinae) to narrow and elongate (i.e., Emesinae). There usually are five nymphal instars although Fitchia aptera Stål (DeCoursey 1963) and Melanolestes picipes (Herrich-Schaeffer) (Readio 1927) reportedly only have four.

Reduviids are predaceous (Blatchley 1926, Readio 1927, Schuh and
Slater 1995), but their habits and habitats vary greatly. Most are ambush predators, remaining motionless or stalking potential prey on the foliage of herbs and shrubs (Blatchley 1926). However, peiratines are active nocturnal predators, and most are attracted to lights (Readio 1927); triatomines feed on the blood of humans and other vertebrates and transmit Chagas' disease (Lent and Wygodzinsky 1979); and the esmenines frequently are found on spider webs (Wygodzinsky 1966).

Assassin bugs feed primarily on other insects and, thus, are considered beneficial. However, as is typical of predaceous bugs, they occur in low numbers. Thus, even though beneficial, the reduviids, in North America, have been studied little, either biologically or taxonomically (McPherson 1992).

During the early twentieth century, Blatchley (1926) and Readio (1927) authored monographs on North American reduviids, which included keys and original notes on biology. In recent years, work on this group has consisted primarily of life history studies of individual species (e.g., DeCoursey 1963; Swadener and Yonke 1973 a, b, c, 1975). In addition, a few state lists with notes on biology have been published (e.g., Torre-Bueno 1923, Connecticut; Froeschner 1944, Missouri; Elkins 1951, Texas; Drew and Schaefer 1963, Oklahoma; McPherson 1992, Michigan).

Identification of North American reduviids to species level is problematic due to the lack of recent comprehensive keys. Slater and Baranowski (1978) authored keys to the common genera, with brief descriptions of several species. Generic and species revisions (e.g., Barber 1929–1930; Elkins 1954; Wygodzinsky and Usinger 1964; Wygodzinsky 1966; Giacchi 1969, 1984; Lent and Wygodzinsky 1979; Coscaron 1983; Hart 1986) have decreased the usefulness of Blatchley’s (1926) and Readio’s (1927) keys for some groups. The only source available for the identification of nymphs is the generic key of Fracker and Usinger (1949).

Little is known about the reduviids of Illinois. Van Duzee (1917) listed nine species from Illinois and an additional 11 from surrounding states (defined here as Minnesota, Wisconsin, Michigan, Indiana, Kentucky, Tennessee, Arkansas, Missouri, and Iowa). Malloch (1920) increased the state total to 27 (including Sinea diadema [Fabricius], which he listed as Achollia diadema [Fabricius]). His list included nine of the 11 species listed by Van Duzee (1917) from surrounding states (Rhynocoris v. ventralis [Say]) and Pnirotis modesta (Banks were not included). Froeschner (1988) listed 28 species from Illinois, including all those from the earlier lists except Fitchia spinosula Stål and Onecocephalus apiculatus Reuter and an additional 15 from surrounding states (Hagerty 1999, Table 1). Finally, Pseudometapterus umbrosus (Blatchley) (McPherson 1991a) and F. spinosula (McPherson et al. 1992) were added, increasing the number of species to 30. Even though the state fauna is diverse, no reduvid lists specifically for Illinois, or for smaller geographic regions within the state, have been published since Malloch (1920). Therefore, the purposes of this study were to survey the reduvid fauna of southern Illinois and to determine county distributions, times of occurrence of adults and nymphs, and associated habitats. Southern Illinois was defined as the eleven southernmost counties in the state (i.e., Jackson, Williamson, Saline, Gallatin, Union, Johnson, Pope, Hardin, Alexander, Pulaski, and Massac) (Fig. 1).

Malloch's list actually increased the state total to 30, but two of the species, Ploiarola tuberculata Banks (see Froeschner 1988) and Melanolestes abdominalis Herrich-Schaeffer (see McPherson et al. 1991), are invalid, and Barce annulipes Stål and B. fraterna Say currently are listed as subspecies of B. fraterna.
Figure 1. Southern Illinois map showing counties surveyed and the three collecting subareas.

MATERIALS AND METHODS

This study was conducted from April to November 1996 and from March to November 1997 and 1998, from before until after the insects became active, respectively, during each year. During 1996, most effort was devoted to finding productive collecting sites. As a result, samples were collected sporadically. During 1997 and 1998, samples were collected weekly, the entire study area being sampled three times per year (i.e., May to June, July to August, and September to October). Because the area was large, it was subdivided into three smaller areas with the Southern Illinois University campus (SIUC) serving as a home base (Fig. 1). During each of the three bimonthly sampling periods, each subarea was sampled daily at various locations over a 4-day period. Therefore, sampling of the entire study area per year occurred during 36 daily collecting trips. Supplemental collections were made in Jackson County throughout the survey to examine the life histories of some species more closely. Occasional collecting trips also were made from December through February in Jackson County to locate overwintering sites.

Sampling was conducted along major roads with side trips to promising habitats. Insects were collected by sweeping, beating foliage, and handpicking along roadsides, grassy fields, and forest edges. Additional potential sites were examined including under logs, debris, rocks, and bark; and at lights at night. Portable blacklights were used at several locations to attract specimens in wooded areas. Also, Townes Malaise traps (1 m high, 2 m long) (see Townes 1972) were set up in a weedy field in Jackson County and checked weekly from June through October 1997 and from March through October.
Field data (e.g., collection sites, times of occurrence of developmental stages, types of habitat) were supplemented with data associated with specimens housed in the Southern Illinois University Entomology Collection (SIUEC). Several of the SIUEC specimens were collected in the La Rue Pine Hills Ecological area, now the La Rue-Pine Hills Research Natural Area, in Union County.

Field-collected specimens were preserved in 70% EtOH and taken to the laboratory for identification. Adults were identified using keys by Blatchley (1926) and Slater and Baranowski (1978) and keys in revisionary studies that included southern Illinois taxa (e.g., Hart 1986). Nymphs were identified to genus using Fracker and Usinger (1949) and to species using published descriptions of immature stages and a synoptic collection (see below).

**Synoptic collection.** For problematic specimens, a synoptic collection was made by allowing field-collected adults to reproduce and preserving the resulting nymphs in various instars. Adults were placed on moistened disks of filter paper in petri dishes (approximately 9 cm diam, 1.5 cm deep) and provided two to four specimens of *Drosophila* sp. per day per adult as food. Approximately four to six drops of distilled water were added daily to keep the filter paper moist.

Petri dishes were checked daily for eggs, which were removed and placed in similar dishes on filter paper moistened as described above for adults.

Nymphs were kept in petri dishes on moistened filter paper as described above and provided one or two specimens of *Drosophila* sp. per nymph per day as food. The dishes were examined daily, molts observed, and exuviae removed. Nymphs were grouped by molting date to determine instars accurately.

Eggs, nymphs, and adults were kept in incubators maintained at 26 ± 0.5°C and an 18L: 6D photoperiod (130 ft-c).

Field-collected nymphs were determined to instar by comparing individuals with the synoptic collection, with published descriptions, and by using standard morphological features (e.g., ratio of antennal segment lengths, head capsule size and shape, wing pad length, and development of external genitalia).

**RESULTS**

Reduviid Species and Subspecies Accounts.

**Subfamily Ectrichodiinae**

**Genus Rhiginia**

*R. cruciata* (Say). This species often occurs under logs (Blatchley 1926, Elkins 1951) and stones (Elkins 1951) and apparently overwinters as adults in these same places (Torre-Bueno and Brimley 1907, Brimley 1938, Froeschner 1944). It also has been swept from vegetation and beaten from dead pine tops and palmetto leaves (Blatchley 1926), collected from pitcher plants (Wray and Brimley 1943), and collected frequently at lights during the summer (Elkins 1951).

During the survey, three adults and one nymph were found in Jackson, Union, and Johnson counties, collectively. They were found inside a building (1 adult; 6 May); in the webbing of a theridiid spider, *Anelosimus studiosus* (Hentz) (1 adult; 13 May); on a rotten cypress log in a swampy area (1
nymph, apparently a fifth instar; 13 September); and by sweeping low shrubs along a wooded roadside (1 adult; 16 May).

An additional 34 adults are housed in the SIUEC; additional counties represented include Williamson and Alexander. They were collected from 14 April to 9 November, the majority during April and May (n = 19, 55.9%) and October and November (n = 9, 26.5%). Additional label information indicates specimens were collected on a log in a wooded area (n = 1; 23 June), from inside rotten logs (n = 2; 7, 9 November), by sweeping vegetation (n = 1; 14 May), and with a Malaise trap (n = 2; 1-8 May, 8-15 May).

The survey and SIUEC data suggest that this species is univoltine and overwinters as adults.

**Subfamily Emesinae**

**Tribe Metapterini**

**Genus Barce**

*B. fratera* (Say). This species seems to prefer moist protected places (Readio 1927). Reported collection sites, among many others, include debris (Mills 1931, Drew and Schaefer 1963); Spanish moss (Elkins 1951); under rocks on the ground among grasses and weeds in fields (Froeschner 1944); beneath boards and loose bark, on foliage, under cover along borders of ponds and in cultivated grounds (Blatchley 1926); on the surface of water among bulrushes (Hussey 1922a); from a grassy bank near a pool among grass roots, under leaves of a mullein plant near a brook, and under boards and sticks in a grassy area by an ox-bow lake (Readio 1927). It also has been collected at lights (Elkins 1951, Wygodzinsky 1966, McPherson 1992) and from spider webs (Wygodzinsky 1966).

This species overwinters as adults, as eggs, or in both stages (Readio 1927). Adults and nymphs have been collected as late as October (Readio 1927) and copulation has been observed as late as 20 November (Blatchley 1926). Overwintering individuals have been found in bunches of Spanish moss (Blatchley 1926); beneath logs, boards, and old rails (Blatchley 1926, Readio 1927); and along edges of low cultivated fields (Blatchley 1926). Early instars have been found in early spring (Readio 1927).

During the survey, four adults were collected, all from Jackson County. They were collected at lights (n = 1; 12 September), with a Malaise trap (n = 1; 30 September–7 October), on a spider web on a sandstone bluff (n = 1; 20 October), and under a board in a weedy field (n = 1; 28 February); the February specimen apparently was overwintering.

An additional nine adults, from Williamson, Union, and Alexander counties, are housed in the SIUEC. They were collected between 27 May and 29 October. Additional label information indicates that specimens were collected from a window flight trap on 27 June (n = 1) and from mowed grass in a cemetery on 11 September (n = 1).

**Genus Emesaya**

*E. brevipennis brevipennis* (Say). This subspecies has been collected under bridges (e.g., Gates and Peters 1962); from sheds, barns, out-buildings (e.g., Uhler 1884; Banks 1909; Wickham 1909, 1910; Howes 1919; Torre-Bueno 1923, 1925; Blatchley 1926; Readio 1927; Froeschner 1944; Gates and Peters 1962; Slater and Baranowski 1978), vegetation (e.g., Banks 1909; Torre-Bueno 1923, 1925; Blatchley 1926; Froeschner 1944) including trees (Uhler 1884, Wickham 1909, Gates and Peters 1962), flood
debris, Spanish moss (Elkins 1951), and screens (Brown and Lollis 1963); and in association with spider webs (Banks 1909, Wickham 1910, Howes 1919, Readio 1927, Usinger 1941, Brown and Lollis 1963, Slater and Baranowski 1978).

This subspecies reportedly is univoltine (Banks 1909) and overwinters as eggs (Howes 1919, Readio 1927). Nymphs occur in the spring and much of the summer (Uhler 1884, Wickham 1910, Readio 1927), and adults occur during the summer and fall (Uhler 1884, Wickham 1910, Readio 1927, Brown and Lollis 1963, McPherson 1992). Eggs are deposited in the summer and fall (Uhler 1884, Wickham 1910, Howes 1919, Readio 1927, Brown and Lollis 1963) and are attached to spider webs (Readio 1927, Brown and Lollis 1963), rafters of wooden structures (Howes 1919, Readio 1927), and, possibly, twigs of bushes and trees (Uhler 1884).

During the survey, 28 adults and 25 nymphs were found in Jackson, Saline, Gallatin, Union, Pope, Hardin and Alexander counties, collectively. They were collected on spider webs on rock outcrops (19 adults, 25 nymphs), from roots along a washed-out creek bank (1 adult), on spider webs under a concrete bridge (2 adults), and by sweeping shaded, herbaceous vegetation (4 adults) and pine trees (2 adults). Adults were collected from 1 July to 9 November, the majority \( n = 22, 78.6\% \) from August to September; early instars were collected (2 seconds, 8 thirds) from 3 June to 24 June, and late instars (3 fourths, 12 fifths) from 24 June to 1 September.

An additional 34 adults and 43 nymphs are housed in the SIUEC; additional counties represented include Williamson and Massac. Adults were collected from 23 July to 10 November, the majority \( n = 24, 70.6\% \) during September and October; early instars (3 firsts, 7 seconds, 4 thirds) were collected on 27 June and late instar nymphs (2 fourths, 27 fifths) from 20 June to 3 September.

The survey and SIUEC data suggest that this species is univoltine and overwinters as eggs, supporting the statements of Banks (1909), Howes (1919), and Readio (1927).

**Genus Pseudometapterus**

*P. umbrosus* (Blatchley). This species has been beaten from the fallen leaves of a royal palm in a dense hammock (Blatchley 1926) and collected from Spanish moss (Wygodzinsky 1966).

During the survey, 43 adults were found in Jackson and Union counties, collectively. They were taken on spider webs and plants (*Heuchera parviflora*) on sandstone bluffs (n = 41), and on spider webs on limestone bluffs (n = 2). They were collected from 13 April to 24 November, the majority \( n = 30, 69.8\% \) during August and September. These data suggest the species is univoltine and overwinters as adults.

This species was reported from Illinois by McPherson (1991a) based on two male adults housed in the SIUEC. Both specimens were collected on 27 July 1972 in the La Rue-Pine Hills Ecological Area, Union Co.

\(^3\)In a separate study (unpublished data), we found this subspecies is bivoltine; in the present study, we, as did so many earlier investigators, missed the spring generation.
**Subfamily Hammacerinae**  
*Genus Microtomus*

*M. purcis* (Drury) (STATE RECORD). This species has been collected under bark (Blatchley 1926, Brimley 1938, Froeschner 1944, Elkins 1951, Drew and Schaefer 1963, Slater and Baranowski 1978) and at lights (Blatchley 1926). This insect probably is univoltine (Readio 1927); it overwinters as both adults and nymphs (Torre-Bueno and Brimley 1907, Readio 1927, Brimley 1938, Froeschner 1944) under bark (Torre-Bueno and Brimley 1907, Brimley 1938). Adults have been found in Missouri from 24 September to 3 March and young nymphs from November to December (Froeschner 1944); adults and third through fifth instars were collected in Texas on 7 March (Readio 1927).

During the survey, four adults were found, all from Union County. They were collected at lights on 3 (n = 1) and 7 (n = 3) September. An additional 31 adults, from Jackson, Williamson, and Johnson counties, are housed in the SIUEC. They were collected from 23 August to 20 October, the majority (n = 17, 54.8%) during September. Additional label information indicates that five of the adults (n = 3; 25 August) (n = 2; 30 August) were collected at lights.

The survey and SIUEC data suggest that this species is univoltine, supporting the opinion of Readio (1927).

**Subfamily Harpactorinae**  
*Genus Acholla*

*A. multispinosa* (De Geer). This species has been collected from trees (e.g., Torre-Bueno 1923, 1925; Blatchley 1926; Readio 1926, 1927; Elkins 1951) including oak (Van Duzee 1894, Readio 1927), elm (Smith 1909), *Crataegus* (Blatchley 1926), hickory (Hussey 1922a), walnut (Readio 1927); from other vegetation (Lugger 1900, Blatchley 1926); and on bare ground in open places (Blatchley 1926). It feeds on other insects (Lugger 1900, Torre-Bueno 1923). It also has been observed wandering over the nests of a thomisid spider, *Philodromus canadensis* Emerton, suggesting that it preys on the eggs or the young spiders (Auten 1925).

This species reportedly is univoltine and overwinters as eggs (Readio 1927), which are cemented to twigs (Readio 1926, 1927). The eggs hatch in the spring and nymphs are found during much of the summer (Readio 1927). Adults are found in August and September in Kansas (Readio 1927) and as late as October in Indiana (Blatchley 1926).

During the survey, two adults and two nymphs were found in Jackson, Gallatin, and Pulaski counties, collectively. They were collected from a spider web under a bridge (1 adult; 12 October); by sweeping a semiwooded, grassy roadside (1 adult; 1 September) and herbaceous vegetation along a roadside (1 third instar; 15 June); and by beating understory shrubs and small trees (1 fifth instar; 8 July).

An additional adult, housed in the SIUEC, was collected with a window flight trap (height, 4.0 m) from Alexander County on 7 September 1979.

**Genus Apiomerus**

*A. crassipes crassipes* (Fabricius). This reduviid occurs on trees, shrubs, and flowers (Blatchley 1926, Froeschner 1944, Elkins 1951, Swadener and Yonke 1973a) in wooded (Blatchley 1926, Froeschner 1944)
and semiwooded (Swadener and Yonke 1973a) areas and open fields (Froeschner 1944, Elkins 1951); specific plants include hazel, juniper (Blatchley 1926), pine (Uhler 1884), thistle (Elkins 1951), and persimmon (Swadener and Yonke 1973a). It feeds on plant lice, young caterpillars (Uhler 1884), bees (e.g., Knowlton and Taylor 1951, Bouseman 1976a), and a variety of other insects (Thompson and Simmonds 1965).

This subspecies is univoltine and overwinters as late instars (Swadener and Yonke 1973a) that emerge in early spring (Froeschner 1944). Adults occur from March (Uhler 1884) or April (Swadener and Yonke 1973a) into the fall (Uhler 1884, Swadener and Yonke 1973a). Eggs are laid in spring (Uhler 1884) and early summer (Swadener and Yonke 1973a), and nymphs are found during the fall (Froeschner 1944, Swadener and Yonke 1973a).

During the survey, 16 adults were found in Jackson, Saline, and Hardin counties, collectively. They were collected with a Malaise trap in a weedy field ($n = 3$), by sweeping herbaceous vegetation in fields ($n = 9$) and along roadsides ($n = 3$), and by sweeping shrubs in a wooded area ($n = 1$). Specimens were collected from 3–10 June to 16–19 July.

An additional 61 adults and one nymph are housed in the SIUEC; additional counties represented include Williamson, Union, Pope, and Alexander. The adults were collected between 25 May and 3 August, the majority ($n = 52, 85.2\%$) during June and July. A fourth instar was collected on 29 April 1971.

The survey and SIUEC data suggest that this species is univoltine, supporting the statement of Swadener and Yonke (1973a).

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**Genus Arilus**

*A. cristatus* (L.). This species occurs on trees and shrubs (e.g., Barber 1920, Blatchley 1926, Readio 1926, Froeschner 1944, Elkins 1951, Swadener and Yonke 1973b) but can be collected from other vegetation (Barber 1920, Blatchley 1926, Readio 1926, Elkins 1951, Drew and Schaefer 1963, Whitcomb and Bell 1964, Wheeler and Stimmel 1983). It feeds on a wide variety of insects including, among many, the fall webworm, *Hyphantria cunea* (Drury); imported cabbageworm, *Pieris rapae* (L.); Mexican bean beetle, *Epilachna varivestis* Mulsant (Thompson and Simmonds 1965); tent caterpillar, *Malacosoma* sp. (Surface 1906); orangdog, *Papilio cresphontes* Cramer (Watson 1918); and bollworm, *Helicoverpa zea* (Boddie) (Whitcomb and Bell 1964).

*A. cristatus* is univoltine (Readio 1927, Todd 1937). It overwinters as eggs (Garman 1916; Readio 1926, 1927; Todd 1937; Froeschner 1944; Swadener and Yonke 1973b) that are laid in clusters in the fall on the bark of tree trunks and twigs (Garman 1916; Barber 1920; Readio 1926, 1927; Froeschner 1944; Swadener and Yonke 1973b). The eggs hatch the following spring, and nymphs are found from May to July and adults from June to October (Froeschner 1944). Copulation occurs in the fall (Barber 1920) and the eggs are laid shortly thereafter (Garman 1916; Readio 1926, 1927).

During the survey, 36 adults and 157 nymphs were collected; all counties were represented. They were swept from trees (14 adults, 12 nymphs), shrubs (16 nymphs), grasses (4 nymphs), herbaceous vegetation along wooded edges (12 adults, 73 nymphs), herbaceous understory vegetation (12 nymphs), and herbaceous vegetation in fields and along roadsides near wooded areas (39 nymphs); and handpicked from goldenrod (*Solidago* sp.) (1 adult), a limestone bluff (1 adult), a spider web (1 nymph), man-made objects (i.e., houses, sheds) (5 adults), and at lights (3 adults). Egg clusters ($n = 13$) were found in the fall on the bark of sassafras (*Sassafras albidum*) and beech (*Fagus grandifolia*). Adults were collected from 8 July to 25 November, the
majority \( (n = 24, 66.7\%) \) during August and September; first instars \( (n = 5) \) were collected from 16 May to 27 June, second instars \( (n = 2) \) 22 May to 29 May, third instars \( (n = 24) \) 27 May to 1 July, fourth instars \( (n = 80) \) 3 June to 14 July, and fifth instars \( (n = 46) \) 10 June to 4 August.

An additional 53 adults and 24 nymphs are housed in the SIUEC. The adults were collected from 3 July to 10 November, the majority \( (n = 36, 67.9\%) \) during August and September; early instars (17 firsts, 1 third) were collected from 1 May to 12 June and late instars (4 fourths, 2 fifths) from 12 June to 15 August. Additional label information indicates that specimens were collected from pine trees (1 adult; 26 August), from a window flight trap (1 adult; 12 September), and at lights (1 adult; 18 September); also, 17 first instars were collected on their egg cluster on 1 May.

The survey and SIUEC data indicate that this insect is univoltine and overwinters as eggs, supporting the statements of Readio (1926), Todd (1937), Froeschner (1944), and others.

**Genus Fitchia**

*F. aptera* Stål. This species has been found at the bases of grass clumps in old or abandoned fields (DeCoursey 1963, Slater and Baranowski 1978); in grass along streams and ponds and in shady protected places (Elkins 1951); on bushes (Smith 1909); under rocks, logs, and boards (Smith 1909, Blatchley 1926, Froeschner 1944); on wooded hillsides (Froeschner 1944); and in sandy upland fields (Blatchley 1926) and salt meadows (Smith 1909, Blatchley 1926). Adults occasionally have been swept from tall grass, especially in early evening; during the day, they remain on the ground (DeCoursey 1963). Nymphs can be found on the ground, usually in grassy areas (DeCoursey 1963). This species also has been collected from pitcher plants (Wray and Brimley 1943).

This bug overwinters as adults under boards, stones, and around the roots of grass clumps (DeCoursey 1963).

During the survey, five adults were found in Jackson, Williamson, and Alexander counties, collectively. One adult was collected from the roots of a grass clump along the edge of a grassy field (10 April); the others were swept from herbaceous vegetation along a forest edge in the evening \( (n = 2; 18, 19 June) \), herbaceous vegetation along a roadside \( (n = 1; 25 September) \), and a grassy field \( (n = 1; 13 May) \).

One specimen, collected 29 May 1968 from Pope County, is housed in the SIUEC. No additional label information is available.

**Genus Pselliopus**

*P. barberi* Davis. This reduviid occurs on various types of vegetation (Elkins 1951, Drew and Schaefer 1963) including trees (Blatchley 1926, Froeschner 1944) such as plum (Swadener and Yonke 1975), oak, elm (Blatchley 1926), and sycamore (Readio 1927). It feeds on *Molorchus bimaculatus* Say (Cerambycidae), *Lygus* sp. (Miridae) (Swadener and Yonke 1975), and *Nomada (Nomada) illinoensis* Robertson (Apidae) (Bouseman 1976b).

*P. barberi* is univoltine and overwinters as adults (Readio 1927, Froeschner 1944, Swadener and Yonke 1975) under rocks (Froeschner 1944, Swadener and Yonke 1975), loose bark, logs (Froeschner 1944), and leaves (Readio 1927, Froeschner 1944); adults have been found in large numbers in curled sycamore leaves or rolls of sycamore bark (Readio 1927). Copulation occurs in the spring (Readio 1927, Froeschner 1944) and fall (Davis 1912).
Nymphs have been found during June, July (Froeschner 1944, Swadener and Yonke 1975), and August (Froeschner 1944).

During the survey, 40 adults and seven nymphs were found in Jackson, Saline, Gallatin, Union, and Hardin counties, collectively. They were collected under bark of dead trees (2 adults), from the trunks of sycamore trees (31 adults), by beating a tree (1 nymph), and by sweeping herbaceous vegetation (7 adults, 6 nymphs). Adults were collected from 13 April to 22 October, the majority (n = 36, 90%) during September and October; two copulating pairs were collected from the trunks of sycamore (*Plantanus occidentalis*) on 17 October. An early instar (1 third) was taken on 27 June, and late instars (1 fourth, 5 fifths) were collected from 1 August to 17 September.

