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COVER ILLUSTRATION

*Bombus sp.*, (Hymenoptera: Apidae) nectaring at *Aster*. Photograph by Eugene Kenaga.
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WATER QUALITY OF THE WEST BRANCH OF THE DUPAGE RIVER AND KLINE CREEK, ILLINOIS, AS EVALUATED USING THE ARTHROPOD FAUNA AND CHEMICAL MEASUREMENTS

Chris E. Petersen

ABSTRACT

The water quality of the West Branch of the DuPage River (W. Branch) and Kline Creek, a tributary of the W. Branch, were examined. Both streams are located in rapidly developing DuPage County, IL. Using Hilsenhoff's biotic index of the arthropod fauna and selected chemical measurements, the W. Branch was found to be moderately polluted and Kline Creek moderately to severely polluted. High mean biotic index measurements ranging from 6.28 to 7.97, ammonia-nitrogen readings of 1.0-3.9 ppm, nitrate-nitrogen readings of 0.4-1.6 ppm, chloride readings of 231-313 ppm, and orthophosphate readings of 0.3-0.5 ppm reflect organically polluted waters in both streams. Stream channelization and modification may also be contributing to the less than optimal water quality at the headwater of the W. Branch.

From 1980 through 1988 the population of DuPage County, Illinois, grew from 658,858 to 760,800 people (DuPage County Planning Department, personal communication). As a result of the urbanization, the county has experienced a reduction and fragmentation of open space. As a means to estimate the impact of development on the natural environment, the water qualities of the West Branch of the DuPage River (W. Branch) and a tributary were examined using stream arthropod and chemical indicators. Stream analysis is practical for estimating human impacts because streams, receive anthropogenic inputs through surface runoff, ground water, and direct discharge. Also, arthropods inhabiting streams show species specific tolerances to these inputs (Hilsenhoff 1977, Paine and Gaufin 1956, Wilson and McGill 1977). The W. Branch is an ideal stream to survey in DuPage County because it transects the county by flowing north to south.

The 40 km W. Branch is part of the 3553 km² Des Plaines River drainage basin located mostly in Northeastern Illinois (Illinois Environmental Protection Agency 1988). The average gradient of the W. Branch is about 1.1 m/km. Over 70% of the first 30 km of the stream surveyed in this study is bordered by seven DuPage County Forest Preserves which encompass 2340 hectares of mostly mesophytic forests. However, this section directly, or indirectly via tributaries, receives discharges from nine waste water treatment plants that service many of the more than 215,000 people living in the residential areas along the W. Branch. One such tributary which was examined is Kline Creek, a 5 km long stream originating just

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Table 1. — Sampling stations and their locations along the West Branch of the DuPage River (W. Branch) and Kline Creek, IL. Distance of a station from the headwater area is listed beside the stream’s name in the parentheses.

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallard Lake</td>
<td>50 m upstream from the Hanover Park Waste Water Treatment Plant, Hanover Park</td>
</tr>
<tr>
<td>(W. Branch-1.9 km)</td>
<td></td>
</tr>
<tr>
<td>Timber Ridge</td>
<td>Timber Ridge Forest Preserve, West Chicago</td>
</tr>
<tr>
<td>(W. Branch-13.6 km)</td>
<td></td>
</tr>
<tr>
<td>McDowell Grove</td>
<td>McDowell Grove Forest Preserve, Naperville</td>
</tr>
<tr>
<td>(W. Branch-30.0 km)</td>
<td></td>
</tr>
<tr>
<td>Kline Creek</td>
<td>100 m upstream from the junction with the W. Branch, West Chicago</td>
</tr>
<tr>
<td>(Kline Creek-4.5 km)</td>
<td></td>
</tr>
</tbody>
</table>

above a waste water treatment plant in Carol Stream, IL. The stream has an average gradient of about 3.3 m/km and joins with the W. Branch 14 km from the W. Branch’s head-water.

Since the 1970's, channelization and modification of the W. Branch above the Mallard Lake Station has been ongoing. New single-family homes and a bridge were built within this time about the station. The disturbance to the W. Branch at the station is apparent by the fragments of concrete and other construction material that compose most of the larger substrate (>10cm diameter).

The Hilsenhoff Biotic Index (Hilsenhoff 1977, 1982, 1987) was used to evaluate water quality in reference to arthropods. Hilsenhoff’s index is designed to measure water quality in organically enriched waters such as what was anticipated with the W. Branch and Kline Creek. The index is also standard procedure used by the Illinois Environmental Protection Agency (1988).

MATERIALS AND METHODS

Three sampling stations were established along the West Branch and a fourth along Kline Creek (Table 1). The procedure for collecting stream arthropods at these stations followed that described by Hilsenhoff (1987). Stations were located in riffle areas having depths of <10 cm. A D-frame aquatic net facilitated collections taken from October 1989 through April 1990 at two week intervals when not interrupted by high water and icing over. When possible, sampling continued until it was obvious that more than 100 arthropods were collected. Only 50 from Kline Creek and 55 from the McDowell Grove station could be collected on 14 October, 1989, and 5 March, 1990, respectively. Arthropods were preserved in 70% ethanol. The first randomly selected 100 arthropods for samples consisting of ≥100, or all for samples of <100, were identified to species if possible and to genus if not.

Selected chemical measurements were taken monthly from each of the four sampling stations using Lamotte Chemical kits (LaMotte Chemical Products Company). Chemicals measured were those commonly associated with organic pollution: ammonia-nitrogen, nitrate-nitrogen, chloride, and orthophosphate. During each sampling day, measurements were taken at all four stations within an 8 hour period.
Table 2.—Arthropods collected from the West Branch of the DuPage River and Kline Creek according to pollution tolerance value (PTV) and sampling station. Symbols: ML = Mallard Lake station, TR = Timber Ridge station, MG = McDowell Grove station, and KC = Kline Creek station.

<table>
<thead>
<tr>
<th>Order</th>
<th>Species</th>
<th>PTV</th>
<th>ML</th>
<th>TR</th>
<th>MG</th>
<th>KC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphipoda</td>
<td><em>Hyallela azteca</em> Saussure</td>
<td>8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Isopoda</td>
<td><em>Asellus intermedius</em> Forbes</td>
<td>8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Odonata</td>
<td><em>Argia</em> spp.</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Enallagma</em> spp.</td>
<td>9</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Hetaerina americana</em> Fabricius</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemeroptera</td>
<td><em>Baetis intercalaris</em> McDunnough</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Caenis</em> spp.</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Potamanthus</em> spp.</td>
<td>4</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Sagenacron</em> interpunctum (Say)</td>
<td>7</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Stenoneema</em> terminatum (Walsh)</td>
<td>4</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Tricorythodes</em> spp. Ulmer</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Megaloptera</td>
<td><em>Sialis</em> spp.</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coleoptera</td>
<td><em>Dubiraphia</em> vittata (Melsheimer)</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Stenelmis crenata</em> (Say)</td>
<td>5</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>S. vittipennis</em> Zimmerman</td>
<td>5</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trichoptera</td>
<td><em>Ceratopsyche</em> bronta Ross</td>
<td>6</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Cheumatopsyche</em> spp.</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Hydropsyche</em> betteni Ross</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Diptera</td>
<td><em>Tipula</em> spp.</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Chironomis</em> spp.</td>
<td>10</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Cricotopus</em> spp.</td>
<td>7</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Eristalis</em> spp.</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Guttipelopia</em> spp.</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Microspectra</em> spp.</td>
<td>7</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Polypedilium</em> spp.</td>
<td>6</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td><em>Simulium</em> vittatum Zetterfield</td>
<td>8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Table 2 provides a faunal list of arthropods according to sampling station and pollution tolerance values assigned to each species. Except for the caddisfly, *Cheumatopsyche* (Trichoptera), arthropod pollution tolerance values used in the computation of biotic indices (BI’s) were taken from Hilsenhoff (1987).

*Cheumatopsyche* was reassigned a value of 6 instead of Hilsenhoff’s 5. Justification for the reassignment came from the degree of chemical pollution and the identification of adult *Cheumatopsyche* that were trapped along the W. Branch and Kline Creek with an ultraviolet light during April-October, 1990. Only *C. petiti* (Banks) and *C. campyla* Ross, which are known to be pollution tolerant (Ross 1944), were collected.

Mean biotic indices from each sampling station (Table 3) reflect fair to poor water
Table 3.—Mean biotic index values ± standard deviations (\( \bar{x} \) BI ± calculated from the West Branch of the DuPage River and Kline Creek sampling stations. The biotic indices are interpreted as follows: 0-3.50 indicates excellent water quality; 3.51-4.50 very good water quality; 4.51-5.50 good water quality; 5.51-6.50 fair water quality; 6.51-7.50 fairly poor water quality; 7.51-8.50 poor water quality; and 8.51-10.00 very poor water quality. Symbol: n = the sample size.

<table>
<thead>
<tr>
<th>Location</th>
<th>( \bar{x} ) BI ± s</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallard Lake</td>
<td>7.97 ± 0.14</td>
<td>16</td>
</tr>
<tr>
<td>Timber Ridge</td>
<td>7.04 ± 0.44</td>
<td>14</td>
</tr>
<tr>
<td>McDowell Grove</td>
<td>6.28 ± 0.71</td>
<td>15</td>
</tr>
<tr>
<td>Kline Creek</td>
<td>7.43 ± 0.53</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 4.—LaMotte chemical analyses from four sampling stations along the West Branch of the DuPage River and Kline Creek. Mean concentrations ± standard deviations (\( \bar{x} \) ± s) are given in ppm (parts per million). All sample sizes = 5. Also included are concentrations that can be expected from relatively unpolluted waters (Clark 1977, Klein 1962). Symbols: PO4 = orthophosphate; ML = Mallard Lake station; TR = Timber Ridge station; MG = McDowell Grove stations; and KC = Kline Creek station.

<table>
<thead>
<tr>
<th>Location</th>
<th>Chemical</th>
<th>Ammonia-nitrogen</th>
<th>Nitrate-nitrogen</th>
<th>Chloride</th>
<th>PO4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td></td>
<td>1.4 ± 0.9</td>
<td>0.7 ± 0.4</td>
<td>244 ± 82</td>
<td>0.4 ± 0.6</td>
</tr>
<tr>
<td>TR</td>
<td></td>
<td>1.2 ± 0.4</td>
<td>0.5 ± 0.4</td>
<td>231 ± 63</td>
<td>0.3 ± 0.3</td>
</tr>
<tr>
<td>MG</td>
<td></td>
<td>1.0 ± 0.0</td>
<td>0.4 ± 0.4</td>
<td>294 ± 91</td>
<td>0.4 ± 0.4</td>
</tr>
<tr>
<td>KC</td>
<td></td>
<td>3.9 ± 1.3</td>
<td>1.6 ± 2.5</td>
<td>313 ± 51</td>
<td>0.5 ± 0.6</td>
</tr>
</tbody>
</table>

Concentration that can be expected from relatively unpolluted waters:
- Ammonia-nitrogen: <0.2 ppm
- Nitrate-nitrogen: Virtually absent
- Chloride: <250 ppm
- PO4: <50 ppm

In conclusion, biotic indices from both the W. Branch and Kline Creek reveal arthropod communities characteristic of moderately to severely polluted waters.
Stream channelization and modification may also be contributing to the apparent less than optimal water quality, especially at the headwater of the W. Branch.

ACKNOWLEDGMENTS

This research was supported by a grant from the Conservation Foundation of DuPage County. I thank B. Petersen, B. Anderson, and T. Ruehlmann who commented on the manuscript.

LITERATURE CITED


J. D. Usis¹,² and B. A. Foote¹

ABSTRACT

A coal mine about 2.2 km upstream from Stillfork Swamp Nature Preserve, Carroll Co., Ohio was suspected of causing a reduction in *Limnephilus indivisus* caddisflies in the south half of the preserve. Second instar *L. indivisus* larvae collected from the south half of the preserve and from two control areas were reared in cages at the site of collection and at the other two sites in a replicated experiment. Elevated total dissolved solids in water samples from within rearing enclosures displayed strong correlation (r² = 0.864) with increased mortality when compared to larvae reared in unaffected areas. This investigation suggests that larvae of *L. indivisus* are useful in biomonitoring of wetlands impacted by acid-mine drainage, and potentially other perturbations.

The Blum Coal Company began mining activities on 26 November 1985, ca. 2.2 km upstream from Stillfork Swamp Nature Preserve, Carroll Co., Ohio (Fig. 1). Because pre-perturbation data on Trichoptera existed (Usis and MacLean 1986), an intensive survey of the caddisflies inhabiting Stillfork Swamp was conducted from the spring of 1986 through the fall of 1988 to evaluate changes (Usis 1990).

Based upon 56 light-trap collections made in 1984, Usis and MacLean (1986) reported that *Limnephilus indivisus* Walker represented the most abundant caddisfly at Stillfork Swamp. However, equal numbers of light-trap collections made during 1986, 1987, and 1988 indicated that their population had dramatically declined (853 in 1984, 94 in 1986, 33 in 1987, and 98 in 1988). Nimmo (1966) suggested that increases or declines in light-trap catch size might be attributed to variations in factors such as temperature, wind, moonlight, and trap placement. Night-time temperature has even been shown to influence the percentage of females in light trap catches (Andersen 1978). Analysis of air temperature records at the time of nightly collection revealed that they did not vary by more than a few degrees in subsequent years. Field observations also did not reveal other physical factors that would account for the substantial declines in numbers of *L. indivisus*. Unfortunately, only a few studies have monitored populations of Trichoptera for several seasons (McElravy et al. 1982, Resh 1976, 1982; Haag et al. 1984, McElhone et al. 1987, McElravy and Resh 1987), and the natural variability in size of trichopteran populations is relatively unknown. As a consequence of its population reduction, *L. indivisus* was selected for a field rearing experiment to determine if numerical reduc-

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²Current address: Department of Biological Sciences, Youngstown State University, Youngstown, OH 44555.
Figure 1. Map showing Stillfork Swamp Nature Preserve, located in Augusta and Washington townships, and strip-mine permit area, located in Washington township, Carroll County, Ohio.

Tions could be attributed to surface mining activities. The life history and behavior of *L. indivisus* are relatively well known (Mickel and Milliron 1939, Noval and Sehnal 1963, 1965; Wiggins 1973, Richardson and Mackay 1984).

**MATERIALS AND METHODS**

Submerged screen enclosures allow water, fine silt, and detritus to exchange between enclosure and pool, providing largely natural conditions for trichopteran larvae (Colburn 1984). Nine wood-framed enclosures (31cm × 31cm × 31cm) with bottom and sides covered by 2 mm mesh PVC-coated fiberglass screen were placed in wetland pools at south Stillfork Swamp and each of two control areas, which were vegetatively similar, one week prior to beginning the experiment. These control areas were the north Stillfork Swamp which is isolated from mine drainage by a railroad (Fig. 1), and a wetland near Leetonia, which is in a different watershed. Enclosure tops were covered with 6 mm (1/4") plate glass permitting easy access. At the start of the experiment decaying water smartweed (*Polygonum natans*) and giant bur-reed (*Sparganium eurycapum*) were placed into the enclosures to provide a substrate for larval feeding and case construction. These substrates represent the preferred feeding and casemaking materials for *Limnephilus indivisus* at Stillfork and Leetonia.
Source Location of *Limnephilus indivisus*

<table>
<thead>
<tr>
<th>Rearing Enclosure Location</th>
<th>North RR Stillfork Swp.</th>
<th>South RR Stillfork Swp.</th>
<th>Leetonia Swamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd instar Larvae</td>
<td>25 individuals per enclosure a,b,c (CN)</td>
<td>25 individuals per enclosure a,b,c (SN)</td>
<td>25 individuals per enclosure a,b,c (LN)</td>
</tr>
<tr>
<td>2nd instar Larvae</td>
<td>25 individuals per enclosure a,b,c (NL)</td>
<td>25 individuals per enclosure a,b,c (SL)</td>
<td>25 individuals per enclosure a,b,c (CL)</td>
</tr>
</tbody>
</table>

Figure 2. Experimental design utilized for rearing *Limnephilus indivisus* (Walker), a 3 x 3 contingency table (ANOVA Model I) with nine treatments each with three replicates (a, b, c). Symbols for treatments 1st letter indicates the larval source (N = north, S = south, L = Leetonia, C = control when larval source and rearing habitat are the same); 2nd letter indicates larval rearing location.

RESULTS AND DISCUSSION

Larvae construct cases of vegetation and as they grow attach more vegetation to increase the size of their cases. When they reach their 5th and final instar, cases typically measure 22-25mm. If the larva dies, the case remains. Its size can be used to determine at what instar mortality occurred. Survivorship calculations depended on accounting for all cases. Table 1 lists mortality of reared *Limnephilus indivisus*. Of 675 larvae, 173 completed their 5th instar and were sealed in their cases as pupae or pre-pupae and had attached themselves to decaying giant bur-reed or water swamps. On 30 March 1988 second instar larvae were collected at each of the three study sites. Figure 2 illustrates the experimental design. The 25 larvae reared in each enclosure were checked biweekly at each site from 30 March – 2 June. Measurements on temperature, dissolved oxygen, pH, conductivity, and total dissolved solids (TDS) were gathered from rearing enclosures during each visit. On 2 June, enclosures were removed from rearing locations and larval cases (occupied or empty) were sorted by instar and placed in 80% ethanol.

By transferring larvae to different rearing locations and establishing controls, a 3 x 3 contingency table containing 9 separate treatment groups generated a Model I analysis of variance (ANOVA) (Zar 1984). The results were analyzed with ANOVA after the data were transformed to arcsin √(%) mortality to obtain a normal distribution (Steel and Torrie 1960). Significantly different means (P ≤ 0.05) were separated by Tukey’s multiple range test (Zar 1984).
Table 1. — Larval survivorship of *Limnephilus indivisus* Walker reared in enclosures in wetland areas impacted or not impacted by strip-mining between March 30 and June 2, 1988 (refer to Fig. 2 for listing of treatment symbols).

| Description of Specimen | CNa | CNb | CNc | SNa | SNb | SNc | LN | LNa | LNb | LNc | CSa | CSb | CSc | NSa | NSb | NSc | LSa | LSB | LSc | CLa | CLb | CLc | NL | NLb | NLC | SL | SLb | SLc | Totals |
|-------------------------|-----|-----|-----|-----|-----|-----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2nd Instar Case Empty (open) | 0   | 2   | 1   | 3   | 4   | 4   | 0   | 6   | 3   | 11  | 7   | 8   | 9   | 7   | 3   | 9   | 10  | 1   | 0   | 1   | 3   | 2   | 0   | 4   | 5   | 2   | 108  |
| 3rd Instar Case Empty (open) | 0   | 2   | 1   | 3   | 4   | 4   | 0   | 6   | 3   | 11  | 7   | 8   | 9   | 7   | 3   | 9   | 10  | 1   | 0   | 1   | 3   | 2   | 0   | 4   | 5   | 2   | 108  |
| 4th Instar Case Empty (open) | 0   | 2   | 1   | 3   | 4   | 4   | 0   | 6   | 3   | 11  | 7   | 8   | 9   | 7   | 3   | 9   | 10  | 1   | 0   | 1   | 3   | 2   | 0   | 4   | 5   | 2   | 108  |
| 5th Instar Case Empty (open) | 0   | 2   | 1   | 3   | 4   | 4   | 0   | 6   | 3   | 11  | 7   | 8   | 9   | 7   | 3   | 9   | 10  | 1   | 0   | 1   | 3   | 2   | 0   | 4   | 5   | 2   | 108  |
| 5th Instar Case (closed) | 0   | 2   | 1   | 3   | 4   | 4   | 0   | 6   | 3   | 11  | 7   | 8   | 9   | 7   | 3   | 9   | 10  | 1   | 0   | 1   | 3   | 2   | 0   | 4   | 5   | 2   | 108  |
| Larva inside – Live | 2   | 0   | 1   | 1   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 2   | 1   | 2   | 1   | 2   | 1   | 2   | 1   | 2   | 1   | 10  |
| Larva inside – Dead | 2   | 3   | 0   | 1   | 1   | 2   | 3   | 1   | 4   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 2   | 1   | 2   | 1   | 2   | 1   | 2   | 1   | 26  |
| Pupa inside – Live | 8   | 7   | 9   | 4   | 2   | 4   | 7   | 5   | 6   | 2   | 2   | 2   | 4   | 3   | 3   | 2   | 4   | 10  | 9   | 8   | 9   | 6   | 9   | 4   | 5   | 4   | 140 |
| Pupa inside – Dead | 3   | 2   | 4   | 1   | 0   | 1   | 2   | 0   | 0   | 0   | 1   | 0   | 1   | 1   | 0   | 0   | 0   | 1   | 0   | 1   | 1   | 3   | 0   | 1   | 0   | 1   | 23  |
| Adult – Male | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 1   |
| Adult – Female | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |
| Larva Location Unknown | 0   | 4   | 2   | 2   | 3   | 6   | 7   | 9   | 4   | 14  | 0   | 7   | 5   | 6   | 3   | 16  | 10  | 7   | 2   | 5   | 3   | 0   | 5   | 4   | 7   | 4   | 6   | 141 |

| No. of Survivors | 10  | 7   | 10  | 6   | 2   | 5   | 7   | 5   | 6   | 2   | 2   | 2   | 5   | 4   | 3   | 2   | 4   | 11  | 10  | 9   | 7   | 9   | 4   | 5   | 5   | 153 |
| Mean No. of Survivors/Treatment | 9   | 4.33 | 6   | 2   | 2   | 2   | 5   | 4   | 3   | 2   | 4   | 11  | 10  | 9   | 7   | 9   | 4   | 5   | 5   | 153 |
| Mean Survivorship Rate/Treatment | 0.36 | 0.17 | 0.24 | 0.08 | 0.15 | 0.12 | 0.33 | 0.33 | 0.19 | 0.44 | 0.40 | 0.36 | 0.36 | 0.28 | 0.36 | 0.16 | 0.20 | 0.200.23 |

Survivorship Rate

0.40 0.28 0.40 0.24 0.08 0.08 0.8 0.28 0.20 0.24 0.88 0.88 0.88 0.08 0.20 0.16 0.12 0.08 0.16 0.44 0.40 0.36 0.36 0.28 0.36 0.16 0.20 0.200.23
Figure 3. Histogram showing *Limnephilus indivisus* survivorship for all treatments and replicates (refer to Fig. 2 for listing of treatment symbols).

smartweed foliage or the screen mesh of the enclosure. Upon examination of these sealed cases, 23 pupae were recorded as dead with only the exoskeleton remaining; several had a white fungal growth covering much of the inside of the case. Bert(1982) reported that a species of *Entomophthora* can infect *Limnephilus externus* Hagen. Three adults had emerged from their sealed cases, not by removing the thick filter plugs at the ends of the case which the larva constructs before pupation, but by cutting through the silken linings of the case approximately 2-3mm from the anterior end. This behavior has not previously been reported for *L. indivisus* by other observers. The rearing experiment was terminated before adult emergence to facilitate collection and quantification of mortality while live individuals were still inside their cases.

