# THE GREAT LAKES ENTOMOLOGIST

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Head of a black fly larva, *Simulium vittatum* Zetterstedt (Diptera: Simuliidae). SEM photograph by Dr. Douglas Craig, Department of Entomology, University of Alberta.

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ABSTRACT

The species composition, succession, and seasonal abundance of immature simulids occurring in the Rose Lake Wildlife Research Area in lower Michigan are presented. Selected physical and chemical characteristics of streams in the above area were examined and compared in relation to faunal distributions. Comparisons of species differences between permanent and temporary streams were made utilizing the functional group concept based on feeding mechanisms.

Keys and illustrations are presented for the identification of larvae and pupae of four genera (Prosimulium, Simulium, Stegopterna, Cnephia) and 19 species of Simuliidae known to occur in lower Michigan. Two species, Cnephia ornithophilia and Simulium vernum, were recorded for the first time in Michigan.

Few studies have been conducted on the black flies (Diptera: Simuliidae) of Michigan. Wu (1931) studied various aspects of the biology and life history of several Simulium species in northern lower Michigan. Laboratory experiments were also conducted on factors influencing larval black fly distribution in streams. She concluded that larvae had a definite requirement for current and that high dissolved oxygen content of the water was not the determining factor for their presence or absence. Gill and West (1955) recorded biological observations on several species of black flies in Michigan's Upper Peninsula. Tarshis (unpubl. data, 1963-1973) and Desser et al. (1978) investigated the role of black flies in waterfowl disease transmission in the Upper Peninsula (mainly Seney National Wildlife Refuge), where the former author recorded 55 species (I. B. Tarshis, pers. comm.). Ross and Merritt (1978) studied the population dynamics of five species of black flies in the Lower Peninsula and their responses to selected environmental factors. They found that stream temperature was the most important physical factor regulating larval black fly population dynamics, determining hatching time and developmental rates.

This study was initiated to: (1) determine the species composition, succession, and seasonal abundance of immature simulids in the Rose Lake Wildlife Research Area in lower Michigan; (2) examine selected physical and chemical characteristics of streams in the above area in relation to faunal distributions; and (3) provide a standard key to the major genera and species of immature black flies found in Michigan's Lower Peninsula. Prior to this paper, there have been no published keys to Michigan Simuliidae.

MATERIALS AND METHODS

Extensive collections of Simuliidae were made at the Rose Lake Wildlife Research Area (RLWRA) from March, 1975, through May, 1977, (Fig. 1, Table 1). This 1350 ha research area in Clinton and Shiawassee counties, Michigan, is located 13 km northeast of the Michigan State University campus. In addition, over 4000 specimens of black flies (mainly Simulium spp.) were sorted and identified from stream invertebrate survey collections made throughout the Lower Peninsula during June through September.
Table 1. List of species and collection sites of immature black flies from the Rose Lake Wildlife Research Area.

<table>
<thead>
<tr>
<th>Species</th>
<th>Site Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><em>Prosimulum fuscum</em> Syme &amp; Davies</td>
<td>X</td>
</tr>
<tr>
<td><em>P. gibsoni</em> (Twinn)</td>
<td>X</td>
</tr>
<tr>
<td><em>P. mixtum</em> Syme &amp; Davies</td>
<td>X</td>
</tr>
<tr>
<td><em>P. multidentatum</em> (Twinn)</td>
<td>X</td>
</tr>
<tr>
<td><em>P. mysticum</em> Peterson</td>
<td>X</td>
</tr>
<tr>
<td><em>Cnephas dacotensis</em> (Dyar &amp; Shannon)</td>
<td>X</td>
</tr>
<tr>
<td><em>C. ornithophilla</em> Davies, Peterson &amp; Wood</td>
<td>X</td>
</tr>
<tr>
<td><em>Stegoptera mutata</em> (Malloch)</td>
<td>X</td>
</tr>
<tr>
<td><em>Simulium aureum</em> Fries</td>
<td>X</td>
</tr>
<tr>
<td><em>S. decorum</em> Walker</td>
<td>X</td>
</tr>
<tr>
<td><em>S. excisum</em> Davies, Peterson &amp; Wood</td>
<td>X</td>
</tr>
<tr>
<td><em>S. pugetense</em> (Dyar &amp; Shannon)</td>
<td>X</td>
</tr>
<tr>
<td><em>S. venustum</em> Say complex</td>
<td>X</td>
</tr>
<tr>
<td><em>S. venum</em> Macquart complex</td>
<td>X</td>
</tr>
<tr>
<td><em>S. verecundum</em> Stone &amp; Jarnback complex</td>
<td>X</td>
</tr>
<tr>
<td><em>S. vittatum</em> Zetterstedt</td>
<td>X</td>
</tr>
</tbody>
</table>
Fig. 1. The Rose Lake Wildlife Research Area, showing collection sites.