An additional 68 adults and one nymph are housed in the SIUEC; additional counties represented include Williamson, Johnson, and Pope. The adults were collected between 28 March and 28 November, the majority during April and May (n = 21, 30.9%) and September and October (n = 40, 58.8%). A fifth instar was collected on 7 September.

The survey and SIUEC data indicate that this insect is univoltine and overwinters as adults, supporting the statements of Readio (1927), Froeschner (1944), and Swadener and Yonke (1975).

*P. cinctus* (Fabricius). This species is found on a variety of plants (Uhler 1884; Torre-Bueno 1923; Blatchley 1926; Readio 1926, 1927; Elkins 1951; Drew and Schaefer 1968) but often is associated with trees (Readio 1926) including red cedar (Swadener and Yonke 1975), oak, hickory (Uhler 1878), and pine (Uhler 1884). It feeds on several insect pests including the chinch bug, *Blissus l. leucopterus* (Say) (Thompson and Simmonds 1965); and Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Chittenden 1907).

This species is univoltine (Readio 1927, Swadener and Yonke 1975) and overwinters as adults (Readio 1927, Froeschner 1944, Swadener and Yonke 1975) under bark (McAtee 1912, Froeschner 1944) and rocks (Froeschner 1944). Copulation (Froeschner 1944) and oviposition (Readio 1927, Swadener and Yonke 1975) occur in the spring. Eggs often are glued to the bark of pine trees (Uhler 1884). Nymphs are found during the summer (Readio 1927), with fifth instars most common in August (Swadener and Yonke 1975). The subsequent adults are found in late summer and early fall (Readio 1927).

During the survey, 10 adults and 15 nymphs were found in Jackson, Saline, Gallatin, Union, Johnson, Pope, and Hardin counties, collectively. They were collected by sweeping herbaceous vegetation (7 adults, 14 nymphs), shrubs, and low trees (2 adults); and by beating trees and bushes (1 adult, 1 nymph). Adults were collected from 29 May to 20 October and distributed evenly throughout this period. Nymphs were collected (2 thirds, 1 fourth, 12 fifths) from 24 June to 31 August.

An additional 23 adults and two nymphs are housed in the SIUEC; Williamson represented an additional county. The adults were collected between 25 April and 14 October, the majority (n = 12, 52.2%) during September. The nymphs were collected on 13 July (1 fifth) and 1 August (1 fourth).

The survey and SIUEC data indicate that this insect is univoltine and overwinters as adults, supporting the statements of Readio (1927) and Swadener and Yonke (1975).

**Genus Rocconota**

*R. annulicornis* (Stål) (STATE RECORD). This species has been beaten from foliage along the margins of a dense wet hammock in Florida (Blatchley 1926).

During the survey, seven adults and one nymph were found in Jackson,
Williamson, Union, Pope, and Alexander counties, collectively. They were swept from shrubs in a wooded area (1 adult), trees and shrubs along a limestone bluff (1 adult), dense woody understory vegetation (2 adults), and herbaceous roadside vegetation (1 adult, 1 fifth instar); taken at lights (1 adult); and captured with a Malaise trap in a weedy field (1 adult). Adults were collected from 9 June to 21 September and the nymph was collected on 21 August.

An additional six specimens are housed in the SIUEC. They were collected in the La Rue-Pine Hills Research Natural Area, Union County, from 16 May to 17 September.

An additional six specimens are housed in the SIUEC. They were collected in the La Rue-Pine Hills Research Natural Area, Union County, from 16 May to 17 September.

**Genus Sinea**

*S. complexa* Caudell (STATE RECORD). This species is found on leaves and stems near the bases of plants (Swadener and Yonke 1973b). It is associated with grass, flowers (Elkins 1951), red clover (Swadener and Yonke 1973b), goldenrod (Froeschner 1944), weedy vegetation (Swadener and Yonke 1973b), and agricultural crops (Werner and Butler 1957).

This bug apparently is bivoltine and overwinters as adults (Swadener and Yonke 1973b); one individual was found overwintering in a grass clump (Froeschner 1944).

During the survey, eight adults and two nymphs were found in Jackson, Saline, Alexander, and Pulaski counties, collectively. The adults were collected from 2 June to 26 September, and one fourth and one fifth instar on 10 June, all by sweeping grassy vegetation.

An additional four adults and two nymphs are housed in the SIUEC; additional counties represented include Williamson and Union. The adults were collected from 14 June to 14 September, and the nymphs (2 fifth instars) on 15 September and 23 October.

*S. diadema* (Fabricius). This common reduviid often is found in grassy (Hussey 1922a, Readio 1924, Blatchley 1926, Elkins 1951, Drew and Schaefer 1963) and weedy (Hussey 1922b, Readio 1924, Blatchley 1926, Froeschner 1944, Slater and Baranowski 1978) vegetation. Specifically, it has been collected from alfalfa (Readio 1924, Knowlton and Harmston 1940), soybean (Wheeler and Stimmel 1983), clover (Torre-Bueno 1923, 1925; Procter 1938, 1946), goldenrod (Readio 1924, 1927; Procter 1938, 1946; Strickland 1953), trees, shrubs, Spanish moss (Elkins 1951), thistle, asters (Blatchley 1926), and daisy (Readio 1927). It feeds on a wide variety of insects (Smith et al. 1943, Knowlton 1944a, Gates and Peters 1962) including flies, bees (Readio 1924), and caterpillars (Torre-Bueno 1923, Knowlton and Harmston 1940). Specific examples include the fall cankerworm, *Alsophila pometaria* (Harris); tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois); spring cankerworm, *Paleacrita vernata* (Peck); stalk borer, *Papaipema nebris* (Gueneé); western yellow striped armyworm, *Spodoptera praefica* (Grote); European corn borer, *Ostrinia nubilalis* (Hübner); Mexican bean beetle; birch leaf miner, *Fenusa pusilla* (Lepeletier); forage looper, *Caenurgina erechtea* (Cramer) (Thompson and Simmonds 1965); and boll weevil, *Anthonomus g. grandis* Boheman (Whitcomb and Bell 1964).

This species is bivoltine and overwinters as adults (Readio 1924, 1927). Eggs are laid on stems and leaves of plants or other objects (Readio 1924, 1927). Nymphs are found from May through October (Froeschner 1944), reaching maturity in early June, and are found in "scores" during July and August (Blatchley 1926). Adults are found from June through October in Missouri (Froeschner 1944).

During the survey, 73 adults and 49 nymphs were collected; all counties were represented. They were swept from herbaceous vegetation in sunny
areas (45 adults, 30 nymphs) and from grasses (25 adults, 19 nymphs), and handpicked from goldenrod (3 adults). Adults were collected from 13 May to 20 October, the majority in June \((n = 19, 26.0\%)\) and during September and October \((n = 51, 69.9\%)\); early instars (2 firsts, 7 seconds, 10 thirds) were collected from 13 May to 25 July, and late instars (21 fourths, 9 fifths) from 13 May to 1 September.

An additional 99 adults and 15 nymphs are housed in the SIUEC. The adults were collected from 12 May to 31 October, the majority in June \((n = 18, 18.2\%)\) and during September and October \((n = 71, 71.7\%)\); early instars (2 thirds) were collected from 1 August to 1 September, and late instars (6 fourths, 7 fifths) from 9 June to 12 September.

The survey and SIUEC data suggest that this species is bivoltine and overwinters as adults, supporting the statements of Readio (1924, 1927).

\textbf{S. spinipes} (Herrich-Schaeffer). This species has been collected from weedy (Blatchley 1926, Froeschner 1944) and grassy (Elkins 1951, Drew and Schaefer 1963) areas, from foliage along woodland borders (Blatchley 1926, Swadener and Yonke 1973b), and from forested areas (Torre-Bueno 1925; Readio 1926, 1927; Elkins 1951); specific trees include hickory, walnut, pawpaw, elms, and oaks (Readio 1927); nymphs have been found in semiclosed flower heads of Queen Anne's Lace (Swadener and Yonke 1973b). This reduviid feeds on Say stink bug, \textit{Clorochroa sayi} (Stål) (Caffrey and Barber 1919, Thompson and Simmonds 1965); cotton fleahopper, \textit{Pseudatomoscelis seriatus} (Reuter); tarnished plant bug; and boll weevil (Whitcomb and Bell 1964).

This species apparently is univoltine and overwinters as adults (Readio 1927) under dead leaves and rubbish (Blatchley 1926). The bugs emerge in early spring (Readio 1927), and oviposition occurs from late April and early May to early August (Readio 1927). The resulting nymphs reach maturity from early July to late in the season (Readio 1927). Fourth and fifth instars have been collected most frequently during July in Missouri (Swadener and Yonke 1973b).

During the survey, 53 adults and 109 nymphs were collected; all counties were represented. They were swept from shaded herbaceous vegetation along forest edges (44 adults, 96 nymphs), trees (5 adults, 5 nymphs), and grasses (2 nymphs); and handpicked from sassafras (1 adult), Queen Anne's lace \textit{(Daucus carota)} (3 nymphs), goldenrod (2 adults, 1 nymph), sumac \textit{(Rhus sp.)} (2 nymphs), and a spider web (1 adult). Adults were collected from 2 May to 16 October, the majority \((n = 35, 66.0\%)\) during September and October; early instars (1 first, 4 seconds, 16 thirds) were collected from 19 May to 26 September, and late instars (24 fourths, 59 fifths) from 22 June to 29 September. One copulating pair was noted on goldenrod on 21 September. A fifth instar was observed inserting its beak in a flower of goldenrod on 29 September.

An additional 81 adults and 29 nymphs are housed in the SIUEC. The adults were collected from 20 March to 3 November, the majority \((n = 55, 67.9\%)\) during September and October; early instars (2 thirds) were collected on 29 June and 20 July, and late instars (13 fourths, 14 fifths) from 29 June to 17 September.

The survey and SIUEC data indicate that this insect is univoltine and overwinters as adults, supporting the statements of Readio (1927).

\textbf{Genus Zelus}

\textbf{Subgenus Zelus}

\textit{Z. (Z.) luridus} Stål. This bug has been collected from trees (Hussey 1922a; Torre-Bueno 1923; Readio 1926, 1927; Froeschner 1944; Procter 1946;
West and DeLong 1955; Slater and Baranowski 1978), shrubs (Blatchley 1926, Readio 1927, West and DeLong 1955, Slater and Baranowski 1978), weedy fields (Froeschner 1944), and low herbage (Blatchley 1926); specific trees include staghorn sumac (Blatchley 1926), ironwood, maple (West and DeLong 1955), hickory, pawpaw (Readio 1927), and basswood (Readio 1927, West and DeLong 1955).


*Z. luridus* is univoltine (Readio 1927, Edwards 1966). Nymphs overwinter as fourth or fifth instars (Readio 1927, West and De Long 1955) and have been found overwintering in curled leaves (Readio 1927). Adults appear in late April in Missouri (Froeschner 1944), mid-May in Kansas (Readio 1927), mid- to late May in Michigan (McPherson 1992) and Ontario (West and DeLong 1955), and early June in New York (Van Duzee 1894). Oviposition occurs from mid-June into August (Readio 1927) with eggs laid on the foliage of such trees as ironwood, maple, and basswood (West and DeLong 1955). The nymphs mature during the rest of the summer (Readio 1927, West and DeLong 1955).

During the survey, 15 adults and 77 nymphs were found in Jackson, Williamson, Saline, Union, Johnson, Pope, Alexander, and Pulaski counties, collectively. They were collected by sweeping and handpicking shaded herbaceous vegetation along forest edges (6 adults, 41 nymphs), sweeping shrubs (2 adults, 2 nymphs); sweeping and beating trees (6 adults, 22 nymphs); and handpicking from the surface of limestone bluffs (4 nymphs), man-made items (e.g., cars, window screens, park shelters) (1 adult, 7 nymphs), and poison ivy (*Rhus radicans*) (1 nymph). The adults were collected from 8 May to 6 August, the majority during May (n = 7, 46.7%) and August (n = 6, 40.0%); early instars (1 first, 1 second, 16 thirds) were collected from 8 July to 17 October and late instars (20 fourths, 39 fifths) from 20 February to 27 May and 8 July to 17 October.

An additional 47 adults and 22 nymphs are deposited in the SIUEC. The adults were collected from 28 April to 27 September, the majority (n = 20, 42.6%) during May; and the nymphs (9 fourths, 13 fifths) from 27 April to 17 November. Additional label information indicates specimens were collected from leaf litter (1 fifth instar; 27 April), with a UV light trap (1 adult; 11 June), and in a window flight trap (1 adult; 27 June).

The survey and SIUEC data suggest that this species is univoltine and overwinters as nymphs, supporting the statements of Readio (1927), West and DeLong (1955), and Edwards (1966).

**Subfamily Peiratinae**  
**Genus Melanolestes**

*M. picipes* (Herriech-Schaeffer). This common and widespread species has been found under stones, rocks (e.g., Walsh and Riley 1869; Torre-Bueno and Brimley 1907; Blatchley 1926; Readio 1926, 1927; Brimley 1938; Froeschner 1944; Elkins 1951; Gates and Peters 1962; Drew and Schaefer 1963), logs (e.g., Walsh and Riley 1869; Blatchley 1926; Readio 1926, 1927; Froeschner 1944; Elkins 1951; Drew and Schaefer 1963), planks and boards (e.g., Hart 1907, Torre-Bueno 1925), dead bark (Torre-Bueno and Brimley 1907, Blatchley 1926, Brimley 1938), and debris (Blatchley 1926, Elkins 1951). It also is attracted to lights (e.g., Readio 1926, 1927; Froeschner 1944, Elkins 1951; McPherson 1992). It feeds on May beetle adults and larvae (Readio 1927) and various subterranean insects (Walsh and Riley 1869).
This insect is univoltine (Readio 1927) and overwinters as adults under rocks, stones (Readio 1927, Smith et al. 1943, Gates and Peters 1962), and logs (Blatchley 1926); and in tree stumps (Readio 1927). Adults become active in the spring and commonly are found under rocks (Readio 1927). Oviposition occurs under stones; the eggs are inserted in the ground, leaving only the starlike tops visible (Readio 1926, 1927). The eggs hatch in less than a month, and the nymphs mature during the rest of the summer, becoming adults by fall (Readio 1927). Adults are found from early May to late October in Michigan (McPherson 1992).

During the survey, 35 adults and 3 nymphs were found in Jackson, Williamson, Saline, Gallatin, Union, and Pulaski counties, collectively. They were collected under the bark of dead trees (4 adults, 1 nymph), rocks (4 adults), logs, boards (3 adults), and a pile of old shingles (1 nymph); from leaf debris (1 adult); in rotten logs (2 adults), spider webs (7 adults, 1 nymph) and a house (1 adult); by sweeping grasses (1 adult); and at lights (12 adults). The adults were collected from 20 February to 16 November, the majority (n = 19, 54.3%) during April and May; the nymphs were found on 18 July (1 third), 1 August (1 fourth), and 23 August (1 fourth). Two adults, apparently overwintering, were collected on 14 and 16 November in rotten logs.

An additional 278 adults and two nymphs are housed in the SIUEC; additional counties represented include Pope, Hardin, Alexander, and Massac. The adults were collected from 1 April to 28 November, the majority (n = 214, 77.0%) during April and May; the nymphs (2 fourths) were collected on 9 August and 4 October.

The survey and SIUEC data indicate that this insect is univoltine and overwinters as adults, thus supporting the conclusions of Readio (1927), Smith et al. (1943), and Gates and Peters (1962).

**Genus Sirthenea**

*S. stric carinata* (Fabricius). Nymphs have been found beneath boards along the margins of ponds in Florida; and beneath stones and logs, usually in damp places, in Indiana (Blatchley 1926). This subspecies also has been collected from flowers of *Garberia fruticosa* (1 nymph) (Blatchley 1926), under a rock (an adult, presumably) (Readio 1927), and at lights (e.g., Van Duzee 1909, Torre-Bueno 1923, McPherson 1992). In Michigan, 38 adults were collected between 27 June and 12 September (McPherson 1992).

During the survey, three adults were found, all in Jackson County. They were collected at lights on 6 May, 12 May, and 13 July.

An additional 27 adults and four nymphs are housed in the SIUEC. Additional counties represented include Williamson, Union, and Pope. The adults were collected from 20 May to 21 October, the majority (n = 15, 55.6%) during September. The nymphs were collected on 23 March (1 third instar), 18 April (1 fourth), 4 May (1 fifth), and 29 September (1 fifth).

The limited data suggest that this species is univoltine and overwinters as adults, nymphs, or in both stages.

**Subfamily Saicinae**

**Genus Oncerotrachelus**

*O. acuminatus* (Say). This species has been collected in grasses (Elkins 1951, Blinn 1994), debris (Blatchley 1926, Slater and Baranowski 1978), rubbish and weeds in low ground or on edges of stubble fields (Uhler 1884), moist situations (Blatchley 1926, Froeschner 1944, Elkins 1951, Slater and
Baranowski 1978), spider webs (Fracker and Bruner 1924), and pitcher plants (Wray and Brimley 1943); and at lights (Blatchley 1926, Froeschner 1944, Elkins 1951, Slater and Baranowski 1978, Blinn 1994).

This species overwinters as adults under leaves in woodlands (Readio 1927), as many as 50 individuals (presumably adults) having been found together beneath logs and other cover (Blatchley 1926). Adults have been collected throughout the year in Missouri (Froeschner 1944).

During the survey, 48 adults were found in Jackson, Gallatin, and Union counties, collectively. They were swept from grasses along a wooded roadside (n = 1) and from herbaceous vegetation in a moist low area (n = 2), and collected at lights (n = 45). They were collected from 12 May to 21 September, the majority (n = 42, 87.5%) during May and June.

An additional 56 adults are housed in the SIUEC; additional counties represented include Williamson, Hardin, and Alexander. They were collected from 10 April to 10 November, the majority (n = 51, 91.1%) from April to June.

Although the data are limited, they suggest that this species is univoltine.

**Subfamily Stenopodainae**

**Genus Narvesus**

*N. carolinensis* Stål. This species has been found beneath rocks (Readio 1927, Froeschner 1944, Elkins 1951) and logs (Readio 1927, Elkins 1951); it also is attracted to lights (Blatchley 1926, Readio 1927, Froeschner 1944, Elkins 1951).

Nymphs are collected in the spring and probably overwinter as late instars; the eggs of this species probably are laid in late June and early July (Readio 1927).

During the survey, 34 adults were found in Jackson and Union counties, collectively. They were collected at lights from 14 June to 12 July, the majority (n = 30, 88.2%) from mid- to late June.

An additional 33 adults are housed in the SIUEC; additional counties represented include Williamson, Saline, Pope, and Alexander. They were collected from 29 April to 17 October, the majority (n = 25, 75.8%) during June.

The survey and SIUEC data suggest that this species is univoltine.

**Genus Oncocephalus**

*O. geniculatus* (Stål) (STATE RECORD). This species has been found beneath rocks (Readio 1927, Elkins 1951), boards (Blatchley 1926, Readio 1927, Elkins 1951), and logs (Elkins 1951). It also is attracted to lights (Readio 1927, Elkins 1951).

This reduviid overwinters as nymphs in several instars and probably is univoltine (Readio 1927). Adults have been collected in late spring and early summer, and nymphs from mid-June to late November (Readio 1927). Eggs are inserted in the ground with their tops visible (Readio 1927).

During the survey, three adults were found in Jackson and Union counties, collectively. They were collected at lights on 16 June, 18 June, and 12 July. In addition, four late instars that probably are *O. geniculatus* were found beneath a pile of asphalt shingles in a grassy area (n = 3; 10 April) and under the bark of a dead tree (n = 1; 2 April) in Jackson County.

One adult, collected 6 June 1966 from Jackson County; and one late instar nymph, probably *O. geniculatus*, collected 17 November 1973 from Union County; are housed in the SIUEC.
Genus *Pnirontis*

*P. modesta* Banks (STATE RECORD). This species has been collected at lights (Elkins 1951). One specimen was swept from foliage along a canal in Florida (Blatchley 1926).

During the survey, 62 adults were found in Jackson and Union counties, collectively. They were collected at lights (n = 56), by sweeping grasses (n = 5), and with a Malaise trap in a weedy field (n = 1). The bugs were collected from 1–8 April to 3 September, the majority (n = 54, 87.1%) during May and June.

An additional 40 adults are housed in the SIUEC; additional counties represented are Williamson, Pope, Alexander, and Massac. The insects were collected from 18 April to 25 October, the majority (n = 27, 67.5%) during May and June.

The survey and SIUEC data suggest that this species is univoltine.

Genus *Pygolampis*

*P. pectoralis* (Say). This species has been found under rocks and boards (Readio 1927, Elkins 1951) and beneath loose bark of oak stumps in high dense woods (Blatchley 1926). It also has been found in grass (Elkins 1951), including bluegrass (Wirnter 1904), sifted (nymphs) from weed debris in low moist grounds (Blatchley 1926), and collected at lights (Readio 1927, Elkins 1951).

This insect apparently overwinters as both adults and nymphs under rocks (Readio 1927), boards (Blatchley 1926, Readio 1927), “chunks,” and other cover along roadsides and edges of upland woods (Blatchley 1926). Adults are active in the spring in Kansas (Readio 1927), and have been collected between 2 May and 13 September in Michigan (McPherson 1992).

During the survey, 39 adults were found in Jackson and Union counties, collectively. They were collected at lights from 6 May to 24 June, the majority (n = 27, 69.2%) during June.

An additional 126 adults and one nymph are housed in the SIUEC; additional counties represented include Williamson, Saline, Pope, Pulaski, and Massac. The adults were collected from 4 April to 24 September, the majority (n = 78, 61.9%) during May; a late instar was collected on 16 April 1993.

The survey and SIUEC data suggest that this species is univoltine.

Genus *Stenopoda*

*S. spinulosa* Giacchi. This species has been collected under boards, logs, and rocks (Elkins 1951); on branches and twigs (Uhler 1884); in dead leaves of cabbage and royal palms, and in weed debris (Blatchley 1926); from pitcher plants (Wray and Brimley 1943); and at lights (Readio 1927, Elkins 1951). It feeds on caterpillars (Uhler 1884, Ashmead 1895).

This insect overwinters as nymphs (Blatchley 1926, Froeschner 1944). Adults are found from mid-June to mid-August, and late instars from late October to mid-June (Froeschner 1944).

During the survey, nine adults were found in Jackson and Union counties, collectively. They were collected at lights (n = 7; 14 June–13 July), with a Malaise trap in a weedy field (n = 1; 10–16 July), and in a spider web (n = 1; 3 June).

An additional 36 adults and one nymph are housed in the SIUEC; additional counties represented include Williamson, Saline, Pope, Alexander, and Massac. The adults were collected between 6 May and 14 September, the ma-
majority (n = 24, 66.7%) during May and June; the nymph (late instar) was collected on 27 September. Additional label information indicates that specimens were collected from a mullein plant (1 adult; 2 September), from a grassy field (1 late instar; 27 September), with a Malaise trap (1 adult; 12–19 June), and with window flight traps (10 adults; 6 June–5 September).

The survey and SIUEC data suggest that this species is univoltine.

Subfamily Triatominae
 Tribe Triatomini
 Genus Triatoma

*T. sanguisuga* (LeConte). This species, the bloodsucking conenose, often can be found in man-made structures including houses (e.g., Uhler 1876, 1884; Kimball 1894; Elkins 1951; Mead 1965; Slater and Baranowski 1978), chicken houses (Kimball 1894, Brimley 1938, Elkins 1951, Mead 1965), dog houses (Elkins 1951, Mead 1965), barns (Kimball 1894, Elkins 1951, Mead 1965), and outhouses (Mead 1965). Natural habitats include rodent nests (Elkins 1951), including those of the wood rat (*Neotoma* sp.) (Usinger 1944, Mead 1965); hollow trees and stumps (Wirtner 1904, Mead 1965); palmetto boots and trunks (Mead 1965); under bark of oak and pine (Blatchley 1926, Mead 1965); and in weeds in damp places (Blatchley 1926). It feeds on insects (Marlatt 1896, Lugger 1900, Mead 1965, Slater and Baranowski 1978) and the blood of various vertebrates (e.g., frogs, lizards, rodents and other mammals) (Kimball 1894, Smith et al. 1943, Gates and Peters 1962, Mead 1965).

This reduviid is well known mostly because adults sometimes enter man-made structures to feed on the blood of humans (e.g., Uhler 1876, 1884; Marlatt 1896, Lugger 1900, Mead 1965) and domestic animals (e.g., dogs, horses) (Kimball 1894, Mead 1965). Even more seriously, it transmits *Trypanosoma cruzi* Chagas (Davis et al. 1943), the microorganism that causes Chagas' disease (Mead 1965, Slater and Baranowski 1978). The adults are nocturnal (Kimball 1894, Mead 1965, Slater and Baranowski 1978) and attracted to lights (Kimball 1894, Marlatt 1896); during the day, they hide in clothing, furniture (Kimball 1894) and other secretive places (e.g., cracks in floors and walls) (Marlatt 1896, Mead 1965).