Survivorship rates in all enclosures are shown in Fig. 3. Larval survival was not the same for all treatment groups or replicates. Most survivorship rates [proportion (X/n)] observed for this experiment were below the 30% value and required arcsine transformation. The arcsine survivorship values resulted in an F statistic equal to 12.53***, highly significant, since F0.001(1)8,18 = 6.48 (Table 2), indicating that treatments do not share means in common. Because a significant F value resulted from the analysis of variance, the Tukey test was applied to the means ranked in order of magnitude. This multiple comparison test revealed that the mean survival ratios described three distinct groups - (Low survival: CS, LS); (Medium survival: NS, SN, SL, LN); (High survival: NL, CN, CL) (refer to Fig. 2 for description of treatments).

It was the control groups (CN, CS, CL) that were of primary interest, because these groups could reveal whether wetland areas of Stillfork Swamp Nature Preserve were being impacted by surface-mining activities. Figure 4a compares mortality in control treatments. In both Stillfork Swamp north of the RR tracks (CN) and Leetonia swamp (CL) similar mortalities of approximately 60% were observed during development from 2nd instar to adult; but larvae occupying southern Stillfork Swamp locations (CS) suffered 92% mortality rates and especially high mortality during the 2nd instar.
Table 2 — Single factor analysis of variance (ANOVA) of arcsine transformed survival ratios for reared *Limnephilus indivisus* Walker (refer to fig. 2 for treatment headings).

HO = There is no difference in survival of larvae among treatments. (i.e., Is variability among treatments greater than variability within treatment?)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>CN</th>
<th>SN</th>
<th>LN</th>
<th>CS</th>
<th>NS</th>
<th>LS</th>
<th>CL</th>
<th>NL</th>
<th>SL</th>
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</thead>
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<tr>
<td>Replicate a</td>
<td>0.3923</td>
<td>0.2933</td>
<td>0.3195</td>
<td>0.1643</td>
<td>0.1643</td>
<td>0.2027</td>
<td>0.4155</td>
<td>0.3687</td>
<td>0.2358</td>
</tr>
<tr>
<td>Replicate b</td>
<td>0.3195</td>
<td>0.1643</td>
<td>0.2657</td>
<td>0.1643</td>
<td>0.2657</td>
<td>0.1643</td>
<td>0.3923</td>
<td>0.3195</td>
<td>0.2657</td>
</tr>
<tr>
<td>Replicate c</td>
<td>0.3923</td>
<td>0.2933</td>
<td>0.2933</td>
<td>0.1643</td>
<td>0.2358</td>
<td>0.2358</td>
<td>0.3687</td>
<td>0.3687</td>
<td>0.2657</td>
</tr>
</tbody>
</table>

Source of Variation  | SS  | DF  | MS  |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.1778</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Groups</td>
<td>0.1505</td>
<td>8</td>
<td>0.0188</td>
</tr>
<tr>
<td>Error</td>
<td>0.0274</td>
<td>18</td>
<td>0.0015</td>
</tr>
</tbody>
</table>

\[ F = \frac{\text{Group MS}}{\text{Error MS}} = 12.53 \text{ ***} \]

F 0.05(1) 8,18 = 3.01
F 0.01(1) 8,18 = 4.28
F 0.001(1) 8,18 = 6.48

Mortality of all larvae (CS, NS, LS) reared in the southern area of Stillfork Swamp was similar with 50% mortality or greater observed between the 2nd and 3rd instars (Fig. 4b). Larvae taken north of the RR tracks and transferred to other locations (NS, NL) only showed substantial reductions when reared in southern Stillfork Swamp locations (NS) (Fig. 4c). Survivorship in the Leetonia swamp was similar to those observed north of the RR tracks at Stillfork Swamp (compare Fig. 4d & 4e). Southern source larvae transferred to rearing locations north of the RR tracks (SN) and Leetonia swamp (SL) showed improved levels of survivorship by almost double when compared to the southern control treatment (CS) (Fig. 4f). However, levels of survivorship were still relatively low.

Table 3 lists water quality data which were collected at the three habitat locations from within enclosures (Stillfork Swamp — north and south of RR tracks and Leetonia Swamp) during the rearing of *Limnephilus indivisus*. Water temperatures during larval development at the three different locations reflected similar warming rates. Leetonia swamp remained only slightly warmer during the study. Richardson and Mackay (1984) have observed that temperature primarily controls the rate of development for *L. indivisus* which was probably similar for these three locations. Dissolved oxygen, inversely related to water temperature, reflected similar saturation levels (all near or at 100%) for all enclosures and rearing locations. On 23 May 1988 the dissolved oxygen level within southern Stillfork Swamp rearing locations was 9.4 mg/ml (93% saturation), the lowest oxygen concentration recorded. Hydrogen ion concentrations (pH) although not similar, were not statistically different (\( F = 2.07, \) where \( F_{0.05, 2, 15} = 3.68 \)). The mean pH at southern locations was 5.17; at northern locations, 5.59; and at Leetonia Swamp, 6.27. In all locations, pH slowly increased from March to June. The lowest pH, 4.7, was recorded on 30 March 1988 for locations south of the RR tracks, Stillfork Swamp. North RR track locations registered 5.1 at that same time.

Conductivity readings between locations, although not statistically different (\( F = 3.26, F_{0.05, 2, 15} = 3.68 \)), did show some variability (Fig. 5). There was a general trend toward decreasing conductivity over the course of the experiment and the lowest levels recorded on 2 June. Total dissolved solids (TDS) proved to be the most
variable (Fig. 6) and were statistically different between locations with an \( F = 5.65^* \) (0.025, 2, 15 = 4.77). More significant is the difference in dissolved solids on 30 March 1988 when larvae were placed in their enclosures. Southern locations had two to three times higher TDS and conductivity readings on this date than northern or Leetonia habitats. We are uncertain whether intensity in mining activity remained constant during this rearing experiment.

The design of the field experiment allowed several statements about the impact of surface mining on *Limnephilus indivisus* to be made. *Limnephilus indivisus* is a shredder that inhabits the temporary pools within many northeastern Ohio wetlands and swamps. Wetland areas within Stillfork Swamp which were regularly flooded by Still Fork Creek in the spring of 1988 received effluents commonly associated with acid-mine drainage. Increased conductivity and elevated total dissolved solid concentrations were strongly correlated \( (r^2 = 0.864) \) with decreased survivorship of larvae reared at southern swamp locations. Controls established in northern areas and in a similar wetland habitat of another watershed known not to be receiving acid-mine drainage did not suffer these high mortality rates (92%). But mortality in
Table 3—Water quality data in enclosures during rearing of *Limnephilus indivisus* larvae.

<table>
<thead>
<tr>
<th>Date/Location</th>
<th>Temperature °C</th>
<th>pH</th>
<th>Conductivity µmhos/cm</th>
<th>Dissolv. Oxy. mg/ml</th>
<th>TDS mg/L</th>
</tr>
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<tbody>
<tr>
<td><strong>South RR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/30/88</td>
<td>3</td>
<td>4.7</td>
<td>766</td>
<td>13.5</td>
<td>798.1</td>
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<td>4/13/88</td>
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<td>4.8</td>
<td>513</td>
<td>15.2</td>
<td>489.3</td>
</tr>
<tr>
<td>4/24/88</td>
<td>6</td>
<td>5.6</td>
<td>746</td>
<td>12.5</td>
<td>451.7</td>
</tr>
<tr>
<td>5/14/88</td>
<td>11.2</td>
<td>6.4</td>
<td>453</td>
<td>10.8</td>
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<td>13</td>
<td>6.4</td>
<td>445</td>
<td>9.4</td>
<td>296.8</td>
</tr>
<tr>
<td>6/2/88</td>
<td>14</td>
<td>6.2</td>
<td>261</td>
<td>12.2</td>
<td>472.1</td>
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<tr>
<td>Mean Value</td>
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<td>630.67</td>
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</tr>
<tr>
<td>Std. Dev</td>
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<td>0.78</td>
<td>193.99</td>
<td>2.03</td>
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<td>5.1</td>
<td>380</td>
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<td>472</td>
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<td>13</td>
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<td>109.69</td>
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<tr>
<td>3/30/88</td>
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<tr>
<td>4/13/88</td>
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<td>6.4</td>
<td>451</td>
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<tr>
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<td>10.9</td>
<td>189.4</td>
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<td>381</td>
<td>11.2</td>
<td>291.5</td>
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<td>7.2</td>
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<td>Mean Value</td>
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<td>330.67</td>
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</tr>
<tr>
<td>Std. Dev</td>
<td>4.51</td>
<td>0.50</td>
<td>99.55</td>
<td>0.95</td>
<td>86.82</td>
</tr>
</tbody>
</table>

controls was high (60%); however, type 2 or 3 survivorship curves are common in many aquatic insect species (Resh and Rosenberg 1984). It is felt that this mortality rate reflects a true mortality estimate experienced by this species under natural conditions.

Hydrogen ion concentration (pH) has been shown to be critical for most Trichoptera (Havas and Hutchinson 1982), but some limnephilids, e.g., *Limnephilus pallens* (Banks), apparently can tolerate extended periods at pH's much lower than 4.5. Chris Stefanov, the ODNR field inspector for the mining site, stated that sediment ponds located on the permit site routinely had pH's readings in the 5.0—4.5 range. At no time during this study did we obtain water samples from Still Fork Creek or from rearing enclosures with pH values below 4.7. Wiederholm (1984) has indicated that the effects of low pH in acid-mine waste water are often difficult to separate from the effects of suspended solids and heavy metals. Consequently, it is highly unlikely that pH was the single critical variable affecting larval mortality. It is more likely that an interaction involving a number of factors produced poor survival for this species.

Colburn (1983) reported that larval survival and adult development of *Limnephilus assimilis* (Banks) was reduced as temperature increased in desert ponds with high
Figure 5. Water conductivities within rearing enclosures during *Limnephilus indivisus* larval development.

Figure 6. Total dissolved solids (TDS) within rearing enclosures during *Limnephilus indivisus* larval development.
salinities. Apparently, high temperatures coupled with the high conductivities due to elevated ion concentrations interrupted the larva's osmo-regulatory system and caused increased mortality. We suspect that some similar condition might have affected L. indivisus. Conductivity (≈ 780 μmhos/cm) and dissolved solid concentrations (≈ 800 mg L⁻¹) were extremely high in southern swamp areas in early spring of 1988. In general, dissolved metals are more toxic than metals in other forms (e.g., as precipitates) and their solubility is strongly affected by pH and temperature. Apparently such synergistic effects increase the negative influence of acid-mine water on many freshwater invertebrates (Wiederholm, 1984). After loss of ice cover in early spring, water temperature increases and larval growth and development rapidly occurs. Death for many larvae occurred during their 2nd instar, and was especially noticeable in southern rearing locations (Table 1). Solem (1983) reported that a critical time for survival of 1st or 2nd instars larvae of Limnephilus stigma Curt., an inhabitant of temporary vernal pools in Norway, was when ice was present and the substrate frozen. Perhaps, spring is a critical time for larval development of L. indivisus before the pools dry-out in mid-June. Stresses caused by elevated total dissolved solids and conductivity may have affected this insect's ability to regulate ion exchange within its chloride epithelium. Wichard and Komnick (1973) indicated that larvae of Limnephilidae possess circumscribed areas, known as chloride epithelia, on abdominal segments II—VII which function as osmoregulatory organs able to remove chloride ions and other electrolytes from the water passing through their cases. These ions are subsequently transferred to the hemolymph in compensation for ions lost from excretion.

Regardless of the exact mechanism which caused L. indivisus mortality, the evidence suggests that acid-mine drainage was the contributing factor in the decline of this species. The high degree of sensitivity shown by this species to acid-mine drainage also suggests that this caddisfly or congeneric species are potential candidates for wetland managers to utilize when assessing the influence of upstream strip-mining, and possibly other perturbations.

LITERATURE CITED


Mickel, C. E. and H. E. Milliron. 1939. Rearing the caddis fly, Limnephilus indivisus Walker


EASTERN PINE SEEDWORM, CYDIA TOREUTA (LEPIDOPTERA: TORRICIDAE) IN RED PINE CONES IN WISCONSIN

S. A. Katovich and H. M. Kulman

ABSTRACT

*Cydia toreuta* population densities, prolonged diapause behavior, parasitism and adult emergence patterns were examined over four years at two red pine locations in Wisconsin. Last-instar densities ranged from 0.54 to 3.18 per cone. This was considered a wide range for this species in red pine. Population clumping was evident at last-instar densities below 2.90, however no consistent pattern was evident between years. Clumping disappeared at populations greater than 2.90 last-instars. Prolonged diapause varied from 7.8 to 38.9 days. Parasitism rates varied from 10.9 to 46.6%. *Phanerotoma toreuta* (Hymenoptera: Braconidae) was the most abundant parasite at both sites and emerged in unison with male *C. toreuta*. Estimation of percent of last-instars undergoing prolonged diapause prior to spring emergence can be accomplished using forced emergence though cones should be collected after 31 January. Estimation of percent parasitism can be made as early as November. Resident moth populations could be estimated prior to spring flight utilizing this information. Emergence occurred over an approximately 2 week period between mid-May and early June. The majority of male moths emerged prior to females.

The eastern pine seedworm, *Cydia toreuta* (Grote) feeds on the seeds of red pine (*Pinus resinosa*) and other North American conifers including jack pine (*P. banksiana*), loblolly pine (*P. contorta*), shortleaf pine (*P. echinata*), and Virginia pine (*P. virginiana*) (Hedlin et al. 1981). Infested cones have no external indicators of attack. One to three larvae may inhabit red pine cones (Lyons 1957a), with each larva consuming 4-10 seeds (Mattson 1978). Red pine cones contain 30-50 seeds (Lyons 1965). In red pine, last-instars overwinter within the cone axis. Pupation occurs the following spring. A proportion of the overwintering larvae may not pupate, but remain in prolonged diapause until the spring of the following year (Lyons 1957a). One major parasite, *Phanerotoma toreuta* Caltagirone (Hymenoptera: Braconidae) has been reported (Lyons 1957a, Harbo and Kraft 1969).

Previous studies on red pine seed production indicated that this species was a minor seed damaging agent (Lyons 1957b, Mattson 1978); however recent studies found it to be a major seed consumer in certain years (Katovich et al. 1989a).

This study investigated *C. toreuta* at two red pine sites in Wisconsin over a four year period. The objective was to provide information on life history, parasitism,
and prolonged diapause; and how each of these may be incorporated into potential sampling and control efforts.

MATERIALS AND METHODS

Site 1 was a Wisconsin Department of Natural Resources red pine seed orchard in Grant County (southwestern Wisconsin). It was planted in 1970 and produced cones since 1984. Site 2 was a widely spaced red pine planting in St. Croix County, Wisconsin (westcentral Wisconsin). It was planted in 1972 and produced cones since 1984. At both sites, trees were growing on an approximately 6.1 by 6.1 m grid.

Last-instar density, prolonged diapause, parasitism and adult emergence were investigated at site 1 in 1985 and 1986, and at site 2 in 1985-88. Since C. toreuta spend 11 months of their 12 month life cycle within cones, the sample unit chosen was a cone which had matured the previous fall. Cones were collected in mid-April, approximately 5 weeks before field emergence. At site 1, cones were collected from 15 randomly selected trees. Each tree was divided into 4 cells: North- and south-facing crown aspects, and upper- and middle-crown levels. No lower-crown level was used because few cones were located in this level. Five cones per cell were collected from each sample tree. All cones were picked if five were not present.

At site 2 in 1985, 20 trees were randomly selected and divided into two cells: North- and south-facing aspects. In 1986, 1987 and 1988, 24, 18 and 15 trees, respectively, were randomly selected and divided into 6 cells: North- and south-facing crown aspects and upper-, middle- and lower-crown levels. Five cones were collected from each cell. All cones were picked if five were not present.

Student's t-test comparisons for independent samples were used to test equality of means when comparing north- versus south-facing aspects or when comparing upper- versus middle-crown levels at site 1. Analysis of variance (ANOVA) was used when comparing all cells at either site or when comparing upper-, middle- and lower-crown levels at site 2. Duncan's (1955) multiple range test was used to separate significantly different means (P = 0.05).

Cones were placed in uncovered shallow pans and held at 24°C and a 15:9 light:dark cycle until day 20 when individual cones were isolated in a 0.47 l (1 pint) cardboard carton with lid. Larvae in infested cones kept at this regime required approximately 25 days to break diapause, pupate and begin emergence (Harbo and Kraft 1969). Each container was checked daily to note number of male and female moths and parasites that emerged from each cone. After emergence, cones were dissected to record numbers of (1) C. toreuta larvae in prolonged diapause, which was defined as living larvae which had not pupated; (2) dead C. toreuta larvae; (3) dead C. toreuta pupae and/or adults which failed to emerge; and (4) dead parasites that failed to emerge. Larval counts per individual cone at the time of cone collection were then reconstructed by adding emerged moths to numbers 1, 2 and 3, and by substituting one C. toreuta larva for each parasite. Harbo and Kraft (1969) have shown that the parasite Phanerotoma toreuta is solitary. Since other parasites were rare in this study, and when they were present, only single specimens emerged, it was assumed that they were also solitary.

In addition, at site 2, cone collections were made on 5 November and 5 December, 1986 and 5 January and 25 April, 1987. Collected cones were held at 24°C and a 15:9 light:dark cycle. Comparisons were made between percent parasitism and percent prolonged diapause among the four collection dates. Percent data obtained for each cone was transformed using arc sine √percent (Gomez and Gomez 1984), ignoring uninfested cones. Data was analyzed using ANOVA and individual means were separated using Duncan's (1955) multiple range test (P = 0.05).

In order to observe actual field emergence at site 2 in 1986 and 1987, 450 cones were randomly collected 15 days after pupation was initially observed. Cones were
Table 1. — Number of last-instars and emerging adults per cone of *Cydia toreuta* at site 1, Grant Co., 1985 and 1986, and site 2, St. Croix Co., Wisconsin, 1985, 1986, 1987 and 1988.