(1970-1977) by the Michigan Department of Natural Resources (Fig. 2). Material from the Michigan State University Entomology Museum and private collections were also examined.

Immature black flies were collected in streams from both natural substrates such as stones, vegetation, and submerged wood, as well as artificial substrates including ceramic tiles and plastic tapes (Williams and Obeng, 1962; Lewis and Bennett, 1974). The insects were preserved in the field in 95% ethanol, or returned to the laboratory attached to substrates in 1 liter plastic bags or containers. Larvae were reared in glass aquaria (after Tarshis, 1968) using stream water without a food supplement. Field-collected pupae were reared singly on moist filter paper in petri dishes until emergence. Biting adult flies were collected from penned deer and elk at the Rose Lake Wildlife Research Center and from horses on nearby farms. Larval head capsules and adult genitalia were placed in glycerine or mounted on slides to make specific identifications. Material was cleared 8-10 hours in 10% KOH, dissected, then mounted in Euparol® and examined under a compound microscope. Taxonomic concepts of the species involved in this study closely follow those in Stone and Jammback (1955), Davies et al. (1962), Wood et al. (1963), Stone (1964) and Peterson (1970, 1977, 1978).

During the winter and spring of 1976, qualitative collections of associated stream insects were made at all study sites in the RLWRA (Fig. 1). These were preserved in 95% ethanol and later identified to family or genus.

Current velocities of each stream were measured during the spring of 1976 and 1977 with a Gurley Pygmy current meter and then used to calculate discharge. Regression equations (Gill, 1978), which estimated discharge from water depth ($R^2 > .9$), were used during the winter of 1977 when ice cover prohibited the use of a current meter. Substrate type and abundance were noted at each sampling site (Table 2).

Chemical properties of the streams were investigated at Sites 5, 9, 10, 12, 13, 16, and 17 (Fig. 1) during the winter and spring of 1977. Phenolphthalein and methyl orange alkalinity, total hardness, free carbon dioxide, and dissolved oxygen were measured in the field with a Hach® water chemistry kit. Sites were visited bi-weekly and samples taken at three times during the day: (1) 0730-0930 hours; (2) 1215-1400 hours; and (3) 1635-1825 hours. The longest holding time of a sample (on ice) before analysis was 2.5 hours. Phosphate and nitrate were measured on two dates with a Tecnicon® auto-analyzer.
Table 2. Characteristics of streams in the Rose Lake Wildlife Research Area.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Nature Stream Flow</th>
<th>Width</th>
<th>Depth</th>
<th>Substrate(s)(^a)</th>
<th>Surrounding Vegetation</th>
<th>Additional Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vermillion Creek</td>
<td>Permanent</td>
<td>3-10 m</td>
<td>1-1.5 m</td>
<td>Stones, submerged wood &amp; trailing vegetation</td>
<td>Lowland brush &amp; woods, &amp; upland woods</td>
<td>Largest stream in the study area.</td>
</tr>
<tr>
<td>Mud Creek</td>
<td>Permanent</td>
<td>1.5-5 m</td>
<td>1-1 m</td>
<td>Stones, gravel &amp; submerged wood &amp; vegetation</td>
<td>Marsh, upland &amp; lowland woods</td>
<td>Source at Site 27; low summer discharge</td>
</tr>
<tr>
<td>Site 12</td>
<td>Permanent</td>
<td>1-2 m</td>
<td>1-1 m</td>
<td>Stones, gravel &amp; trailing grasses</td>
<td>Open meadows</td>
<td>Empties into Vermillion Creek</td>
</tr>
<tr>
<td>Sites 1, 2 &amp; 17</td>
<td>Permanent</td>
<td>1-2 m</td>
<td>.15-.5 m</td>
<td>Submerged wood &amp; vegetation</td>
<td>Lowland brush &amp; upland woods</td>
<td>Drains a spring-fed lake</td>
</tr>
<tr>
<td>Sites 13, 20 &amp; 21</td>
<td>Temporary</td>
<td>.75-2 m</td>
<td>.1-75 m</td>
<td>Trailing grasses</td>
<td>Marsh &amp; lowland brush</td>
<td>Drains large lake; completely frozen in winter</td>
</tr>
<tr>
<td>Sites 9 &amp; 10</td>
<td>Temporary</td>
<td>1-2 m</td>
<td>.1-.5 m</td>
<td>Submerged wood &amp; vegetation</td>
<td>Marsh &amp; lowland brush</td>
<td>Drains two small lakes</td>
</tr>
<tr>
<td>Site 6</td>
<td>Temporary</td>
<td>.3-.5 m</td>
<td>.02-.1 m</td>
<td>Gravel &amp; fallen leaves</td>
<td>Gravel pit (no vegetation)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Substrates from which immature black flies were collected.
RESULTS AND DISCUSSION