This species overwinters as adults and partly grown nymphs (Walsh and Riley 1869, Marlatt 1896, Wirtner 1904, Froeschner 1944) under bark of trees or any similar protection (Walsh and Riley 1869, Marlatt 1896, Wirtner 1904). In Missouri, adults have been collected throughout the year and nymphs from 11 December to 20 April (Froeschner 1944). Eggs apparently are laid, and nymphs occur, outdoors (Marlatt 1896). Adults usually enter houses in April and May (Marlatt 1896).

During the survey, four adults and 10 nymphs were found in Jackson and Union counties, collectively. They were collected from under the bark of dead trees (10 nymphs), at lights (2 adults), and in spider webs (2 adults). The adults were collected from 4 August to 9 November, early instars (first-thirds, n = 2) on 12 March, and late instars (fourths and fifths, n = 8) from 12 March to 15 June.

An additional 23 adults and 10 nymphs are housed in the SIUEC; additional counties represented include Williamson, Johnson, and Pope. The adults were collected from 26 January to 28 September, one early instar (first-third) was collected 29 June, and late instar nymphs (fourths and fifths, n = 9) were collected from 13 April to 15 October. Additional label information indicates that specimens were collected in a weedy field (1 adult, 3 September) and at lights (1 adult, 22 September).

The survey and SIUEC data suggest that this species overwinters as
adults and nymphs, supporting the work of Walsh and Riley (1869), Marlatt (1896), and Froeschner (1944).

**Species not collected during the survey but represented in the SIUEC.**

**Subfamily Emesinae**
**Tribe Leistarchini**
**Genus Ploiaria**

*P. hirticornis* (Banks) (STATE RECORD). This species is reported from Washington, D. C., North Carolina, Florida, Louisiana (Froeschner 1988), and Missouri (McPherson 1991b). Specimens have been found beneath a board on the site of an old house, beaten from dead leaves of cabbage palmetto, sifted from roots of grass tufts (Blatchley 1926), and captured with a Malaise trap (McPherson 1991b, label information); the Malaise trap specimens were collected between 17 and 21 July in Missouri.

A late (fourth or fifth) instar is housed in the SIUEC. It was collected 4–18 November 1966 from the La Rue Pine Hills Ecological Area, Union County.

**Subfamily Harpactorinae**
**Genus Zelus**
**Subgenus Pindus**

*Zelus (P.) tetracanthus* Stål. This bug occurs in weedy (Froeschner 1944, Swadener and Yonke 1973c) and grassy areas (Readio 1927, Elkins 1951); and on trees (e.g., Blatchley 1926; Downes 1927; Procter 1938, 1946; Elkins 1951), bushes, (Elkins 1951), and flowers (Elkins 1951, Strickland 1953). Specific plants include red clover, ragweed, goldenrod (Swadener and Yonke 1973c), alfalfa (Drew and Schaefer 1963), cedar (Banks 1910, Swadener and Yonke 1973c), spruce (Downes 1927), and pine (Blatchley 1926). This bug also has been collected at lights (Swadener and Yonke 1973c) and in beach drift (Torre-Bueno 1915). It feeds on the beet leafhopper, *Circulifer tenellus* (Baker) (Knowlton and Harmston 1940, Thompson and Simmons 1965); tarnished plant bug; and bollworm (Whitcomb and Bell 1964).

This species is univoltine and overwinters as fourth and fifth instars in leaf litter and clumps of grass along fence rows and at the bases of trees (Swadener and Yonke 1973c). Nymphs emerge in the spring and adults are collected from mid-May to early September in Missouri (Swadener and Yonke 1973c) and from early June to mid-August in Michigan (McPherson 1992).

Three adults are housed in the SIUEC; counties represented include Jackson and Williamson. They were collected on 24 April 1963, 20 July 1963, and 30 September 1987.

**Subfamily Peiratinae**
**Genus Rasahus**

*R. hamatus* (Fabricius) (STATE RECORD). This species has been found under rocks, logs (Froeschner 1944, Elkins 1951), and boards (Blatchley 1926); swept from borders of wet hammocks; and collected at lights (Blatchley 1926). Little is known about the life cycle of this insect. In Missouri, adults have been collected during June, and nymphs from 15 September to 2 June (Froeschner 1944).
Two adults are housed in the SIUEC. They were collected on 22 May 1960 and 7 June 1957 in Jackson County.

**Subfamily Reduviinae**

*Genus Reduvius*

*R. personatus* (L.). This species often is associated with houses or other buildings (e.g., Uhler 1878; Torre-Bueno 1923, 1925; Blatchley 1926; Readio 1927, 1931; Drew and Schaefer 1963; Slater and Baranowski 1978). It also has been found under logs (Elkins 1951, Drew and Schaefer 1963) and boards (Uhler 1878); in rodent nests (Elkins 1951, Drew and Schaefer 1963); and at lights (e.g., Hussey 1922a; Torre-Bueno 1923; Blatchley 1926; Readio 1927, 1931; Smith et al. 1943; Knowlton 1944b; Elkins 1951; Gates and Peters 1962). It feeds on other insects including bed bugs (e.g., Torre-Bueno 1923, Blatchley 1926, Smith et al. 1943, Knowlton and Taylor 1951, Gates and Peters 1962, Thompson and Simmonds 1965, Slater and Baranowski 1978).

This bug has been reported as univoltine (Readio 1927, 1931) and semivoltine (Scudder 1992). It overwinters as nymphs (usually fourth or fifth instars) that become adults the following May or June; eggs and nymphs are found for the rest of the warm season (Readio 1927). Adults are found from May to September in Kansas (Readio 1931) and Michigan (McPherson 1992) and May to early October in Canada (Scudder 1992). Eggs are laid singly in dusty corners of dwellings (Readio 1931) or out-of-the-way places (Readio 1926).

Nine adults are housed in the SIUEC; counties represented include Jackson, Williamson, Union, and Pope. The bugs were collected between 12 April and 4 August; none was collected after 1972.

**Subfamily Saicinae**

*Genus Saica*

*S. elkinsi* (STATE RECORD). This recently described species has been reported from Virginia, North Carolina, Florida, Mississippi, Louisiana, Arkansas, and Missouri (Blinn 1994). It has been collected from tall fescue and at lights (Blinn 1994).

A late (fourth or fifth) instar is housed in the SIUEC. The specimen was collected 29 April 1971 in Jackson County.

**Subfamily Stenopodainae**

*Genus Pnirontis*

*P. languida* Stål (STATE RECORD). This species is collected commonly at lights in Texas (Elkins 1951).

An adult from Williamson County, collected 10 August 1957, is housed in the SIUEC.

**DISCUSSION**

The nonphymatine reduviid fauna is well represented in southern Illinois. Thirty-one species and subspecies are recorded, 9 of which are state records (Table 1); the remaining 22 represent 73.3% of the taxa known for Illinois (Hagerty 1999, Table 1).
Table 1. List of southern Illinois nonphymatine Reduviidae

<table>
<thead>
<tr>
<th>Taxon</th>
<th>No. Examined</th>
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<tbody>
<tr>
<td><strong>SUBFAMILY ECTRICHODIINAE</strong> Amyot and Serville</td>
<td></td>
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<tr>
<td><em>Rhiginia cruciata</em> (Say)*b</td>
<td></td>
</tr>
<tr>
<td><strong>SUBFAMILY EMESINAE</strong> Amyot and Serville</td>
<td></td>
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<tr>
<td><strong>TRIBE LEISTARCHINI</strong> Stål</td>
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<tr>
<td><em>Ploiaria hirticornis</em> (Banks)<em>b</em></td>
<td>1A</td>
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<tr>
<td><strong>TRIBE METAPIERINI</strong> Stål</td>
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<tr>
<td><em>Barce fraterna</em> Say)*ab</td>
<td></td>
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<tr>
<td><em>Emesaya b. brevipennis</em> (Say)*ab</td>
<td></td>
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<tr>
<td><em>Pseudometapterus umbrosus</em> (Blatchley)*ab</td>
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<tr>
<td><strong>SUBFAMILY HAMMACERINAE</strong> Schumacher</td>
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<tr>
<td><em>Microtomus purcis</em> (Drury)*ab</td>
<td>35A</td>
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<tr>
<td><strong>SUBFAMILY HARPACTORINAE</strong> Amyot and Serville</td>
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<tr>
<td><em>Acholla multispinosa</em> (De Geer)*ab</td>
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<tr>
<td><em>Apionerus c. crassipes</em> (Fabricius)*ab</td>
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<tr>
<td><em>Arilus cristatus</em> (L.)*ab</td>
<td></td>
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<tr>
<td><em>Fitchia aptera</em> Stål)*ab</td>
<td></td>
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<tr>
<td><em>Pselliopus barberi</em> Davis)*ab</td>
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<tr>
<td><em>Pselliopus cinctus</em> (Fabricius)*ab</td>
<td></td>
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<tr>
<td><em>Roconota annulicornis</em> (Stål)*ab</td>
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<tr>
<td><em>Sinea complexa</em> Caudelli)*ab</td>
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<tr>
<td><em>Sinea diadema</em> (Fabricius)*ab</td>
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<tr>
<td><em>Sinea spinipes</em> (Herrich-Schaeffer)*ab</td>
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<tr>
<td><em>Zelus (Zelus) luridus</em> Stål)*ab</td>
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<tr>
<td><em>Zelus (Pindus) tetracanthus</em> Stål)*b</td>
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<tr>
<td><strong>SUBFAMILY PEIRATINAE</strong> Amyot and Serville</td>
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<tr>
<td><em>Melanolastes picipes</em> (Herrich-Schaeffer)*ab</td>
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<tr>
<td><em>Rasahus hamatus</em> (Fabricius)*ab</td>
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<td><em>Sirthenea stria carinata</em> (Fabricius)*ab</td>
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<td><strong>SUBFAMILY REDUVIINAE</strong> Latreille</td>
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<td><em>Reduvius personatus</em> (L.)*b</td>
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<td><strong>SUBFAMILY SAICINAE</strong> Amyot and Serville</td>
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<tr>
<td><em>Onicerotachelus acuminatus</em> (Say)*ab</td>
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<tr>
<td><em>Saica elkinsi</em> Blinn)*b</td>
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<td><strong>SUBFAMILY STENOPODAINAE</strong> Amyot and Serville</td>
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<tr>
<td><em>Narves carolinensis</em> Stål)*ab</td>
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<td><em>Onocephalus geniculatus</em> (Stål)*ab</td>
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<tr>
<td><em>Pnironits languida</em> Stål)*ab</td>
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<tr>
<td><em>Pnironits modesta</em> Banks)*ab</td>
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<tr>
<td><em>Pygolampis pectoralis</em> (Say)*ab</td>
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<tr>
<td><em>Stenopoda spinulosa</em> Giacch)*b</td>
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<td><strong>SUBFAMILY TRIATOMINAE</strong> Jeannel</td>
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<td><strong>TRIBE Triatomini</strong> Jeannel</td>
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<tr>
<td><em>Triatoma sanguisuga</em> (LeConte)*ab</td>
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</table>

* New Illinois state record.
* Taxon collected during survey.
* Taxon represented in SIUEC.
* A = Adult, N = nymph.
Table 2. Taxa collected during survey and associated collection sites\(^a\)

<table>
<thead>
<tr>
<th>Taxon</th>
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<th>HV</th>
<th>FE</th>
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<td>Ectrichodiinae Amyot and Serville</td>
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<td><em>Rhiginia cruciata</em> (Say)</td>
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<td>Emesinae Amyot and Serville</td>
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<td>Hammacerinae Schumacher</td>
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(Continued)
Peiratinae Amyot and Serville

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<tr>
<td><em>Sirthenea stria carinata</em> (Fabricius)</td>
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Saicinae Amyot and Serville

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Stenopodainae Amyot and Serville

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<td><em>Pnirontis modesta</em> Banks</td>
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<tr>
<td><em>Pygolampis pectoralis</em> (Say)</td>
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Triatominae Jeannel

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</tr>
</thead>
<tbody>
<tr>
<td><em>Triatoma sanguisuga</em> (LeConte)</td>
<td>2A</td>
</tr>
</tbody>
</table>

---

*Abbreviations: FE = forest edge; GV = grassy vegetation; HV = herbaceous vegetation; LT = lights; MT = Malaise traps; SW = associated with spider webs; TS = trees and shrubs; UB = under bark; UR = under rocks, logs, boards.

*1A = adult, N = nymph.

*Numbers of individuals do not always correspond to those in text because the sites listed here are more inclusive.*
These insects were collected from a wide variety of sites throughout the study area (Table 2). The most productive sites were lights (13 taxa, 218 individuals), herbaceous vegetation (10 taxa, 192 individuals), and forest edges including trees and shrubs (10 taxa, 409 individuals).

Some generalizations are possible about the habits and habitats of these insects at the subfamily level in southern Illinois (Table 2). Whether these generalizations will hold for a larger geographical area remains to be seen.

The ectrichodiines (i.e., *R. cruciata*) were collected in or near wooded areas.

The emesines (e.g., *E. b. brevipennis*) were found primarily on limestone and sandstone bluffs and often associated with spider webs. These sticklike predators remained motionless on the substrate unless disturbed.

The hammacerine (i.e., *M. purcis*) adults were collected at lights in small numbers.

The harpactorines were found on various types of vegetation and are diurnal. *S. spinipes* was found primarily on shaded herbaceous vegetation along forest edges and in the adjacent trees and shrubs, whereas *S. complexa* and *S. diadema* were found on grasses and herbaceous vegetation along sunny roadsides and in fields. Harpactorines were never or rarely (*R. annulicornis, 1 specimen; A. cristatus, 3 specimens*) collected at lights. These bugs generally are slow-moving predators, stalking prey on vegetation. The exception is *A. c. crassipes*, which is swift moving and readily takes flight.

The peiratines (e.g., *M. picipes*) are primarily nocturnal and attracted to lights. During the day, they were found under rocks, boards, logs, and bark. They are fast moving and difficult to catch.

The saicine (i.e., *O. acuminatus*) adults were collected in large numbers at lights during the early summer; when disturbed, they moved quickly and took flight readily. In addition, several individuals were swept from herbaceous vegetation.

Stenopodaine adults were attracted to lights in high numbers, and collected in Malaise traps in low numbers, during the spring and early summer. Adults of *P. modesta* were swept from vegetation, and nymphs of *O. genticulatus* were found under bark of dead trees and under shingles. When discovered, these insects were slow-moving. No other specimens were collected elsewhere.

Adult triatomines (i.e., *T. sanguisuga*) were taken at lights, and nymphs were found under the bark of dead trees. None was found in association with humans or domestic animals.

Sufficient data were collected on the majority of southern Illinois taxa to suggest that most species, regardless of subfamily, are univoltine, the exception being *S. diadema*, which apparently is bivoltine. A similar conclusion was reached by Readio (1927) in his study of the Reduviidae. However, as in the case of *E. b. brevipennis* (see footnote 3), further work may show that more species are bivoltine. Most species overwintered as adults, the primary exceptions being *A. cristatus* and *Z. luridus*, which overwintered as eggs and nymphs, respectively.

ACKNOWLEDGMENTS

We thank the following faculty and staff of Southern Illinois University at Carbondale: B. M. Burr and W. G. Dyer (Department of Zoology) for their critical reviews of an early version of the manuscript, J. A. Beatty (Department of Zoology) for identification of spiders, and M. A. Mibb (Department of Plant Biology) for identification of selected plant species. We also thank zool-
ogy graduate student J. D. Bradshaw for help in fieldwork and input on collection techniques. We thank the U. S. Forest Service for granting us permission to collect in the La Rue-Pine Hills Research Natural Area (Union County, IL) and R. G. Smith (U. S. Forest Service) for granting permission to collect in the Shawnee National Forest exclusive of the Research Natural Areas. Finally, we are very grateful to C. W. Schaefer, University of Connecticut, Storrs; and A. G. Wheeler, Jr., Clemson University, Clemson; for their excellent reviews of the submitted manuscript. This article is part of a thesis submitted to Southern Illinois University, Carbondale, by A. M. H. in partial fulfillment of the requirements for the M. S. degree in zoology.

LITERATURE CITED


THE APHIDS (HOMOPTERA: APHIDIDAE) ASSOCIATED WITH BELL PEPPERS AND SURROUNDING VEGETATION IN SOUTHERN ILLINOIS

Godfrey H. Kagezi1,2, David J. Voegtlin3, and Richard A. Weinzierl4

ABSTRACT

Outbreaks of cucumber mosaic virus (CMV) disease, caused by an aphid-transmitted pathogen, greatly reduced yields of bell pepper in southern Illinois in the mid-1990s. To provide the basis for further studies of the roles of individual aphid species in virus transmission, we surveyed aphid flights in and around pepper fields in 1996 and 1997 by using suction traps, interception nets, landing traps, sweep nets, and hand-picking. We collected 78 species of aphids, 15 of which have been reported to transmit CMV to peppers. The most abundant species taken from suction traps and interception nets in combination were Lipaphis erysimi, Rhopalosiphum padi, Rhopalosiphum maidis, Schizaphis graminum, and Aphis craccivora. All of these species are known to transmit CMV to peppers, but the phenology of R. maidis in Illinois suggests it is not the vector that brings CMV to pepper fields to initiate disease outbreaks. Brachycerus helichyri was relatively abundant in 1996 in May and June when a CMV outbreak may have been initiated; it was absent in 1997, and CMV infections were rare that season. Two species, Carolinaia carolinensis and Myzus hemerocallis were recorded for the first time in Illinois.

In the mid 1990's, outbreaks of cucumber mosaic virus (CMV) increased in prevalence and severity in commercial fields of bell peppers in southern Illinois, causing near total crop losses in some fields in 1995 and 1996 (Kagezi 1998). CMV is transmitted in a nonpersistent manner by over 60 species of aphids, 23 of which are known to act as vectors in peppers (Kennedy et al. 1962, Raccah et al. 1985, Katis 1989, Basky and Raccah 1990). It infects over 800 species of plants in 85 plant families (Palukaitis et al. 1992). Although outbreaks of CMV in southern Illinois appear to result from field transmission of the virus by aphids (not from infected seed or the use of infected transplants), the identities of the aphid vectors and the alternate hosts of the strain of CMV involved in pepper infections in this region are unknown. Viruses that are transmitted in a nonpersistent manner may be moved short distances by the local movements and feeding probes of resi-

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dent aphid species (Irwin and Ruesink 1986) or transported over long distances by migrating aphids (Zeyen and Berger 1990). As a result, local or distant flora may serve as sources of CMV.

In monitoring aphid flights in and around crop fields, researchers have used suction traps to capture aphids flying just above the crop canopy (Taylor and Palmer 1972, Plumb 1976, Raccah 1983, Raccah et al. 1985), colored pan or landing traps to detect species landing in the crop (Irwin 1980, Raccah 1983, Halbert and Pike 1985, Raccah et al. 1985, Schultz et al. 1985, Gray and Lambert 1986, Halbert et al. 1986, Boiteau 1990), vertical interception nets (Irwin 1980, Halbert et al. 1981, 1986), and more direct collecting techniques such as hand-picking and sweep-netting (Blackman and Eastop 1984). To determine the species composition and seasonality of the aphids associated with peppers in southern Illinois and thereby provide the basis for further examination of their roles as virus vectors, we used multiple collection methods to sample the aphid fauna in and around pepper fields in Johnson and Union counties in 1996 and 1997. The results of our aphid survey efforts are reported herein. Studies of disease epidemiology and the vector roles of certain species are yet to be completed and will be published separately.

MATERIALS AND METHODS

To characterize aphid flights into and around pepper fields, aphids were collected by use of suction traps and interception nets in and adjacent to pepper fields near Belnap in Johnson County, Illinois, in 1996 and 1997. In 1997, landing traps, sweep nets, and hand-picking were also used at the field site near Belnap. In addition, interception nets, landing traps, sweep nets, and hand-picking were used in 1997 to make collections at an additional pepper field near Anna in Union County, Illinois. All field sites were located in the area where CMV outbreaks had been severe. This region of Illinois is known as the Coastal Plain Division and is characterized by major bottomland areas along the Cache, Ohio and Mississippi Rivers and areas of low hills capped by Cretaceous and Tertiary sand, gravel and clay. The bottomlands are the northernmost extension of the Gulf Coastal Plain Province of North America, and bald cypress-tupelo gum swamps and associated plant species grow in these areas. Much of the bottomland farm ground is seasonally flooded and remains uncultivated for extended periods in the spring. These uncultivated fields become covered with a variety of weed species that are hosts to many of the known vectors of CMV. Early spring composites, crucifers, cool season grasses and sedges are abundant in these fields. Conventional cropping of soybeans and corn in this region has not been economical, and tracts of land can be found in a variety of successional stages, returning to the oak-hickory-gum dominated riparian forest. The mix of weedy fields, old field successions, and extant riparian forest provides a great diversity of hosts for aphids. This area also is characterized by a relatively mild climate that often is suitable for vector species capable of surviving milder winters as colonies on host plants.

Two suction traps (Fig. 1) were used, one in the middle of a 30-ha bell pepper field and the second 5–10 meters outside the west edge of the same field. These traps, operated on 12-volt batteries, used fans rated at 9.3 m³ (100 ft³) per minute. The intake for the traps was 1–1.25 m above the ground and about 0.5 m above the crop canopy at maturity. Aphids were collected in jars containing a 1:1 polyethylene glycol: water mixture and were later isolated from other insects under a dissecting microscope, mounted on slides,
Figure 1. Battery-powered suction trap used to monitor aphid flights in and adjacent to bell pepper fields in southern Illinois, 1996–1997.

and identified. Suction traps were operated continuously during daylight hours from 13 May to 2 September 1996 and from 15 May to 10 October 1997. Collection jars were exchanged two to three times weekly.

Two stationary vertical interception nets similar to those described by Halbert et al. (1981) and consisting of 24 × 20-mesh netting, 1.07 m high and up to 10 m long (BioQuip, Gardena, CA), were suspended between steel posts in the interior of and along the upwind edge of pepper fields. Nets were suspended perpendicularly to the wind at the time of collections; they were repositioned and re-oriented when wind direction changed. The bottom of the nets rested on the soil surface. Collections from nets usually spanned two days during each sampling period. During the two days, a morning (0600 to 1000 h), a mid-day (1000 to 1500 h), and a late-day (1500 to 2000 h) collection were made. Alate aphids landing on interception nets were collected
using fine brushes and immediately caged individually on virus-free pepper seedlings to assess their roles in virus transmission, then removed after 3 to 12 h and preserved in 70% ethanol for identification. Interception nets were operated during four periods in May and June and one period each in July, August and September of 1996, and weekly from May to August in 1997.

In 1997, aphids were sampled by means of landing traps to determine which species might be settling in pepper fields. Traps were made of plastic sandwich boxes (approximately 12 x 12 cm), each with a green ceramic tile (Irwin 1980) covering the bottom. They were filled with water and mounted at canopy level and used on the same sampling dates as interception nets (in 1997 only). Four to 10 traps were used per field, and aphids were collected from the traps using a fine brush each evening of operation. In addition, aphids were collected directly from herbaceous and woody plants in the borders and woods surrounding pepper fields during the 1997 season. Aphids were taken from plants using a fine brush or by sweeping the vegetation with a net, used in inoculation experiments on virus-free pepper seedlings, and then preserved for identification (as described above for aphids collected from interception nets).

Trapped aphids were sorted into morphospecies categories by the senior author, who also made slide mounts of representative morphs to verify the homogeneity of each category. All mounted aphids were identified by David Voegtlin. Voucher specimens were deposited in the collection of the Illinois Natural History Survey, Champaign, Illinois.

For analysis, counts from suction traps were pooled for each sampling period. To illustrate the seasonal occurrence of key species, aphid counts for each sampling period were graphed (Figs. 2-7), and bars representing relative densities were placed at the median date for each sampling period. Where aphids were collected from interception nets for 2 or 3 days in succession, total counts for the period were graphed at the first or median date, respectively.

RESULTS AND DISCUSSION

More than 2,400 individual aphids representing more than 78 species were collected from interception nets and suction traps during the two years of study (Table 1). Four additional species were collected only from surrounding vegetation. Of the aphid species we collected, 15 have been reported to transmit CMV to peppers under field conditions (Raccah et al. 1985, Basky and Raccah 1990).

Aphid flights into pepper fields (as measured by interception nets and suction traps) were much lighter in 1997 than in 1996. In order of abundance, Lipaphis erysimi (Kaltenbach), Rhopalosiphum padi (L.), Rhopalosiphum maidis (Fitch), Schizaphis graminum (Rondani), and Aphis craccivora (Koch) (all reported as vectors of CMV) were collected in greatest numbers from the suction traps and interception nets in combination. A total of 1,675 individuals of these species were taken by these two methods; this total represented approximately 68 percent of all the specimens taken by the suction traps and interception nets. Seasonal patterns of occurrence of these species plus Brachycaudus helichrysi (Kaltenbach) are illustrated in Figures 2–7.