<table>
<thead>
<tr>
<th>Site</th>
<th>Year</th>
<th>No. of Cones Sampled</th>
<th>Larvae/Cone ± SE</th>
<th>Adults/Cone ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1985</td>
<td>300</td>
<td>1.12 ± 0.05</td>
<td>0.21 ± 0.03</td>
</tr>
<tr>
<td>1</td>
<td>1986</td>
<td>323</td>
<td>0.54 ± 0.10</td>
<td>0.15 ± 0.02</td>
</tr>
<tr>
<td>2</td>
<td>1985</td>
<td>184</td>
<td>2.17 ± 0.10</td>
<td>1.07 ± 0.10</td>
</tr>
<tr>
<td>2</td>
<td>1986</td>
<td>712</td>
<td>1.02 ± 0.05</td>
<td>0.63 ± 0.04</td>
</tr>
<tr>
<td>2</td>
<td>1987</td>
<td>330</td>
<td>2.94 ± 0.04</td>
<td>1.60 ± 0.06</td>
</tr>
<tr>
<td>2</td>
<td>1988</td>
<td>450</td>
<td>3.18 ± 0.06</td>
<td>1.42 ± 0.05</td>
</tr>
</tbody>
</table>

Table 2. — Number of last-instars ± standard error by crown aspect and crown level for *Cydia toreuta* at site 1, Grant Co., and site 2, St. Croix Co., Wisconsin. Dashed lines indicate no samples were taken.

<table>
<thead>
<tr>
<th>Site and Year</th>
<th>Crown Aspect</th>
<th>Crown Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
<td>South</td>
</tr>
<tr>
<td>Site 1 1985, n = 300</td>
<td>1.1 ± 0.1a</td>
<td>1.2 ± 0.1a</td>
</tr>
<tr>
<td>Site 1 1986, n = 323</td>
<td>0.5 ± 0.1a</td>
<td>0.6 ± 0.1a</td>
</tr>
<tr>
<td>Site 2 1985, n = 184</td>
<td>2.1 ± 0.1a</td>
<td>2.1 ± 0.1a</td>
</tr>
<tr>
<td>Site 2 1986, n = 712</td>
<td>1.1 ± 0.1a</td>
<td>1.0 ± 0.1a</td>
</tr>
<tr>
<td>Site 2 1987, n = 330</td>
<td>3.0 ± 0.1a</td>
<td>3.2 ± 0.1a</td>
</tr>
<tr>
<td>Site 2 1988, n = 450</td>
<td>3.1 ± 0.1a</td>
<td>3.2 ± 0.1a</td>
</tr>
</tbody>
</table>

Means within the same row followed by the same letter are not significantly different (P = 0.05). Multiple comparisons made by Duncan's multiple range test. Two-sample comparisons made by Student's t-test.

Placed into 1 pint cardboard containers with lids which were kept in the field under a 2 m tall plywood roofed structure. Absence of sides on the structure allowed free air flow. Containers were checked daily for emerged insects. All emerged moths were sexed.

**RESULTS AND DISCUSSION**

Mean density of last-instars per cone varied from 0.54 ± 0.04 at site 1 in 1986, to 3.18 ± 0.06 at site 2 in 1988. Number of last-instars in a sample cone ranged from 1 to 7. Mean number of adults emerging per cone varied from 0.15 ± 0.02 at site 1 in 1986, to 1.60 ± 0.06 at site 2 in 1987 (Table 1).

Based on x-ray analysis of seeds from 1988-collected cones at site 2, which indicated that 73 % of seeds in all cones had been consumed and that less than 3 % of cones were uninfested (Katovich et al. 1989a), populations approaching 3 larvae per cone appeared very high for this species. These populations appear to be close to the maximum for this species in red pine cones, since it is unlikely that all of the seeds will be consumed, even at these unusually high population densities because larvae do not leave infested cones and move to others which may not be infested. Also, cannibalism has been reported for this species when larval numbers are high within
Table 3. — Percent prolonged diapause and percent parasitism in *Cydia toreuta* larvae collected in red pine cones at four different dates, site 2, St. Croix County, Wisconsin. Cones subjected to 24°C and a 15:9 light:dark cycle.

<table>
<thead>
<tr>
<th>Cone Collection Date</th>
<th>Number of Cones</th>
<th>Mean Percent ± SE</th>
<th>Prolonged Diapause</th>
<th>Mean Percent ± SE</th>
<th>Parasitism</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 1986</td>
<td>238</td>
<td>54.0 ± 2.9b</td>
<td>10.3 ± 1.1a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December 1986</td>
<td>309</td>
<td>64.4 ± 2.8a</td>
<td>13.3 ± 1.9a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 1987</td>
<td>229</td>
<td>37.2 ± 1.9c</td>
<td>12.6 ± 1.2a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 1987</td>
<td>340</td>
<td>35.8 ± 1.9c</td>
<td>11.0 ± 1.0a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Means within the same column followed by the same letter are not significantly different (*P* = 0.05), using Duncan's multiple range test.

individual cones (Kraft 1968), making it difficult for several larvae to coexist within cones.

In no cases were significant differences (*P* = 0.05) found between mean number of larvae per cone from north- or south-aspect cones (Table 2). Significant differences were found when comparing crown level means (Table 2), but differences were not consistent at a given location between years. At site 1 in 1985, more larvae per cone were found in upper- than in middle-level cones (*t* = -4.02, 298 df, *P* < 0.001), while in 1986 more larvae per cone were found in middle- than in upper-level cones (*t* = -3.04, 321 df, *P* = 0.003). At site 2 in 1986, fewer larvae per cone were found in lower-than in either middle- or upper-level cones (MSE = 0.48, *F* = 40.2, 2 df for treatment and 709 df for error, *P* < 0.001). In 1987 and 1988 when larval populations were highest no differences were found between crown levels (*P* = 0.05).

Previous studies have implicated cone distribution within tree crowns as influencing *C. toreuta* distribution (Kraft 1968, Rauf and Benjamin 1983). In both of those studies insect distribution followed cone distribution. That was not necessarily the case in this study. At site 2 in 1985, 86 and 87 south-facing cones did not produce more larvae per cone despite being significantly more abundant than cones on other crown aspects (Katovich 1988).

A clumped distribution pattern has been previously reported in jack pine cones (Kraft 1968). In this study, since differences did exist between mean number of larvae per cone by crown level, clumping appeared to be evident for populations less than 2.90 larvae per cone. However, no consistent discernable pattern was evident from year to year, which makes it difficult to utilize this behavior in designing a sampling plan. Therefore, when sampling populations to obtain mean number of larvae per cone, cone collections need to be made from throughout the tree crown. The exception to this would be at high populations, approaching 3 larvae per cone, where clumping apparently disappears and sampling would no longer need to be evenly distributed throughout tree crowns.

At site 1, prolonged diapause was 7.8 and 38.9 % in 1985 and 1986, respectively. At site 2, prolonged diapause was 10.2, 9.3, 34.1 and 16.2 % in 1985, 1986, 1987 and 1988, respectively. Lyons (1957a) likewise found degree of prolonged diapause varied from year to year and between localities in the same year. Delayed emergence is common among cone and seed insects and is generally considered a survival adaptation in the event of a cone crop failure (Tripp 1954, Hedlin 1964).

Percentage of the larval population undergoing prolonged diapause was significantly affected by date of cone collection (Table 3). Cones collected in November and December had a significantly greater percentage of larvae remaining in prolonged diapause when brought indoors than did cones collected in either January or April (MSE = 786, *F* = 34.0, 3 df for treatment, 1112 df for error, *P* < 0.001). The
Table 4. — Parasites and percent parasitism of *Cydia toreuta* larvae in red pine cones, site 1, Grant Co., WI, and site 2, St. Croix Co., WI. Cones were collected in mid-April each year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Parasite</th>
<th>Percent Parasitism</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Site 1</td>
</tr>
<tr>
<td>1985</td>
<td><em>Phanerotoma toreuta</em></td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td><em>Exeristes comstockii</em></td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td><em>Campoplex sp.</em></td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>24.9</td>
</tr>
<tr>
<td>1986</td>
<td><em>P. toreuta</em></td>
<td>39.8</td>
</tr>
<tr>
<td></td>
<td><em>E. comstockii</em></td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td><em>Campoplex sp.</em></td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>46.6</td>
</tr>
<tr>
<td>1987</td>
<td><em>P. toreuta</em></td>
<td>– –</td>
</tr>
<tr>
<td></td>
<td><em>E. comstockii</em></td>
<td>– –</td>
</tr>
<tr>
<td></td>
<td><em>Campoplex sp.</em></td>
<td>– –</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>– –</td>
</tr>
</tbody>
</table>

1Hymenoptera, Braconidae  
2Hymenoptera, Ichneumonidae

January and April sample means were not significantly different (*P = 0.05*). Bakke (1970) reported the time required for termination of diapause in larvae of *Cydia strobilella* varied considerably in cones collected in the fall, whereas the population was much more homogenous concerning that characteristic in cones collected in early spring.

The percentage of larvae exhibiting prolonged diapause is variable from year-to-year. Consequently, estimating number of emerging adults from larval counts will be inaccurate unless adjusted for numbers of larvae which will extend their life cycle through prolonged diapause. Therefore, a reliable estimation of prolonged diapause would prove valuable. Cone collections after 31 January in Wisconsin and subsequent forced moth emergence should provide reliable estimates for prolonged diapause.

Parasitism was prevalent at both sites in all study years, ranging from 10.9 to 46.6 % (Table 4). *Phanerotoma toreuta* was the major parasite, and has been reported as the most commonly collected parasite of *C. toreuta* in past studies in the Upper Peninsula of Michigan (Harbo and Kraft 1969) and in Ontario (Lyons 1957a). Two other parasites, *Exeristes comstockii* (Cresson) and *Campoplex sp.* (Hymenoptera: Ichneumonidae), were collected. *E. comstockii* is a common parasite of lepidopterous larvae attacking conifer foliage, cones and growing tips (Yates 1967, Bradley 1974). It has been reported as a parasite of *C. toreuta* (Ciesla and Bell 1966, Harbo and Kraft 1969). Harbo and Kraft (1969) state that *E. comstockii* parasitize *C. toreuta* larvae in early spring prior to moth emergence. However, in this study adult *E. comstockii* did emerge from winter collected cones, indicating that at least some parasitization was occurring the previous fall or late-summer. *Campoplex sp.* has not previously been reported parasitizing *C. toreuta*, though various *Campoplex* species have been reported as parasites of other *Cydia* seed feeding species in North America (Keen 1958).

At site 2, in 1987, no differences were found in number of *P. toreuta* adults per
Figure 1. Field emergence of *Cydia toreuta* males and females, and *Phanerotoma toreuta* (Parasites) adults at a red pine site in St. Croix County, Wisconsin (site 2), in 1986 (top) and 1987 (bottom). Emergence occurred between 23 May and 4 June 1986, and between 9 and 24 May 1987.

cone between crown levels (upper = 0.30±0.05, middle = 0.34±0.05, lower 0.35±0.05). Data from 1987 was used because no differences in mean total larvae of *C. toreuta* per cone had been found. Therefore, number of *P. toreuta* per cone was equivalent to percent parasitism by this species.
Percent parasitism by *P. toreuta* was not affected by cone collection date. Percent parasitism rates were not significantly different between cones collected in November, December, January or April (*P* = 0.05) (Table 3). Therefore, cone samples can be collected as early as November to obtain reliable estimates of percent parasitism.

Field emergence of *C. toreuta* occurred over a 13-day period in 1986, 23 May through 4 June, and a 16-day period in 1987, 9 May through 24 May (Figure 1). In both years, males emerged first with the majority emerging over a two-day period. Female *C. toreuta* emerged after the majority of males. *Phanerotoma toreuta* generally emerged in unison with male *C. toreuta*. Female *P. toreuta* oviposited in eggs of *C. toreuta*. These results are in general agreement with those reported for Ontario by Lyons (1957a), though he reported emergence approximately one month later.

The initial capture of male moths could be used as a timing technique for application of some control practice applied against adults. Insecticide sprays aimed at the females could be timed for application at a given interval following initial male moth collection. The sex pheromone for *C. toreuta* has been identified (Katovich et al. 1989b), and could be used with traps to capture male moths. Unfortunately, any broad spectrum treatment may also impact *P. toreuta* adults which are present at the same time. Adult *P. toreuta* were not attracted to *C. toreuta* pheromone (unpublished data) and therefore the pheromone could be utilized without directly impacting adult parasite populations.

Though *C. toreuta* has been generally considered an uncommon cone inhabitant and therefore a minor pest of red pine seed production (Lyons 1957b, Mattson 1978), it is shown in this study to be capable of high larval populations of greater than 3 larvae per cone. It appears unlikely that populations much higher would be encountered in red pine cones. This information should provide a reference when comparing future population levels. Further, the collection of cones from November through May and subsequent forced emergence could serve as a valuable indicator of potential moth populations of this species. If an estimate of prolonged diapause is required collections should occur after 31 January, while if predictions of parasitism alone are necessary, then cones could be collected at anytime during that period.

**ACKNOWLEDGMENTS**

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**LITERATURE CITED**


LOCATION AND CONDITION OF WHITEMARKED TUSSOCK MOTH (LEPIDOPTERA: LYMANTRIIDAE) COCOONS IN A MICHIGAN BLACK WALNUT PLANTATION

Louis F. Wilson

ABSTRACT

Whitemarked tussock moth, *Orgyia leucostigma*, cocoons were monitored in a black walnut, *Juglans nigra*, plantation in Michigan from 1978 to 1981. Larvae spun cocoons on the exposed bark of the bole (29.6%), in crevices on the bole formed by pruning wounds (17.5%), beneath limbs (24.2%), and in branch crotches (28.7%). Parasites and predators destroyed 88% of the pupae in their cocoons. The tussock moth population, although moderate to high in the egg stage, decreased sufficiently in the larval stages each year to cause no more than 5% defoliation to individual trees.

The whitemarked tussock moth, *Orgyia leucostigma* (J.E. Smith), is a native defoliator that feeds on many species of trees, including black walnut, *Juglans nigra* (Nixon and McPherson 1977). In mixed-tree hardwood forests this insect is seldom abundant, but it can cause severe defoliation in monoculture hardwood forests, cities, and parks (Martineau 1984). When conditions are favorable, outbreaks develop rapidly, and then subside in one or two additional seasons, apparently as a result of natural enemies (Browne 1968, Howard 1897, Johnson and Lyon 1988). However, a single heavy defoliation by this tussock moth can reduce tree growth and subject trees to attack by secondary insects and diseases. From 1975 to 1978, this insect was particularly abundant in portions of the eastern United States and Canada where it denuded tree crowns over large acreages (Martineau 1984).

In 1978, during an investigation of a black walnut plantation near Keeler, Van Buren County, Michigan, light defoliation by the whitemarked tussock moth was observed. The level of defoliation increased in 1979. In the vicinity of Keeler, tussock moth adults appear from mid- to late July, and a few are present as late as September. The wingless females oviposit on or near their empty cocoons. After the eggs overwinter, most larvae hatch from April through June. They mature in 5 to 6 weeks and then spin silken cocoons on the bark of the host. The pupal stage lasts 2 to 3 weeks.

The objectives of the study reported here were (1) determine the location and condition of tussock moth cocoons, (2) assess tussock moth population levels, and (3) predict if these populations would be injurious to the walnut trees.

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MATERIALS AND METHODS

This study was made in a black walnut plantation near Keeler, Michigan, from 1978 to 1981. The trees were planted 3.4 to 3.7 m apart from 1971 to 1973 using 1-0 and 2-0 seedlings. Thereafter, the 12-acre stand was cultivated and fertilized (NPK 18-18-18) annually. Over several years the trees received both corrective and lateral pruning. Eight 0.08 ha circular plots (diam. 32.5 m) were established in 1978 to measure tree growth and to monitor insect infestations. Tree density ranged from 55 to 66 per plot for a total of 498 trees.

Tussock moth cocoons were noted in each plot in fall 1978 when the trees were 3.7 to 5.4 m tall. In 1979, we noted that many larvae were present during the summer, and on 15–17 October, we recorded the locations of all cocoons on all plot trees. Then, all cocoons, except those with egg masses on them, were removed in plots 1 and 3 and their condition noted. Cocoons with egg masses were tallied as emerged adult females. Ten egg masses were removed from the plots and reared in the laboratory. The stand was examined again in mid-August 1980, with defoliation assessed in 5% increments; each tree was inspected by two people, with the average value recorded. On 1 October 1980, cocoons were counted on 10 randomly selected trees in each plot. The study was terminated in late summer 1981, after the trees were examined for tussock moth defoliation.

RESULTS AND DISCUSSION

This insect is occasionally multivoltine in the northern United States (Johnson and Lyon 1988), but there was only one generation each year of this study. Larval densities were relatively low in the summer of 1978, and the scarce cocoons were concentrated in the southeastern corner of the plantation. Larvae were more abundant during 1979, but no trees suffered more than 5% defoliation. In addition, there were 847 cocoons observed in 1979 on the plots — an average of 1.7 cocoons per tree (range 0 to 12). Cocoons once again were most abundant in the southeastern plots 1 and 3, and relatively sparse in the northwestern plots 5 and 7. Plot 8, which was isolated from the other plots by about 200 m, had the fewest cocoons.

The whitemarked tussock moth probably first entered the black walnut plantation during 1976 or 1977. Apple orchards that surround the plantation may have been the source of the infestation. Apparently the moth entered the stand in the southeast corner and then spread throughout the rest of the plantation. The southeast corner, however, maintained the highest population throughout this study.

Approximately 47% of the cocoons observed in 1979 were on the boles of the trees — 29.6% on the bark surface and 17.5% in crevices formed by pruning wounds (Table 1, Fig. 1). The remaining cocoons were either beneath limbs (24.2%) (Fig. 2) or in branch crotches (28.7%) (Table 1).

Of the 341 cocoons removed from plots 1 and 3 (including those attached to egg masses left on the trees), 12% yielded cast pupal cases and 88% contained dead pupae. Parasitic Hymenoptera and parasitic Diptera emerged from 43% and 3% of the pupae, respectively. Examination of cadavers indicated that predators attacked 7% of the pupae, and pathogens killed 33%. The cause of the remaining 2% mortality could not be determined.

Howard (1897) identified 21 species of parasites and 11 species of predators attacking various stages of the tussock moth. Also, he noted that birds readily fed on the colorful larvae. Raizenne (1952) listed 12 species of parasites that apparently were responsible for keeping outbreaks under control in Canada. In our study, natural enemies may have reduced the population sufficiently to keep defoliation below 5%.

In summer 1980, larvae were again present on several trees, but fall defoliation was no greater than that done by the 1979 population. The cocoon count for the
Figure 1. Whitemarked tussock moth cocoon in a pruning wound.

Table 1. Locations of whitemarked tussock moth cocoons (N = 847) on 498 black walnut trees in a Michigan plantation in 1979.

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean (range)/tree</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beneath limb</td>
<td>0.42 (0–6)</td>
<td>205</td>
<td>24.2</td>
</tr>
<tr>
<td>Limb-crotch</td>
<td>0.48 (0–6)</td>
<td>243</td>
<td>28.7</td>
</tr>
<tr>
<td>Bole</td>
<td>0.51 (0–6)</td>
<td>251</td>
<td>29.6</td>
</tr>
<tr>
<td>Bole-wound</td>
<td>0.29 (0–4)</td>
<td>148</td>
<td>17.5</td>
</tr>
</tbody>
</table>

Eight plots, however, was estimated at 2,356 cocoons. This was 4.7 cocoons per tree, or nearly three times more abundant than in 1979. Nevertheless, the population collapsed in 1981 due to unknown causes. Raizenne (1952) noted that viruses often depleted tussock moth populations in Canada.

The 75 egg masses recorded in the plots in 1979 averaged 362 eggs per mass (range 333 to 478). Egg masses were not counted in 1980, but they probably were more abundant than in 1979, because the cocoon population increased from 847 in 1979 to 2,356 in 1980.

Not all the eggs reared in the laboratory hatched, and larvae that emerged lived only a few hours. This suggests that they may require food shortly after eclosion.
Howard (1897) showed that many eggs of *O. leucostigma* did not hatch during natural outbreaks, and many larvae starved to death because they were too far from foliage at eclosion. All egg masses found in the present study were on the boles and branches, and many were a meter or more from foliage.