The 16 species of Simuliidae collected from the RLWRA are listed in Table 1. *Stegopterina mutata* Malloch, *Simulium verecundum* Stone and Jamnback complex, and *S. vittatum* Zetterstedt were the three most widespread and abundant species, while *S. excisum* Davies, Peterson, and Wood, *S. pugetense* Dyar and Shannon, *S. venustum* Say complex, and *S. vernum* Macquart complex were collected infrequently. *Cnephia ornithophila* Davies, Peterson, and Wood and *S. vernum* were recorded for the first time in Michigan. In addition to those species listed in Table 1, the following species were recorded from other areas of the Lower Peninsula: *Simulium jenningsi* Malloch, *S. luggeri* Nicholson and Mickel, and *S. tuberosum* (Lundström).

The species composition and seasonal occurrence of immature black fly populations in seven creeks of the RLWRA are shown in Figure 3. Life cycle patterns of some species varied among different streams. For example, *Prosimulium fuscum* Syme & Davies, *P. mixtum* and *Stegopterina mutata* overwintered as larvae in Mud and Vermillion Creeks.
(which flow under the ice), but did not hatch from eggs until late February at Sites 13, 20 and 21 (which freeze solid in winter) (Fig. 3). Similar observations were made for S. "vereundum" and S. vittatum, whose occurrence and number of summer generations vary with permanence of the stream (Fig. 3; Mud Creek and Sites 13, 20 and 21).

**Genus PROSIMULIUM Roubaud**

Five univoltine species of *Prosimulium* were collected during the study. Low autumn and winter discharge followed by spring flooding from melting snow produced second cohorts of *mixtum* and *fuscum* in 1977 (Ross and Merritt, 1978). Oviposition by *Prosimulium* species occurs in flight when the female taps her abdomen on the water's surface and releases eggs. Eggs settle to the bottom and diapause until autumn or the following spring (Peterson, 1970).

**Subgenus PARAHELODON Peterson**

*gibsoni* (Twinn). Overwintering eggs of *gibsoni* hatch in mid-March, and larvae develop rapidly (Fig. 3). Emergence begins four to five weeks later and lasts approximately two weeks. Females, whose mouthparts are not adapted for taking a blood meal, contain mature eggs upon emergence (Davies et al., 1962).

**Subgenus PROSIMULIUM Roubaud**

*fuscum* Syme and Davies and *mixtum* Syme and Davies. These species were widely distributed in the study area and always occurred together (Table 1). Their life cycles varied in different streams, but they usually began hatching in mid-November and developed slowly during the winter months (Fig. 3). Larval growth was rapid following snowmelt and increasing water temperatures in late February; synchronous pupation occurred in late March. Adults were collected from late March to early May. Both species fed on deer, elk, and horses, while *mixtum* also engorged on humans. L. Davies (1961) found *fuscum* to be autogenous for the first gonotrophic cycle, with less than 10% of parous females surviving to become biting pests. In contrast, *mixtum* was largely anautogenous, and nulliparous females readily fed on man (L. Davies, 1961).

multidentatum (Twinn). The life cycle of this species varied among creeks (Fig. 3). Larvae overwintered in streams which continued to flow beneath the ice and pupation occurred in mid-March. In creeks which were frozen until spring, eggs hatched in late February, and these larvae pupated in early April. Adults were collected as late as 20 April. No data on adult feeding were obtained, although females are capable of taking a blood meal (Peterson, 1970).