To date, inoculation trials using field-collected aphids have not identified the aphid species most important in transmitting CMV to peppers in southern Illinois. In the absence of such findings, the flight phenology of common and suspect species may provide clues for further investigations. The seasonal capture data we obtained for five of six such species (Figs. 2–5 and Fig.
7) indicate patterns of occurrence that include abundance in May and June. This timing would allow them to have been important vectors of CMV, given the timing of disease outbreaks in early July of 1996 and previous years.

**Most abundant species.** *Lipaphis erysimi*, which reached peak numbers in late May (Fig. 1), can overwinter as eggs on *Brassica* spp., although Hottes and Frison (1931) note that all their collections contained only viviparous adults. Most collections of this species in Illinois have been made on cultivated species of *Brassica*, however, its host range includes many native species of Brassicaceae that might serve as overwintering hosts.

*Rhopalosiphum padi* (Fig. 3) is a species that can survive milder winters on winter wheat. Studies of this species (Voegtlin and Halbert 1998) show that clones collected in Illinois are incapable of producing sexuales. The presence of winged individuals in early spring is thus either the product of surviving overwintering colonies or the result of immigration. The extensive host range of *R. padi* is comprised primarily of grasses. This aphid is a common component of trap catches over agricultural fields in Illinois in the spring, and our peak captures of this species in late September (Fig. 3) are also typical in Illinois, as emerging winter wheat is infested with winged adults. The source of these winged adults is not known but is likely to the north where cereals and other grasses are still growing.

*Schizaphis graminum* (Fig. 4) can also be found on winter wheat well into the winter, and in mild winters colonies survive on this crop. We observed an early spring peak and movement into pepper fields well into the summer. This species is known to lay eggs on *Poa pratensis* and may, as *R. padi* does, move north as each growing season progresses. More commonly known as the greenbug, *S. graminum* is comprised of many biotypes and is one of the major pests of sorghum in the southern and central United States. Its host range is large and comprised mainly of grasses.

*Aphis craccivora* is somewhat of a mystery in Illinois. Hottes and Frison (1931) did not collect this species, and it has been uncommon in extensive trapping efforts in corn and soybean fields in northern and central Illinois. It was relatively abundant, however, in both suction trap and interception net catches in this study (Fig. 5). It is polyphagous, with a marked preference for plants in the family Fabaceae. Blackman and Eastop (1984) state that this species is primarily anholocyclic throughout its range and that sexuales are uncommon. In this manner it is similar to *R. padi* and *S. graminum* in either overwintering as colonies or immigrating each season.

It seems unlikely that *Rhopalosiphum maidis* plays an important role in introducing CMV to pepper fields, because it is virtually absent during May and June (Fig. 6) when initial virus transmission appears to have occurred in 1996 (and in previous years). Instead it became common only in July and August. Hence, it is possible that *R. maidis* may contribute to within field transmission that occurs throughout the summer. The delay in the appearance of *R. maidis* is due to its inability to reproduce sexually in North America and its failure to overwinter successfully on cereals, even in mild winters. To reach Illinois, it must migrate from milder southern regions each year. The timing illustrated in Fig. 6 is very typical of the phenology of *R. maidis* in other areas of Illinois as well.

*Brachycaudus helichrysi*, another species not found by Hottes and Frison (1931), is also a known vector of CMV. Primary hosts are *Prunus* spp. and secondary hosts are most often in the Asteraceae (e.g. *Achillea*, *Chrysanthemum*, *Matricaria*, *Senecio*, *Erigeron*, and *Ageratum*) and Boraginaceae. Only two specimens were collected in 1997, though it was abundant in May 1996 (Fig. 7). Because many more *B. helichrysi* were captured on interception nets in 1996 (when CMV became prevalent) than in 1997, its role as a possible
Table 1. Aphid species collected in or adjacent to pepper fields in southern Illinois using suction traps (S), interception nets (I), sweep nets (N), landing traps (L), or hand-picked by brush (H) from plants, 1996 and 1997.

<table>
<thead>
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<th>Collected by</th>
<th>Total from suction traps</th>
<th>Total from interception nets</th>
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<td>2</td>
</tr>
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<td>1</td>
<td></td>
</tr>
<tr>
<td><em>Acrhythosiphon pisum</em> (Harris)</td>
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<td>6</td>
</tr>
<tr>
<td><em>Acrhythosiphon</em> sp.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><em>Anoecia corni</em> (Fabricius)</td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Anoecia cornicola</em> (Walsh)</td>
<td>S, I</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><em>Anoecia oenothereae</em> (Wilson)</td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aphids coreopsis</em> (Thomas)</td>
<td>S, I</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><em>Aphids craccvora</em> (Koch)</td>
<td>S, I</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td><em>Aphids fabae</em> subsp. solanella Theobald</td>
<td>S, I, H</td>
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</tr>
<tr>
<td><em>Aphids folsonii</em> (Davis)</td>
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</tr>
<tr>
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<td>7</td>
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<tr>
<td><em>Aphids helianthi</em> (Monell)</td>
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<td><em>Aphids illinoisensis</em> (Shimer)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><em>Aphids nasturtii</em> (Kaltenbach)</td>
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<td></td>
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</tr>
<tr>
<td><em>Aphids rubifolii</em> (Thomas)</td>
<td>I</td>
<td></td>
<td></td>
</tr>
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<td><em>Aphids spiraeola</em> (Patch)</td>
<td>S, I</td>
<td>2</td>
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<tr>
<td><em>Aphids thaspii</em> (Oestlund)</td>
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<td>1</td>
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<tr>
<td><em>Aulacorthum solani</em> (Kaltenbach)</td>
<td>I</td>
<td></td>
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</tr>
<tr>
<td><em>Brachycaudus helichrysi</em> (Kaltenbach)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><em>Capitophorus hippophae</em> (Walker)</td>
<td>S, I</td>
<td>1</td>
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</tr>
<tr>
<td><em>Carolinaia carolinensis</em> (Smith)</td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Chaitophorus minutus</em> (Tissot)</td>
<td>S</td>
<td>1</td>
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<td><em>Chaitophorus populicola</em> (Thomas)</td>
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Table 1. (Continued)

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<td>Uroleucon ambrosiae (Thomas)</td>
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<td>Uroleucon (Lammersius) sp.</td>
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<td>Uroleucon (Lammersius) gravicorne</td>
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<tr>
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<tr>
<td>Uroleucon chrysanthemi (Oestlund)</td>
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<td></td>
<td>4</td>
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<td>Uroleucon eupatoricolens (Patch)</td>
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</tr>
<tr>
<td>Uroleucon nigrotuberculatum (Olive)</td>
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<td>2</td>
<td></td>
</tr>
<tr>
<td>Uroleucon reynoldse (Olive)</td>
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<td></td>
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<td>8</td>
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</tbody>
</table>

*Potential vectors of CMV in peppers, as reported by Raccab et al. (1985) and Basky and Raccab (1990).*

**Potential vectors of CMV** may be especially worthy of further investigation. This species was not captured in suction traps, even in May 1996 when it was abundant on interception nets. This is particularly surprising because the height of the suction trap intake was approximately equal to the height of the top of the interception nets. There are no obvious reasons for the difference in captures between these trapping methods.

**Other potential vectors collected in lesser numbers.** *Aphis fabae* subsp. *solanella* Theobald was collected from nightshade, *Solanum nigrum*, and curly dock, *Rumex crispus*, in weedy areas adjacent to pepper fields. *Aphis fabae* is a known vector of CMV, but it is not known if this subspecies...
Figures 2 and 3. Seasonal abundance of *Lipaphis erysimi* (Kaltenbach) and *Rhopalosiphum padi* (L.) in suction trap (S) samples and interception net collections (N) in southern Illinois, 1996–1997. See text for details on sample collections and calculations of totals.
Figures 4 and 5. Seasonal abundance of *Schizaphis graminum* (Rondani) and *Aphis craccivora* (Koch) in suction trap (S) samples and interception net collections (N) in southern Illinois, 1996–1997. See text for details on sample collections and calculations of totals.
Figures 6 and 7. Seasonal abundance of *Rhopalosiphum maidis* (Fitch) and *Brachycaudus helichrysi* (Kaltenbach) in suction trap (S) samples and interception net collections (N) in southern Illinois, 1996–1997. See text for details on sample collections and calculations of totals.
has been tested and implicated in the transmission of CMV. In Illinois, *Aphis fabae* (Scopoli) uses *Euonymus* and *Viburnum* as primary hosts and migrates to a wide range of secondary hosts in the spring.

*Aphis nasturtii* (Kaltenbach) was collected from horseweed, *Erigeron canadensis*. This is a third species not recorded by Hottes and Frison and also not recorded in earlier epidemiological studies in soybeans and corn in central and northern Illinois. Stroyan (1984) suggests that this is probably a species complex and that American populations have a broader host range than the European species. Patch (1938) lists a broad host range for *A. nasturtii* (as *Aphis abbreviata* Patch), including plants from 28 different families. Most common among these are genera in the Asteraceae.

*Aphis nerii* (Boyer de Fonscolombe), commonly known as the milkweed-Oleander aphid, is found mainly on plants in the families Asclepiadaceae and Apocynaceae. It also occasionally colonizes plants in other families, including Euphorbiaeaceae, Asteraceae, and Convolvulaceae (Blackman and Eastop 1984). It is unlikely that *Aphis nerii* overwinters in southern Illinois because none of its preferred hosts are available. It is rarely found in Illinois before mid-summer and does not form sexuales. In the fall, colonies of viviparous females continue to feed on hosts until they are killed by frost.

*Acyrthosiphon pisum* (Harris) and *Therioaphis trifolii* (Monell) feed on a wide range of plants in the family Fabaceae. The most likely host plants for both species in southern Illinois are alfalfa and sweet clover.

Only three vector species, *Aphis gossypii* (Glover), *Myzus persicae* (Sulzer), and *Macrosiphum euphorbiae* (Thomas), are known to colonize pepper plants (Blackman and Eastop 1984). None of these was seen colonizing peppers or collected in any abundance in traps, and their biology in the area is not known. It is possible that they can survive holocyclicly, but most specimens of these three species were collected in mid to late summer, suggesting that they are not the product of populations that overwinter either as colonies or eggs.

*Sitobion avenae* (Fabr.) is another species that can survive milder winters in colonies on winter wheat in Illinois. It has a wide host range of grasses and several other monocotyledons (Blackman and Eastop 1984). Most of our specimens were collected in early spring.

**Other species and notes.** The other species collected in this survey (as recorded in Table 1) consist of a mix of native and exotic aphids, some of which have been collected before in the region but never reported as present in Illinois. Two such species are *Carolinaia carolinensis* (Smith) and *Myzus hemerocallis* (Takahashi), both captured on interception nets. *Carolinaia carolinensis* is described from specimens taken on poison ivy, *Rhus radicans*, and Smith (1980) suspects that it alternates to plants in the family Cyperaceae. Blackman and Eastop (1984) reported that *M. hemerocallis* attacks basal parts of young leaves of daylily, *Hemerocallis* spp., but there are no host records for this species in Illinois.

Though landing traps have proven useful in other epidemiological studies, only three species, *A. nerii*, *Glabromyzus rhois* (Monell), and *R. maidis*, were caught in them in pepper fields. It is possible that the color of the tiles used in these traps did not match closely enough the background color of pepper foliage. If the reflected light from these tile traps matches closely that of the surrounding crop, it can be assumed that the aphids landing in the trap will also be landing on the crop. Continued use of these traps will depend on identification of a tile that matches pepper foliage.

Although 15 species collected in this survey have been implicated in the transmission of CMV to peppers in other regions, it is possible that other species are responsible for carrying and transmitting this virus in the south-
ern Illinois pepper production area. Nonetheless, even though our inoculation studies did not allow us to identify the key vector species (one or more) involved in CMV outbreaks, we suspect that the vectors are among the species we collected. Movement of the virus may be accomplished by multiple species, with the transfer of the virus from local weed hosts to peppers effected by different species than those that effect the within-field movement of the virus.

As noted earlier, the region in Illinois where this work was done is a large flood plain with extensive riparian areas along the Cache River. The diversity of plants in these riparian areas and abundance of uncultivated flood plain fields provide abundant host plants for native and non-native aphid species. Future work will focus on the biology (local host plants, overwintering hosts, and flight phenology) of the known vector species discussed above and such native aphids as *Uroleucon ambrosiae* (Thomas), an aphid commonly collected in the vicinity of the pepper fields from thistle, *Cirsium discolor*.

ACKNOWLEDGMENTS

The authors thank Jeff Kindhart, Houston Hobbs, and Susan Ratcliffe for their hard work on this project and Mike Irwin, Gail Kampmeier, Cleora D'Arcy, and Darin Eastburn for their advice and assistance. This work was supported by the Ugandan government’s IDEA program (Investment in Developing Export Agriculture) and by C-FAR, the Illinois Council for Food and Agricultural Research. This paper represents a portion of the M.S. thesis of Godfrey H. Kagezi.

LITERATURE CITED


FIRST RECORDS OF CECIDOMYIA CANDIDIPES (DIPTERA: CECIDOMYIIDAE) IN WISCONSIN

Steven J. Krauth

ABSTRACT

First report of Cecidomyia candidipes from five Wisconsin counties.

Gagne (1978) presented a systematic analysis of Cecidomyia, the pitch midges, containing 11 species: eight from North America and three from Eurasia. Cecidomyia candidipes Foote (Diptera: Cecidomyiidae: Cecidomyinae: Cecidomyini) has been reported in the literature from New Brunswick, Ontario, Quebec, Connecticut, Illinois, Maryland and New York exclusively on white pine, Pinus strobus Linnaeus. C. candidipes is of potential concern to agricultural commodity inspectors of the Wisconsin Department of Agriculture Trade and Consumer Protection (WDATCP) as a potential pest of Christmas tree plantations. The first specimens were submitted to the author for identification in 1997. Scouting for white pine damage is done by looking for oozing pitch masses on the main trunk. The orange to pink colored larvae were found in the pitch while cocoons of pupae were found in the pitch, just outside the pitch and on bark or twigs well away from the pitch flow (D. Hall, personal communication). Department of Natural Resources (DNR) personnel field collected and incubated pupae at room temperature (65-70°F).

Larvae were identified by R. L. Gagne of the Systematic Entomology Laboratory, Washington D.C. The first adult reared was identified by the author, confirmed by Gagne, and the remaining adults were identified by the author. All the specimens are deposited in the University of Wisconsin Insect Research Collection, Department of Entomology, Madison WI.

RESULTS


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ACKNOWLEDGMENTS

Thanks to collectors: M. Guthmiller, D. Hall, and T. Lanigan, at the DNR and S. Chic, K. Jerabek and D. Schumacher at the WDATCP. Thanks also to Dr. D. K. Young and an anonymous reviewer for reading and providing constructive changes to the manuscript.

LITERATURE CITED

DISTRIBUTION OF AN EXOTIC PEST, AGROMYZA FRONTELLA
(DIPTERA: AGROMYZIDAE), IN MANITOBA, CANADA.

J. G. Lundgren1, R. C. Venelle1,2, J. Gavloski3, W. D. Hutchison1 and G. E. Heimpel1

ABSTRACT

Agromyza frontella is an exotic alfalfa pest from Europe that was first detected in North America in 1968 and has since spread westward into Ontario and the north central United States. Informal surveys had detected A. frontella in Manitoba, but its distribution throughout this province was unknown. In 1998 we collected alfalfa stems to detect plant damage and sweep samples to detect adult A. frontella and the parasitoid Dacnusa dryas throughout the alfalfa growing region of Manitoba. In south central Manitoba, 100% of stems were damaged by A. frontella, and > 100 adults/10 sweeps were recorded at several sites. In west central Manitoba, no plants were damaged and < 10 adults/10 sweeps were observed. We believe this region to be near the western edge of A. frontella distribution. The most important introduced parasitoid of A. frontella, D. dryas, was not detected which suggests that D. dryas has not invaded Manitoba.

The alfalfa blotch leafminer, Agromyza frontella (Rondani) (Diptera: Agromyzidae), is an exotic pest from Europe and was first detected in North America in 1968 (Miller and Jensen 1970). Since its arrival, populations of A. frontella have spread westward at a rate of 48–80 km/yr (Hendrickson and Plummer 1983). By 1974 A. frontella had been detected in Quebec, eastern Ontario and the Maritime provinces (Harcourt et al. 1988). In eastern Ontario, populations reached levels that warranted insecticide treatments (Harcourt et al. 1988). Reports of the continued spread of A. frontella were scarce until 1994, when it was discovered in Minnesota (Hutchison et al. 1997). In 1996, informal surveys detected A. frontella in Manitoba, but the distribution of A. frontella throughout the province was not determined.

Agromyza frontella appears to have an adverse impact on alfalfa yield and quality (Hendrickson and Plummer 1983). Female flies cause plant damage by puncturing alfalfa leaflets with their ovipositors and feeding on plant juices. The puncture and feeding results in characteristic “pinhole” damage (Bereza 1979). Larvae also damage leaflets by feeding beneath the epidermis of leaves, creating question mark-shaped blotch mines. Yield losses ranging from 7–17% with annual losses of $13 million have been reported in infested areas (Hendrickson and Plummer 1983). Mined leaflets may also incur a reduction in crude protein (Hendrickson and Day 1986).

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In Ontario and the northeastern US, the introduced parasitoid *Dacnusa dryas* (Nixon) (Hymenoptera: Braconidae) has been identified as the most effective biological control agent of *A. frontella* (Hendrickson and Plummer 1983, Drea and Hendrickson 1986, Guppy et al. 1988). After initial releases of *D. dryas*, it was hoped that populations of the parasitoid would prevent or accompany the spread of *A. frontella*. However, there were areas where additional releases of *D. dryas* were required (Hendrickson and Plummer 1983). Alfalfa fields where *A. frontella* has escaped *D. dryas* have incurred high levels of damage (Harcourt et al. 1988). Releases of *D. dryas* into these areas have been successful at reducing pest populations to acceptable levels.

The objectives of this study were to document the current distribution of *A. frontella* and to detect the presence of *D. dryas* in Manitoba. *Agromyza frontella* has successfully invaded regions as far west as western Ontario and Minnesota. For this reason and the known biology of *A. frontella* (summarized in Guppy 1981), we hypothesized that *A. frontella* will establish and integrate into all alfalfa-producing regions of Manitoba. Though *D. dryas* has established in much of the present range of *A. frontella* (e.g., Harcourt et al. 1988), the parasitoid has not yet been detected during the recent expansion of *A. frontella* into Minnesota (Hutchison et al. 1997). The history of *D. dryas* releases and this parasitoid's lower rate of spread relative to *A. frontella* (Hendrickson and Plummer 1983) lead us to hypothesize that *D. dryas* has not yet established in Manitoba. Determining the distribution of *A. frontella* and *D. dryas* in Manitoba is the first step in assessing the risk that this pest poses to alfalfa production in Manitoba.

**MATERIALS AND METHODS**

**Data Collection.** Field sampling was conducted from 4–30 July 1998. Sites were arbitrarily selected throughout the alfalfa growing region of southern Manitoba (Fig. 1). For each sample site, latitude and longitude were estimated using a hand-held Global Positioning System. The nearest town name was also recorded.

Adult insects were sampled using a 38-cm diameter, circular sweep net. A sample consisted of the contents of 10 sweeps of the alfalfa canopy (e.g., Hutchison et al. 1997). Nine samples were taken for a total of 90 sweeps per site. Each sample was immediately placed into a sealable plastic bag, kept cool and dry, and overnight express-mailed to the University of Minnesota. All samples were kept frozen until processing.

Each sample was examined at 10–50× magnification and separated into three groups: hymenopteran parasitoids, *A. frontella* adults, and other insects. All braconid parasitoids were examined to determine whether they belonged to the genus *Dacnusa* using the key of Marsh et al. (1987). After processing, insects were preserved in 70% ethanol for future identification. Adult *A. frontella* were identified according to Hutchison et al. (1997). Voucher specimens of *A. frontella* adults were deposited in the insect museum, Department of Entomology, University of Minnesota.

Stem samples were taken from each field at the time of sweep sampling. Thirty stems were selected arbitrarily, cut at the soil surface, and placed into a paper bag. Samples were kept cool and dry, and overnight express-mailed to the University of Minnesota. Upon receipt, samples were frozen until processing.

For each stem sample, trifoliates were examined for pinholes (evidence of feeding by adult females) and mines (evidence of *A. frontella* reproduction). If one or more trifoliates contained either pinhole or mining damage on a given
stem, the stem was classified as damaged. For 10 damaged stems from each site, the number of pinholed trifoliates, number of mined trifoliates and the total number of trifoliates per stem were recorded. For sites where < 10 stems were damaged, trifoliates on all affected stems were examined. In cases where a trifoliate had both mining and pinholing, the trifoliate was recorded only as mined.

**Data Analysis.** For each site, data from sweep samples were condensed to the mean number of adults per 10 sweeps. The data from plant damage were converted to the mean percent of damaged trifoliates/stem per site. All data were incorporated into a geographically referenced database. Data were imported into Arcview GIS 3.0 (Environmental Systems Research Institute, Redlands CA) to analyze the geographic distribution of adult populations and plant damage. Isoclines between sample locations were generated with Spatial Analyst 1.1 (ESRI, Redlands, CA), and interpolations were created with data from the nearest 8 sites.

To detect regional differences in infestation levels, the sampled region was divided into three sections (Fig. 1): the western section incorporates all sites west of Minnedosa inclusive, the central section is defined as the area between Ste. Rose du Lac and Fisher Branch, and the eastern section incorporates all sites east of Teulon inclusive. Number of adults/10 sweeps, percentage of mined trifoliates/stem and percentage of pinholed trifoliates/stem from all sites in a section were subjected to analysis of variance with means
RESULTS

Agromyza frontella adults were detected throughout southern Manitoba (Fig. 2). The highest numbers of adults were in the central third of the sampled region (Table 1), and at Beausejour (597 adults/10 sweeps). The lowest numbers of adults were in the northern and eastern portions of the sampled region. Two samples taken from separate sites near Fisher Branch yielded 0.9 adults/10 sweeps and no adults, respectively. These were the only sites where no adults were observed. Daenusa dryas was not detected in any of the samples.

The percentage of trifoliates with mines was greatest in the central third of the sampled region, reaching 35.5% mined trifoliates/stem at McCreary (Fig. 3). Much of the rest of the sampled region had ≤ 5% mined trifoliates/stem. Ten of the sampled sites had no mining damage, and these sites were distributed throughout southern Manitoba. The percentage of stems with pinholes was also most severe in the central third of the sampled region (Fig. 4).

The percentage of stems with pinholes or mines was highest just west of Lake Manitoba (Figs. 3–4). Less than 3%-damaged trifoliates/stem were observed in areas in the northwestern portions of the sampled region and for Dugald. These areas of lowest damage per stem corresponded to areas of lowest adult populations (Fig. 2).
Table 1. Regional comparison of adult densities and plant damage caused by *Agromyza frontella*.

<table>
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<th>Western Region*</th>
<th>Central Region</th>
<th>Eastern Region*</th>
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<td>Adults/10 sweeps (±SEM)</td>
<td>9.1 ± 3.6A</td>
<td>89.0 ± 29.1A</td>
<td>116.7 ± 97.1A</td>
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<td>% mined trifoliates/stem (±SEM)</td>
<td>1.1 ± 0.5A</td>
<td>9.5 ± 3.3B</td>
<td>3.0 ± 1.9AB</td>
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<td>% pinholed trifoliates/stem (±SEM)</td>
<td>16.2 ± 5.3ab</td>
<td>33.6 ± 6.3a</td>
<td>11.8 ± 4.2b</td>
</tr>
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</tr>
</tbody>
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* The western region corresponds to the area west of Minnedosa, and the eastern region includes the area east of Teulon.

Means within rows followed by the same letter are not statistically different as determined by analysis of variance and LSD (capital letter: α = 0.1; lowercase letter: α = 0.05). To conform with assumptions of ANOVA, adult counts and percentage of trifoliates with mines were transformed following log10(Y+1) and ARCSIN(SQRT(Y/100)), respectively. Transformed data not shown.

DISCUSSION

We believe the geographical distribution of adult counts and plant damage in Manitoba reflects the initial phases of the invasion process. Vermeij (1996) describes an ecological invasion in four stages: arrival, establishment, integration, and spread. Arrival involves the dispersal of individuals into a recipient region; establishment occurs when a population is maintained through local reproduction; integration occurs as the invader and recipient...
Figure 4. Percentage of trifoliates on 30 alfalfa stems with ≥ 1 Agromyza frontella pinholes in southern Manitoba.

biota adapt to each other; and spread is the local dissemination of individuals from integrated populations into adjacent habitats or regions. Though the invasion process is a continuum, these divisions are useful in examining demographic trends. Our results suggest that *A. frontella* has passed through the arrival stage and is in the establishment stage throughout southern Manitoba.

For populations in the establishment stage we would expect to detect mining, adult populations and pinholing levels. The phenomena associated with the establishment stage appear to be most evident in the central portion of the sampled region. Level of mining in the central third of the sampled region is significantly higher than the western third suggesting populations of *A. frontella* have been established in south-central Manitoba longer than in southwest Manitoba.