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A DESCRIPTIVE STUDY OF THE POPULATION DYNAMICS OF ADULT DIABROTICA VIRGIFERA VIRGIFERA (COLEOPTERA: CHRYSOMELIDAE) IN ARTIFICIALLY INFESTED CORN FIELDS

N. C. Elliott\textsuperscript{1,2}, J. J. Jackson\textsuperscript{1}, G. R. Sutter\textsuperscript{1}, and D. A. Beck\textsuperscript{1}

ABSTRACT

The influence of corn plant phenology on the dynamics of adult western corn rootworm, Diabrotica virgifera virgifera, populations was studied during 1988 and 1989 in corn fields artificially infested with eggs. Fifty percent of adult emergence from the soil occurred by day 194 in 1988 and day 203 in 1989. In both years, adult emergence was synchronized with corn flowering, eggs were recovered in soil samples approximately four days after reproductive females were first observed in the population, and oviposition was essentially complete about 25 days after it began. The number of reproductive female beetle-days accumulating per m\textsuperscript{2} was similar in both years. Approximately two times as many eggs were laid in 1988 (1239 eggs /m\textsuperscript{2}) as in 1989 (590 eggs /m\textsuperscript{2}). The difference in egg density may have been caused by differences among years in the temporal synchrony of reproductive beetles with flowering corn. Daily survival rates of adults were high while corn was flowering; exhibited a gradual decline during grain filling; and decreased rapidly during the grain drying stage.

The western corn rootworm, Diabrotica virgifera virgifera LeConte, is among the most destructive insect pests of corn, Zea mays, grown in the midwestern United States. The species is univoltine and overwinters in the egg stage. Eggs, larvae, and pupae are subterranean. Eggs hatch in the spring, and larvae feed on the roots of corn plants. Larval feeding reduces the ability of corn plants to absorb nutrients and moisture from the soil and makes them susceptible to lodging. Adults emerge from the soil in the summer and feed primarily on the leaves, silks, and pollen of corn.

The potential for large, damaging, larval populations in fields is generally determined by the number of eggs laid there the previous summer; however highly variable and unpredictable mortality during the immature life stages makes prediction of damage difficult. The number of eggs laid per unit area in a field is related to the density of female beetles, their fecundity, and residence time in the field. Beetles of both sexes feed on a variety of corn tissues, but survival and fecundity rates vary with the tissues upon which they feed, and consequently, on the growth stage of corn plants in the field (Elliott et al. 1990a). Dispersal rates of adults are also influenced by corn plant phenology. Beetles are attracted to fields of silking and pollinating

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corn, but tend to leave fields in which corn has advanced to more mature stages of growth (Hill and Mayo 1974, Godfrey and Turpin 1983).

Recent advances in laboratory rearing methods for *D. virgifera* that permit production of large numbers of *D. virgifera* eggs (Jackson 1986) have made it possible to infest relatively large field plots with eggs at densities similar to those encountered in naturally infested fields. Field tests conducted over several years have failed to demonstrate differences in the biology of beetles developing from eggs laid by colony beetles and those developing from eggs laid by field collected beetles (J. R. Fisher unpublished data). Thus, artificial infestation may be a useful method for initiating *D. virgifera* field populations with dynamics similar to those of naturally occurring populations.

Previous studies of the seasonal population dynamics of adult *D. virgifera* related patterns of adult emergence from the soil, oviposition, and population change to calendar date and heat units (Hein and Tollefson 1985, Hein et al. 1988). There have been no studies of adult *D. virgifera* field populations in which the processes of emergence from the soil, reproductive development, oviposition, and mortality were studied in relation to corn plant phenology. Our objectives were to measure beetle emergence from the soil, sex ratio, reproductive development, mortality, and oviposition in relation to time during the growing season and corn plant phenology. Because extreme annual variation in the climate of eastern South Dakota (particularly during winter) makes natural infestations of *D. virgifera* sporadic and unpredictable, we chose to conduct our studies in artificially infested fields.

### MATERIALS AND METHODS

Field studies were conducted in eastern South Dakota during 1988 and 1989. Each year, a single 0.4 ha field on a research farm located adjacent to the USDA, ARS Northern Grain Insects Research Laboratory, Brookings, South Dakota, that had been planted to wheat the previous year (1988) or fallowed (1989) was infested with *D. virgifera* eggs obtained from a laboratory colony maintained by the methods of Jackson (1986). Corn (*Pioneer 3978*) was planted and fields were infested with eggs on 12 May each year. The entire length of each row of corn in a field was infested with eggs at population densities of 2612 and 2275 eggs per m² in 1988 and 1989, respectively, using methods described by Sutter and Branson (1986). Corn was planted at densities of 5.22 and 4.77 plants per m² in 1988 and 1989, respectively.

To facilitate sampling each year, the field was partitioned into 12 rectangular sub-plots of equal size. Two emergence traps similar to those described by Fisher (1984) were positioned at random locations within each sub-plot (total 24 traps). The emergence traps used were 0.91 m wide in 1988 and 1.0 m wide in 1989 (one row width) and were 0.61 m in length (three times the plant spacing within rows). Each trap was centered over three plants within a row. Emerged beetles were collected from traps three times weekly on alternate days. The number and sex of beetles in each collection were recorded.

The population density of adult beetles in the field was determined three times each week by counting all beetles on an entire corn plant and the soil surface and weeds surrounding the plant. Beetles were counted on each of four plants selected in a haphazard fashion from within each sub-plot (total 48 plants). Hanway's (1966) 0–10 numeric rating system was used to estimate the growth stage of each sampled corn plant. We combined plant phenology data into three groups. We considered corn plants in the field to be in the flowering stage from the date at which 10% of plants had advanced at least to stage 4 (tassel visible) to the date at which 90% of plants had advanced beyond stage 5.5 (pollination complete, silks beginning to turn brown), plants to be in the grain filling stage from the date at which more than 90% of plants had progressed beyond stage 5.5 to the date at which 90% of plants had
advanced beyond stage 8 (a few kernels with dents), and plants to be in the grain drying stage from the date at which more than 90% had advanced to stage 9 (all kernels with dents).

Soil samples were taken once each week beginning approximately one week after beetles began to emerge from the soil and continuing until the study was terminated. Each soil sample consisted of 12 subsamples (one from each sub-plot). A subsample consisted of 10 cylindrical cores taken with a 5.4 cm diameter bulb-setter to a depth of 15 cm. Each core was taken directly within a row at the base of a corn plant selected in a haphazard fashion from within the sub-plot. The 10 cores were sifted through a 1 cm screen, thoroughly mixed, and 0.47 l of soil was removed for processing. Eggs were washed from each subsample using the method of Shaw et al. (1976) and floatation in magnesium sulphate. All *D. virgifera* eggs were counted and identified to species by chorion sculpturing (Atyeo et al. 1964).

On the date the study was terminated each year, an estimate of the absolute population density of eggs was obtained using the frame method (Foster et al. 1979). The frame was one-half the row width long and one-half the plant spacing within rows wide. A sample consisted of 24 subsamples (two subsamples from each sub-plot); each subsample consisted of the soil dug to a depth of 20 cm within a single frame placed at the base of a plant chosen at random from within the sub-plot. Soil from each subsample was sifted and mixed as described above, and 0.47 l of soil was removed for processing. Eggs were washed from the soil, counted, and identified to species as described above.

Twice weekly, 50–75 female beetles were collected from within the field, taken to the laboratory, and dissected to determine their reproductive status. A 1 to 5 scale was used to rate ovarian stage of development (Cinereski and Chiang 1968). Beetles with ovaries rating 1–2 were considered reproductively immature, beetles rating 3–4 were reproductively mature, and beetles rating 5 were post-reproductive (Short and Hill 1972).

Survival rates of beetles were estimated once each week. One-hundred female and 50 male beetles were collected from within the field and placed in screen cages described by Elliott et al. (1990a). Each cage enclosed a single plant, and 5 male and 10 female beetles were placed in a cage. Growth stages of the 10 caged plants were representative of those in the field. Cages were left in place for 48 hours after which the number of surviving beetles of each sex was determined. A proportional daily survival rate was calculated from survival data for each 48 hour period. In making calculations we assumed that the survival rate of beetles was constant each day during the 48 hour period.

Total beetle-days per m² over the season were calculated for components of the adult population by fitting a cubic spline function to observed time series of population density data and calculating the area under the curve using numerical integration.

RESULTS

**Adult Emergence.** Dates of completion of 50% of adult emergence varied by about 10 days among years, from day 191 for males and day 196 for females in 1988, to day 199 for males and day 206 for females in 1989 (Fig. 1). In both years emergence was synchronized with the time period during which corn in the field was flowering. About 70% of males and females emerged while corn was flowering in 1988 and about 85% of males and 90% of females emerged during flowering in 1989. Shapes of cumulative emergence curves were similar among sexes (Fig. 1), but emergence of males began and was completed about 5 days earlier than emergence of females. Adult emergence extended over a longer time period in 1988 than in 1989.

Approximately 1.5 times as many beetles emerged in 1988 as in 1989 (Table 1). The difference in total emergence probably resulted from a combination of differ-
Figure 1. Cumulative emergence of adult male and female *D. v. virgifera* from the soil. Horizontal bars at the top of each figure represent the time period during which corn was flowering (>10% of plants flowering to >90% post-flowering).

Table 1. — Beetle-days accumulated per m$^2$ and number of beetles emerging per m$^2$ by various components of *D. v. virgifera* populations in corn fields in 1988 and 1989.

<table>
<thead>
<tr>
<th>Year</th>
<th>1988</th>
<th>1989</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beetle-days/m$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total (male + female)</td>
<td>765.8</td>
<td>697.0</td>
</tr>
<tr>
<td>female</td>
<td>455.4</td>
<td>390.7</td>
</tr>
<tr>
<td>pre-reproductive female</td>
<td>222.7</td>
<td>168.0</td>
</tr>
<tr>
<td>reproductive female</td>
<td>230.3</td>
<td>219.3</td>
</tr>
<tr>
<td>post-reproductive female</td>
<td>2.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Beetles emerging/m$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total (male + female)</td>
<td>72.1</td>
<td>49.5</td>
</tr>
<tr>
<td>female</td>
<td>50.6</td>
<td>30.2</td>
</tr>
</tbody>
</table>

ences in initial egg densities (2612 eggs per m$^2$ in 1988 versus 2275 eggs per m$^2$ in 1989) and immature survival (2.8% in 1988 versus 2.2% in 1989).

More females than males emerged both years, 70% in 1988 and 61% in 1989. Due to the higher total emergence and larger proportion of females emerging in 1988, about 1.7 times as many female beetles emerged per m$^2$ in 1988 as in 1989.

Population Structure. The population density of adults in the field increased rapidly in both years and peaked about two weeks after emergence began (Fig. 2). Males were more abundant initially, reflecting their earlier emergence, while females became increasingly dominant as the season progressed. Populations of both males and females peaked while corn was flowering (Fig. 2).

The total number of beetle-days per m$^2$ accumulating during the season by various components of the adult population in 1988 and 1989 are listed in Table 1. Slightly more total beetle-days accumulated in 1988 (765.8 beetle-days/m$^2$) than in 1989 (697.0 beetle-days/m$^2$). This observation is consistent with the fact that beetle emergence was greater in 1988 than in 1989 (Table 1). However, the ratio of beetle-days per m$^2$ in 1988 to that in 1989 equals 0.91, and is considerably greater than the corresponding ratio of the numbers of beetles emerging per m$^2$ among the two years.
(0.69), indicating that mortality, emigration, immigration, or a combination of these factors occurred at different rates in 1988 and 1989.

The proportion of females in the population, based on the ratio of female beetle-days to total beetle-days, was smaller in both years (59% in 1988 and 56% in 1989) than the proportion of females emerging in the field (70% in 1988 and 61% in 1989). Naranjo (1990a, 1990b) demonstrated that from 14 to 24% of pre-reproductive adult females migrate, and that the migration rate of young adult males is only about one-half that of females of similar age. The most plausible explanation for the discrepancy in sex ratios calculated from emergence and total seasonal occurrence is differential emigration of male and female beetles from the field. However, other explanations include differences in the sampling efficiency of plant counts for males and females, and sampling error in determining sex ratios based on numbers of emerging beetles and from beetles collected from plants.

Estimates of reproductive female beetle-days per m² were similar in both years (Table 1). In both years, reproductive females began to appear in the population approximately five days after the appearance of the first females in the field (Fig. 3). The proportion of reproductively mature females in the population increased steadily as the season progressed. In 1988 the population density of reproductive females peaked while corn was in the flowering stage, in 1989 the peak was less well defined, but appeared to occur during grain filling (Fig. 3). In 1988, 112.9 out of a total of 230.3 reproductive female beetle-days accumulated during flowering (49% of the total), while in 1989 only 49.9 out of a total of 219.3 reproductive female beetle-days accumulated during flowering (23% of the total). Post-reproductive females were not collected until late in the season each year, and did not constitute a significant proportion of the female population until the last few sampling dates each year (Fig. 3).

Oviposition. The first soil sample containing eggs each year was collected approximately four days after the appearance of reproductive females in the field. Egg densities plateaued by day 222 in 1988 and between days 220 and 230 in 1989. Thus, in both years there were approximately 25 days from the onset to the completion of oviposition.

Frame sampling yielded estimates of the mean number of eggs per m² of 1239 (SE = 219.8) and 590 (SE = 116.7) in 1988 and 1989, respectively. Based on a two sample t-test, the two means differed significantly ($t = 2.6; P = 0.006$). End-of-
Figure 3. Population density of adult female *D. v. virgifera*. Solid vertical bars represent the density of post-reproductive females, stippled bars represent the density of reproductive females and empty bars represent total female density. Horizontal bars at the top of each figure represent corn plant growth stage (horizontal striped bar, >10% flowering to >90% post-flowering; empty bar, >90% post-flowering to >90% in grain drying stage; vertical striped bar, >90% in grain drying stage.

season egg densities were approximately 1/2 in 1988 and 1/4 in 1989 of initial densities.

**Adult Survival.** A two sample z-test was used to compare proportional survival rates of males and females calculated from data pooled over all sampling dates within each year. Proportional survival did not differ significantly among the sexes in 1988 (z = 1.1; *P* = 0.28) or in 1989 (z = 1.6; *P* = 0.11). Therefore, we pooled survival data for the two sexes to assess seasonal survival patterns. Patterns in daily survival rates during the season differed somewhat among years (Fig. 4). However, a general trend in daily survival rates was apparent; survival rates were near 1 each year while corn was flowering, exhibited a gradual decline during grain-filling, and decreased at a more rapid rate during the grain drying stage (Fig. 4).

**DISCUSSION**

Immature development of *D. virgifera* is primarily dependent on temperature (Jackson and Elliott 1988), although development may be retarded slightly in extremely dense immature populations (Elliott et al. 1989), apparently as a result of competition for food. We found that when time was expressed on a calendar scale,
emergence of adult *D. virgifera* from the soil differed markedly among years in spite of identical planting and infestation dates each year. Calendar date has been proposed as a useful method for predicting the timing of beetle emergence in corn fields (Bergman and Turpin 1986), and in many years with similar temperatures during spring and summer, emergence may occur at approximately the same time. In years during which seasonal temperatures differ markedly from those typical for a region, as they did in eastern South Dakota in 1988, calendar date may provide poor prediction of the timing of beetle emergence.

Adult emergence and population development were synchronized with corn plant phenology, although the degree of synchrony differed somewhat among years. Ludwig and Hill (1975) found that beetles feed primarily on corn. Beetles tend to move to another corn field upon leaving a field and do not forage much in other plant communities (Hill and Mayo 1980). Lance et al. (1989) found that adults emigrate from cornfields at an increasing rate as corn plants progress beyond the flowering stage of development. Elliott et al. (1990a) found that survival and oviposition decrease as the corn upon which adults feed progresses beyond flowering to the grain filling stage; oviposition and survival proceeded at reduced rates during grain filling, but decrease to very low levels during the grain drying stage.

In the present study, reproductive development and oviposition occurred primarily while corn in the field was flowering, and oviposition was essentially complete 25 days after females began to oviposit. Furthermore, oviposition levels were relatively low. Hein and Tollefson (1985) observed significant oviposition occurring over a longer period, about 45 days, in corn fields in Iowa. The relatively short ovipositional period and low egg densities observed in our fields may be explained as follows. Our study was conducted during two years in which very dry weather prevailed during summer. As a result, corn in our fields progressed rapidly through the grain filling and drying stages each year. Furthermore, beetle populations in most nearby corn fields were typically one-tenth or less as dense as those in our artificially infested fields (N.C.E. personal observation). As a result of the rapid maturation of corn in our fields, mortality and emigration of beetles from our fields would proceed rapidly as corn became less acceptable as food. However, because our study plots were essentially isolated from corn fields with large resident western corn rootworm populations, very few of these beetles would be replaced by immigrants from neighboring corn fields. The net result would be a relatively short ovipositional period that was well synchronized with corn flowering. In regions where beetle populations are generally high, oviposition probably occurs for a
longer time in most fields because of the interaction among beetle populations from different fields. Because of the differential attractiveness of fields to dispersing beetles, the duration of the ovipositional period in a field in such regions may depend on the phenology of the corn plants in the field relative to those in nearby fields (Hill and Mayo 1974, Godfrey and Turpin 1983).

When maintained in the laboratory on a near optimal diet, *D. virgifera* adults can achieve an average life span of 94.8 days (Branson and Johnson 1973). In our study beetles suffered rapidly increasing mortality at relatively young ages suggesting that the deteriorating quality of corn as food plays an important role in the population dynamics of *D. virgifera*.

The nearly two times greater end-of-season egg density in 1988 than in 1989 is inconsistent with the observation that similar numbers of reproductive female beetle-days accumulated each year. With similar seasonal densities of reproductive females we would expect similar oviposition levels. A possible explanation for the discrepancy in egg densities may be that the number of reproductive female beetle-days accumulating while corn in the field was flowering differed markedly among years. In 1988, 112.9 reproductive female beetle-days accumulated per m² while corn in the field was flowering, while in 1989 only 49.9 reproductive female beetle-days accumulated during flowering. Beetles of identical age fed flowering corn are much more fecund than beetles fed post-flowering corn, and the difference in fecundity increases as corn upon which they are fed becomes increasingly more mature (Elliott et al. 1990a). Dividing total end-of-season egg densities by the number of reproductive female beetle-days accumulated per m² during the flowering period yields an estimate of 11.0 eggs per reproductive female beetle-day in 1988, compared with an estimate of 11.8 in 1989; these estimates are very similar. The observation that approximately 3/4 of eggs had been laid each year by the time corn had completed flowering (Fig. 3) lends support to the contention that most oviposition in our fields occurred by beetles feeding on flowering corn early in their reproductive lifetimes. The results suggest that although emigration, mortality, or both factors occurred at a more rapid rate in 1988 than in 1989, perhaps partially due to the short duration of the grain filling stages that year, the number of reproductive females present while corn was flowering was the primary determinant of total oviposition in both fields. Temporal synchrony of adult populations with flowering corn may play a critical role in the population dynamics of *D. virgifera* through its influence on dispersal, mortality, and oviposition rates.

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SCREEN BARRIERS FOR REDUCING INTERPLOT MOVEMENT OF THREE ADULT PLANT BUG (HEMIPTERA: MIRIDAE) SPECIES IN SMALL PLOT EXPERIMENTS

Mark S. Wipfli¹, John L. Wedberg² and David B. Hogg²

ABSTRACT

Fiberglass screen barriers 1.2 m high were erected around small (7.3 x 3.7 m) plots of birdsfoot trefoil, *Lotus corniculatus*, to study the effectiveness of screen barriers in reducing adult plant bug migration into small field plots. Screened and unscreened (control) plots were sprayed with an insecticide at the onset of the experiment, and subsequent adult mirid migration into these trefoil plots was measured by sweep net samples during the following 24 day period. Combined adult *Adelphocoris lineolatus*, *Lygus lineolaris*, and *Plagiognathus chrysanthemi* densities were significantly lower in screened versus unscreened plots with 37%, 28%, and 23% fewer adults at 7, 17, and 24 days, respectively, following insecticide application. Although these barriers were inexpensive and simple to construct, we conclude that they were not practical and effective enough for reducing adult mirid migration in small plot experiments of this type.