*mysticum* Peterson. *P. mysticum* overwintered in the larval stage in lower Michigan, as in Ontario (Mansingh et al., 1972) (Fig. 3). Mature larvae were collected in mid-March and pupated in late March. Adults were captured feeding on deer in late April.

**Genus CNEPHIA Enderlein**

dacotensis (Dyar and Shannon). Eggs of this univoltine species hatched from late March to mid-April, depending on water temperature during the spring. Larval development was rapid, and pupation occurred six weeks after eclosion (Fig. 3). Emergence took place in May and was concentrated within a few days. Flies mated on streamside objects (e.g., rocks, vegetation, logs, and culverts) soon after emerging, and females oviposited in flight. *C. dacotensis* females possess weak mouthparts and are incapable of taking a blood meal (Krafchick, 1942; Nicholson, 1945). Although Davies et al. (1962) reported that this species was highly parasitized by mermithid nematodes, parasitized larvae were not observed in this study.

ornithophilia Davies, Peterson and Wood. Larvae of *ornithophilia* overwintered in large streams such as Vermillion Creek (Fig. 3, Table 2), which flow throughout the winter.
Mature larvae were collected from late February through March and pupation occurred during March and early April (Fig. 3). Eggs of this species did not hatch until March in creeks which froze solid during the winter, and pupation occurred in late April (Fig. 3, Sites 13, 20 and 21). Bennett (1960) reported that *ornithophilia* (under the name *Cnephia* "U") fed on woodland birds (e.g., crow and ruffed grouse) 1.5-7.5 m above the forest floor. This species is capable of transmitting the sporozoan parasite *Leucocytozoon simondi* Mathis and Leger to waterfowl in the laboratory (Tarchis, 1972, 1976).

**Genus STEGOERTNA** Enderlein

*mutata* (Malloch). Although diploid (bisexual) and triploid (parthenogenetic) forms of this species occur together in Ontario (Basrur and Rothfels, 1959), no attempt was made in the present study to separate them. Second cohorts of this univoltine species were also produced in 1977 as in *P. mixtum/fuscum* (Ross and Merritt, 1978). *S. mutata* overwintered as eggs or larvae, depending on the extent of ice in the stream (Fig. 3). Eggs that produced overwintering larvae hatched in January, and larval growth was slow until water temperatures increased in early March. Pupation occurred from late March through mid-April, and adults were collected from mid-April to early May. Overwintering eggs hatched in March and adults emerged in late April (Fig. 3). Larvae of *S. mutata* were parasitized by *Caudospora brevicauda* Jamnback (Protozoa: Microsporida) with infection rates as high as 20%. Females of this species were collected feeding on penned deer and elk.

**Genus SIMULIUM** Latrielle

Subgenus EUSIMULIUM Roubaud.

Species of this subgenus are primarily ornithophilic, feeding on buds in a variety of habitats, and are known vectors of avian blood parasites (Fallis and Bennett, 1958; Bennett, 1960; Anderson and DeFoliart, 1961; Stone, 1964).

*aureum* Fries complex. This multivoltine species complex overwintered in the egg stage and may have two or three generations per year. Eggs hatched in late March and first generation pupae were present in early May (Fig. 3). Eggs, larvae and pupae of other generations occurred throughout the summer until late September (Fig. 3). Engorged females were collected from ruffed grouse exposed 6.0-7.5 m above the forest floor in June (Fig. 1, Site 15; J. N. Stuht, pers. comm.). These findings agreed with Bennett's (1960) data on feeding habits and occurrence of *aureum* in late summer. Some members of the *aureum* complex serve as vectors of *Leucocytozoon bonasae* Clarke, a blood parasite of ruffed grouse (Fallis and Bennett, 1960).

*excisum* Davies, Peterson and Wood. *S. excisum* is a univoltine species which overwinters in the egg stage. Following hatching, larvae developed rapidly in early March and pupation occurred in mid-April (Fig. 3). Bennett (1960) collected females of this species (under the name *S. subexcisum*) engorging on ducks along lake shores, but further studies on its feeding habits are needed (Davies et al., 1962).