Geographic regions possessing adult populations that are not yet reproducing may be in the arrival stage. For areas where *A. frontella* had recently arrived, we would expect to see a lower ratio of mines/adult. Though the western third of the sampled region exhibits only 1.1% mined trifoliates/stem (Table 1), the number of adults is proportionally lower, and the ratio of mines/adult is not significantly different from the central third. It is likely that the western third of the sampled region is a younger infestation, but our data suggests that *A. frontella* is currently established in southwestern Manitoba.

The mechanisms for the lower level of pinholing in the eastern region relative to the central region (Table 1) and increased variance in adult numbers within the eastern sites (Table 1) are unknown. Processes associated with the latter part of the establishment (Brown 1993) and/or integration stages may explain the patterns observed in the eastern region. Different environ-
mental restrictions (climatic or habitat quality) and levels of biotic resistance between sites are likely to become more evident in the latter stages of invasion. For the integration stage we might also expect to discern genetic adaptation of *A. frontella* populations in response to local environments.

We recognize that a single sample from a field does not completely describe local population dynamics, and we caution readers not to interpret divisions of population densities represented in our maps too literally. However, our sampling strategy does provide a "snapshot" of a continually evolving process. Further studies to assess the impact of *A. frontella* on alfalfa yield and quality are required to determine the possible implications that *A. frontella* may have for Manitoba alfalfa producers.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**


TWO NEW SPECIES OF COCHYLINI (LEPIDOPTERA: TORTRICIDAE: TORTRICINAE) FROM THE EASTERN UNITED STATES

Eric H. Metzler

ABSTRACT

Intensive collecting in prairie and oak barrens habitats in Ohio and Indiana revealed two undescribed species of Cochylini (Lepidoptera: Tortricidae): Aethes patricia, new species, and Cochylis rueli, new species. Illustrations of adults, male and female genitalia, and distribution maps are provided. Aethes patricia may be prairie remnant dependent in Ohio and Indiana.

Because less than 1% of the once extensive North American grasslands called tall grass prairies are extant, this habitat is a critical, highly depleted natural resource. Although flora and vertebrate fauna of North American prairies have received considerable scientific investigation, knowledge of the insect fauna of this system is virtually non-existent. Because insects dominate life on earth (Borror et al. 1992), and because prairies are a complete ecosystem (Transeau, 1935), research on prairie insects is warranted. The description of the species in this paper is one contribution towards knowledge of prairie fauna. The species are described at this time to make available the names and data for agencies responsible for managing the type localities.

Powell (1983) listed 110 species of Cochylidae (=Cochylini), of which 58 were considered incertae sedis. Razowski's (1997) review of species found in Canada was the first illustrated accounting of Cochylini in North America. Otherwise the Nearctic fauna is not well known with as many as 2/3 of the species in the Nearctic potentially undescribed (M.G. Pogue, pers. comm.).

MATERIALS AND METHODS

For several years I conducted inventories of night flying insects in various remnant prairie sites in Ohio and Indiana. Monthly samples were collected from April through October in diverse habitats. On each night when samples were taken, black light traps were set in arrays; all traps in each array were operated on the same night. The array in Erie Co., Ohio was 6 traps, the array in Newton Co., Indiana was 6 traps, and the array in Jasper-Pulaski Wildlife Area, Indiana was 7 traps. In Indiana all traps in each array were within 4.8 km of each other, and in Ohio all traps were within 1.6 km of each other. Similar arrays were organized in Lucas and Wyandot counties, Ohio. Over 1,000 species of moths were identified.

The black light traps used in the arrays were patterned after the stan-

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standard USDA Elisco® traps, using a 15 watt fluorescent black light bulb (bl) powered by 12 volt batteries and Cyanogas® as the killing agent. The traps were deployed in the late afternoon and retrieved at dawn the following morning. All specimens of moths were removed from the samples and sorted to species. Additional specimens of CochyIini were borrowed from the Academy of Natural Sciences, Philadelphia, (ANSP), Carnegie Museum of Natural History (CMNH), Cornell University (CUIC), Field Museum of Natural History (FMNH), Florida State Collection of Arthropods (FSCA), George J. Balogh (GJBC), Illinois Natural History Survey (INHS), Edward C. Knudson (ECKC), Bryant Mather (MATH), U.S. National Museum of Natural History (USNM), Mississippi Entomological Museum (MEMU), and Valeriu Albu (VAIC). Abbreviations are directly from, or formed in accordance with, Arnett et al. (1993).

Genitalia were examined following procedures outlined in Clarke (1941) and Hardwick (1950). Abdomens were removed from the moths, wetted in 70% ethyl alcohol, and soaked in 10% KOH. Genitalia were dissected in distilled water, stained with Safranin O in water, dehydrated in 98% isopropyl alcohol, cleared in xylene, and slide mounted in Canada balsam. I examined the genitalia of 99 males and 29 females.

The genitalia were photographed with the aid of a Leitz Aristophot photomicrographic apparatus using transmitted light. For photographs of adults, I used an Aristo DA-10 light box; the background was an 18% gray card.

Forewing lengths were measured to the nearest mm, using an ocular reticle. Forewing measurements were from the base to the tip. Descriptive colors were from Ridgway (1912) and Smithe (1974, 1975, 1981). Terminology for elements of wing pattern follows Bradley et al. (1973); morphology and genitalic structures follow Horak (1984).

**Aethes patricia Metzler, new species**
(Figures 1a, 2, 4)

**Diagnosis:** The adult, which resembles *Aethes fernaldana* (Walsingham, 1879), is recognizable by the buff color of the forewing with a salmon and kingfisher rufous-colored, median fascia extending from the costa obliquely towards the tornus through the cell, and a median dorsal fascia that ends in an acute point at the cell. The fascia and other markings are outlined with reflective white scales. The male genitalia, with sickle-shaped socii are typical for the genus. It is separated from *A. fernaldana* by the shape of the valva. The apex of the valva of *A. patricia* has a strong tooth, absent in *A. fernaldana*. The saccular region of the valva, robust in *A. patricia*, is reduced in *A. fernaldana*; edged with dense setae in *A. patricia* and only a few setae in *A. fernaldana*.

**Description.** Adult male (Fig. 1a): Head: Vertex tufted, laterally with buff colored scales blending to pale buff medially. Front pale buff blending to buff laterally; cinnamon behind the eye. Labial palpus, basal segment short, pale cinnamon, smoothly scaled laterally, loosely scaled ventrally; median segment more than one half total length, smoothly scaled laterally with ventral and dorsal tufts, inner surface buff, outer surface buff distally blending to cinnamon basally with scattered darker scales; apical segment short, smoothly scaled, buff with specks of burnt orange. Antenna filiform, scape salmon anterior, pale buff posterior, ventral surface naked, dorsal surface scaled, base of each segment pale buff, basal ⅔ cinnamon distally, distal ⅓ with two or three pale buff scales per segment; base of each segment with dense ⅔ circle of sensory setae, some longer than width of flagellar segment.
Figure 1. a, Paratype male of *Aethes patricia* Metzler new species. b, Holo­type male of *Cochylis ringsi* Metzler new species.
Thorax: Dorsally concolorous with head. Posterior scales of tegulae upturned, sometimes recurved anteriorly. Mesothorax slightly tufted posteriorly. Metathorax slightly tufted dorsally; smoothly scaled ventrally, shining pale buff. Legs: Prothoracic coxae fuscous and shining fuscous, pale buff ventrally; femur shining fuscous, pale buff ventrally; tibia shining fuscous, pale buff ventrally; tarsomeres with acute triangular shining fuscous scales, each segment distally with pale buff, last segment distally ringed with pointed contrasting pale buff scales. Mesothoracic coxae fuscous, pale buff ventrally, with distal patch of tawny scales; femur shining fuscous, pale buff ventrally; tibia shining fuscous, pale buff ventrally; tarsomeres with acute triangular shining fuscous scales, each tarsomere distally ringed with pointed contrasting pale buff scales. Metathoracic coxae pale buff; femur pale buff; tibia pale buff, tibial spurs from pale buff to fuscous; tarsomeres pale buff. Forewing: length 5.2–7.0 mm, mean 6.3 mm, n = 62. Ground color buff, pale buff, and reflective pale buff, basal \( \frac{2}{3} \) of many scales reflective; markings delineated with salmon-, kingfisher rufous-, and reflective pale buff scales; basal fascia buff basally, darkening outwardly, outlined with reflective scales; median costal fascia in two parts, from costa to \( \frac{2}{3} \) salmon outlined with burnt orange, distal \( \frac{2}{3} \) buff and salmon, few distal burnt orange scales; median dorsal fascia offset from inner margin by reflective scales, triangular, salmon outlined with burnt orange, acute mid-wing point at edge of cell; basal subcosta and costal subapical patch buff and salmon; subterminal area alternating patches of buff and reflective scales with occasional burnt orange scales; fringe reflective pale buff. Underside mostly fuscous with patches of reflective scales appearing striated, subterminal cells between veins with pale reflective scales, veins dark, terminal line pale; outer half of costa buff crossed with narrow fuscous bars; fringe reflective pale scales. Hindwing: Ground color reflective pale with fuscous-tipped scales giving a striated pattern; veins slightly darker; fringe pale at base, darkening to pale fuscous, terminal \( \frac{2}{3} \) pale. Underside ground color reflective pale fuscous with darker-tipped scales appearing striated; costal \( \frac{2}{3} \) darker; Sc, R, and M1 veins lined with contrasting dark-tipped scales. Abdomen: First tergite with base smoothly scaled mesally, reflective pale buff, rest of tegrite pale fuscous; segments 2–7 pale buff basally, pale fuscous distally giving a ringed appearance; terminal segment pale fuscous. Genitalia (Fig. 2a, b): Tegumen robust. Socii joined from base to \( \frac{2}{3} \) length, distally sickle shaped as for genus. Uncus absent. Gnathos absent. Transtilla well developed with elongate mesal process. Vinculum arms free. Valva with two lobes broadly connected, outlined with dense setae appearing fuzzy; apex at costa ending in a short tooth; saccular area expanded with large basal lobe. Aedeagus curved ventrally with broad terminal ventral tooth, cornuti absent. Adult female: Superficially similar to male except sensory setae on ventral surface of antennae sparse, no longer than width of flagellar segment. Forewing: length 5.9–7.3 mm, mean 6.9 mm, n = 6. Genitalia (Fig. 2c): Ovipositor lobes elongate, narrow, lightly sclerotized. Anterior and posterior apophyses slender. Eighth sternum heavily sclerotized, lateral ovoid sclerotized areas conspicuous. Ductus bursa heavily sclerotized; longitudinal ridges, slightly curved from right to left. Corpus bursae transparent, coalescent with ductus bursa, extending under eighth sternum on left side and posterior to opening of ductus bursae. Signa absent.

Figure 2. Genitalia of *Aethes patricia* Metzler new species: a, male genital capsule, aedoeagus removed. b, aedoeagus. c, female genitalia.
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Paratypes collected by Eric H. Metzler were deposited in the collections of John G. Franclemont, Cornell University, Ithaca, New York; The Ohio Lepidopterists, Ohio State University Museum of Biological Diversity, Columbus, Ohio; Natural History Museum of Los Angeles County, Los Angeles, California; Michigan State University, East Lansing, Michigan; Eric H. Metzler, Columbus, Ohio; Canadian National Collection, Ottawa, Ontario; American Museum of Natural History, New York, New York; The Natural History Museum, London, England; Florida State Collection of Arthropods, Gainesville, Florida; Institute of Systematics and Experimental Zoology, Kraków, Poland; and Carnegie Museum of Natural History, Pittsburgh, Pennsylvania.

Distribution and Biology. Aethes patricia occurs from Ohio, north to Kalamazoo Co., Michigan, and west to Iowa (Fig. 4). The specimens from Adams, Erie, Lucas, and Wyandot counties, Ohio and northwestern Indiana were collected in high-quality prairies and oak savannas. No specimens of A. patricia were collected in traps placed in adjacent second-growth forests, or old fields, on the same nights. The life history is unknown.

Etymology. This species is named for my constant companion and spouse, Patricia A. Metzler, who assisted me with all my research in prairies in Ohio, Indiana, and Iowa. Patricia is a noun in apposition.
Discussion. One male from Erie Co., Ohio is heavily flushed with burnt orange scales thus giving it a different appearance. No specimens tabulated in the database of nearly 100,000 records of the Ohio Survey of Lepidoptera, supported with funds donated to the Ohio Wildlife Diversity & Endangered Species Program, nor any specimens in the extensive collections of Lepidoptera made by Annette F. Braun in diverse habitats in Ohio, were collected outside high quality prairies in Ohio. This description provides a name for a species that, in Ohio and northwest Indiana, may be prairie remnant dependent (Panzer et al. 1997). The type locality is one such habitat owned by the Ohio Division of Wildlife. Several other agencies and organizations, including The Nature Conservancy, Ohio Division of Natural Areas and Preserves, Indiana Division of Nature Preserves, and Toledo MetroParks, which own these properties, can add this to the list of species which inhabit prairies under their stewardship.

Cochylis ringsi Metzler, new species (Figures 1b, 3, 5)

Diagnosis. Cochylis ringsi is tentatively described in the genus Cochylis based on a combination of characters including uncus absent, basally fused triangular socii originating from the tegumen, cleft valva with prominent saccular area, vinculum arms free, stout transtilla, short ductus bursa, and bulbous corpus bursa with complicated sclerotized structures posteriorly. The adult is recognizable by the pale, buff-white forewing ground color with a salmon- and kingfisher rufous-colored median continuous excurved fascia outlined with metallic white-gold scales. The basal fascia blends into the basal area. This species most closely resembles Aethes patricia and looks similar to A. argentilimitana (Robinson, 1869). Cochylis ringsi can be distinguished from both by the genitalia. The socii of the genus Aethes are sickle shaped, and the socii of C. ringsi are not sickle shaped. Cochylis ringsi is the only species of the genus Cochylis in the Nearctic with metallic white-gold scales outlining a continuous excurved salmon- and kingfisher rufous-colored median fascia.

Description. Adult male (Fig. 1b): Head: Vertex tufted salmon-colored laterally integrating to pale buff medially. Front tufted, a mixture of buff, white, and reflective white scales medially, integrating to salmon laterally, and burnt orange ventrally. Labial palpus with basal segment short, smoothly scaled, salmon-colored scales distally with burnt orange; median segment more than one half total length, smoothly scaled laterally, ventral and dorsal tufts, inner surface white, ventral, lateral, and dorsal surfaces distally pale buff changing to salmon, some scales distally burnt orange; apical segment short, smoothly scaled, inner surface white, outer surface buff with specks of burnt orange. Antenna filiform, scape mostly salmon-colored, pale buff dorsally, ventral surface naked, base of each segment with dense half circle of sensory setae, many longer than width of flagellar segment. Thorax: Patagium and tegulae salmon anteriorly, blending to pale buff posteriorly; posterior scales of tegulae upturned, sometimes recurved anteriorly. Metathorax dorsally tufted, salmon-colored laterally, blending to pale buff medially, underside smoothly scaled, buff. Legs: Prothoracic coxae dorsal surface raw amber basally, blending to burnt amber distally, pale buff ventrally; femur raw amber dorsally, pale buff ventrally; tibia with acutely pointed triangular burnt amber scales dorsally, pale buff ventrally; tarsomeres with acute triangular dark tipped shining gold scales dorsally, chamois-color ventrally, pointed contrasting pale buff scales distally. Mesothoracic coxae pale buff; femur raw amber dorsally, pale buff ventrally; tibia with acutely
Figure 3. Genitalia of Cochylis ringsi new species: a, male genital capsule, aedoeagus removed. b, aedoeagus. c, female genitalia.
pointed burnt umber-color tipped triangular scales, pale buff ventrally; tibial spurs with acutely pointed burnt umber-color tipped triangular scales; tarsomeres with acute triangular dark tipped shining gold scales dorsally, chamois-color ventrally, pointed contrasting pale buff scales distally. Metathoracic coxae pale buff; femur pale buff; tibia pale buff; tibial spurs pale buff, a few fuscous scales; tarsomeres acutely pointed scales shining pale buff, a few fuscous scales. *Forewing:* length 4.5–7.3 mm, mean = 5.5 mm, n = 80; ground color and fringe pale pinkish buff; markings delineated with salmon-, kingfisher rufous-, and metallic white-gold scales; basal fascia, median fascia, and base of costa defined by conspicuous kingfisher rufous scales, indistinct salmon scales, and outlines of metallic white-gold scales; basal fascia blends into basal area; median fascia slightly offset distally at M1; costa, inner margin, and outer margin with small spots of kingfisher rufous scales, terminal area outlined with metallic white-gold scales. Under-side mostly fuscous; outer half of costa buff, crossed with narrow fuscous bars; fringe buff. *Hindwing:* Ground color pale drab, slightly paler towards base; veins lined with fuscous; fringe contrastingly pale, base buff, followed by a pale drab line, outer ½ of fringe pale. Underside reflective pale horn color, costal area marked with scattered pale drab scales, Sc, R, and M1 veins.
lined with contrasting dark tipped-scales. **Abdomen:** First terga smoothly scaled, buff; terga 2–7 and sterna pinkish buff, terminal segment buff. **Genitalia** (Fig. 2a, b): Uncus absent. Socii triangular joined from base to ⅔ length, setose. Gnathos absent. Transtilla well developed, mesially constricted. Tegumen robust. Vinculum arms free. Valva broad and elongate, apex at costa ending in a short tooth, dense stout setae on costa and outer margin pointed dorsally. Sacculus robust, elongate, large basal lobe, distal ⅔ with dense stout setae pointed distally. Juxta shield-shaped. Aedeagus curved ventrally 35° near middle, vesica with dense scobinations; cornuti absent. **Adult female:** superficially similar to male except sensory setae on ventral surface of antennae sparse, no longer than width of flagellar segment, and color of legs. Prothoracic coxae pale horn-color mixed with fuscous dorsally, pale buff ventrally; femur pale horn-color mixed with fuscous dorsally, pale buff ventrally; tibia acutely pointed triangular scales pale horn-color with pale fuscous dorsally, pale buff ventrally; tarsomeres with acute triangular dark tipped shining gold scales dorsally, chamois-color ventrally, pointed contrasting pale buff scales distally. Mesothoracic coxae pale horn-color mixed with fuscous dorsally, pale buff ventrally; femur pale horn-color mixed with fuscous dorsally, pale buff ventrally; tibia with dark tipped shining gold scales, tibial spurs

Figure 5. Distribution records of *Cochylis ringsi* Metzler new species.
with dark tipped shining gold scales; tarsomeres with acute triangular dark tipped shining gold scales dorsally, chamois-color ventrally, pointed contrasting pale buff scales distally. Metathoracic coxae pale buff; femur pale buff; tibia pale buff, tibial spurs pale buff; tarsomeres pale buff.

**Forewing:** length 5.0-5.7 mm, mean = 5.3 mm, n = 7. Genitalia (Fig. 2c): Ovipositor lobes elongate, narrow, lightly sclerotized. Anterior and posterior apophyses slender. Eighth sternite and tergite heavily sclerotized. Ductus bursa a short sclerotized ring. Corpus bursa bulbous, attached to the ductus bursa by a narrow membranous ring, heavily sclerotized posteriorly with lateral sclerotized lobes, right lobe surrounds a tear-drop shaped membranous structure, left lobe shorter, a wrinkled margin surrounds an ovoid shaped membranous structure. Signa absent.


EHM 233), 1 ♀, R. Acciavatti (CMNH). Charleston South Hills, 1 VII 1989, 1 ♀, Val Albu (VAIC). Paratypes collected by Eric H. Metzler were deposited in the collections of Roy W. Rings, Palmetto, Florida; John G. Francelmont, Cornell University, Ithaca, New York; The Ohio Lepidopterists, Ohio State University Museum of Biological Diversity, Columbus, Ohio; Natural History Museum of Los Angeles County, Los Angeles, California; Michigan State University, East Lansing, Michigan; Eric H. Metzler, Columbus, Ohio; Canadian National Collection, Ottawa, Ontario; American Museum of Natural History, New York, New York; The Natural History Museum, London, England; Florida State Collection of Arthropods, Gainesville, Florida; Institute of Systematics and Experimental Zoology, Kraków, Poland; and Carnegie Museum of Natural History, Pittsburgh, Pennsylvania.

**Distribution and Biology.** Cochylis ringsi has been found from South Carolina to Indiana and Alabama, west to Iowa, Missouri, Oklahoma, and Arkansas (Fig. 5). The specimens from northwestern Indiana were collected in high-quality oak barrens on sandy soils. No specimens of *C. ringsi* were collected in traps placed in nearby second-growth forests, prairies, wet meadows, nor old fields, on the same nights. The life history is unknown.

**Etymology.** This species is named for my very close friend, and colleague, Roy W. Rings; ringsi is the possessive genitive case.

**Discussion.** The characters of this species are not congruent with any described genus of Cochylini, and placement in the genus *Cochylis* is tentative. *Cochylis ringsi* lacks the elongate mesal process of the transtilla, present in most species of *Cochylis*. Most females of the similar Palaearctic genus *Stenodes* have an elongate ductus bursa, and sclerotizations of the corpus bursa are not at the juncture of the ductus bursa and the corpus bursa. Until a complete analysis of generic characters provides a better definition, a proposal for a new genus is premature. I selected a genus already recorded from the Nearctic.

This description provides a name for a species that, in northwest Indiana, occurred in two high-quality oak savannas. The type locality located within the larger Kankakee macrosite, is one such habitat owned by the Indiana Chapter of The Nature Conservancy, and is managed as a reservoir of biodiversity. Conrad Savanna is actively managed to enhance and maintain a mosaic of oak barrens/savanna and prairie habitats.

**ACKNOWLEDGMENTS**

I am indebted to Michael G. Pogue for providing me with access to his files on the Cochylini of North America. P.T. Dang allowed me to photograph the types and genitalia of Cochylini in the Canadian National Collection. Patricia A. Metzler, my wife and constant companion, and my mother, Lois Metzler, faithfully carried collecting equipment, lent support, and provided excellent company on many collecting trips. For lending specimens I thank George J. Balogh; Kathleen R. Zeiders, Illinois Natural History Survey; Philip Parrillo, Field Museum of Natural History; John A. Rawlins, Carnegie Museum of Natural History; John W. Brown, U.S. National Museum of Natural History; Richard L. Brown, Mississippi Entomology Museum; E. Richard Hoebeke, Cornell University; Bryant Mather; Valeriu Albu; and Don Azuma, Philadelphia Academy of Natural Sciences. Charles V. Covell, Jr., P.T. Dang, Julian P. Donahue, John B. Heppner, Ron Leuschner, Eric L. Quinter, Jozef Razowski, Michael Sabourin, William E. Miller, Jim Vargo, and Donald J. Wright searched for specimens in collections under their care. This research was funded by The Nature Conservancy, Indiana Chapter under a KOSE.
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LITERATURE CITED


PITCH MASS BORER, A NEW CLEARWING MOTH RECORD FOR OHIO
(LEPIDOPTERA: SESIIDAE)

Foster Forbes Purrington and David J. Horn

ABSTRACT

We report the Pitch Mass Borer clearwing moth, Synanthedon pini, from Vinton Furnace Experimental Forest, Dundas, Vinton County, Ohio, the first record for this state. A mature larva and two pupae were excised from resin masses of Scrub Pine, Pinus virginiana, a new host record, in early May 1999.

Approximately 30 species of clearwing moths (Lepidoptera: Sesiidae) were listed from Ohio in 1987 by Purrington and Metzler (1987), based primarily on voucher specimens kept in two research collections housed at the Museum of Biological Diversity of The Ohio State University, namely The O.S.U. Collection of Insects and Spiders, and the moth and butterfly collection of the Ohio Lepidopterists. Recently we recorded the capture of Synanthedon arkansasensis Duckworth & Eichlin for the first time in Ohio (Purrington and Horn 1996). Here we newly report the presence of the Pitch Mass Borer, S. pini (Kellicott) in this state, and we record it in a new host, scrub pine, Pinus virginiana Mill.


The life cycle of the eastern pitch mass borer is apparently two years, like that of its two western congeners, S. novaroensis (Hy. Edwards) and S. sequoiae (Hy. Edwards) (Eichlin and Duckworth 1988). Hosts are all Pinaceae, especially white pine, Pinus strobus and Norway spruce, Picea abies. Several other pines and spruces have been reported as hosts.

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RESULTS AND DISCUSSION

On 5 May 1999 we extracted a mature larva and two teneral S. pini pupae from resinous masses on boles of Scrub Pine, Pinus virginiana. Host trees were ca. 35 cm DBH, and part of a local concentration of this pine that is otherwise widely and thinly scattered in an upland mixed-oak forest comprising the Vinton Furnace Experimental Forest near Dundas, Vinton County, in southeastern Ohio. This forest is ca. 60 years old, and co-managed by Mead Paper Co. and the USDA Forest Service.

Braun (1961) notes native scrub pine is widespread in Ohio, especially on non-calcareous soils of disturbed areas. It is the most common of native pines in southeastern Ohio (Dean et al. 1946).