The alfalfa plant bug, *Adelphocoris lineolatus* (Goeze), tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and *Plagiognathus chrysanthemi* (Wolff) are common insect pests of birds foot trefoil, *Lotus corniculatus*, in northern sections of the United States and southern Canada (Copeland et al. 1984, Guppy 1958, MacCollom 1967, Neunzig and Gyrisco 1955, Wipfli et al. 1989, 1990). These and other adult mirids frequently disperse short and long distances (Hughes 1943, Craig 1963, Guppy 1963, Khattat and Stewart 1980), but fly relatively low. Ridgway and Gyrisco (1960) found that 93% and 69% of *L. lineolaris* fly within 1.8 and 0.9 m respectively, above the ground. Crosby & Leonard (1914) reported that few *L. lineolaris* adults flew over a 1.8 m cloth-wire fence erected around a nursery. McPherson et al. (1983) showed that 70% adult *L. lineolaris* fly 2.0 m or less, and 35% fly 1.0 m or less from the ground. They also reported that *Plagiognathus* spp. fly even lower, with nearly 50% adults flying within 1.0 m from the ground.

Adult *A. lineolatus*, *L. lineolaris*, and *P. chrysanthemi* are capable of quickly dispersing into insecticide-treated plots from untreated areas thus confounding treatment effects (Wipfli 1987). An effective and economical means of reducing mirid movement into and out of plots is necessary to prevent masking of treatment effects in small experimental plots. The purpose of this study was to evaluate the effectiveness and practicality of 1.2 m high screen barriers in preventing adult mirid movement into small, insecticide-treated plots.

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MATERIALS AND METHODS

The study was conducted in a 2 ha field of birdsfoot trefoil (cultivar Leo), at the University of Wisconsin Agricultural Research Station-Ashland, Wisconsin.

The experiment consisted of two treatments, screened and unscreened, applied across four blocks. The screened treatment consisted of barriers constructed out of 1.2 m high, gray fiberglass insect netting (1.6 mm mesh), which was erected around the plot perimeters. The netting was supported vertically with six 1.5 m metal fence posts driven 0.3 m into the soil. The unscreened treatment (= control) contained no netting barrier. Plots were 7.3 x 3.7 m, and a randomized complete block design was employed.

On 23 June 1986, malathion (57% emulsifiable concentrate) was applied to all plots at a rate of 1.4 kg/ha using a knapsack sprayer. On this date, the majority of mirids in the trefoil were fourth and fifth instars, with adults comprising less than 10% of the population. The trefoil was approximately 40 cm tall.

Mirid migration into the study plots was measured by sweep samples taken at 1, 7, 17 and 24 d after insecticide application. Sweep samples consisted of 20 pendulum sweeps each and were taken with a 38 cm diameter sweep net while walking a “U-shaped” pattern through each plot. In addition, ten samples of 20 sweeps each were taken in the trefoil surrounding the plots just prior to insecticide application to estimate potential “mirid migration pressure” on the study plots. Samples were transferred to nylon bags and placed in a freezer until mirids were counted.

Sweep count data were transformed (square root \(x + 1\)) to homogenize sample variance, and analyzed using two-way analysis of variance (two treatments x four blocks). Means were compared using Duncan’s multiple range test at \(P = 0.05\) (Duncan 1955).

RESULTS AND DISCUSSION

*Adelphocoris lineolatus* and *P. chrysanthemi* comprised the majority (>90%) of mirid species present in the plots and surrounding trefoil. Combined mirid populations consisted mostly (>80%) of nymphs at the time of insecticide application, but adults were most abundant at 7, 17 and 24 d following insecticide application.

Mirid densities in the trefoil surrounding the study plots averaged 16.5 plant bugs/sweep at the time of insecticide application, which is a relatively high density in trefoil (Wipfli et al. 1989), thus providing high “migration pressure”. The insecticide reduced mirid densities to nearly zero for adults, (1 d post-insecticide-application) and nymphs of all three species (Table 1). Movement of nymphs into plots following insecticide application was negligible in both screened and unscreened treatments.

The screen barriers significantly reduced adult plant bug movement into sprayed plots throughout the study (ANOVA, \(P < 0.05\) (Fig. 1). At 7 d post-insecticide application, there were 37% fewer total adult mirids in the screened versus unscreened plots. Seventeen days after treatment, screened plots had 28% fewer total adult mirids than unscreened plots. On the last sampling date, screened plots had 23% fewer adults than unscreened plots.

The barriers were most effective in reducing *P. chrysanthemi* movement, as adult densities in screened plots were significantly lower than unscreened plots at 17 and 24 d post-insecticide treatment (Table 1). This greater effectiveness is probably a reflection of the flight height differences between the three species. *Plagiognathus* spp. fly closer to the ground than *L. lineolaris* and *A. lineolatus* (McPherson et al. 1983). Adult *A. lineolatus* densities in screened plots were significantly lower only at 7 d after insecticide application. *Lygus lineolaris* numbers remained low in both treatments throughout the entire sampling period with densities in screened plots significantly lower than unscreened only at 24 d after insecticide application. These barriers were simple to construct and required approximately 4 h for two people to
Figure 1. Sweep counts of combined Adelphocoris lineolatus, Lygus lineolaris, and Plagiognathus chrysanthemi adults in screened and unscreened plots of birdsfoot trefoil following insecticide application (Bars indicate ± SEM).

Table 1.—Adult densities of Adelphocoris lineolatus (A. l.), Lygus lineolaris (L. l.) and Plagiognathus chrysanthemi (P. c.) in birdsfoot trefoil at various post-insecticide-application intervals in screened (S+) and unscreened (S-) plots.

<table>
<thead>
<tr>
<th>Mirid Species</th>
<th>1 d</th>
<th>7 d</th>
<th>17 d</th>
<th>24 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. l.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S+</td>
<td>S-</td>
<td>S+</td>
<td>S-</td>
</tr>
<tr>
<td></td>
<td>0.5a</td>
<td>0.0a</td>
<td>17.5a</td>
<td>35.8b</td>
</tr>
<tr>
<td>L. l.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S+</td>
<td>S-</td>
<td>S+</td>
<td>S-</td>
</tr>
<tr>
<td></td>
<td>0.0a</td>
<td>0.0a</td>
<td>0.5a</td>
<td>1.0a</td>
</tr>
<tr>
<td>P. c.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S+</td>
<td>S-</td>
<td>S+</td>
<td>S-</td>
</tr>
<tr>
<td></td>
<td>0.8a</td>
<td>0.5a</td>
<td>34.8a</td>
<td>47.0a</td>
</tr>
</tbody>
</table>

Means in respective rows for each date followed by the same letter are not significantly different using ANOVA and Duncan's (1955) multiple range test (P < 0.05).

We conclude that these barriers were not sufficiently practical and effective to justify their use in small plot experiments of this type. However, these barriers may be more effective in reducing immigration with lower flying insects. Taller barriers would probably be more effective in reducing immigration, but at an increase in time and cost.
ACKNOWLEDGMENTS

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TOXIC PHENOLIC GLYCOSIDES FROM *POPULUS*: PHYSIOLOGICAL ADAPTATIONS OF THE WESTERN NORTH AMERICAN TIGER SWALLOWTAIL BUTTERFLY, *PAPILIO RUTULUS* (LEPIDOPTERA: PAPILIONIDAE)

J. Mark Scriber¹, Richard L. Lindroth², and James K. Nitao¹

ABSTRACT

The phenolic glycosides tremulacin and salicortin found in quaking aspen, *Populus tremuloides*, and other members of the Salicaceae, are known to be toxic to larvae of the Eastern tiger swallowtail butterfly, *Papilio glaucus*, but not to the Canadian tiger swallowtail, *P. canadensis*. Larvae of the western tiger swallowtail, *P. rutulus*, were not killed nor were their growth rates suppressed when fed a mixture of tremulacin and salicortin on black cherry leaves. When the Salicaceae-adapted *P. rutulus* penultimate instar larvae were fed a combination of the two phenolic glycosides and the esterase inhibitor (DEF = S,S,S-tributylphosphorotrithioate), growth was reduced more than 50% compared to controls, and half of the larvae died before completing the instar. Our results indicate that esterase detoxification mechanisms are involved in the western tiger swallowtail, *P. rutulus*, as is also known to be the case for the northern tiger swallowtail, *P. canadensis*. It is not known whether the same esterase isozyme is involved in both species. From an evolutionary perspective such information could help resolve whether the Salicaceae-adapted swallowtails species are a monophyletic group (perhaps due to isolation in the Beringial Pleistocene glacial refuge of Alaska).

The family Papilionidae (swallowtail butterflies) has figured centrally in discussions of chemical ecology and coevolution (Dethier 1954, Ehrlich and Raven 1964, Wiklund 1975, Berenbaum 1983, Miller 1987), yet the chemical bases underlying interactions of this group with their host plants remain relatively unexplored. Much work has been done on the oviposition phase of host acceptance and suitability for a variety of papilionids (e.g., Feeny et al. 1983, 1989; Honda 1986, Nishida et al. 1987). In contrast, research on the biochemical adaptations of *Papilio* larvae to specific phytochemicals has focused on only a few species (Bull et al. 1984, Cohen et al. 1989, Lindroth 1989a). Determining whether related species use homologous enzymatic systems (Fig. 1A) or whether detoxification mechanisms have evolved independently a number of times (Fig. 1B & C) is crucial to understanding the evolution of papilionid host use (Fig. 1, Scriber et al. 1991).

The glaucus group in the genus *Papilio* exhibits some of the most intriguing and well documented patterns of host use in the Papilionidae (Scriber 1988). Although the species in this group are all oligophagous or polyphagous, the larvae exhibit striking differences in their abilities to use hosts. In particular, the ability to feed

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Figure 1. Phenolic glycosides from quaking aspen (Salicaceae) that have the cyclohexanone saligenen esters are toxic to *Papilio glaucus* but not to *P. canadensis*, *P. rutulus*, or *P. eurymedon*. It remains to be determined whether or not the same carboxylesterase enzyme is used in detoxification for all three western species, and if so whether a single or multiple origin is most likely (modified from Scriber et al. 1991).
upon members of the Salicaceae appears to be a significant trait in the evolution of this group. *Papilio glaucus* L., including its Florida populations, (*P. g. australis* R. & J.), and *P. alexiarae garcia* R. & J. are unable to survive on *Populus tremuloides* (quaking aspen); in contrast, larvae of *Papilio canadensis* R. & J., *P. eurymedon* Lucas, and *P. rutulus* Lucas can develop successfully on this plant (Scriber et al. 1989a, b, 1991; Dowell et al. 1990).

Phenolic glycosides, especially salicortin and tremulacin, are responsible for differential performances of *P. canadensis* (a recent elevation from subspecies; see Hagen et al. 1991) and *P. glaucus* on aspen. The compounds exhibit little toxicity against the adapted *canadensis*, but dramatically reduce survival and growth in *glaucus* (Lindroth et al. 1988). Phenolic glycosides are metabolized in *Papilio* by several enzyme systems, including esterase, b-glucosidase and possibly glutathione transferase (Lindroth 1989a, Scriber et al. 1989b). Esterases, however, are primarily responsible for detoxification of the compounds. Esterase activity is 3-fold higher in *canadensis* than in *glaucus*, and is inducible by prior consumption of phenolic glycosides in *canadensis* but not in *glaucus* (Lindroth 1989a, b). Moreover, when *canadensis* larvae consume diets containing phenolic glycosides and an esterase inhibitor, their survival rates decline significantly.

Scriber et al. (1989b) in a series of backcross studies with *canadensis* and *glaucus*, showed that esterase activities generally increased with the proportion of *Papilio canadensis* genes in the genotype, and activity paralleled overall trends in larval survival and feeding performance. They concluded that phenolic glycosides, such as tremulacin, are responsible for differential performance of *Papilio glaucus* subspecies, hybrids and backcrosses fed plants in the Salicaceae, and that detoxification of phenolic glycosides by midgut esterase explains why some *Papilio glaucus* genotypes can effectively utilize these plants.

The western tiger swallowtail, *P. rutulus*, performs very well on quaking aspen and utilizes that host where it co-occurs with *P. glaucus* in western North America (Scriber 1988, Dowell et al. 1991). The studies described in the following report were conducted to assess potential effects of phenolic glycosides on *P. rutulus*, and to determine whether esterases may be involved in their detoxification.

**METHODS AND MATERIALS**

**Collecting and rearing of insects.** Larvae for the feeding studies were obtained from a female *P. rutulus* (#7102) collected in California by Dr. Robert Dowell. Because larvae in the *glaucus* group perform poorly on artificial diets, and because all subspecies of *P. glaucus* effectively utilize black cherry (*Prunus serotina*) leaves, we used these as our basal diet. A crude phenolic glycoside mixture (38% tremulacin, 14% salicortin) was isolated from aspen and applied to cherry leaves using the methods of Lindroth et al. (1988). The four experimental treatments were methanol treated control leaves, the phenolic glycoside mixture applied with methanol, DEF (S,S,S-tributylphosphorotrithioate, an esterase inhibitor) applied with methanol, and a combination of glycosides and DEF (top and bottom sides of leaves, respectively). All larvae were reared on mature black cherry leaves prior to experiments.

For the feeding trials, each replicate consisted of a single, freshly molted fourth instar caterpillar placed in a petri dish (15 x 2.5 cm) containing a treated black cherry leaf. The phenolic glycoside mixture and DEF were applied at 4.0% and 0.01% fresh leaf weight, respectively to reflect natural occurrence. New leaves were provided as needed (3-4 day intervals) until completion of the fourth stadium. Upon completion of each trial we froze a subsample of larvae, then dried (3d, 60°C) and weighed the larvae, frass, and uneaten food. To estimate the proportion dry weight of larvae at the onset of each trial, a subset of newly molted fourth instars from the same cohort were dried and weighed. The proportion dry weight of leaves used in
feeding trials was determined for each batch of leaves provided (36.6% ± 0.5%; 35.5% ± 1.09; 39.9% ± 0.4%) by drying and weighing a sample of each batch of experimental leaves and nutritional indices were calculated on the basis of dry weights, using standard formulae (Waldbauer 1968, Scriber 1977). Growth and consumption rates were calculated on the basis of the duration of the fourth stadium, or until death (if larvae survived more than 5 days). Larvae were housed in a Percival® growth chamber maintained at 25°C with an 18:6 phot:scotophase cycle.

Enzyme assays. Because of the small number of larvae available, we used larvae reared on cherry leaves as well as some larvae from the feeding trials (all diets except phenolic glycosides + DEF) for enzyme preparations. Midguts were removed from fifth instars (3–6 days old, 3–5 larvae per replicate), washed and homogenized as described by Lindroth (1989a). The homogenate was centrifuged at 10,000 g (10 min), and the supernatant was then centrifuged at 100,000 g (60 min). We flash-froze the enzyme solutions in liquid nitrogen and stored them at -70°C until assayed. The final supernatant (containing soluble esterases) was used as the enzyme source in this study. Esterase activity was determined with the I-naphthyl acetate assay (Lindroth 1989c). A modified Folin-phenol procedure (Schacterle and Pollack 1973) was used to measure protein concentration of the enzyme solutions.

Statistics. For the feeding trials we assessed differences among treatment effects by one-way analysis of variance (ANOVA). When the ANOVA F statistic was significant (P < 0.05), we compared treatment means via Tukey's test for unequal sample sizes (Winer 1962, Snedecor and Cochran 1967).

RESULTS

The mean growth rate for larvae fed the glycoside/enzyme inhibitor treatment was half that of those fed the methanol control. While not statistically significant, the leaves treated with glycoside alone produced the fastest growth, the greatest consumption rates, and the highest overall efficiency of all treatments (Table 1).

Larvae of *P. rutulus* grew significantly slower on the treatment with a combination of phenolic glycosides (tremulacin and salicortin) and the esterase enzyme inhibitor (DEF) than did larvae fed either the methanol control or the glycosides alone (Table 1). This poor growth was due to a combination of suppressed consumption rates and lowered biomass conversion efficiency (ECI).

It is noteworthy that half of 6 larvae in the glycoside plus enzyme inhibitor treatment died before completing the stadium, whereas all larvae in the methanol control and the glycoside treatments successfully molted. One larva in the DEF enzyme treatment died before completing the stadium.

Results from the enzyme assays with *P. rutulus* showed relatively low esterase activity. The mean activity for three enzyme preparations from final instar larvae was 1,409 ± 154 nmol/min/mg protein.

DISCUSSION

The phenolic glycosides tremulacin and salicortin from quaking aspen are known to be toxic to *P. glaucus* and its Florida populations (putative subspecies *australis*), but not to *P. canadensis* (Lindroth et al. 1988, Scriber et al. 1989). In this study, a combination of salicortin and tremulacin applied to black cherry leaves did not kill or reduce larval growth performance of the western tiger swallowtail, *Papilio rutulus*. This is consistent with *P. rutulus* feeding on quaking aspen and other members of the Salicaceae plant family (Brower 1958, Scriber 1988, Dowell et al. 1991).

As was observed with the Salicaceae-adapted *P. canadensis* (Lindroth 1989a), *P. rutulus* larvae fed a combination of phenolic glycosides and the esterase inhibitor
Table 1. — Growth performance of penultimate instar *Papilio rutulus* fed black cherry (*Prunus serotina*) leaves treated with methanol, a phenolic glycoside mixture (tremulacin and salicortin), an esterase inhibitor (DEF), and a mixture of glycosides and the esterase inhibitor. Data are presented as a mean ± SE.*

<table>
<thead>
<tr>
<th>Treatment (n)</th>
<th>Survival through instar (%)</th>
<th>Instar Duration (T) (days)</th>
<th>Growth Rate (RGR) mg·mg⁻¹·day⁻¹</th>
<th>Consumption Rate (RGR) mg·mg⁻¹·day⁻¹</th>
<th>Digestibility (AD) (%)</th>
<th>Efficiency (ECD) (%)**</th>
<th>Efficiency (ECI) (%)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>control (methanol) (6) 100%</td>
<td>8.00 a</td>
<td>.209 a</td>
<td>1.197 a</td>
<td>36.8 a</td>
<td>37.6 a</td>
<td>16.9 ab</td>
<td></td>
</tr>
<tr>
<td>phenolic glycosides (6) 100%</td>
<td>5.29 a</td>
<td>.220 a</td>
<td>1.238 a</td>
<td>34.4 a</td>
<td>56.9 a</td>
<td>17.7 a</td>
<td></td>
</tr>
<tr>
<td>inhibitor (DEF) (6) 83%</td>
<td>6.96 a</td>
<td>.181 ab</td>
<td>1.195 a</td>
<td>37.8 a</td>
<td>37.8 a</td>
<td>14.7 ab</td>
<td></td>
</tr>
<tr>
<td>glycosides and inhibitor (6) 50%</td>
<td>7.63 a</td>
<td>.096 b</td>
<td>.916 a</td>
<td>29.6 a</td>
<td>41.8 a</td>
<td>9.3 b</td>
<td></td>
</tr>
</tbody>
</table>

LSD (n.s.) .110 (n.s.) (n.s.) (n.s.) 7.9

*Significant differences (L.S.D.) among means are indicated at p<0.05 level (Tukey's test; Snedecor and Cochran 1967; Winer 1962).

**E.C.D. = efficiency of conversion of digested food to larval mass, E.C.I. = efficiency of conversion of ingested food to larval mass.
DEF were drastically affected. Growth rates were reduced more than 50% compared to larvae on the control and glycoside treatments. Also, half of the larvae died before completing the penultimate instar when fed the glycoside and inhibitor combination, whereas none of them died on the control or glycoside treatments (Table 1). These data, although limited, suggest that functional esterase detoxification enzymes play an important role in the ability of *P. rutulus* to feed on members of the Salicaceae that contain tremulacin and salicortin.

DEF is generally believed to act as a noncompetitive inhibitor of insect esterases, most likely due to phosphorylation of the enzymes (Jao and Casida 1974). Our treatment with DEF applied alone showed that the compound may negatively affect larval performance. Growth rates tended to decline (although not significantly) and one larva died in the treatment. Marginally detrimental effects are not surprising, given that esterases are required for the metabolism of endogenous compounds (e.g., juvenile hormone).

The general esterase activity exhibited by *P. rutulus* was surprisingly low. The value of 1409 nmol/min/mg protein is only slightly higher than that of the unadapted *P. glaucus*, and less than half that of the aspen-adapted *P. canadensis* (Lindroth 1989a, Scriber et al. 1989b). This result illustrates one of the problems that can be encountered in use of model substrates—they do not necessarily indicate activity against the compounds of interest (e.g., phenolic glycosides). Activity of isozymes particularly effective against phenolic glycosides may be masked in determinations of general esterase activity. Unfortunately, the lability of phenolic glycosides in aqueous solutions has thus far precluded development of esterase assays with phenolic glycoside substrates (Lindroth, unpubl. data).