All three immature S. pini remained alive for at least ten days. By 17 May the larva and one pupa had died. The remaining pupa was darkening, with blue-black scales visible on the abdominal terga contrasting vividly with the orange tergum of abdominal segment four, by which both sexes of S. pini can be diagnosed. However, this second pupa also failed to eclose. All three specimens are retained as vouchers in the Departmental collections.

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LITERATURE CITED

WILLIAMSONIA LINTNERI (ODONATA: CORDULIIDAE)—A FIRST MICHIGAN RECORD WITH ADDITIONAL NOTES ON W. FLETCHERI

Stephen Ross¹ and Mark F. O'Brien²

ABSTRACT

Williamsonia lintneri is newly recorded for Michigan, and additional Michigan sites are given for W. fletcheri. Both species appear to be bog/fen-obligate inhabitants, and adults may appear as early as late April in Michigan. In addition, the North American distributions of both species are summarized.

The genus Williamsonia contains two bog-obligate corduliid species found primarily in eastern North America. Williamsonia fletcheri Williamson (the ebony bog-haunter), known from Manitoba eastward (Walker and Corbet 1975), and Williamsonia lintneri Hagen (the ringed bog-haunter), formerly characterized as a NE North American species, with records from New England and the Atlantic Provinces of Canada (Howe 1923, Carpenter, 1993, and summary below). Until quite recently, the larva of W. fletcheri was unknown (Charlton and Cannings 1993), while the larva of W. lintneri was described earlier (White and Raff 1970). These two enigmatic species have been sporadically collected anywhere in their range, and have been characterized as “rare” by most authors.

In 1998, W. lintneri was photographed in Wisconsin (Legler, et al. 1998), and in late April 1999 members of the Michigan Odonata Survey (MOS) were alerted to search for Williamsonia in bog habitats.

On 2 May 1999, the senior author (SR) searched a potential bog habitat in Sheridan Twp., Mecosta Co. After searching among the leatherleaf (Chamaedaphne calyculata), SR proceeded down a two-track path through an aspen growth slightly elevated above the surrounding cedar-woodland wetland. The area then opened up into a shrubby wetland with a path cut through it, apparently illegally (on State land) by someone with an off-road type vehicle. This path led through the swamp for more than a quarter mile. SR searched the length of this path before coming to private land. On return, near the end of the path shortly before re-entering the woodland, a small dragonfly—one of only a few seen in this habitat—was observed sunning itself on a discarded pallet. This specimen turned out to be Williamsonia lintneri, a new Michigan record (Fig. 1). The specimen was preserved and sent to the junior author for verification, and has been deposited in the Univ. of Michigan Museum of Zoology (UMMZ) (#MOS0020630). Subsequently, three other individuals were observed near the same location, two on 9 May

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in a sandy two-track about 0.5 miles from the original site and one on 11 May
very near the original site of discovery.

On several visits afterward no other W. lintneri were found. However, on
9 May, one Williamsonia fletcheri (Fig. 2) was collected in the wetland area
near the site of the original location for W. lintneri. On 11 May three more
were found in the same sandy two-track and one more W. fletcheri was found
nearly a mile away on a gravel road amid numerous tenereal Leucorrhinia in-
tacta (Hagen). The W. fletcheri was easily recognized from the yellow-spotted
Leucorrhinia by its distinctive three light rings on a black abdomen. Both
taxa were easily approached while sunning to dry their still shiny wings
from recent emergence.

The site where Williamsonia was found contributes to the headwaters of
the east branch of the Little Muskegon River by seepage through the large
area of approximately seven sections of wetland in northeastern Martiny and
northwestern Sheridan Townships of Mecosta Co. In the immediate area of
wetland where W. lintneri was found the following plants were noted: Sphag-
num spp. moss, both in standing water and on hummocks; the ferns Ono-
cla sensibilis, Osmunda regalis and O. cinnamonea; Spirea alba, Viola renifolia,
Caltha palustris and several Carex spp. Larger species of plants include the
predominant (about 50%) Vaccinium corymbosum and Ilex verticillata, with
Cornus stolonifera, Alnus rugosa, Populus tremuloides, Acer rubrum, Betula
papyrifera, Salix sp., and Larix laricina comprising the remaining woody
plants.

Other dragonflies in the wetland area were few, but included Epitheca
spinigera Selys, Epitheca canis MacL., and several damselflies, probably
Enallagma boreale Selys and E. cyathigerum (Charp.).

**Additional records for W. fletcheri in Michigan.** Williamsonia
fletcheri, by its very nature of being a spring-emerging species, and a bog-fen
inhabitant, has been collected only rarely in Michigan. Now that MOS activities have placed importance on collecting early in bog habitats, people in the field have turned up more records in the past three years. The following records are not previously recorded in the literature: **MICHIGAN**: Mecosta Co., Sheridan Twp., 05/09–05/11/1999, S. Ross [UMMZ]. Grand Traverse Co., Lost Lake Bog, SW Corner, T27N/R12W/S31, 05/11/1999, Carl Freeman, 1 ♂, [UMMZ]. **Chippewa Co.** Drummond Island-Maxton Plains, 05/30/1997, George Balogh, 1 ♂, [UMMZ]. **Chippewa Co.**, Taquemonon Falls State Park, T49N/R9W, 05/25/1995, David Cuthrell, 1 ♂, [MNFI]. **Chippewa Co.**, Betsy Lake Research Area, T49N/R7W/S09, 05/24/1967, 1 [MNFI]. **Schoolcraft Co.**, Sturgeon Hole Bog, T42N/R16W/S13and14, 05/24/1964, [MNFI]. **Schoolcraft Co.**, Manistique, 05/29/1960, R.L. Fischer, 2m, 1 ♀, [MSU].

**DISTRIBUTION SUMMARIES**

**Williamsonia fletcheri**: CANADA: MANITOBA (Howe 1923, Walker and Corbet. 1975); NEW BRUNSWICK (Walker and Corbet 1975), NOVA SCOTIA (Brunelle 1997b); ONTARIO (Williamson 1923, Walker and Corbet 1975); QUEBEC (Walker and Corbet 1975, Hutchinson and Menard 1999). USA: MAINE (Montgomery 1943); MASSACHUSETTS (Howe 1923, Montgomery 1943 Nikula and Sones 1998); MICHIGAN (Gloyd 1932, Foley 1969, this paper); NEW YORK (Beatty and Beatty 1969, Donnelly 1992a, b; 1993); WISCONSIN (Smith, Vogt and Gaines 1993).

**Williamsonia lintneri**: CONNECTICUT (Wagner and Thomas 1999); MAINE (McCollough 1997, Brunelle 1997a); MASSACHUSETTS (Calvert 1915, Howe 1923, Davis 1940, White and Raff 1970, Nikula and Sones 1997, 1998); MICHIGAN (this paper); NEW HAMPSHIRE (White and Morse 1973); NEW JERSEY (Davis 1913, Barlow 1993); NEW YORK (Howe 1923, Donnelly 1992); RHODE ISLAND (Carpenter 1993, 1998); WISCONSIN (Legler, et al. 1998).
DISCUSSION

Based upon our observations and recent discoveries by others, it appears that *W. lintneri* is far more widespread than previously thought. Further efforts to locate additional populations of this species should concentrate in bog and poor fen wetlands with hummocks and standing water bordered by shrub-carr habitat. These fen-bog-marsh complexes may have floating sphagnum mats or hummock areas with open pools that probably contain *Williamsonia* larvae. The date of 2 May is not the earliest date for *W. lintneri*, indicating that this species may possibly be flying as early as late April in Michigan. According to L.W. Ruth (pers. comm., April 1999), *W. lintneri* started emerging on 26 April in Connecticut, and Howe (1923) gives 1 April–4 June as a range of dates for *W. lintneri*. The record of *W. fletcheri* from Mecosta Co. is the southernmost record for the state. The 9 May record is also the earliest thus far in the state. Whether these early dates are normal or a result of recent warm springs is unknown. It is obvious that only a concerted effort to survey bog and fen habitats in April and May will produce a better overall picture of the distribution and abundance of these two species in Michigan. The amount of potential habitat is indeed staggering, compared to the small sites found in New England. The fact that *W. lintneri* has escaped our notice in the upper Great Lakes region until very recently is a sign that increased attention to our Odonata fauna is resulting in many new state records and range extensions.

ACKNOWLEDGMENTS

We thank David Cuthrell of the Michigan Natural Features Inventory for sharing data [MNFI]; Carl Freeman and George Balogh for their efforts. We also thank Dr. F. W. Stehr for access to the Michigan State Univ. Insect Collection [MSU], and Linda W. Ruth for alerting us to *W. lintneri* habitats. This work was partially funded by U.S. Forest Service Grant #USDA-G-23-98-21-RJVA. This is a publication resulting from the work of the Michigan Odonata Survey.

LITERATURE CITED

SEX RATIO AND SEXUAL DIMORPHISM IN FORMICA EXSECTOIDES,
THE ALLEGHENY MOUND ANT (HYMENOPTERA: FORMICIDAE)

H. C. Rowel, 1, 2 and C. M. Bristow 1

ABSTRACT

We excavated 66 mounds from 6 populations of Formica exsectoides in Michigan jack pine, collecting sexual caste pupae for sex ratio estimates and measurement of dimorphism. Reproductive caste brood was present in only 37 of the 66 mounds, and presence of reproductive caste brood was associated with larger mound surface area. Females were heavier than males, but did not differ from males in energy density. Sexes did not differ in timing or rate of development. Sex ratio estimates based on individual mounds ranged from 1.0 (all male) to 0.08 (female-biased). Four of the six study populations were strongly male-biased, while sex ratio estimates for the remaining populations did not differ from equal investment. While this interpopulation variation may be caused by genetic factors, the equal investment populations were located in or near patches of clear-cut forest, suggesting that environmental impacts should be investigated.

The conspicuous nests of Formica exsectoides Forel, the Allegheny mound ant, are a visual echo of its great ecological importance. Ranging from Ontario to Tennessee and northern Georgia, F. exsectoides form dense populations along forest edges and in persistent grassy clearings (Creighton 1950). In the Great Lakes region, these ants are an important feature in jack pine forests (Bristow et al. 1992). While extensive descriptions of the physical structure, placement, and orientation of mounds exist (McCook 1877, Andrews 1926, Andrews 1929, Cory and Haviland 1938, Haviland 1948, Dimmick 1951), information on the biology of the builders is more limited.

High-density populations of F. exsectoides can dominate the jack pine (Pinus banksiana) landscape in northern and central Michigan. As both ground-level and arboreal predators and participants in mutualistic tending relationships with multiple groups of phloem-feeding homopterans, F. exsectoides may play a vital role in the structure and linkage of ground-dwelling and arboreal communities (Bishop 1998).

F. exsectoides possesses an unusual suite of reproductive and behavioral traits. New colonies are founded through temporary social parasitism of Formica fusca L., in which F. exsectoides queens enter an established F. fusca colony and replace its queen (Wheeler 1933, Starr 1979). F. exsectoides colonies are polygynous (possessing multiple queens) (Bristow et al. 1992).

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Colonies may expand through nest budding; the departure of a queen or queens and a group of workers to establish a new mound (Franks and Holland 1987). This process does not entail complete separation from the "parent" mound, and thus creates colonies that are polydomous (occupying multiple nests) (Oster and Wilson 1978). Finally, F. exsectoides colonies show an unusual lack of intercolony aggression. Greater knowledge of their reproductive biology is essential for understanding how these ants colonize and expand within habitats.

Reproduction, and sex ratio in particular, is of great interest in the study of ants and other social Hymenoptera. Hymenoptera possess a haplo-diploid system of sex determination, which may lead to increased relatedness between diploid female offspring and decreased relatedness between female offspring and their haploid brothers. In Hymenoptera, sex ratio often varies from the equal investment predicted by Fisher (1939), and may be influenced by asymmetric relatedness among siblings, environmental factors, and genetically and environmentally influenced variation in sexual dimorphism.

The extent of sexual dimorphism in weight, energy content, and metabolic costs affects sex ratio and is a key determinant of how investment should be estimated (Boomsma et al. 1995). Simply counting the number of males and the number of females produced by a colony will only reflect true investment if males require the same input as females. While weight is most commonly used as a surrogate measurement for investment, Boomsma (1989) found that this led to an overestimate of colony investment in females, by overlooking the higher respiration rate of males. Boomsma's proposed correction is now widely employed, but few studies investigate other possible differences between males and females, such as energy density, which might obscure true investment ratios.

The abundance of variation in hymenopteran sexual investment has fostered the growth and testing of a rich body of evolutionary theory concerning kin selection, parent-offspring conflict and the evolution of sociality (Hamilton 1964, Trivers and Hare 1976, Charnov 1982, Nonacs 1986, Crozier and Pamilo 1996). The unusual biology of F. exsectoides makes it potentially informative to this theory (Oster and Wilson 1978, Starr 1979, Bourke and Franks 1995), but useful tests are impossible without prior information on reproductive biology and sex ratio.

The purpose of this study is to describe sex ratio in F. exsectoides. This description necessarily includes measurement of sexual dimorphism in both weight and energy content, interpopulation variation in sex ratio and dimorphism, and potentially correlated colony characteristics such as mound size and spacing. These data are an essential foundation for further study of this species. While such data may be the basis for predictions in testing sex ratio theory, knowledge of F. exsectoides reproduction will also improve understanding of this ecologically complex ant species and be of broad use to researchers interested in the biology and conservation of other members of the jack pine community.

METHODS AND MATERIALS

Site locations. Study sites were located in Oscoda, Crawford, and Roscommon counties, in the northern lower peninsula of Michigan. Because all sites were noncontiguous and located at least 1 km apart, we assumed discrete populations. Vegetation consisted predominantly of jack pine with interspersed red pine (Pinus resinosa), northern pin oak (Quercus ellipsoidalis), and cherry (Prunus spp.). Understory vegetation consisted primar-
illy of blueberry (Vaccinium angustifolium), sand cherry (Prunus pumila), bracken fern (Pteridium spp.) and grasses (Carex spp.). All sites were located in 50 to 70 year-old stands, with the exception of site 4, which had been recently clear-cut.

**Brood collection and measurement.** Partial excavations of 66 mounds from 6 sites were performed from 18 July to 26 July 1996. For each mound, a comparative index of mound surface area (longest slope x shortest slope) and the distance to the nearest neighboring mound were recorded. Presence or absence of reproductive caste brood was determined by excavating the mound to approximately 0.5 m below ground level (or until reproductive caste pupae were found). Reproductive caste pupae are easily distinguished from worker pupae by size and coloration.

Samples of 30–90 reproductive caste pupae were collected from mounds found to contain reproductive caste brood. Pupae were dried and weighed. Sex was determined visually after removing the pupal case. Some pupae had not developed enough for sex to be distinguishable by morphology; these were scored as “undeveloped” and excluded from further analysis. Stage of pupal development was scored from 0 (undeveloped) to 3 (fully developed, pigmented, ready to eclose). A few adults had partially emerged—these were given a score of 3.5. Analysis of covariance was used to analyze pupal dry weights, with sex as the primary analysis variable and stage of development as the covariate (PROC ANCOVA, SAS Systems Inc., 1990).

**Energy content.** Caloric densities of pupae were measured using a semi-micro calorimeter (Parr Instrument Company, Moline, IL). Heat of combustion in calories/g ($H_c$) was calculated by the equation:

$$H_c = \frac{(B \times \Delta T) - ((f_1 - f_2) \times 1400)}{sample\ weight}$$

where $B$ is a caloric constant, calculated through calibration with benzoic acid, $\Delta T$ is the change in temperature occurring during combustion, and $(f_1 - f_2) \times 1400$ is a correction factor accounting for the amount of fuse wire used to ignite the sample.

Since measurement accuracy declines sharply in samples below 0.01g weight (Parr 1991), 3–5 individuals of each sex were measured together. At least three samples from each site were analyzed to determine energy content of males; it was often not possible to analyze three (or any) samples of females, as fewer females were available. The data were analyzed using a nested analysis of variance in the following hierarchy: days (mounds (sex)). The variable “days” accounts for variation in calorimeter performance during the analysis.

**Calculation of sex ratio.** Sex ratio was estimated numerically (number of males/total number of pupae) and by dry weight (dry weight of males/dry weight of total sample). As pupae within samples were usually of the same developmental stage, weights were not corrected for developmental stage. Numerical and weight-based sex ratio estimates were compared to each other using a paired t-test. As male ants have been shown to have higher respiration rates than females (MacKay 1985, Boomsma 1989), weight-based sex ratios were corrected for differences in metabolic rate using Boomsma’s (1989) energetic cost ratio. These corrected ratios were compared between mounds and between sites using a nested analysis of variance. Boomsma-corrected sex ratios were also correlated to mound surface area and distance to nearest neighbor using PROC CORR (SAS Systems Inc., 1990).
Table 1. *Formica exsectoides* sampling data and sex ratios, by site. \( n \) = total number of pupae collected, \( n_r \) = number of pupae used to calculate sex ratios, \( M_n \) = numerical proportion of males in total sample, \( M_w \) = proportion of male investment by dry weight, \( M_{bw} \) = Boomsma (1989) cost ratio. Boomsma cost ratio is generated by correcting dry weight ratios with Boomsma's (1989) energetic cost ratio: (weight males/weight total)^0.7.

<table>
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<th>Mounds</th>
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<th>Sampled</th>
<th>n</th>
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<th>( M_n )</th>
<th>( M_w )</th>
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<tr>
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<td>64</td>
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<td>222</td>
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RESULTS

**Mound measurements and collection of brood.** Reproductive pupae were only found in 37 of 66 partially excavated mounds. Of these 37, only 33 mounds contained sufficient pupae (25-30) for sex ratio sampling. Table 1 provides a summary of excavations, sampling, and sex ratios for each site. Sites 4 and 6 contained relatively few mounds. A total of 1530 pupae were collected. Twenty pupae were removed from the analyses due to damage that caused inaccuracy in weight measurements or uncertainty about sex. Of the remaining sample, 134 pupae had not developed sufficiently for sex to be morphologically distinguishable; these were classified as "undeveloped", and are subtracted from the total pupae sampled to provide the value \( n_r \) (number of pupae for ratios) shown in Table 1.

Mound surface area ranged from 0.9 m² to 12.5 m². Distance to nearest neighboring mound ranged from 1 m to 51 m. Only active/inhabited mounds were counted as "neighbors". The mean surface area index for mounds found to produce sexual brood was marginally greater than that for mounds that produced only worker brood (\( F = 3.84, \text{df}_e = 46, p = 0.0560 \)), but this relationship was variable among sites (Figure 1). Distance from nearest neighboring mound did not appear to be associated with production of sexual brood (\( F = 0.03, \text{df}_e = 46, p = 0.8662 \)) (Figure 2).

**Weight and development.** Females were heavier than males (\( F = 160, \text{df}_e = 1353, p < 0.0001 \)). The mean female weight (least squares mean, corrected for developmental stage using ANCOVA) across all sites was 0.0101 (stderr = 0.00007; \( n = 276 \)). The mean male weight across sites was 0.0081 (stderr = 0.00004; \( n = 1100 \)).

While significant differences in pupal weights of both sexes existed among sites, variation in weights was also found among mounds within sites. Male and female pupal dry weights are shown in Figure 3.

Some of this weight variation was linked to variation in stage of pupal development. Significant negative regression relationships existed between development stage and pupal dry weight for both sexes (Figure 3). The regression slopes were similar between sexes, but development stage explained less variation in male weight (\( r^2 = 0.1787 \)) than in females (\( r^2 = 0.2934 \)), due to the presence of outliers in the male weight data. Mean stage of pupal development was not different among mounds or among sites.
Energy Content. There was no significant difference between energy density (corrected Hₑ) of male and female pupae (F = 0.35, dfₑ = 74, p = 0.5576) (Figure 4). The least-squares means of energy density for males was 5526.2 cal/g, and for females 5507.9 cal/g. The overall nested ANOVA model: Hₑ = day (site (sex)) was not significant at p = 0.5001 (F = 0.88, dfₑ = 74). As pupae could not be combusted individually, it was impossible to test for differences in caloric density among stages of development.

Sex Ratios. As males and females were not different in energy content, caloric content data could not be used to estimate sex ratio. Numerical and dry-weight estimates of sex ratio were statistically different (t = 5.64997, df = 32, p = 0.0001). Due to the differences between male and female weights, using numbers of individuals to estimate sex ratio overestimated investment in males by an average of 2.8% compared to estimates based on weights. Whether this difference would be meaningful in a larger context depends largely on the precision of theoretical predictions tested. Applying Boomsma's (1989) correction increases the male bias to a greater extent than using the original numerical investment ratio. As sex ratio estimates based on dry weights seem more accurate in determining investment, and the Boomsma correction is accepted by convention, Boomsma-corrected weight ratios are discussed in the remainder of this article.

Sex ratios were predominantly male-biased, but ranged from all-male (1.0) to almost all-female (0.08). Although considerable variation in sex ratio
Figure 2. Average distance (m) to nearest neighboring mound for *F. exsectoides* mounds with and without reproductive caste brood. The number of mounds sampled at each site is reported in Table 1. Error bars represent one standard deviation.

was present within sites, polydomy of *F. exsectoides* colonies makes mound to mound comparisons questionable without further genetic information. Thus sex ratio estimates from all mounds within a site are treated as samples of a single population, and only comparisons between population averages were performed. Population mean numerical and weight-based sex ratios are shown in Table 1.

Analysis of variance showed differences in sex ratio among sites ($F = 3.1$, $df_e = 27$, $p = 0.0245$) (Figure 5). Sites fell into two categories: male-biased (sites 1, 2, 3, & 6), and sites with sex ratios not differing from 50/50 or equal investment (sites 4 & 5). Sites 4 and 5 contained male-biased mounds, but these were balanced by female-biased mounds.

**DISCUSSION**

**Mound measurements and collection of brood.** The relatively low percentage of *F. exsectoides* mounds containing reproductive brood may be explained in the context of a polydomous colony—one or a few mounds within the colony may contain all of the colony's sexual offspring. The environment in some mounds might be better suited for production (or pupation) of sexual offspring. Gain in efficiency of brood care might arise from clustering sexual brood in a few mounds, rather than scattering it among many. Alternatively,
Figure 3. Dry weight (g) of male and female *F. exsectoides* sexual caste pupae. Developmental stages are based on pigmentation, sclerotization, and definition of adult features. These stages range from 0 (still larval, unable to determine sex by morphology) to 3.5 (partially emerged from cocoon). Regression slopes shown were significant at $p < 0.0001$.

A lack of production of sexual forms may reflect allocation to asexual colony expansion (budding). Budding should be a more successful method of expansion within habitats, since it does not depend on availability of *F. fusca* host nests. Alate sexual forms are usually vulnerable to predation during dispersal (Hölldobler and Wilson 1990), and may be an unnecessary investment in stable habitats.

While mound surface area is not a good surrogate for direct measures of worker population (Cory and Haviland 1938), or even mound volume (Brissetow et al. 1992), the measurement has some value in comparisons between established mounds and newly-formed buds. As mound size increases over time (Andrews 1926, Haviland 1948), the tendency for mounds producing sexual brood to be larger in surface dimensions than mounds producing only workers may reflect differences in colony maturity (Figure 1). Measurements of distance to the nearest neighboring mound may be expected to reflect crowding, local competition for resources, and frequency of budding, all factors of potential influence on reproductive allocation within a mound. Current data do not show an effect of neighbor distance on reproduction (Figure 2).

**Weight and development.** Differences in pupal development within and between mounds may arise from environmental factors (mound temperature, placement of pupae within mound), colony factors (time of egg-laying, maternal effects, nutrition), or genetic factors influencing development time. The data obtained in this study give no indication that males and females...
differ in development rates or emergence times (Figure 3). While sex of “undeveloped” pupae cannot be determined (inviting conjecture that differences in development time may obscure the true sex ratio), relatively equivalent proportions of males and females at each developmental stage lends support to the contention that “undeveloped” pupae represent a random assortment of males and females.

Weight data indicated significant dimorphism between males and females, but the difference between sexes was small relative to that shown by many ant species (Boomsma 1989, Crozier and Pamilo 1996). This is consistent with the founding biology of *F. exsectoides*—species with dependent (non-claustral) founding tactics, such as budding and social parasitism, require less investment per female. Founding biology also explains the lack of difference in male and female energy density, as females do not require large fat reserves for founding new colonies.

The sexual dimorphism in weight was partially masked by the presence of male weight outliers. These were usually males that were as heavy or heavier than females. These males were often also outliers with respect to appearance, possessing disproportionately large heads. The presence of these “heavy” males might indicate a dispersal polymorphism such as that described by Fortelius et al. (1987) and Agosti and Hauschteck-Jungen (1987) in *Formica exsecta* L., in which small males dispersed while larger males mated in the vicinity of the nest. The low frequency of these males among *F. exsectoides* sampled argues against that explanation. Alternatively, these males could be diploid. Nipson's (1978) study, as well as the colony structure and mating behavior of *F. exsectoides*, suggests that significant inbreeding

Figure 4. Energy density ($H_c$, measured as cal/g) of male and female *F. exsectoides* reproductive caste pupae. Error bars represent one standard deviation.
Figure 5. Sex ratio of *F. exsectoides* populations, based on dry weight measurements of sexual caste brood. Boomsma's (1989) correction for metabolic costs has been used. Each value represents the mean of mounds sampled from that site; sampling data are provided in Table 1. Error bars represent one standard deviation. Letters 'a' and 'b' are used to indicate statistically significant differences between populations.

may occur within populations. Inbreeding may lead to the production of diploid individuals homozygous at sex-determining loci—intended females who are morphologically male and reproductively dysfunctional (Crozier 1971, Pamilo et al. 1994). The presence of diploid males as a significant fraction of the reproductive brood produced would lead to overestimation of male investment, and should be investigated in the future.