Given that our studies were conducted with offspring from a single butterfly, we caution that the results should be considered preliminary. Nevertheless, our results do indicate that phenolic glycosides, at naturally occurring concentrations, are not toxic to *P. rutulus*. Moreover, they suggest that esterases are the metabolic basis for resistance to the compounds. We hope in our future research to define more clearly the genetic basis and geographic extent of the esterase resistance mechanism in *P. rutulus*, and to determine if this detoxification system is the same as in *P. canadensis*. Such knowledge will be useful from an evolutionary viewpoint because it may contribute to our understanding of whether *P. canadensis*, *P. rutulus*, and *P. euryomedon* are of a monophyletic origin (e.g., in a Beringial refuge, Scriber 1988, Hagen and Scriber 1991, Hagen et al. 1991), or if this Salicaceae detoxification system arose several times independently (Fig. 1).

ACKNOWLEDGMENTS

This research was supported in part by the USDA Competitive Grants Program (87-CR-1-2581 and 90-37153-5263), and the National Science Foundation (BSR 88-01184). Additional support from the Agricultural Experiment Stations in Michigan (Projects 8051 and 8072) and Wisconsin (Hatch Project 3211), the College of Natural Science of Michigan State University and the Graduate School of the University of Wisconsin, Madison is gratefully acknowledged. We thank Miel Barman, Robert Dowell, Robert Lederhouse, Bruce Giebink and Annie Weisbrod for their help with these studies.

LITERATURE CITED


---. 1991. Foodplants and evolution within the


FIRST REPORT OF *ALLONEMOBIIUS GRISEUS* AND *PSINIDIA FENESTRALIS* IN OHIO
(ORTHOPTERA: GRYLLIDAE AND ACRIDIDAE)

Harvey E. Ballard, Jr. 1

ABSTRACT

Occurrences of *Allonemobius griseus* and *Psinidia fenestralis* in Ohio are published for the first time. Apparent restriction of these species to the sand deposits of northwestern Ohio, their localized distribution in scattered, non-contiguous blowouts, and habitat loss presently occurring from residential and commercial development nearby, are justifications provided for the formal state listing and conservation of these Orthoptera in Ohio.

During mid-August, 1990 in the Oak Openings region west of Toledo in Lucas County, Ohio, I discovered populations of two Orthoptera previously unreported from Ohio. The grizzled ground cricket, *Allonemobius griseus griseus* (E. M. Walker), sang frequently from the thatch surrounding clumps of big bluestem grass in the sparsely vegetated sand barrens around sand blowouts, where it commonly associated with *A. allardi* (Alexander & Thomas). The sand locust, *Psinidia fenestralis fenestralis* (Audinet-Serville), was found on the unstabilized open sand of one blowout, but was greatly outnumbered by other acridids. Other Orthoptera in the immediate vicinity of the blowouts and their depauperate sand barrens included the gryllids *Allonemobius allardi* and *Oecanthus quadripunctatus* Beutenmueller; and the acridids *Melanoplus sanguinipes* (Fabricius), *Spharagemon bolli bolli* (Scudder), and *Spharagemon collare* (Scudder). I found *A. griseus* to be frequent in appropriate habitat at both The Nature Conservancy's Kitty Todd Preserve in Sec. 11, Harding Township, and at the Oak Openings Metropark in Sec. 21, Swanton Township where I secured a male and female as vouchers. I noted two individuals of *P. fenestralis* at the Kitty Todd Preserve, where I captured a male as a voucher. Specimens are deposited at the University of Michigan Museum of Zoology.

Cantrall (1968) recorded *A. griseus* from Michigan as far south as Washtenaw County, but excluded it from southwestern Michigan. However, I recently discovered populations of the species in Berrien and Van Buren Counties in sand barrens of old dunes. McCafferty & Stein (1976) reported it from a very few counties in northwestern Indiana. Neither Blatchley (1920) nor Vickery & Kevan (1985) reported it from Ohio. The two sites in the Oak Openings region represent the southernmost extent of the currently known range of *A. griseus*.

Blatchley (1920) reported the species in the Midwest as reaching as far east as Indiana, but surmised that *P. fenestralis* might someday be found in Michigan and Ohio. Later, Cantrall (1968), Otte (1984), and Vickery & Kevan (1985) reported *P. fenestralis* from Berrien County, Michigan, and Otte noted it also from Monroe

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County, MI, just north of Lucas County, Ohio. The single confirmed site for Ohio represents the easternmost occurrence of this species in the Midwest, but it also ranges along the Atlantic Coast (Otte 1984).

During methodical searches for natural communities in the Oak Openings region, I noted several other sand barrens sites, and a smaller number of unvegetated sand blowouts, which would probably support additional populations of *A. griseus* and *P. fenestralis*, respectively. These were scattered sporadically across approximately 40 square miles of the extant Oak Openings region and were usually isolated from each other by large expanses of cropland or forest. Both species might also occur near Lake Erie on sand dunes east of Toledo.

It is fortunate that *A. griseus* and *P. fenestralis* have been found thus far on tracts protected for their natural values. Nevertheless, residential and commercial development is proceeding at a staggering pace in the Oak Openings region, and the survival of both species is threatened in this area of Ohio. The occurrence of both species at the edges of their known Midwest distributions, the localized occurrence of suitable habitat in northwestern Ohio, and increasing alteration of the landscape by residential and commercial development, justify the formal listing and monitoring of these species as a first step in the conservation of the state's imperiled orthopteran fauna.

ACKNOWLEDGMENTS

I am grateful to Mary Huffman of the Ohio Chapter of The Nature Conservancy, and to Jim Toppin and Janet Traub of Whitehouse, Ohio for field assistance.

LITERATURE CITED


NEW MICHIGAN STATE RECORD FOR A SPHECINE WASP, 

**PODIUM RUFIPEPS** (HYMENOPTERA: SPHECIDAE)

David P. Cowan¹

ABSTRACT

*Podium rufipes*, previously unrecorded from Michigan, has been found occupying trap nests in the southwestern lower peninsula.

The recorded range for *Podium rufipes* Fabricius is the eastern United States from Iowa eastward to New York in the north and southward on into Central and South America (Bohart and Menke 1963), and although previously unknown in Michigan (O'Brien 1989), it is not surprising to discover populations in the southern part of the state. I reared a total of seven individuals from trap nests (artificial nest sites consisting of 20 x 20 x 150 mm blocks of wood with a hole drilled lengthwise to a depth of 125 mm) at two localities. In Allegan County the trap nests were placed along the margin of a dry oak forest with scattered white pines, and in Kalamazoo County the nests were put along a brushy strip between a mesic forest and a red pine plantation. The nests were provisioned and sealed during July of 1986 and 1987 and the adult progeny emerged in mid-June of 1987 and 1988.

Previous studies indicate that females of *P. rufipes* prefer to use preexisting cavities as nest sites. Rau (1937) found them using the vacated mud cells of *Sce­liphron* and Krombein (1967,1970) observed nesting in trap nests. My observations agree closely with Krombein's. Unlike many wasps that move into trap nests (Krom­bein 1967), the cavity was not partitioned into a series of cells for rearing multiple offspring. Instead, only one offspring was reared in each nest stick using paralyzed cockroaches as prey. The nests were sealed at the entrance with a plug of debris that was plastered over on the outside with resin. Rau (1937) determined that the resin is obtained from pine trees. Krombein (1967,1970) found that cockroaches used as prey belong to the genera *Labiblatella*, *Chorisoneura*, *Eurycoticis*, *Caribalata*, and *Parcobalata*. He also found that in South Carolina and Florida *P. rufipes* has several generations per year, but Rau's 1937 observations in Missouri and mine in Michigan indicate that northern populations are univoltine.

This species is rare in collections and this may reflect the wasp's cryptic habits and difficulty capturing quickly moving wasps on logs and branches in forests. They may also have particular habitat requirements that restrict their distribution. The cockroaches that *P. rufipes* preys on may be most abundant in the dead trees and leaf litter of deciduous forests, but pines are required as a source of resins to seal the nests. Krombein's habitat descriptions (1967,1970) and mine all indicate a mixture of broad-leafed trees and conifers.

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LITERATURE CITED


AUPLOPUS CARBONARIUS, A PALEARCTIC SPIDER WASP, EXTENDS ITS RANGE TO MICHIGAN (HYMENOPTERA: POMPILIDAE)

Frank E. Kurczewski and Mark F. O'Brien

ABSTRACT

Three females of Auplopus carbonarius, a Palearctic species detected recently in southeastern New York, were collected in a Malaise trap in Ann Arbor, Michigan, during the summer of 1988. Females of the species can be separated morphologically from those of the similar A. variolarum by the polished and essentially impunctate pygidium, dusky wings, and median clypeal tooth.

Nolfo (1983) reported that Auplopus carbonarius Scopoli, a Palearctic spider wasp belonging to the tribe Auplopodini, had successfully established itself in New York State (Rockland and Nassau Counties). Three females of this species were collected in a Malaise trap in Ann Arbor, Washtenaw County, Michigan, on 15-18 and 27-31 July, and 11-14 August 1988. This is a considerable range extension (ca. 800 km).

Problematic identification resulted from using Townes' (1957) key to the Nearctic species of Auplopus, in which the specimens key to Auplopus variolarum Townes. However, A. variolarum is known only from a female holotype from the Chisos Mountains, Texas (Townes 1957, Krombein 1979). Our specimens of A. carbonarius are entirely black, but under high magnification (25x) the tarsi, maxillary and labial palps, tegulae, clypeal lip and tooth and sting are fuscous. The apical one-third of the mandible is rufous as indicated by Nolfo (1983). The pygidium is fuscous in coloration, polished and essentially impunctate, whereas that of A. variolarum is punctate (Townes 1957). The latter characteristic, wing density, and shape of clypeal lip can be used to separate females of the two species. The three females of A. carbonarius compare perfectly with determined specimens of this species from northeastern Europe in the UMMZ.

Mud plastered to the midtibiae of one female (15-18 July 1988) evinces its behavior of constructing mud cells to hold its spider prey. Amputation of the spider's legs is commonplace in this genus (Evans and Yoshimoto 1962). Nothing has been published about its behavior in North America, but in Europe the species provisions its multicelled nests with no less than eight families of mostly errant spiders, with a preponderance of records from the family Clubionidae (Richards and Hamm 1939, Grandi 1954). A cell is made before the spider is captured and capped over with mud after the provisioning is completed (Evans and Yoshimoto 1962).

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DISCUSSION

It is notable, but not surprising, that *A. carbonarius* has extended its range from that reported by Nolfo (1983). Mud nests of this species and other auplopodines are likely to be cryptic and could be dispersed through commerce such as shipments involving wooden pallets or cargo containers. A similar pattern of distribution has been reported in the Great Lakes region and eastern Canada for *Trypoxylon clavicerum* Lepeletier & Serville (Sphecidae: Larrinae) (Coville 1984). The New World sphecine, *Sceliphron caementarium* (Drury), has spread via commerce to Europe, Australia, and the Pacific Islands (Bohart and Menke 1976). Interestingly, many of the pompilid and sphecid species that have extended their ranges considerably are mud-daubers or hollow-cavity nesters. It is also likely that *A. carbonarius* has a much wider distribution in North America than we report.

LITERATURE CITED


MOTHS OF THE DOUGLAS LAKE REGION
(EMMET AND CHEBOYGAN COUNTIES),
MICHIGAN: IV. GEOMETRIDAE (LEPIDOPTERA)¹

Edward G. Voss²

ABSTRACT

An account, with known flight periods indicated, of 165 species of Geometridae concludes listing of the "macrolepidoptera" from the northern tip of the Lower Peninsula of Michigan. About 44% of these are previously unreported for the region, and 12 species are previously unreported for Michigan in earlier lists for the state.

The Geometridae are a rather large and distinctive family of Lepidoptera, the larvae variously known as inchworms, measuring worms, loopers, cankerworms, or geometers. Such names derive from the looping walk that results from an absence of prolegs at the middle of the caterpillar, which brings the legs from the rear end up to the thoracic legs; it then straightens out the resulting loop by extending the fore part of the body.

In 1915, Welch listed 23 species of this family from the Douglas Lake region. Moore (1955) included 98 species from Emmet and Cheboygan counties. The present list includes 165 species from these two counties, which share the northern tip of the Lower Peninsula of Michigan. This increase of 617% from the 1915 list has been exceeded only in the Noctuidae (Voss 1981, 1984) and similarly results not so much from expansion of the "region" around the University of Michigan Biological Station to include all of two counties as it does from an increase in the number of collectors and greater alertness to the diversity of Lepidoptera. Nevertheless, numerous additional species may be expected in the future.

The format of this annotated list varies only slightly from that of previous installments (Voss 1970, 1981, 1984). With only a few duly noted exceptions, the nomenclature, author citations, sequence, and numbers follow the latest checklist (Hodges et al. 1983). For ease of cross-reference and recognition of synonymy, the number from the previous checklist (McDunnough 1938) is given in parentheses at the end of each annotation. The counties from which each species has been collected are followed by the earliest and latest dates of capture for adults in the two-county region. For the rarest species, usually when there is a single collection, the year is generally added along with whatever additional data are available. County names in parentheses represent published reports (Moore 1955) which I have been unable to substantiate from specimens in the collections examined. These collections, with abbreviations for the institutional ones, are cited under Acknowledgments. Only two species

¹Contribution from the University of Michigan Biological Station.
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(6299 and 6815) are included solely on the basis of published reports that cannot be verified or disposed of.

The present list concludes presentation of the traditional “macrolepidoptera” from the region. In 1944 I made my first collections associated with definite dates and localities in the neighborhood of the family cottage in Mackinaw City, situated in Emmet County just west of the Cheboygan County line. Starting in 1949, I have spent a part of each summer at the University of Michigan Biological Station (referred to in the list as UMBS) on Douglas Lake in Cheboygan County, about 20 miles south of Mackinaw; University property extends on the west nearly to Pellston. Many fine specimens (in UMMZ) were collected, chiefly in the 1930’s, by Max M. Peet on the northeast side of Burt Lake, scarcely over three miles from the Station campus. So most records on which this list is based have come from a relatively small portion of the total region, and from near the county line.

A broad sketch of the vegetation in the area is in the third installment of this moth list (Voss 1984). Unfortunately, I have not yet been able to pursue as I would have liked the matter of relationship between the flora and its lepidopterous visitors, whether larvae or adults.

Unless explicitly indicated to the contrary, all mention herewith of larval food plants is not original from this region, but is based on reports in literature (e.g. Prentice 1963, Ferguson 1975, McGuffin 1958–1988, Morris 1980, Bolte 1990). Such plants are sometimes mentioned when a species occurs in a very restricted habitat, is rare although food plants are common, has a particularly interesting food plant, or otherwise seems to warrant comment. Host plants are rarely mentioned for species that feed on diverse taxa. It is clear that abundance of adults is often not related to abundance of larval food plants. *Semiothisa* is an especially diverse genus for species ranging from very narrow host specificity to rather broad tastes.

In the annotations, I have tried to account for all previously published reports for the region, whenever the synonymy is not obvious or the reports are based on misidentifications. Only a few comments on useful identification features are offered. There are several works helpful in determining specimens and clarifying synonymy, besides the treatments cited for particular genera or other groups. McGuffin’s *Guide to the Geometridae of Canada* (1967–1988) is well illustrated in color, with keys, and covers all subfamilies except Larentiinae (of which *Eupithecia* is beautifully treated by Bolte 1990). Forbes (1948) also has keys. Covell (1984) is reasonably complete for our area, nomenclaturally up to date, well illustrated, and provided with helpful hints on identification. Holland’s classic *Moth Book* (1903) is still sometimes useful for color illustrations, and so are the plates in Morris (1980).

**Subfamily Archiearinae**

6256. *Archiearis infans* (Mösch.). Cheboygan: 22 April. Taken only by Nielsen. Donahue and Newman (1967) observed this species in Otsego County (immediately south of Cheboygan Co.) puddling at a damp area by a bog, where it was heavily preyed upon by a song sparrow. (4023)

**Subfamily Ennominae**

6261. *Heliomata cycladata* G. & R. Cheboygan: 15 June–6 July. Although Moore (1955) listed this attractive moth only from the southern Lower Peninsula, it is frequently taken at light at UMBS, where its preferred larval food plant, black locust (*Robinia pseudoacacia*), has been well established since the late 1940’s. (4662)

6270. *Protitame virginalis* (Hulst). Emmet, Cheboygan: 20 June–14 Aug. Frequent, as might be expected for a species whose larvae feed on aspens (*Populus* spp.), and often found at light. (4785)

6273. *Itame pustularia* (Gn.). Emmet, Cheboygan: 3 July—18 Aug. Note that this is not *Itame pustularia* (Hbn.) of Moore (1955), which is *E. latiferugata* (above). The present species was listed by Moore as *Physostegania pustularia* Gn., following the 1917 Barnes and McDunnough checklist. (4663)


6275. *Itame evagaria* (Hulst). Emmet: 18 June-7 Aug. Listed by Moore (1955) only from the southern Lower Peninsula. 1 have collected it at light, including gasoline lantern in Mud Lake bog (Inverness Tp.). (4750)

6276. *Itame occiduaria* (Pack.). Emmet, Cheboygan: 18 July-4 Aug. This western species seems to have been collected only rarely in the Great Lakes region. Covell (1970b) cites it from a single Wisconsin locality, in Oneida County, the same county as cited by Ferguson (1953). I collected a male 4 Aug. 1947 (MSU) at incandescent light at Mackinaw City, on a warm, cloudy night that also produced such rarities as *Euxoa manitobana* Mc. and *Cryptopala acadiensis* (Bethune). The only Michigan record given by Moore (1955) is based on a specimen (UMMZ) from Douglas Lake collected 18 July 1934 [no collector stated]. The only other Michigan specimen I have seen is from Schoolcraft County (MSU). (4749)

6277. *Itame argillacearia* (Pack.). Cheboygan: 25 June-18 July. I took three males during the day at Mud Lake bog in Inverness Tp.; also comes to light. Listed by Moore (1955) as *I. inceptaria*. The larvae are reported to feed on *Vaccinium*. (4748)

6278. *Itame sulphurea* (Pack.). Emmet, Cheboygan: 2 July-11 Aug. Most specimens, including all females, have been taken in bogs (Mud Lake, Inverness Tp.; Galloway Lake, Carp Lake Tp.), by day or at light. Some males have been taken at mercury vapor light and UV light near UMBS and some are diurnal. The strikingly dimorphic yellow females are much less often taken than males. Larval food plants are reported as *Vaccinium* spp. and *Myrica gale*. (4751)


6280. *Itame loricaria* (Evers.). Emmet, Cheboygan: 2-18 July. Taken at light in 1950 (Voss) and 1937 (Peet, UMMZ). (4797)


6282. *Itame argillacea* (Pack.). Emmet, Cheboygan: 25 June—18 July. I took three males during the day at Mud Lake bog in Inverness Tp.; also comes to light. Listed by Moore (1955) as *I. inceptaria*. The larvae are reported to feed on *Vaccinium*. (4748)

6283. *Itame sulphurea* (Pack.). Emmet, Cheboygan: 2 July—11 Aug. Most specimens, including all females, have been taken in bogs (Mud Lake, Inverness Tp.; Galloway Lake, Carp Lake Tp.), by day or at light. Some males have been taken at mercury vapor light and UV light near UMBS and some are diurnal. The strikingly dimorphic yellow females are much less often taken than males. Larval food plants are reported as *Vaccinium* spp. and *Myrica gale*. (4751)


6285. *Itame loricaria* (Evers.). Emmet, Cheboygan: 2-18 July. Taken at light in 1950 (Voss) and 1937 (Peet, UMMZ). (4797)


6287. *Itame sulphurea* (Pack.). Emmet, Cheboygan: 2 July—11 Aug. Most specimens, including all females, have been taken in bogs (Mud Lake, Inverness Tp.; Galloway Lake, Carp Lake Tp.), by day or at light. Some males have been taken at mercury vapor light and UV light near UMBS and some are diurnal. The strikingly dimorphic yellow females are much less often taken than males. Larval food plants are reported as *Vaccinium* spp. and *Myrica gale*. (4751)


6289. *Itame loricaria* (Evers.). Emmet, Cheboygan: 2-18 July. Taken at light in 1950 (Voss) and 1937 (Peet, UMMZ). (4797)


6291. *Itame subcessaria* (Wlk.). Cheboygan: 15 July 1950. I took one fresh male at light at UMBS. Not previously reported from Michigan. (4754)


6293. *Semiaothista aemulataria* (Wlk.). Emmet, Cheboygan: 1-26 July. Listed by Moore (1955) only for the southern Lower Peninsula. Unlike some species of the genus, the larvae of this species and the next feed on a number of deciduous trees (Prentice 1963). (4665)

6294. *Semiaothista ulsterata* (Pears.). Emmet, Cheboygan: 30 June—15 July. (4664)


6296. *Semiaothista bicolorata* (F.). Cheboygan: 30 June—5 July. The specimens are a good match with McGuffin's figures (1972, figs. 71 & 72); according to Ferguson (in litt.) this is in fact a new species, allied to the next, with larvae on jack pine. Listed by Moore (1955, as *Macaria bicolorata*) from Chippewa, Schoolcraft, and Iosco counties. (4673)


6298. *Semiaothista sexmaculata* (Pack.). Cheboygan: 17 July—11 Aug. I have two specimens; the July one was taken at light at UMBS and the Aug. one at light in Mud Lake bog (Inverness Tp.). Previously reported for Michigan (Newman & Nielsen 1973, Ferguson 1974) only from the southern Lower Peninsula. The larval food plant is tamarack. (4687)

recently (1974) described species feed on white pine, *Pinus strobus*. Ferguson reported it only from the southern Lower Peninsula.