**Sex Ratio.** The strong male bias in sex ratio displayed by *F. exsectoides* is surprising, as relatedness asymmetries in eusocial Hymenoptera are expected to result in worker preference for a female bias (Trivers and Hare 1976). The male bias observed is consistent with observed sex ratios for other ant species that display colony expansion through budding (Bourke and Franks 1995, Pamilo and Rosengren 1983). Unfortunately, budding is associated with a suite of characteristics, such as polygyny and polydomy that may equally influence sex ratio (Boomsma 1993). The extent of any or all of the above traits may be related to genetic, social, or environmental factors.

Our observation that sites located within (site 4) or near (site 5) recently clear-cut forests had sex ratios not different from 50/50, while all other sites had strongly male-biased sex ratios (Figure 5) suggests an environmental influence. Two environmental factors with strong potential effects on female investment are food and availability of nest sites. Food availability may contribute directly to sex ratio, either through developmental effects (lack of
food results in fewer sexuals, more workers (Deslippe and Savolainen 1995, Herbers and Banschbach 1998) or by influencing reproductive allocation. The theory of local resource competition (Clark 1978) states that, in a resource and dispersal-limited environment, male production will be favored since female offspring will compete directly with the mother for resources. While this theory is not consistent with observations in this study (clear-cut areas may be expected to have reduced food resources), it is possible that differences in sex ratio among sites represent population-level strategies for coping with ecological conditions. The effect of environment on sex ratio may also be indirect. Herbers (1986, 1993) discusses the impact of ecological factors on queen number, which may affect sex ratio by altering the relatedness structure of the colony. Detailed comparisons between populations along a gradient of environmental conditions would be necessary to determine the existence of these strategies and the factors regulating them.

Understanding patterns of reproduction in *F. exsectoides* is an essential preliminary to understanding the population dynamics of this species and how those dynamics shape its relationship to the surrounding community. Factors that make sex ratio studies of *Formica exsectoides* difficult, such as polydomy, social parasitism, and specialization on transient habitats, increase the need to perform such studies, since understanding sex ratio and reproductive dynamics in only discrete, monogynous laboratory colonies gives an incomplete picture of the interaction of genetic and environmental factors in shaping reproductive strategy. Before integrating sex ratio studies in large-scale evolutionary analyses, researchers must understand the extent of variation present. This study indicates that intraspecific variation in sex ratio exists in *F. exsectoides*, whether due to environmental or genetic influences. As significant variation in sex ratio occurred between sites within a specific habitat (jack pine), whole species generalizations of sex ratio based on one or two studies will surely misrepresent true sex ratio dynamics of many ant species.

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LITERATURE CITED


NEW DISTRIBUTION RECORDS FOR MINNESOTA ODONATA

Wayne P. Steffens\textsuperscript{1} and William A. Smith\textsuperscript{2}

ABSTRACT

Several Minnesota state record Odonata, \textit{Aeshna subarctica}, \textit{Ophiogomphus anomalus}, \textit{Stylogomphus albistylus}, \textit{Stylurus scudderi}, and \textit{Coenagrion interrogatum} are reported, along with notes on the distribution and habitat of \textit{Aeshna sitchensis}. New county records for Minnesota Odonata are also reported.

Recent literature on Minnesota Odonata is limited. Hamrun et al. (1971) reported on the county distribution of the seventy Anisopteran species known at that time. Other publications have since become available, but these are not widely known. Carrol and Gunderson (1995) mapped the county distribution for 86 Anisopteran species reported from earlier literature as well as museum specimens, but overlooked the \textit{Aeshna sitchensis} Hagen reported by Walker (1912). We have used their booklet as a guide in determining the new Anisopteran county and state records. Westfall and May (1996) list 30 damselfly species for the state but do not provide any county level information. The most recent published account of the county distribution of Minnesota Zygopterans is Whedon (1914), dealing only with the southern part of the state. All damselflies collected during our surveys were considered county records due to a lack of published data indicating otherwise.

MATERIALS AND METHODS

We collected over 7700 exuviae, larvae, and adults at 85 sites at eastern, central and northern Minnesota rivers and peatlands in 1998 and 1999. An additional 1509 odonate specimens collected between 1991–1998 by other workers were also identified. Voucher specimens of state records will be deposited at the University of Minnesota Insect Collection in St. Paul.

RESULTS AND DISCUSSION

AESHNIDAE

\textit{Aeshna subarctica} Walker. We collected \textit{A. subarctica} in three counties in August 1998. We collected specimens at Pine Creek Scientific Natural

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Area (SNA) in Roseau County, Red Lake SNA in Beltrami County, and Mulligan Lake SNA in Lake of the Woods County. A. subarctica has been reported to inhabit spruce-tamarack bogs (Walker 1958), and that is largely true for these new locations. Most of our specimens were collected in or adjacent to forested black spruce (Picea mariana) and tamarack (Larix laricina) bogs, the former tree being dominant. The groundcover consisted of typical Minnesota bog-forest vegetation including Ledum groenlandicum, Chaemadaphne spp. and other ericaceous shrubs, sedges, and Sphagnum spp. The Pine Creek SNA specimen, an adult male, was collected near the edge of a spring fen and the adjacent bog forest, and one exuvia was collected in a spring fen channel just inside the Manitoba border. A single male and female were collected at Red Lake SNA at the edge of a forested bog and the adjacent fen. At both sites the specimens were collected as they foraged the sparse, stunted conifers of the forested bog edges. The two adult males collected at Mulligan Lake SNA were taken as they foraged along a trail through a spruce and tamarack bog. STATE RECORD.

Aeshna sitchensis Hagen. Though A. sitchensis was reported for Duluth (St. Louis County) by Walker (1912) it had not been confirmed in the state since then. Boole et al. (1974) reported possible larvae of A. sitchensis (and A. septentrionalis), but do not provide a location and place doubt on their own determinations of larval Aeshna. We collected adults in Koochiching, Roseau, and Lake of the Woods counties in August 1998. At the Pine Creek SNA, A. sitchensis were seen numerous times in open areas of fen, and a female was collected in a narrow spring fen clearing. They were also collected in a spring fen in the Sprague Creek SNA several miles to the east. Two males were collected and a female was observed ovipositing in moist peat at the edge of a spring fen channel. The spring channels are choked with bladderwort (Utricularia spp.) and Buckbean (Menyanthes trifoliata), and the pH of surface water was 7.1, as measured with an Oakton® pHTestr 2. Several A. sitchensis larvae were also collected here. The Koochiching County site, Lost River SNA, was a similar spring fen habitat. Three adult males and one larva were collected at Lost River. The Lake of the Woods County adult male was collected at the Winter Lake Road SNA, a large fen/water track dominated by sedges and shrubs. A. sitchensis may be more common in northwest Minnesota than our surveys and past literature indicate, as only a small percentage of these habitat types were surveyed. STATE RECORD.

Aeshna umbrosa Walker. Lake of the Woods County. COUNTY RECORD.

Aeshna verticalis (Hagen). Roseau County. COUNTY RECORD.

Basiaeschna janata Say. Carlton, Crow Wing, Morrison counties. COUNTY RECORDS.

GOMPHIDAE

Ophiogomphus anomalus Harvey. Gary Montz of the Minnesota Dept.of Natural Resources reported recent collections of Ophiogomphus anomalus Harvey from Minnesota to the authors. We inspected two mid-late instar O. anomalus larvae collected by Montz from two different sampling stations from the Pigeon River in Cook County, MN, plus five mid-late instar larvae from four different stations in adjacent Ontario, Canada in 1992 and 1993. These sites are distributed over some 15 river miles. The Pigeon River was characterized as a high gradient stream with very good to excellent water quality. Most study sites contained similar substrate to other streams.
in northeastern Minnesota—i.e. boulder/cobble mixture over a sand or sand/gravel bottom. Unlike most streams in northeast Minnesota that are cold water trout streams, the Pigeon River is a cool to warm water stream. We also collected a dozen exuviae of *O. anomalus* on the upper St. Louis River in St. Louis County in June 1999. The nearest known stations for *O. anomalus* are two streams in the Thunder Bay District of Ontario (Don Sutherland pers. comm.) four streams in Iron and Gogebic counties in the western Upper Peninsula of Michigan, and the Saint Croix River in Burnett County, WI (unpublished data from W.A. Smith, 1998, and Michigan Natural Features Inventory, 1998). STATE RECORD.

**Stylogomphus albistylus** (Hagen). We observed emergence of *S. albistylus* on the St. Louis River in St. Louis County in June 1999. This is the same site where *O. anomalus* exuviae were collected. We collected several *S. albistylus* exuviae at this location, and several more at another site several miles upstream. STATE RECORD.

**Stylurus scudderi** (Selys). Ten *S. scudderi* exuviae were found at one location on the Sturgeon River in Koochiching County in late August 1998. The Sturgeon River is about 18 m wide, with a substrate of sand, rubble, and boulders, and moderate current. This is the only known site for *S. scudderi* in Minnesota, the nearest station being the Brule River in Bayfield County, WI. *S. scudderi* is also found in the Kenora and Thunder Bay Districts of Ontario (Don Sutherland, pers. comm.). The Sturgeon River site is the western-most location of the species in the U.S. STATE RECORD.

**Dromogomphus spinosus** Selys. Itasca County. COUNTY RECORD.

**Gomphurus fraternus** (Say). Aitken, Carlton, Crow Wing, Itasca, Lake of the Woods, Morrison counties. COUNTY RECORDS.

**Gomphurus vastus** Walsh. Aitken, Carlton, Cass, Crow Wing, Itasca, Lake of the Woods, Morrison, Stearns counties. COUNTY RECORDS.

**Gomphurus ventricosus** Walsh. Carlton, Koochiching, Lake of the Woods, St. Louis, Washington counties. COUNTY RECORDS.

**Gomphus viridifrons** Hine. Carlton, Itasca, Koochiching, St. Louis counties. COUNTY RECORDS.

**Gomphus exilis** Selys. Pine County. COUNTY RECORD.

**Gomphus graslinellus** Walsh. Kanabec County. COUNTY RECORD.

**Gomphus lividus** Selys. Carlton, Itasca counties. COUNTY RECORDS.

**Ophiogomphus colubrinus** Selys. Koochiching, Lake of the Woods, Morrison counties. COUNTY RECORDS.

**Ophiogomphus rupinsulensis** (Walsh). Koochiching, Washington counties. COUNTY RECORDS.

**Stylurus amnicola** (Walsh). Koochiching, St. Louis counties. COUNTY RECORDS.

**Stylurus notatus** (Rambur). Koochiching, Lake of the Woods, St. Louis counties. COUNTY RECORDS.

**Stylurus spiniceps** (Walsh). Koochiching, Pine, St. Louis counties. COUNTY RECORDS.

**COENAGRIONIDAE**

**Coenagrion interrogatum** (Hagen). An adult male and female were collected in the Sand Lake SNA in Lake County. This species has not been reported in the literature on Minnesota zygopterans (Wilson 1909, Whedon 1914, Westfall and May 1996). STATE RECORD.

**Enallagma cyathigerum** (Charpentier). St. Louis County. COUNTY RECORD.
Enallagma ebrium (Hagen). Lake County. COUNTY RECORD.
Nelhellenia irene (Hagen). Lake, Koochiching counties. COUNTY RECORDS.

LESTIDAE

Lestes forcipatus Rambur. Although L. forcipatus was listed as questionable for Minnesota by Westfall and May (1996), it was reported for Blue Earth County by Whedon (1914), and we collected a single female in Roseau County. COUNTY RECORD.

Lestes congener Hagen. Lake of the Woods, Roseau counties. COUNTY RECORDS.

Lestes disjunctus Selys. Koochiching County. COUNTY RECORDS.

Lestes unguiculatus Hagen. Koochiching, Roseau counties. COUNTY RECORDS.

MACROMIIDAE

Didymops transversa (Say). Chisago, Washington counties. COUNTY RECORDS.

Macomia illinoiensis Walsh. Carlton, Koochiching counties. COUNTY RECORDS.

CORDULIIDAE

Epitheca canis McLachlan. Roseau County. COUNTY RECORD.

Epitheca spinigera Selys. Morrison County. COUNTY RECORD.

Dorocordulia libera (Selys). Koochiching County. COUNTY RECORD.

Neurocordulia yamaskanensis Provancher. Koochiching, Pine, St. Louis counties. COUNTY RECORDS.

Somatochlora forcipata (Hagen). Koochiching, St. Louis counties. COUNTY RECORD.

Somatochlora franklini (Selys). Beltrami, Cook, Pine, St. Louis counties. COUNTY RECORDS.

Somatochlora kennedyi Walker. Pine County. COUNTY RECORD.

Somatochlora minor Calvert. Beltrami, Koochiching, Lake of the Woods counties. COUNTY RECORDS.

Somatochlora walshii (Scudder). Koochiching, St Louis counties. COUNTY RECORDS.

LIBELLULIDAE

Leucorrhinia hudsonica (Selys). Koochiching, Pine, St. Louis counties. COUNTY RECORDS.

Leucorrhinia intacta (Hagen). Roseau County. COUNTY RECORD.

Libellula pulchella Drury. Koochiching County. COUNTY RECORD.

Libellula quadrimaculata Linnaeus. Roseau County. COUNTY RECORD.

Sympetrum costiferum (Hagen). Roseau County. COUNTY RECORD.
Sympetrum danae (Sulzer). Lake of the Woods, Roseau counties. COUNTY RECORDS.

Sympetrum vicinum (Hagen). Roseau County. COUNTY RECORD.

ACKNOWLEDGMENTS

We thank Gary Montz of the Minnesota Department of Natural Resources for allowing us to report his O. anomalus state record and several county records. We thank the Michigan Natural Features Inventory Program (a partnership between the Michigan Dept. of Natural Resources and The Nature Conservancy) for sharing results from recent odonate surveys in Michigan. We thank Dr. James Duncan (Manitoba Natural Resources) for assisting with surveys, Don Sutherland (Ontario Ministry of Natural Resources) for providing Ontario records, David and Gary Leonhardt of Waskish Minnesota for local habitat advice and the loan of an ATV, and Polaris Industries of Roseau Minnesota for providing vehicles and guides to help reach remote sites. Support for this project was received from the Minnesota Nongame Wildlife Tax Checkoff and the Minnesota Chapter of the Nature Conservancy through the Minnesota Department of Natural Resources, Division of Fish and Wildlife, Natural Heritage and Nongame Research Program.

LITERATURE CITED


HABITAT CHARACTERIZATION OF FIVE RARE INSECTS IN MICHIGAN
(LEPIDOPTERA: HESPERIIDAE, RIODINIDAE, SATYRIDAE;
HOMOPTERA: CERCOPIDAE)

Keith S. Summerville$^{1,2}$ and Christopher A. Clampitt$^1$

ABSTRACT

Over 80 species of insects are listed as endangered, threatened, or special concern under Michigan's endangered species act. For the majority of these species, detailed habitat information is scant or difficult to interpret. We describe the habitat of five insect species that are considered rare in Michigan: Lepyronia angulifera (Cercopidae), Prosapia ignipunctus (Cercopidae), Oarisma poweshiek (Hesperiidae), Calephelis mutica (Riodinidae), and Neonympha mitchellii mitchellii (Satyridae). Populations of each species were only found within a fraction of the plant communities deemed suitable based upon previous literature. Furthermore, individuals of each species were observed to be closely affiliated with just a few vegetation associations within larger plant communities. Restriction of these species to particular microhabitats was determined to be, in part, due to ecological or behavioral specialization of each insect species. We believe that the most holistic management and conservation practices for these rare insects in Michigan should focus on protecting the integrity of both the plant community and the microhabitat upon which these species depend.

Insects are one of the most species-rich groups of organisms on Earth (Samways 1995). This species diversity translates to a high degree of functional diversity, and forms the basis for complex linkages among populations and communities (Price 1997). Recognition of the importance of conserving insect species has developed rapidly in recent years, with considerable emphasis being placed on metapopulation stability, minimum viable population estimation, and extinction thresholds (e.g., Samways 1995, Hanski et al. 1995, Britten et al. 1994.

Despite such recent theoretical improvements, insect conservation biology suffers from a lack of empirical information concerning the precise habitat requirements of many rare or declining species (Price 1997). In Michigan, eight insect species are listed as endangered, 11 as threatened, and 66 are of special concern (Michigan Department of Natural Resources 1994). Detailed habitat data should be collected for these species in order to better understand their ecological requirements, and to assist land managers concerned with insect conservation (Noss and Cooperrider 1994). We focused our attention on a small sub-set of these insects, specifically five species known to

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occur in Michigan’s imperiled wetland communities: *Lepyonia angulifera* Uhler (angular spittlebug); *Prosapia ignipectus* Fitch (red-legged spittlebug); *Oarisma poweshiek* Parker (poweshiek skipper); *Calephelis mutica* McAlpine (swamp metalmark); and *Neonympha mitchellii mitchellii* French (Mitchell’s satyr). All of these species are listed as special concern in Michigan except for *N. m. mitchellii*, which is considered endangered under both state and federal law.

*Lepyonia angulifera* is a small, hump-backed spittlebug characterized by chocolate brown wings and a weakly inflated cibarium (Hamilton 1982). This spittlebug is considered common in the Caribbean Islands, and populations of *L. angulifera* are known from many states in the eastern United States. The food plants for this species are varied and include: *Sporobolus indicus* (L.) R. Br. (smut-grass), *Cyperus swartzii* Diet., and various other sedges for nymphs; and for adults, *Gossypium hirsutum* L. (cotton) in addition to a variety of monocots (Doering 1930, 1942; Metcalf and Bruner 1943, Hamilton 1982).

*Prosapia ignipectus* is a black spittlebug characterized by unmarked wings and scarlet infusions on the ventral surface, which are especially apparent near the leg bases and abdominal joints (Hamilton 1977, 1982). Nymphs have been reported to feed on the underground parts of *Andropogon scoparius* Michaux (little bluestem), with adults feeding aboveground on *A. scoparius* and other grasses (Hamilton 1982). Sandy prairies and barren communities stretching from the New England states through southern Pennsylvania appear to be the most frequently occupied habitats (Morse 1921).

*Oarisma poweshiek* is a medium-size, dark skipper with a conspicuous orange patch on the leading edge of the dorsal forewing and silvery-white veins on the ventral side of the wings (Scott 1986). It is found in grassy lake margins, moist meadows, and tallgrass prairie. Its natural host plant(s) are poorly known, but it has been reported to feed on *Eleocharis elliptica* Kunth (golden-seeded spikerush), other sedges, and (“reluctantly” in the lab) *Poa pratensis* L. (Kentucky bluegrass) (Scott 1986). Although limited by a small sample size, Borkin (1994) noted that *Sporobolis heterolepis* Gray and *Andropogon scoparius* (potentially) serve as oviposition sites.

*Calephelis mutica* is a small butterfly with a reddish-brown upper wing surface highlighted by two rows of silver median dots (Scott 1986). It is distinguished from congenerers by its habitat (wetlands), and its preference for thistles, primarily *Cirsium muticum* Michaux (swamp thistle) and *Cirsium altissimum* L. (tall thistle; Iftnier et al. 1992). Records for *Calephelis mutica* within the United States are scattered, but include many mid-central states such as Indiana, Ohio, Kentucky, Pennsylvania, and New York (Opler and Krizek 1984).

*Neonympha mitchellii mitchellii* is a chocolate brown satyr with submarginal rows of closely spaced, yellow rimmed “eyespots” (Scott 1986). While larval *N. m. mitchellii* have been reared on several species of *Carex* (sedge) and *Scirpus* (bulrush), it has been hypothesized that *Carex stricta* Lam. (tussock sedge) is the natural host (Shuey 1997, McAlpine et al. 1960). Extant populations of *N. m. mitchellii* are geographically restricted to two states: Michigan and Indiana. Ohio and New Jersey supported historical populations of the butterfly; however, adults have not been recorded in either state for some time.

The purpose of this paper is to present habitat and behavioral data for these five insect species using a combination of field work and literature synthesis. General habitat features are interpreted in terms of management and conservation biology. It is hoped that by clearly defining species’ habitats, en-
FIGURE 1: The Lower Peninsula of Michigan. We studied the habitat requirements of five rare insects in six counties: Newaygo (N), Van Buren (V), Berrien (B), Cass (C), Jackson (J), Washtenaw (W), and Lenawee (L).

Entomologists will gain crucial information required to discover new populations, and natural area managers will be better equipped to manage these populations and the habitats that support them.

MATERIALS AND METHODS

Field surveys for each rare species were conducted on six sites managed by The Nature Conservancy in the lower peninsula of Michigan (Figure 1). Privately owned land falling adjacent to managed preserves was included in our sampling design with landowner consent. All of our study sites occurred in the following Michigan counties: Newaygo, Van Buren, Berrien, Cass, Jackson, Washtenaw, and Lenawee. Each study site was visited early in the field season and divided into community types based upon vegetation. Community types included in this study are listed in Table 1 according to county.
Table 1. Community types included in our surveys. Community type names follow Faber-Langendoen et al. (1996). For each community type, the dominant plant species are listed, followed by a general description of the principal structure layers found in each community.

<table>
<thead>
<tr>
<th>County</th>
<th>Approx. acres</th>
<th>Community types present</th>
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<tbody>
<tr>
<td>Berrien</td>
<td>75</td>
<td>Central Mesic Tallgrass Prairie <em>(Andropogon gerardii—Sorghastrum nutans—(Sporobolus heterolepis)—Liatris spp.—Ratibida pinnata)</em> Herbaceous Vegetation</td>
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<td>Cinquefoil—Sedge Prairie Fen <em>(Pentaphylloides floribunda /Carex sterilis—Andropogon gerardii—Cacalia plantaginea)</em> Shrub Herbaceous Vegetation</td>
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<td>Dogwood—Willow—Poison Sumac Shrub Fen <em>(Cornus ammonium—Salix spp.—Rhus vernix—Rhamnus lanceolata)</em> Fen Shrubland</td>
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<td></td>
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<td>Tussock Sedge Wet Meadow <em>(Carex stricta—Carex spp.)</em> Herbaceous Vegetation</td>
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<tr>
<td>Cass</td>
<td>300</td>
<td>Central Tamarack—Red Maple Rich Swamp <em>(Larix laricina—Acer rubrum / Rhamnus alnifolia, Vaccinium corymbosum)</em> Forest</td>
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<td>Dogwood—Willow—Poison Sumac Shrub Fen <em>(Cornus ammonium—Salix spp.—Rhus vernix—Rhamnus lanceolata)</em> Fen Shrubland</td>
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<td>Tussock Sedge Wet Meadow <em>(Carex stricta—Carex spp.)</em> Herbaceous Vegetation</td>
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<td>Jackson</td>
<td>500</td>
<td>Central Tamarack—Red Maple Rich Swamp <em>(Larix laricina—Acer rubrum / Rhamnus alnifolia, Vaccinium corymbosum)</em> Forest</td>
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<td>Cinquefoil—Sedge Prairie Fen <em>(Pentaphylloides floribunda /Carex sterilis—Andropogon gerardii, Cacalia plantaginea)</em> Shrub Herbaceous Vegetation</td>
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<td>Dogwood—Willow—Poison Sumac Shrub Fen <em>(Cornus ammonium—Salix spp.—Rhus vernix—Rhamnus lanceolata)</em> Fen Shrubland</td>
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<td></td>
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<td>Midwest Calcareous Seep <em>(Carex spp.—Cladium mariscoides—Rhynchospora capillacea—Tofieldia glutinosa)</em> Herbaceous Vegetation</td>
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<td>Tussock Sedge Wet Meadow <em>(Carex stricta—Carex spp.)</em> Herbaceous Vegetation</td>
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<td>Lenawee</td>
<td>700</td>
<td>Cinquefoil—Sedge Prairie Fen <em>(Pentaphylloides floribunda /Carex sterilis—Andropogon gerardii—Cacalia plantaginea)</em> Shrub Herbaceous Vegetation</td>
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<td>Dogwood—Willow—Poison Sumac Shrub Fen <em>(Cornus ammonium—Salix spp.—Rhus vernix—Rhamnus lanceolata)</em> Fen Shrubland</td>
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<td>County</td>
<td>Approx. acres</td>
<td>Community types present</td>
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<tr>
<td>Newaygo</td>
<td>80</td>
<td>Midwest Dry-mesic Sand Prairie (<em>Schizachyrium scoparium</em>—<em>Sorghastrum nutans</em>—<em>Bouteloua curtipendula</em> Dry-mesic Herbaceous Vegetation)</td>
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<td>Van Buren</td>
<td>100</td>
<td>Inland Coastal Plain Marsh (<em>Rhynchospora capitellata</em>—<em>Rhexia virginica</em>—<em>Rhynchospora scirpoides</em>—<em>Scirpus hallii</em> Herbaceous Vegetation)</td>
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<td>Washtenaw</td>
<td>10</td>
<td>Cinquefoil—Sedge Prairie Fen (<em>Pentaphylloides floribunda</em>/<em>Carex sterilis</em>—<em>Andropogon gerardii</em>—<em>Cacalia plantaginea</em> Shrub Herbaceous Vegetation)</td>
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<td>Midwest Calcareous Seep (<em>Carex</em> spp.—<em>Cladium mariscoides</em>—<em>Rhynchospora capillacea</em>—<em>Tofieldia glutinosa</em> Herbaceous Vegetation)</td>
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Potential habitat for both cercopid species (*L. angulifera* and *P. ignipectus*) was assessed with sweep transects through preserves with previously documented populations of each species. For *L. angulifera*, surveys included fen and sedge meadow habitats in Berrien, Lenawee, and Jackson Counties. *Prosapia ignipectus* was sought on preserves with fen and sedge meadow communities in Jackson, Berrien, and Lenawee Counties and prairie communities in Van Burren and Newaygo Counties. The number of transects in each preserve was based on preserve area and the observed heterogeneity of preserve vegetation. Transects were roughly 50 m in length, with approximately 75 net sweeps per transect. Sweep effort was coordinated with adult phenology as reported in Hanna (1970) and Hamilton (1982). Independent sweep samples were taken while walking at a constant pace, swinging a net through the vegetation. Hamilton (1982) was used for specimen identification. The dominant plant species were recorded for each transect. We qualitatively compared habitat attributes between transects in which one (or both) spittlebugs species was found and transects which did not produce species’ occurrences. Collection of individuals within a transect was assumed to indicate utilization of the resources within that transect.

Adult *Oarisma poweshiek* were intensively sought with meander surveys that extended throughout the herbaceous wetlands at the Jackson County site. Less intensive searches were conducted in fen and sedge meadow habitats at the Lenawee and Washtenaw County sites. We attempted to quantify the number of adults seen at the Jackson County site by noting the number of adults seen along each meander survey. Care was taken to note behaviors, with particular attention to nectaring, mating, and interspecific interactions. Differences between habitat patches occupied by adults of *O. poweshiek* and those lacking individuals were assessed.

Surveys for *C. mutica* were conducted on wetlands with historically documented populations in Lenawee, Jackson, Cass, and Washtenaw Counties. *Calephelis mutica* was sought by walking through a preserve, searching for adults. Since adults of *C. mutica* are cryptic and reclusive, butterflies were intentionally flushed by gently brushing a net over the top of the herb layer. Particular attention was given to patches of vegetation with high densities of
the larval host plant, *Cirsium muticum* or the butterfly’s favorite nectar sources, yellow composites (Opler and Krizek 1984). Habitat characteristics that appeared favorable to the growth and health of these plant resources were also noted.

The habitat needs of *N. m. mitchellii* received our most intense scrutiny (Clampitt and Summerville 1998). Prior to the flight period of *N. m. mitchellii*, we established a monitoring transect through wetlands in Cass and Jackson Counties using a modification of the method described by Pollard and Yates (1993). Each transect was divided into seven segments, representing as many potential habitat types (e.g., sedge meadow, prairie fen, open carr, black ash-tamarack swamp) as were found within each wetland community.

During the flight season of *N. m. mitchellii*, the transects were walked a total of nine days, with separate walks at 1030, 1400, and 1730 EDT for a total of 27 surveys per site. Surveys were conducted by walking each transect at a deliberate pace looking ahead, to the sides, and behind to ensure that all butterflies were seen. In an effort to standardize our analyses, only *N. m. mitchellii* seen within one meter of the observer were tallied for density estimation (Pollard and Yates 1993). The time that the observer entered and left each segment was recorded, and individuals of *N. m. mitchellii* that were observed were tallied based upon the segment in which they occurred. An analysis of habitat utilization was made by comparing the distribution of *N. m. mitchellii* among transect segments.

Plant species lists for each segment and site were analyzed using the Michigan Floristic Quality Assessment package (Herman et al. 1996). This package uses the habitat fidelity of wild plants to assess both habitat quality and wetland character of a site. For this, a coefficient of conservativeness (C) and a coefficient of wetness (W) were assigned to each plant species in Michigan. Coefficients of conservativeness were assigned on an 11-point scale, from 0 to 10. A species with a C of 0 grows in weedy or disturbed habitats, while a species with a C of 10 grows only in very specific and natural habitats. Because an intact community is composed of plants with C ranging from 0 to 10, the mean C will typically be near 5.0. A degraded community will have lost the most conservative species, and the mean C will be lower. Similarly, the values of W range from -5 to +5. A species with a W of -5 (obligate wetland species) can only be found in wetlands while a species with a W of +5 (upland species) grows only in uplands. A species with a W of 0 is just as likely to be found in an upland site as in a wetland site. Given a reasonably complete species list for a site, the mean values of C and W provide a good indication of the quality and character of the habitat or transect segment.

**RESULTS**

Despite our intense field surveys in 1997 (approximately 500 person-hours), large populations of target species were seldom observed. Thus, the following results have been compiled based on relatively small sample sizes. The problems of biological rarity will be discussed briefly in the next section.

*Lepyronia angulifera.* Three individuals were collected from the Lenawee County fen. All (two females and one male) were found within one of six sweep transects. This transect ran through a marly fen dominated by *Eleocharis elliptica*, *Scirpus validus* Vahl (softstem bulrush), and *Scirpus americanus* Person (three-square). *Carex stricta* was also present in low densities. Other sweep transects passing through areas of fen or sedge meadow dominated by *C. stricta* or other sedges did not produce this species. Further, transects passing through more mesic areas of fen containing a high cover of
grasses or a high density of shrubs (especially *Rhamnus frangula* L. (glossy buckthorn) did not yield *L. angulifera*. This species was not found in areas of the fen subjected to a prescribed burn within the past year although many burned sites contained vegetation similar to the patch occupied by *L. angulifera*.

Results of surveys at the Jackson County fen were similar. At this site, however, three of seven transects produced *L. angulifera*. Nine *L. angulifera* (seven females and two males) were collected in a marly patch of fen dominated by *Eleocharis elliptica*, *Scirpus validus*, and *Cladium mariscoides* (Muhl)Torrey (twigrush). *Gentianopsis procera* Holm (small fringed gentian) was the dominant forb in this marly patch. Two transects running through patches of fen dominated by *Carex stricta*, *Potentilla fruticosa*, and *Eupatorium maculatum* L. (joe-pye weed) each produced one male. An unidentified *Eleocharis* (spikerush) was also present in these areas at low densities. Three sweep transects in patches of vegetation with varying cover of shrubs (*Comus* spp., *Salix* spp., and *Toxicodendron vernix* (L.) Kuntze) did not yield *L. angulifera*. Sweeping in a patch of fen dominated by *Carex lacustris* Willd. (lake sedge) also failed to produce any individuals of this species.

Thus, on our sites, *Lepyronia angulifera* appears to be restricted to patches of vegetation containing *Eleocharis* (and perhaps also *Scirpus*). The most productive transects at both sites ran through marl flats, which tended to lack a shrub component and did not have a very high density of *Carex* spp. Forb density was uniformly low in these marl flats although *Gentianopsis procera* and, to a lesser extent, *Potentilla fruticosa* were present.

**Prosapia ignipectus.** This species was found in very low densities at both the Lenawee and Jackson County fens, but it was not collected in prairie communities. The only transects to produce *P. ignipectus* were those that passed through mesic prairie fen patches characterized by *Andropogon scoparius*, *Andropogon gerardii* Vitman (big bluestem), *Potentilla fruticosa*, *Eupatorium maculatum*, and *Carex stricta*. In these transects, grasses and forbs occurred at low to moderate densities, and most of the plant density was provided by *C. stricta*. At the Lenawee County fen, these conditions were found in one transect (with only one individual collected). At the Jackson County fen, two individuals were collected. Transects which included shrub species with moderate to high cover, transects with *Carex lacustris* dominant, or transects falling in recently-burned patches of vegetation did not produce *P. ignipectus*. This species was also collected by one of us (Summerville) in association with *Lepyronia gibbosa* Ball (prairie spittlebug) and *Neophilaenus lineatus* L. (lined spittlebug) in sandy prairies along power line rights-of-way in Newaygo County. These prairie remnants support reasonably dense growth of *Andropogon* sp., and are likely to harbor dense populations of rare spittlebugs (Summerville 1998).

**Oarisma poweshiek.** This species was only found to occur at the Jackson County fen site. This skipper was only found in marly areas dominated by *Eleocharis* spp., although its favorite nectar resources, *Rudbeckia hirta* and *Potentilla fruticosa*, appeared to be abundant throughout the site. One exception was a single individual noted nectaring on a *P. fruticosa* in an open fen dominated by *Carex stricta*. This area was separated from a marly *Eleocharis* patch by several hundred meters of open fen and a narrow band of *Larix laricina* (DuRoi) Koch (tamarack). The population of this rare skipper was estimated to be greater than 100 individuals, however, occupied habitat represented roughly 10–15% of the total fen area.

**Calephelis mutica.** This species was found in two of the four potential sites. At the Jackson County fen, nine adults were observed, and at the Lenawee County fen, two adults were noted. All were observed in areas of
low monocot growth with scattered *Rudbeckia hirta*, *R. fulgida* Aiton, *Potentilla fruticosa*, *Solidago* spp. (goldenrod), and *Cirsium muticum*. In general, the monocot cover was provided by *Carex stricta*. This butterfly was frequently observed nectaring on *R. hirta* and, occasionally, *P. fruticosa*. There was no woody vegetation in these patches.

This butterfly was not collected at either the Cass or Washtenaw County sites where it had been reported in the past. At these two sites, shrub cover had become considerable. Although this butterfly’s host plant was found in low densities at both sites, *R. hirta* was conspicuously absent from both sites in 1997. Some *P. fruticosa* occurs at the Washtenaw County site, but it is separated from host plant resources by a dense barrier of shrubs. The *Cirsium muticum* growing in these sites appeared short and stunted, perhaps due to shading.

**Neonympha mitchellii mitchellii.** The transect for monitoring this butterfly at both the Cass and Jackson County sites started under a swamp forest canopy, crossed areas with an open canopy dominated by a variety of native trees or shrubs as well as open areas dominated by native sedges and grasses, and returned to the starting point. Although a complete botanical inventory was beyond the scope of this study, we identified more than 70 native plant species along each transect. With the exception of two transect segments at the Jackson County site, the mean W was less than −1 (Table 2) and the transects were clearly dominated by wetland plant species. The mean C for the transect segments ranged from 3.64 to 4.48 (except 7a and 7b at the Jackson County site), indicating that they crossed reasonably high-quality wetlands (Table 2).

**Neonympha mitchellii mitchellii** was not uniformly or randomly dispersed along the transects. Rather, individuals were highly clumped in specific segments (Table 2). Of the 49 observations of individuals at the Cass County site, 35 (72%) of them occurred within transect segment 5 (moderately open shrub carr). Nearly all other observations occurred within the relatively small segment 2 (open shrub carr). Combining the *N. m. mitchellii* observations from the physiognomically similar transect segments 2 and 5 accounts for roughly 92% of all the individuals observed at the Cass County fen. Similarly, at the Jackson County site, 25 of the 40 (63%) individuals were seen in the two segments that crossed open tamarack savanna. Most of the remaining individuals were seen in an open fen or moderately open savanna. This butterfly was not seen in areas of extremely dense shrub carr or in deciduous forests proximal to *Carex stricta* patches. However, it was observed twice in an open meadow and once in a dense tamarack stand. All of these observations were within 10 meters of more densely populated habitat. Since *Carex stricta* was abundant throughout both wetlands, other factors (e.g., shade provided by woody species) were postulated as contributing factors to the observed distribution of *N. m. mitchellii*. It should also be noted that *N. m. mitchellii* was not seen during 22% (Cass County) to 34% (Jackson County) of the surveys, all of which were conducted during the 1997 flight period. Weather has been postulated as a major determinant of *N. m. mitchellii* flight behavior, and the conditions under which this species can most reliably be found are the subject of a continuing study (Clampitt and Summerville 1998).

**DISCUSSION**

The five insects considered in this study were restricted to specific vegetation assemblages within larger wetland communities. Since their distribu-
Table 2. Habitat characteristics of transect segments included in this study and their use by *N. m. mitchelli*. Values for “Mean C” and “Mean W” calculated using the Floristic Quality Index of Herman et al. (1996). Dominant plant species are listed in order of decreasing estimated relative cover. Vegetation structure was determined by the relative abundance and relative covers of the dominant plant species recorded in each transect segment. “Satyr frequency” refers to the percentage of the surveys in which at least one by *N. m. mitchelli* was seen.

<table>
<thead>
<tr>
<th>Site and Transect Segment</th>
<th>Vegetation Structure1,2</th>
<th>Dominant Plant Species</th>
<th>Mean C</th>
<th>Mean W</th>
<th>Total satyrs seen</th>
<th>Satyr frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cass County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Closed swamp forest</td>
<td><em>Fraxinus nigra, Larix laricina, Cornus foemina</em></td>
<td>4.17</td>
<td>-1.35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Open carr</td>
<td><em>Carex lacustris, Carex stricta, Eupatorium maculata</em></td>
<td>4.48</td>
<td>-3.74</td>
<td>10</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>Dense carr</td>
<td><em>Cornus foemina, Salix sp.</em></td>
<td>4.07</td>
<td>-2.23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Sedge meadow</td>
<td><em>Carex lacustris, Carex stricta, Eupatorium maculatum</em></td>
<td>3.73</td>
<td>-3.73</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Mod. open carr</td>
<td><em>Carex lacustris, Carex stricta, Phalaris arundinacea</em></td>
<td>4.09</td>
<td>-3.03</td>
<td>35</td>
<td>59</td>
</tr>
<tr>
<td>6</td>
<td>Mod. dense carr</td>
<td><em>Cornus foemina, Carex lacustris</em></td>
<td>3.64</td>
<td>-3.18</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Dense carr</td>
<td><em>Cornus foemina, Salix sp., Onoclea sensibilis, Carex lacustris</em></td>
<td>4.00</td>
<td>-2.20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jackson County</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mesic forest</td>
<td><em>Quercus velutina, Carex pensylvanica</em></td>
<td>3.86</td>
<td>0.45</td>
<td>40</td>
<td>66</td>
</tr>
<tr>
<td>2</td>
<td>Mod. open savanna</td>
<td><em>Eupatorium maculata, Carex stricta</em></td>
<td>3.89</td>
<td>-3.00</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>Open savanna</td>
<td><em>Carex stricta, Larix laricina</em></td>
<td>4.30</td>
<td>-2.87</td>
<td>15</td>
<td>46</td>
</tr>
<tr>
<td>4</td>
<td>Closed savanna</td>
<td><em>Carex stricta, Larix laricina</em></td>
<td>4.11</td>
<td>-3.26</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Open savanna</td>
<td><em>Carex stricta, Larix laricina</em></td>
<td>4.46</td>
<td>-2.36</td>
<td>10</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>Open fen</td>
<td><em>Carex stricta, Potentilla fruticosa</em></td>
<td>4.42</td>
<td>-2.06</td>
<td>7</td>
<td>29</td>
</tr>
<tr>
<td>7a</td>
<td>Mesic forest</td>
<td><em>Populus deltoides, Quercus alba</em></td>
<td>3.25</td>
<td>2.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7b</td>
<td>Old field</td>
<td><em>Solidago canadensis, Rubus flagellaris</em></td>
<td>2.70</td>
<td>2.37</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

TOTAL (for both sites) 89

1Cover was estimated as follows: (open = 0–10% woody growth; moderate-open = 10–40% woody growth; moderate-dense = 40–70% woody growth; dense = 70–100% woody growth.

2Carr refers to the growth of underbrush (i.e., shrub-fen community in Table 1). Segments containing savanna-like structure correspond to shrub and herbaceous fen communities described in Table 1.
tion appears to be restricted to relictual wetland communities described above, these species should be considered remnant-dependent in Michigan (sensu Panzer et al. 1997). The microhabitats of these remnant-dependent species appear to be particular seral stages of the plant communities in which they occur. Thus, *Calephelis mutica* occurs in wetland communities, but occupies only an early seral stage of vegetation within that community: low herb growth with no woody component. *Lepyronia angulifera* and *Calephelis mutica* share a similar, early successional wetlands habitat (e.g., neither is found in the presence of shrubby growth), but rely on a vastly different herbaceous microhabitat: *Eleocharis-Scirpus* patches compared with *Cirsium-Rudbeckia* patches. These patches were probably maintained in the past by a combination of factors (e.g., high water table, abundance of aqueous minerals, occasional wildfires, and herbivory from grazing mammals).

Various factors are known to affect the distribution of insect species (Price 1997), and we did not attempt to quantitatively elucidate reasons why the five insect species were restricted to one or two relictual plant communities. At the broadest scale, the distribution of these species is defined by food plant distribution. In the case of *Lepyronia angulifera*, however, Michigan food plants have yet to be precisely identified. Hanna (1970) describes the this specie's hosts as "sedges, in association with cinquefoil, gentian, and pitcher plants at the edges of small bog-like lakes." Marl flats within fens seem to match the character of this habitat description, but we did not observe feeding by adults of *L. angulifera* in the field.

The case of *Prosapia ignipectus* is slightly different from the examples provided by the other four species. *Prosapia ignipectus* is more commonly found in sandy areas from Southern Ontario, throughout New England, to southern Pennsylvania (Hamilton 1982). We collected this species in sandy prairies of Newaygo County, and, in extremely low numbers, in fens. Since so few specimens were obtained in 1997, this observation is difficult to interpret. Perhaps fens with *Andropogon scoparius* serve as sink habitats (sensu; Pulliam 1988) for this species. Nymphs of *P. ignipectus* are known to be subterranean, and it is possible that areas of fen with saturated soil during most of the year foster high mortality rates due to asphyxiation, fungal infestation, or microbial infection. The individuals we observed may have dispersed from more upland communities, however, such communities are lacking in the matrices surrounding each wetland preserve. Historically, prairie fens are likely to have developed within a mosaic of upland dry prairie (on elevated plateaus) with lowland areas supporting wet meadows or fens. Thus, conversion of dry prairie for agriculture or development may have eliminated source populations for fen colonization. If this is the case, populations of *P. ignipectus* in wetlands may be dynamically unstable, and successful conservation of this species in Michigan may depend upon maintaining a linkage of dry prairie and wetland habitats. Further collecting is necessary to assess how *P. ignipectus* uses wetland habitats and whether it can attain large populations within those areas.

*Oarisma poweshiek* rarely strayed from patches of its hypothesized *Eleocharis* host plant, despite the high density of nectar sources occurring in *Carex* dominated fen patches. It should be noted that the *Eleocharis* marl flats occupied by *O. poweshiek* seldom attain the stem density that *Carex* patches attain, and *Eleocharis* marl flats lack the tall forb growth (e.g., *Eupatorium* sp.) commonly observed in sedge fens. Further, *O. poweshiek* was never observed in shrubby patches of prairie fen, even when potential nectar sources were available. Thus, one potential hypothesis explaining *O. poweshiek*'s avoidance of *Carex* patches containing *Rudbeckia* nectar sources is that *O. poweshiek* discriminates suitable habitat from unsuitable habitat.
based on the architecture of the herbaceous layer. Other species of Lepidoptera have been shown to evaluate habitat suitability based upon variation in plant architecture (Rausher 1995).

Our description of the habitat of *O. poweshiek* confirms and extends other authorities' observations. Holzman (1972) asserted that the preferred nectar flower of this skipper was *Lobelia spicata* Lam. (pale-spiked lobelia), with few visits made to other forbs such as *Rudbeckia hirta*. In contrast, we frequently observed individuals of the poweshiek skipper nectaring on *Rudbeckia hirta*. Visits at these flowers were prolonged nectaring bouts; flowers were rarely used for perching behavior. There are close similarities among our Michigan habitat observations and the habitat descriptions for *O. poweshiek* provided by Catling and Lafontaine (1986) for Canada and Borkin (1994) for Wisconsin. The preferred habitat appears to be open wetland dominated by a mixture of grasses, sedges, rushes, and low-growing forbs. Both the Manitoba sites explored by Catling and Lafontaine (1986) and the Michigan sites described here and by Holzman (1972) note the presence of *Eleocharis elliptica* in occupied habitats. Our observations suggest that *O. poweshiek* is reluctant to leave these patches and enter patches having significant woody cover, indicating that dispersal of this skipper may be limited within patchy landscapes. Although Borkin (1994) has demonstrated that *O. poweshiek* may oviposit on other monocot species, their status as suitable host plants remains in question. Further research is required to determine the range of hosts that will support populations of this skipper.

For *Calephelis mutica*, shade provided by shrubs was hypothesized to affect the growth form and quality of *Cirsium muticum*, the butterfly's larval host plant. Further, within many fens, nectar sources (especially *Rudbeckia hirta*) were observed growing in numbers up to, but never within, a half-day shade zone cast by woody growth. Thus, the distribution of *Calephelis mutica* may be defined by resource patch dynamics mediated by the ability of the sun to reach the herb layer throughout the day. The aggressiveness of *Rhamnus frangula* represents a pervasive threat to *Calephelis mutica*, fragmenting and shrinking suitable habitat patches as the shrub spreads. At the Lenawee County site, however, the spread of this shrub is being controlled by cutting the shrubs, treating the stumps with an herbicide, and then burning the area to eliminate reseeds and seedlings. We observed a large number of *Cirsium muticum* and *Rudbeckia fulgida* in recently burned patches. Further research is necessary to assess this butterfly's response to fire and other management practices (e.g., haying or brush cutting).

*Neonympha mitchellii mitchellii* appears to be found in greatest numbers in a mid-seral stage of fen or sedge meadow succession, selecting habitat based upon the presence of its hypothesized host plant, *Carex stricta*, and some threshold amount of carr or tamarack savanna. At many sites, the influence of invasive species (especially *Rhamnus frangula*) and the disruption of key ecological processes such as groundwater quality and quantity and fire, has altered the natural successional pathways of plant communities (Shuey 1997). In the absence of management, the ultimate result from these disruptions will be the elimination of successional dynamics (including patch creation) and the extirpation of the insect species dependent upon shrinking resource bases (Samways 1995).

Our analysis of the habitat of *N. m. mitchellii* confirmed and quantified several decades of entomological observations. We observed this butterfly most often in areas of *Carex stricta* near stands of woody vegetation. As synthesized by Shuey (1997), the majority of *N. m. mitchellii* habitats are sedge-rich fens and sedge meadows with some shrub component. We noted that the species of woody growth varied considerably, ranging from *Larix laricina*, to
Toxicodendron vernix (poison sumac), to Cornus amomum Miller (pale dogwood). This strongly suggests that although woody species provide an important structural character to N. m. mitchellii habitat, the precise species involved are less important. Woody cover may provide shaded zones during the heat of the day, protection from predators, roosting sites during inactive periods, or sheltered oviposition sites. Further research is required to resolve questions of how much structural cover is "optimal" for the butterfly, and to answer questions concerning the role of plant architecture in the butterfly's ecology.

A confounding factor in generalizing about these species' habitats is their rarity, both within a site and within the region. In particular, rarity obscures the interpretation of negative results, making it difficult to determine whether failure to collect a species in a given patch is due to its absence, insufficient sampling, or random effects (Price 1997; Samways 1995). We acknowledge this inherent problem, and believe that continued sampling will fill questionable voids in our data set. Populations of each focal species are found in Michigan counties outside of the scope of research. Cross-referencing of our habitat data with additional habitat information for these species in the Heritage database for Michigan suggests that we have captured the essence of each species' habitat requirements in Michigan.

It is of primary importance to document the habitat requirements of rare species if the administrative mechanisms of biological conservation are to be successful. Furthermore, for current theories of conservation biology to be successfully applied to insects, natural history information must be used to assist with model parameterization, especially patch-occupancy models such as those used for modeling metapopulations, source-sink dynamics or percolation. A large body of theoretical ecology is firmly in place; responsibility now falls to field entomologists to collect vital micro-habitat data akin to the work of ornithologists for avian conservation in previous decades (Samways 1995).

Conservation plans are only as good as the data used to create them. Four of the five species (P. ignipectus is a special case) we considered in this research appear to be habitat specialists at two scales: the community and the microhabitat. Thus, these species may be properly considered wetland specialists; however, it is fundamentally important to recognize that each species also is restricted to a specific (or a few specific) microhabitats within wetland communities. For conservation and management to be successful, an understanding of species' requirements at both scales is important. Neglecting the details of microhabitat specialization may jeopardize efforts to preserve Michigan's insect biodiversity. It is our hope that the information presented in this paper expands our understanding of the insect species Michigan is struggling to protect.

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LITERATURE CITED


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