6349. *Semiothisa banksiana* Fgn. Cheboygan: 5–19 July. The larvae feed only on jack pine, *Pinus banksiana*. Although more widespread northward, the only eastern U. S. record for this species known to Ferguson (1974) was from Schoolcraft County; he predicted that it might prove to be more common.

6351. *Semiothisa oweni* (Swett). Emmet, Cheboygan: 23–30 June. The larvae feed on tamarack, *Larix laricina*. Previously reported from Michigan only from Atlanta [Montmorency Co.] by Ferguson (1974). Three specimens in UMMZ include two females taken at Burt Lake by Peet in 1937 and one male taken at Douglas Lake in 1934 by G. M. Grant; these are the basis of Moore's report (1955) of *S. graniata* (Gnm.) from Cheboygan County. (A fourth specimen det. by Moore as *granitata* is probably *pinistrobata* according to Balogh. *S. granitata* as now understood ranges east and south of the Great Lakes.) My only specimen (like the above, det. Balogh) was taken at incandescent light at Mackinaw City. Covell (1970b) lists a single Wisconsin locality. (4681)

6361. *Semiothisa orillata* (Wlk.). Emmet, Cheboygan: 30 June–15 Aug. The larvae feed only on white-cedar, *Thuja occidentalis*. I note that *S. eremiata* (Gnm.) was reported from Emmet County by Moore (1955), but no specimen has been found on which this report might be based. The only reported larval food plant seems to be goats-rue (*Tephrosia ambiguua*), but the only species of that genus in Michigan (*T. virginiana*) does not range north of the middle of the Lower Peninsula (Voss 1985). Reports of *S. eremiata* from northern Michigan are probably in error. Furthermore, my only specimen determined by Newman as this moth is in fact *Scopula ancillata*, and some MSU specimens are similarly misidentified. (4712)

6386. *Semiothisa ocellinata* (Gnm.). Cheboygan: 24 June–18 Aug. Included here are specimens determined by Newman as *S. nigricoma Warr*. Like *Helimata cycladata* (6261), the principal larval food plant is black locust, relatively recently established on the UMBS campus; absence of any records prior to 1956 is thus understandable. (4723)

6396. *Semiothisa neptaria* (Gnm.). Emmet, Cheboygan: 5–12 Aug. My only specimen, a male (but lacking abdomen) was taken at incandescent light at Mackinaw City in 1945 (det. Balogh). A specimen in UMMZ from Douglas Lake was collected by J. Leonard at light in 1932. The larvae of this and the next two species are reported principally if not entirely on poplars and willows. (4725)

6397. *Semiothisa mellistrigata* (Gnm.). Emmet, Cheboygan: 1–31 July. (4726)

6405. *Semiothisa gnaphosaria* (Gnm.). Emmet: 12–26 June. (4738)

6431. *Hesperumia sulphuraria* Pack. Emmet, Cheboygan: 9–15 July. My only specimen (a female) was taken at light in Pellston in 1950. A male (UMMZ) is from Mud Lake, by C.F. Farrell. Apparently not common in the state; Moore (1955) cited only Chippewa, Cheboygan, and Oscoda counties. These are evidently the same three localities shown in the map by Rindge (1974). Similarly, Covell (1970b) and Rindge indicate only two Wisconsin localities. Although the larval food plants are often stated (e.g. by Covell 1984) to be New Jersey tea (*Ceanothus*) and snowberry (*Symphoricarpos*), both quite local in the Douglas Lake region, the actual host range apparently includes a great diversity of trees and shrubs including even conifers (McGuffin 1977a). (4801)

6436. *Ematurga amitaria* (Gnm.). Emmet, Cheboygan: 28 May–6 July. The few extant specimens are mostly from Mud Lake bog (Inverness Tp.). Doubtless in other bogs and more common early in the season (as it is in other northern Michigan counties). Moore's 28 May specimens (UMMZ; cf. Moore 1922) are from Cecil. The adults are diurnal and the larvae (cranberry spanworm) are reported from a number of peatland trees and shrubs. I took one specimen 18 June 1946 sunning on a dirt road south of Mackinaw City. (4802)


6583. *Anacampytes ephyraria* (Wlk.). Cheboygan: 19–29 July. One specimen was taken at UV light at UMBS in 1988 (Scholtens) and another from 1935 is in the UMBS collection. I
have never collected the species myself. Scholtens also reared a specimen on common St. John’s-wort (*Hypericum perforatum*) and it emerged 15 July 1990. (4916)

6588. *Iridopsis larvaria* (Gn.). Emmet, Cheboygan: 18 June–14 July. (4912)

6590. *Anavitrinella pampinaria* (Gn.). Emmet, Cheboygan: 12 June–6 July. The generic name was spelled as given here when published by McDunnough (1922); the spelling in Hodges et al. (1983) is presumably a typographic error. (4908)


6637. *Eufidonia convergaria* (Wlk.). Cheboygan: 30 June 1968. My only specimen (det. Balogh) was taken at mercury vapor light at UMBS. The larvae are known from pines. (4803a)


6640a. *Biston betularia cognataria* (Gn.). Emmet, Cheboygan: 20 June–8 Aug. I have seen no melanic specimens of the pepper-and-salt moth from this area, but do have two melanic males collected in Oceana County 3–15 July 1944 (mapped by Owen 1961); such males were also collected in Oceana County by Metzler in 1965 and 1966, and in Otsego County by Newman in 1962. (4968)

6654. *Hy pagori s unin punctata* (Haw.). Cheboygan: 21 June–21 July. (4809)

6665. *Erannis tilaria tilaria* (Harr.). Emmet: 17 Sept.–14 October. My specimens were all taken at lighted windows at Mackinaw City (and hence are all males, the females being wingless). Not mapped from this region by Rindge (1975), who notes that the subspecies in the Pacific Northwest feeds rarely on conifers. Larvae of our subspecies, although called the “Linden looper” and named for linden or basswood (*Tilia*) defoliate many deciduous forest, shade, and garden trees and shrubs (Prentice 1973, Talerico 1978). (4964)

6666. *Lomographa semiclarata* (Wlk.). Emmet, Cheboygan: 14 May–21 June. A diurnal species, sometimes common in yards or along roadsides, pausing at damp spots. Both this and the next species were long placed under the later generic name *Bapta* (see Rindge 1979). (4605)

6667. *Lomographa vestaliata* (Gn.). Emmet, Cheboygan: 27 June–20 July. My specimens were all taken at light, although the species is said also to be diurnal. (4606)

6677. *Cabella erythemaria* Gn. Cheboygan: 4 July 1936. One male (UMMZ) collected by Peet at Burt Lake. Of four specimens collected by me in Emmet and Cheboygan counties and identified as *Deilinia erythemaria* by Newman, one is clearly *Protitame virginalis*; the front of the head is white except for a narrow black transverse line just below the bases of the antennae. The other three are *C. varioriaria*; the front of the head is yellowish brown upwards (white below), the palpi are short, and the wings are white with no trace of lines. (See Rindge 1956, p. 23; McGuffin 1981, p. 32.) In *C. erythemaria* the front of the head is yellowish brown throughout, the palpi are longer, and the wings have weak but evident lines. (4614)

6678 *Cabella variaria* Gn. Emmet, Cheboygan: 10 June–2 Sept. (4612)


6731. *Euchlaena madusaria* (Wlk.). Emmet: 30 June 1945. Moore (1955) lists only Josco and Oscoda counties, and only the former is in UMMZ. My specimen is a male taken in the morning at Mackinaw City where an incandescent light had burned the previous night. (5000)
6734. Euchlaena marginaria (Minot). Emmet, Cheboygan: 29 May—17 June. I took one male and one female in 1946 at incandescent light at Mackinaw City. Cantrall took a male (UMMZ) at light at Douglas Lake in 1939. The pm. line on the hind wings encloses a distinct loop; the metathoracic tibiae of the males are only slightly swollen. (5002)

6737. Euchlaena tigrinaria (Gn.). Emmet, Cheboygan: 16 June—1 July. All specimens are males, with very swollen metathoracic tibiae (cf. McGuffin 1981). The pm. line on the hind wings has at most an indistinct loop. My specimens were originally determined by Newman as E. pectinaria (D. & S.), which is not to be expected in Michigan. (5005)


6740. Xanthotype urticaria Swett. Emmet, Cheboygan: 1 July—7 Aug. Frequent at light; rarely diurnal. The dates are those for males, which can usually be determined without dissection by brushing some scales from the ventral part of the end of the abdomen, where the aedeagus is generally visible as a truncate organ bidentate at its apex (cf. figures in Rindge 1978, p. 11; McGuffin 1981, fig 179b). Females which may be this species have been captured as late as 13 Aug. (5010)

6743. Xanthotype sospeta (Drury). Emmet, Cheboygan: 25 June—14 Aug. The aedeagus is more or less spoonlike, without teeth, and can generally be seen without dissection, as above (cf. Rindge 1978, p. 11; McGuffin 1981, fig. 179c). (5007)


6755. Pero morrisonaria (Hy. Edw.). Emmet, Cheboygan: 21 June—2 July. My specimens were originally named by Newman as P. marmoratus (Grossb.) [= P. hubneraria (Gn.)], but can be referred here by the greatly swollen 8th sternite of the male abdomen (cf. Poole 1987). Moore's listing (1955) of P. marmoratus from Cheboygan County is likewise based on specimens (UMMZ) of P. morrisonaria. The larvae of this species are reported commonly on conifers (Prentice 1963), whereas those of the preceding feed on deciduous trees and shrubs. (5080)


6796. Campea perl ala (Gn.). Emmet, Cheboygan: 24 June—15 Aug. (5015)


6798. Ennomos subsignaria (Hbn.). Emmet, Cheboygan: 30 June—12 Aug. Apparently quite rare in the region, although the larvae (elm spanworm) have sometimes been an important defoliator of deciduous trees in areas east of Michigan. (5059)

6804. Petrophora subaeguaria (Wlk.). Emmet, Cheboygan: 23 May—27 June. I have never taken this diurnal species myself; specimens are at MSU and in the Scholtens collection. This is one of the few species whose larvae feed on bracken fern (Pteridium aquilinum), and it should therefore be more common in this area, where bracken is so abundant. (5025)

6807. Tacparia detersata (Gn.). Emmet: 27 May—7 July. Apparently uncommon. My only specimen is a female taken at Mackinaw City 7 July 1945 at incandescent light. R. and K. Dreisbach (MSU) and G. Balogh have collected the species 27 May. The only reported larval food plants are diverse: alder and tamarack (McGuffin 1987). Both this species and the preceding were long placed in Apaecasia until the correct genus was noted by Rupert (1949), who stated that T. detersata was apparently missing in the central and western U. S. Moore (1955) listed only six counties, all in northern Michigan but including neither Emmet nor Cheboygan; Covell (1970b) indicated only three locations in Wisconsin. (5023)

6812. Homochlodes fritillaria (Gn.). Emmet, Cheboygan: 27 May—6 July. Rupert (1949) and McGuffin (1987) have not treated H. lactisparagaria (Wlk.) as a distinct species, although Ferguson (in Hodges et al. 1983) does so, and he has noted (Ferguson 1983) that Morris (1980, pl. 31 fig. 14) shows lactisparagaria, not fritillaria. The white spots on our specimens are less prominent than usually figured and the markings are not as dark as in Rindge (1986, fig. 5). Two specimens were taken at UV light by Scholtens at UMBS 25 June and 6 July. Two specimens (MSU) collected 27 May 1960 in Emmet County by R. and K. Dreisbach could be lactisparagaria, which is an early spring species (Ferguson, in litt.). These taxa are among the relatively few species with larvae on bracken and other ferns, and yet the moths are apparently uncommon in our area. (5022)
6815. *Gueneria similaria* (Wlk.). (Cheboygan): Moore (1955) lists this county for the species (as *G. basaria* [Wlk.]) only on the basis of Welch (1915), whose specimen has not been located. The only reported larval food plant is a fern (*Dryopteris*), so the report is reasonable. (5016)


6822. *Metarranthis duaria* (Gn.). Emmet: 27 May – 22 June. My only specimen is a female taken at incandescent light at Mackinaw City in 1945. R. and K. Dreisbach (MSU) and G. Balogh took the species on 27 May in 1960 and 1990 respectively. The pm. line is much less sharp in this species than in the preceding, and is broken where it crosses the veins. Two specimens of mine, both males, determined as this species by Newman I refer to *M. warnerae*, with strong dark shading before the pm. line, which is continuous. (5050)

6825. *Metarranthis indeclinata* (Wlk.). Cheboygan: 1 July 1950. My only specimen is a pale female which was flying by day in a cedar swamp area ("Reese's Bog"). McGuffin (1987) includes this species in *M. hypochraria* (H.-S.), but others treat it as distinct (the spelling of the latter in Hodges et al. 1983 is presumably a typographic error). (5046a)

6832. *Metarranthis obfirma* (Hbn.). Cheboygan: 9 or 10 May 1987. A specimen in the collection of Dana Gring, taken near Indian River, was examined by Scholtens and Nielsen at a meeting of The Ohio Lepidopterists, and is apparently the only record from the region. (5052)

6834. *Cepphis decoloraria* (Hulst). Cheboygan: 30 June – 3 Aug. Apparently not common in the state. My only specimen was taken 30 June 1950 by Glenn Peterjohn (no locality other than county); three others (UMMZ) were taken at light at Burt Lake by Peet. The larvae have been reported only on *Rubus* spp., "preferring blackberry to raspberry" (Forbes 1948, Ferguson 1975). (5029)


6836. *Anagoga occiduaria* (Wlk.). Cheboygan: 3 July 1937. One specimen (UMMZ) collected by Peet at light at Burt Lake. (5042)


6841. *Plagodis kuetzingi* (Grt.). Cheboygan: 27 June – 11 July. (5031)


6844. *Plagodis alcoolaria* (Gn.). Emmet, Cheboygan: 19 May – 18 July. (5038)

6863. *Caripteta divisata* Wlk. Emmet, Cheboygan: 14 June – 27 July. The hosts for this and other species in the genus are conifers. (5125)


6885. *Besma quercivoraria* (Gn.). Cheboygan: 27 June 1969. One female, taken at mercury vapor light at UMBS. Since the larvae of this species and the preceding feed on species of maple, oak, and birch, it is surprising that the moths are not more common. Among the few Michigan counties listed for each (as *Ellopia endropiaria* and *Metanema quercivoraria*), Moore (1955) included neither Emmet nor Cheboygan. (5145)

6888. *Lambdina fiscellaria* (Gn.) Emmet, Cheboygan: 23 Aug. – 14 Sept. I have seen only three specimens: one (UMMZ) taken by Moore in 1921 at Waugoshance Island and cited by him (1922) from Emmet County; one (UMMZ) taken in 1937 by Peet at light at Burt Lake; and one taken in 1989 by Scholtens at UMBS. The larva (hemlock looper) is an important defoliator of conifers in some regions, but evidently not here. (5146)

bog (Inverness Tp.) and by Rawson at Black Lake (UMMZ). There is also a pair of specimens in the UMBS collection from Mud Lake, labeled “Pupated before viii-18-41 Emerged June 20 '42”; the labels also say “Chamidaphne Looper” suggesting that leatherleaf (Chamaedaphne calyculata) may be a previously unreported host. The moth (chain-dotted geometra) is doubtless more common than the few records indicate; although it is a conspicuous diurnal flyer, it must be overlooked by collectors who do not venture much into bogs in the fall. I have found the adults in Luce County bogs 1 Sept. - 14 Oct. (5152)

6906. Nepytia canosaria (Wlk.). Cheboygan: 14 Aug. - 11 Sept. Specimens are in the MSU, UMMZ, and Scholtens collections. The larvae feed on conifers and one would expect so distinctive and attractive a moth to have been collected more often than it has. Moore (1955) lists two upper Peninsula counties and six Lower Peninsula ones. My only specimen is a male taken at a gasoline lantern in Luce County 22 Aug. 1989. (5109)

6912. Sicya macularia (Harr.). Emmet, Cheboygan: 5 July - 19 Aug. (5161)

6941. Eusarca confusaria Hbn. Emmet, Cheboygan: 8 July - 1 Aug. (5184)

6963. Tetracis crocallata Gn. Emmet, Cheboygan: 26 June - 2 July. (5197)

6964. Tetracis cachexiata Gn. Emmet, Cheboygan: 16 June - 6 July. (5198)


6982. Prochoerodes transversata (Drury). Emmet, Cheboygan: 1 July - 28 Aug. (5211)

7009. Nematoeampa limbata (Haw.). Emmet, Cheboygan: 22 July - 12 Aug. My only specimen was taken in Aug. at incandescent light at Mackinaw City in 1945. Scholtens took one in July 1990 at UV light at UMBS. Evidently rare. (5044)

Subfamily Geometrinae

7048. Nemoria mimosaria (Gn.). Cheboygan: 29 May 1939. One male (UMMZ), taken by Cantrall at light at Douglas Lake. (4048)

7058. Synchloora aerata (F.). Emmet, Cheboygan: 1-29 July. My specimens have all been referred by Balogh to ssp. albolineata Pack., extending slightly south its limit in Michigan as stated by Ferguson (1985, p. 85) to be Iron County, in the western Upper Peninsula. (4070)

7071. Chlorochlamys chloroleucaria (Gn.). Emmet, Cheboygan: 10 June - 9 July. Taken at light and also flushed from grass during the day. (4087)

7084. Hethemia pistasciaria (Gn.). Emmet, Cheboygan: 10 June - 9 July. Taken at light and also flushed from grass during the day. (4087)

Subfamily Sterrhinae

7114. Idaea demissaria (Hbn.). Emmet, Cheboygan: 3 July - 8 Aug. (4180)

7132. Pleuroprocura insularia (Gn.). Cheboygan: 30 June - 9 Aug. I have one male taken in August at mercury vapor light at UMBS in 1964; Scholtens took two females at UV light at the Station, one in August and one in June. (4206)

7139. Cyclophora pendulinaria (Gn.). Cheboygan: 13 June - 18 Aug. Listed by Welch (1915, as Cosymbia lumenaria [Hbn.]); his undated specimen is in UMMZ. Also taken by Scholtens, but never by me. (4211)

and pink moth, the "chickweed geometry" from some of the larval food plants, often diurnal but also attracted to light (taken at carbon arc light and gasoline lantern). (4204)

7157. Scopula cacuminaria (Morr.). Emmet: 22 July 1945. I have one female, found in Mackinaw City on the wooden post of an incandescent streetlight. Moore (1955) recorded this species only from the southern Lower Peninsula, but Covell (1970a) cited and illustrated a specimen from Ramona [Newaygo Co.], somewhat farther north. (4140)

7159. Scopula limboundata (Haw.). Emmet, Cheboygan: 30 June—14 Aug. A very common species and an extremely variable one as well illustrated by Covell (1970a, figs 80-82), McGuffin (1967, figs. 26-32), and others. (4149)

7162. Scopula ancellata (Hulst). Emmet: 28 June-12 Aug. I have four specimens, all taken at incandescent light in 1945 at Mackinaw City. The only previously published Michigan record seems to be from Schoolcraft County (Covell 1970a, p. 153), although there are specimens in MSU from other counties. (See also remarks under 6361 above.) Michigan is on the eastern edge of the range for this species. (4147)

7164. Scopula juncaria (Wlk.). Emmet, Cheboygan: 25 June—29 July. Taken at lights. (4148)

7165. Scopula quadrilineata (Pack.). Cheboygan: 20 June 1989. Two specimens (det. Balogh) taken by Scholtens as diurnal flyers in a clearing near UMBS. Previously unreported from Michigan except for citation of the state in the original description (Packard 1876); however, Covell (1970a) notes that what he has seen of the type series is mixed and he did not see any Michigan specimens. (4143)

7169. Scopula inductata (Gn.). Emmet, Cheboygan: 18 June—8 Sept. (4158)

Subfamily Larentiinae

7182. Dysstroma citrata (L.). Cheboygan: 23 Aug. 1937. One male (UMMZ) taken by Peet at light at Burt Lake. This specimen was determined by Moore as D. truncata (Hufn.), so is the basis for his listing for Cheboygan County. The correct identification has been made by Balogh. (4416)

7189. Dysstroma hersiliata (Gn.). Cheboygan: 30 June-7 July. Larvae have been reported on currant (Ribes). (4420)

7196. Eulithis diversilineata (Hbn.). Emmet, Cheboygan: 4 Aug.—5 Sept. Only two specimens: the August one by Scholtens at UV light at UMBS in 1990; the September one by me at incandescent light at Mackinaw City in 1945. (4401)

7197. Eulithis gracilineata (Gn.). Cheboygan: 24 July—23 Aug. This frequent species and the preceding are not well contrasted in recent literature; the figures by Packard (1876, pl. 8, figs 53 & 54) are helpful. Larvae of both species feed on members of the grape family (Vitaceae). (4401f)


7201. Eulithis testata (L.). Emmet, Cheboygan: 3 July—30 Sept. The larvae are rather broad feeders on woody plants (McGuffin 1958). (4403)

7203. Eulithis molliculata (Wlk.). Emmet: 12-29 Aug. One specimen from each date in 1945, at incandescent light at Mackinaw City. The larvae are reported on ninebark, Physocarpus opulifolius, a common calciphile shrub in the region (McGuffin 1977b). (4404)

7206. Eulithis explanata (Wlk.). Cheboygan: 5 July—12 Aug. The larva are reported on blueberries, Vaccinium spp. (Covell 1984), and the pupae have been found on conifers (Prentice 1963). (4406)

7208. Eulithis serraria (B. & McD.). Cheboygan: 21 July 1989. One specimen (det. Balogh) taken at UV light by Scholtens at UMBS. This is yet another new species for the state. (4408)

7210. Eustroma semiatrata (Hulst). Cheboygan: 26 July 1951. One female, taken at light at UMBS. Reported for Michigan (including this record) by Newman and Nielsen (1973), but earlier reported (as E. nubilata [Pack.]) by Welch (1915), whose undated Douglas Lake specimen is in UMMZ. A handsome and rather boreal species, with larvae reported on fireweed (Epilobium). (4398)


7235. *Hydriomena divisaria* (Wlk.). Cheboygan: 27 June 1969. I have a single specimen (det. Balogh 1990), taken at mercury vapor light at UMBS. The larvae of this uncommon species feed on conifers, whereas alder is the preferred host of the next species. (4484)

7236. *Hydriomena renunciata* (Wlk.). Emmet, Cheboygan: 12 June—3 Aug. A rather common moth. Included here, as determined by Balogh, are all my specimens placed by Newman (1973—1975) as *frigidata* and as *divisaria* (except for the single *divisaria* cited above). Moore (1955) reported only *renunciata* from Cheboygan County (no *Hydriomena* from Emmet), presumably including the old listing by Welch of *autumnalis* (cf. discussion by McDunnough 1954, p. 275). (4485)


7291. *Hydria prunivorata* (Fgn.). Emmet, Cheboygan: 27 June—6 Aug. Our male specimens of *Hydria* are this species, with more or less triangular uncus as figured by Ferguson (1955); females are presumably the same, although the very similar *H. undulata* (L.) could occur.

7293. *Rheumaptera hastata* (L.). Emmet, Cheboygan: 25 May—24 June. A diurnal species, often seen in early summer flitting about the edges of woods. Dates given are for males, which can rather easily be distinguished from *R. subhastata* (Nolcken) by the distinctive sacculus (described by McGuffin 1973), visible ventrally with a little brushing away of a few scales. Females, presumably of the same species, are on the wing until mid-July. I took one female 13 July at the flowers of nine-bark (*Physocarpus opulifolius*), and have seen what presumably was this species visiting the flowers of mountain maple (*Acer spicatum*) in Luce County. In Alaska this species has been a serious defoliator of paper birch (*Betula papyrifera*), as described and well illustrated by Werner and Baker (1977); overall, the larvae are rather general feeders. The amount of white on the wings is quite variable, so that differentiation from *R. subhastata* on the basis of pattern is unreliable. The latter species was mapped by McGuffin (1973) from the tip of the Lower Peninsula. However, the specimen (MSU), determined by McGuffin, on which this map dot is obviously based bears a label clearly reading "Mackinaw [sic] Co." and should therefore have been mapped from the other side of the Straits, in Mackinac County. (4573)

7307. *Mesoleuca ruficillata* (On.). Cheboygan: 27 June 1969. I took one female at mercury vapor light at UMBS. A memorandum in some primitive field notes indicates that a specimen taken 29 June 1944, presumably at Mackinaw City in Emmet County, was lost. For a species whose larvae are reported on bracken and blackberries—both common in the area—this is a remarkably rare species. (4546)


7329. *Anticlea vasiliata* Gn. Emmet 12—27 May. Listed by Moore (1955) only from three counties in the southern Lower Peninsula. My only specimen was taken in 1951 during the day on Waugoshance Point. In MSU are two specimens collected 27 May 1960 by R. and K. Dreisbach. The larvae are known to feed on raspberry (*Rubus*) (Morris 1980). (4587)

7368. *Xanthorhoe labradorensis* (Pack.). Cheboygan: 10—13 Aug. One female at mercury vapor light (in 1965) at UMBS is probably the same species as a male at UV light (in 1989) at the same place (Scholtens) and confirmed by Balogh in 1990. (This taxon is not the same as early misapplication of *labradorensis*, for which McDunnough published *packardata* in 1945 [Canad. Entomol. 77:65].) Moore (1955) listed Cheboygan County for *X. designata* Hufn., based on the listing by Welch (1915, as *Gypsochroa designata*), but what was once called *designata* is now to be called *labradorensis* and Welch's undated specimen (UMMZ) has been determined as this by Balogh. (4511)
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7371. Xanthorhoe iduata (Gn.). Cheboygan: 9 July 1934. One male (UMMZ) taken at Mud Lake (Inverness Tp.) by C.F. [Farrell]. (4527)

7388. Xanthorhoe ferrugata (Cl.). Emmet, Cheboygan: 24 June—15 Aug. (4517)

7390. Xanthorhoe lacustrata (Gn.). Emmet, Cheboygan: 18 June—19 Aug. Species of Xanthorhoe, including this one, have been implicated in the pollination of blunt-leaved orchid, Habenaria obtusa, in northern Lower Michigan (Crawford Co.) and northern Wisconsin (Stoutamire 1968; Thien & Utech 1970). This is an orchid usually pollinated by mosquitoes. (4509)

7394. Epiphrhoe alternata (Müller). Cheboygan: 14 Aug. 1989. Scholtens collected a female at UV light at the Biological Station. Moore (1955) merely cited Welch (1915, as Rheumaptera sociata), whose specimen cannot be found. My only specimen is from Oceana County, 22 July 1944. The larvae are reported only from bedstraw (Galium), of which several species are common in the region. (4551)

7399a. Euphyia unangulata intermediata (Gn.). Cheboygan: 24 June 1959. One female at mercury vapor light at UMBS. (4558)

7414. Orthonama obstipata (F.). Emmet, Cheboygan: 12 June—24 Aug. A very common little moth. The sexes are dimorphic. Larvae found by Sandy Beadle have been reared by Scholtens on the endangered Michigan monkey-flower, Mimulus glabratus var. michiganensis—a previously unreported host plant and host family (Scrophulariaceae). (4535)

7416. Orthonama centrostrigaria (Woll.). Emmet, Cheboygan: 13 June-24 October. The latest date in my records was 15 July until Nielsen reported taking this species in October. (4559)

7419. Hydrelia lucata (Gn.). Emmet: 25 June—16 July. The wings of this species are more or less uniformly marked with grayish scales. According to Ferguson (in litt.), inornata is a later name for the same species. H. condensata (Wlk.) has prominent pure white medial and terminal areas on the forewings (and in older literature is often listed and illustrated as “lucata”); it should be expected in the Douglas Lake region, as a nice series was collected (UMMZ) by Moore at light at St. Ignace, just across the Straits of Mackinac, 5 June—12 July 1927. (4597)

7423. Hydrelia albifera (Wlk.). Emmet, Cheboygan: 8 June—28 July. My only specimen was taken at incandescent light at Mackinaw City. Cheboygan County specimens (UMMZ) are from Burt Lake and Cheboygan; also listed by Welch (1915). One would expect this species to be common, since the larvae are reported on red-osier (Cornus stolonifera) (McGuffin 1958), a very common shrub in the region. (4597)

7430. Trichodezia albovittata (Gn.). Cheboygan: 5 July 1984. One specimen (Scholtens); also listed by Welch (1915) and hence by Moore (1955). A black-and-white diurnal very different from Rheumaptera, with which I have seen it flying elsewhere in Michigan. (4235)

7440. Eubaphe mendica (Wlk.) Emmet, Cheboygan: 19 June—12 Aug. A common moth at light throughout the region. (4599)

7445. Horisme intestinata (Gn.). Emmet, Cheboygan: 12 June—13 Aug. (4393)


7474. Eupithecia miserulata Grt. Emmet, Cheboygan: 9 June—5 July. (4266)

7487. Eupithecia subfuscata (Haw.). Emmet: 18 June—14 July. Evidently our commonest species, as it is in other areas. The larvae are known from many hosts. (4276, as castigata)


7518a. Eupithecia intricata taylorata Swett. Emmet: 28 June—13 July. Two specimens at incandescent light at Mackinaw City (det. Bolte). Not previously reported from Michigan, although the larvae feed primarily on white-cedar and junipers, and one would expect the
species to be more common. Bolte (1990) includes *E. gibsonata* Tayl. in this species. (4320, 4322)

7528. *Eupithecia assimilata* Doubleday. Cheboygan: [date illegible]. One specimen (UMMZ) collected by Peet at Burt Lake and determined by Bolte. Following Bolte (1990), this is the species listed in Hodges et al. (1983) as *E. fumosa* (Hulst). This specimen was determined by Moore as *E. coagulata* (see below). (4330)

7529. *Eupithecia absinthiata* (Cl.). Emmet, Cheboygan: 28 June–9 Aug. I have one specimen collected in 1945 at incandescent light at Mackinaw City, and Balogh took one specimen in Aug. of 1986 in Cheboygan County. Bolte (1990) included *E. coagulata* Gn. in this species, but Moore's listing (1955) of *coagulata* from Cheboygan County is to be referred to the previous species. This is a species of which the larvae are flower feeders. (4336) 7533. *Eupithecia cretaceata* (Pack.). Emmet: 6 Aug 1945. One specimen at incandescent light at Mackinaw City (det. Bolte). Previously unreported from Michigan. Since the usual larval food plant, false hellebore (*Veratrum*) does not occur in the state, the host in this area is presumably the closely related white camas (*Zigadenus glaucus*). An allied species, *E. zigadeniata*, of Texas, feeds on *Z. nuttallii*. The wingspread of *E. cretaceata* is twice as large as in any other Michigan species. (4350)

7538. *Eupithecia gelidata* Masch. Cheboygan: 27 June 1932. Collected by Peet (UMMZ) at Burt Lake. The only Michigan record listed by Moore (1955) is clearly based on this specimen, which has been confirmed by Bolte. (Moore stated that it was determined by McDunnough but did not include the question mark that appears on the determination label. The species was not cited from Michigan by McDunnough [1949].) The larvae of this northern circumpolar moth are mostly found on Labrador-tea (*Ledum*). (4333)


7551. *Eupithecia interruptofasciata* Pack. Emmet, Cheboygan: 10 Aug. – 18 Sept. Two specimens taken by Scholtens in 1989 at UV light at UMBS. I took one at light in Mackinaw City in 1977. The material has been determined by Bolte, who includes North American records of *E. pusillata* (D. & S.) here and notes that the larvae are usually found on *Juniperus communis*, common juniper. (4342a)


7640. *Lobophora nivigerata* Wlk. Emmet, Cheboygan: 23 May – 14 Aug. Several of my specimens were referred by Newman to *L. montanata* Pack., a species reported from two Upper Peninsula counties by Moore (1922). Insofar as my specimens are males, they all have hair pencils on the metathoracic tibiae. Hulst (1896), in describing a new genus (*Talledega*) for *montanata*, declared that it differed from *Lobophora* in the absence of such hair pencils. The larvae of *nivigerata* feed on quaking aspen, *Populus tremuloides*, and other woody plants. (4226)

7648. *Dyspteris abortivaria* (H.-S.). Cheboygan: 21 June – 7 July. Rarely taken at light. I have not collected the species so far north, but there are specimens in the Scholtens and UMMZ collections. The larvae feed on members of the grape family (*Vitaceae*). (4254)
ACKNOWLEDGMENTS

My specimens of Geometridae were all (insofar as then collected) in the hands of the late John H. Newman prior to publication of Newman and Nielsen's 1973 list of moths new to Michigan, but many of the records were not noted in that paper. My specimens (primarily subfamilies other than Ennominae) not checked by Newman before his retirement, plus more recent specimens and puzzles from other collections, were generously examined since 1988 by George Balogh, who has also commented on an early draft of the manuscript and supplied some records from his own collection. Douglas C. Ferguson has commented very helpfully on the manuscript. M. C. Nielsen supplied several additional records from his collection. Brian G. Scholtens, who has collected at UMBS since 1984, has contributed in a major way through his discriminating collecting, aid in identification, and cheerful encouragement. Klaus Bolte has kindly named almost all the available *Eupithecia* specimens. The collections of the University of Michigan Museum of Zoology (UMMZ), Michigan State University Entomological Museum (MSU), and University of Michigan Biological Station (UMBS) have been freely made available. I have collected 76% of the 165 species listed and have them in my personal collection (at Mackinaw City). When the only specimens from the region are in other collections, they are indicated. (about 50% of the species are in the Scholtens collection, 55% in UMMZ and 24% in UMBS.) I am grateful to all those who have determined specimens, provided access to collections, and suggested improvements in the manuscript. The University of Michigan Biological Station has generously supported publication.

LITERATURE CITED


________. 1987 Guide to the Geometridae of Canada (Lepidoptera) II. Subfamily Ennominae 4.


ABSTRACT

Plasticity in the nesting behavior of Lyroda subita, a species that renovates and then uses pre-existing burrows and other subterranean cavities for nesting sites, is illustrated by one female which apparently excavated her burrow from the ground surface. Details of burrow construction are described. Information on nest structure and dimensions and cell contents is presented.

Lyroda subita (Say) is a common species of larrine wasp that inhabits much of North America. Females are often seen transporting paralyzed crickets on the ground and in low flights in broad daylight on bare soil. This species is one of the more heavily cleptoparasitized sphecids with cleptoparasitic frequencies approaching 25-50% at many localities (Evans 1964, Kurczewski and Peckham 1982, Spofford and Kurczewski 1990). Despite such high mortality, the species is relatively abundant throughout much of its range. This abundance may be related to its adaptability in both prey and nest site selection. Although the species usually preys upon nymphal Gryllidae (Kurczewski and Peckham 1982), one female nesting in upstate New York provisioned with Tridactylidae (Kurczewski and Spofford 1985), a behavior reported for an undescribed Australian species of Lyroda by Evans and Hook (1984).

Provisioning females of L. subita are seen commonly during field studies on other solitary wasps, but their burrow construction and nest closure has never been described. One reason for the lack of such information is related to the almost exclusive use of pre-existing burrows and other subterranean cavities as nesting sites by this species (Evans 1964, Kurczewski and Peckham 1982). Lyroda subita has been reported to renovate the tunnels and nests of a variety of insects, including other species of Sphecidae and Cicindelidae, as well as to modify underground crevices and cavities for nesting purposes. I have observed several females nesting within the narrow confines of cracks between concrete patio slabs in both New York and Pennsylvania. In every instance, burrow construction took place below ground level and out-of-sight. The single record of digging from the ground surface reported below fills in gaps about the nesting activities of this species and represents plasticity in its behavior.

As might be expected in a species of digger wasp that renovates preexisting depressions rather than digging from the ground surface, the foretarsal rake of L. subita females is weak and possesses few spines. The mid-and hindlegs of L. subita females are likewise weakly spined, except for the hindtibial spurs. The two parallel rows of spines on the hindtibiae may assist in pushing the soil upward during soil removal.

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Figure 1. Nest of *Lyroda subita*, as seen in side view. All cells are fully provisioned and contain an egg on a paralyzed nymphal *Allonemobius carolinus*.

The pygidium of the female, which also assists in soil removal, is sparsely to densely covered with short, stiff setae and appressed hairs.

On 9 July 1972 at Presque Isle State Park, Erie County, Pennsylvania, I observed a female of *L. subita* pushing damp sand out of an entrance at intervals of 1-4 min. During soil removal, the hindlegs were used to push the damp sand up the burrow; the end of the abdomen, including the pygidium, was then used to bulldoze this sand onto the surface where it accumulated in a semi-circular mound below the entrance. Although initiation of the burrow from the ground surface was not observed, the situation of the entrance being located beneath one end of a flat stone, 5.5 cm long and 0.8 cm high, in soft moist sand and the design of the nest directly beneath the surface (see Kurczewski and Peckham 1982) suggests that the female did not use a preexisting depression. This nest was marked and excavated two days later.

The burrow, 4.5 mm in diameter, entered the sand at a 10° angle to the surface and proceeded at this angle for 6 cm before plunging nearly vertically for an additional 8 cm where it was lost among a series of subterranean flat stones. Three fully provisioned cells were unearthed 2.5 - 4.0 cm beyond this point at depths of 8.5, 8.0 and 7.0 cm beneath the sand surface (Fig. 1). The cells were 6-7 x 12-14 mm in height and length, respectively. The deepest cell contained three paralyzed nymphal field crickets and the two shallower cells, two such crickets each. All prey were identified as *Allonemobius carolinus* Scudder (Gryllidae) (det. A.B. Gurney, Systematic Entomology Laboratory, USDA). The individual crickets had been placed in the cells in a head inward and ventral side up position and weighed (wet) 23-35 (x = 28.6, N = 7) mg. (The wasp weighed 21 mg.) The wasp's eggs, ca. 2.0 x 0.6 mm, were each attached by a cephalic end to either a right (1) or left (2) forecoxal corium of the prey, the caudal end extending to the other side between the fore-and midlegs. One of the eggs hatched during transport to the lab and the feeding larva was photographed 1.5 days later (Fig. 2).
DISCUSSION

Until rather recently, plasticity in nesting behavior of solitary wasps had been little studied and not well documented (Evans 1966, Bohart and Menke 1976, Krombein 1979). More intensive studies are needed to fully disclose the spectrum of variation that remains undiscovered for the vast majority of species. This plasticity may be expressed in the use of unusual prey (Evans 1948, Kurczewski 1966, Kurczewski and Spofford 1985), variation in individual behavioral components (Steiner 1971) or modification in species-specific nesting patterns (Brockmann 1980, Evans 1987, Field 1989). Although a switch from usual to unusual prey is the most frequently observed change in a species-specific behavior pattern, intensive behavioral studies often reveal "hidden" variability in the form of omissions, additions or modifications in behavioral components. The excavation of a burrow from the ground surface in *Lyroda subita*, a species previously known to use only pre-existing holes for nests (Evans 1964, Kurczewski and Peckham 1982), is a significant deviation from its known nesting pattern. However, the mechanics employed by the female for this excavation, i.e., use of hindlegs and abdomen, are probably the same as those used during the renovation of an underground pre-existing burrow or cavity.

LITERATURE CITED


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