*pugetense* (Dyar and Shannon). Larvae of this species were collected only once, in early April at Site 26 (Fig. 1). In Ontario, Davies et al. (1962) reported it to be a univoltine species which overwintered in the larval stage and emerged in early spring. Females have bifid claws and mouthparts suitable for blood feeding. Oviposition occurs in spring, and eggs diapause until autumn (Davies et al., 1962).

*vernum* Macquart complex. Larvae of this species complex were collected only once during the study (at Site 27, see Fig. 1). Although *vernum* (as *latipes*) has been previously recorded from North America (Twinn, 1936), its biology is not well known. This species also feeds on birds (Peterson, 1977).
Subgenus SIMULIUM Latrielle.

decorum Walker. Overwintering eggs of this multivoltine species hatched in March and the larvae developed rapidly, pupating in mid-April and emerging at the end of April (Fig. 3). Larvae, pupae, and adults of the second generation were collected in mid-July, and a third generation may occur, though it was not observed in this study. Females usually oviposit on streamside objects or vegetation which have water covering or

Fig. 3. Seasonal occurrence of simulid larvae and pupae in seven streams in the Rose Lake Wildlife Research Area. Solid line = larvae; broken line = larvae and pupae.
lapping them, but have also been observed ovipositing in flight, similar to *Prosimulium* spp. (Davies et al., 1962). Although *decorum* females may be autogenous for the first gonotrophic cycle (Davies et al., 1962), they have well-developed mouthparts and have been captured engorging on deer and humans (Davies and Peterson, 1956).

**verecondum** Stone and Jamnback complex and *venustum* Say complex. These two species complexes contain many undescribed species with similar life cycles. *S. "venustum"* was collected only once (at Site 12), while "verecondum" was widespread and numerous (Table 1). Both multivoltine species groups overwintered in the egg stage and "verecondum" eggs hatched in early March. Pupae and adults of the latter species group were collected in early to mid-April. Four or five generations may occur, since adults were still on the wing in September and pupae were collected in late November (Fig. 3). Females of both species groups lay their eggs in mats on vegetation at or just below the water's surface. *S. "venustum"* is a major pest in Canada and the northern United States (Stone and Jamnback, 1955; Davies et al., 1962), feeding readily on humans, deer, cattle, horses, and even birds (Davies and Peterson, 1956; Teskey, 1960). *S. "verecondum"* is less annoying to man (Stone, 1964).

Subgenus **PSILOZIA** Enderlein.

**vittatum** Zetterstedt. This multivoltine species was the most numerous and widespread simulid in the study area (Table 1). Eggs of the last summer generation hatched in autumn and larvae grew slowly through the winter (Fig. 3). Pupation began in early March and emergence of this generation occurred in early April. Succeeding generations emerged in mid-June, late July and early September, although some overlap existed (as fig. 3). Oviposition occurs on vegetation and other damp streamside objects, as well as in flight (Davies and Peterson, 1956). *S. vittatum* has been reported to be a major pest of horses and other livestock in some areas of the country (Anderson and DeFoliart, 1961; Townsend et al., 1977). Engorged females were collected from deer, elk and horses in this study. *S. vittatum* is not a serious human pest in this region.

**Seasonal Succession**

Data on seasonal succession of black fly species at selected sites are presented in Figures 4-6. Most species occurred at Site 13 during late winter and spring, with eclosion beginning in March following snowmelt (Figs. 3 and 4). *Prosimulium gibsoni*, *Stegoptera mutata*, *Cnephia ornithophila* and *Simulium* spp. hatched earlier in the month than *Cnephia dacotensis*, since later instars of these species were present when *C. dacotensis* larvae were first collected (Fig. 4; 23 March). First instars of this latter species were the only ones positively identified because the head capsule sclerotization is weaker than that of the other species (Craig, 1974). All eggs of *C. dacotensis* had hatched by 4 April, and pupation of this species and *C. ornithophila* occurred four weeks later, with adults emerging in mid-May (Figs. 3 and 4). The life cycles of *Prosimulium gibsoni* and *Stegoptera mutata* were also short, requiring approximately six weeks from eclosion to pupation (Figs. 3 and 4). The early peak of *Simulium* spp. was largely *S. excisum*, while the later one was 90 to 95% *S. "verecondum"* (Fig. 4). Larval populations declined rapidly in late May following pupation of a large generation of *S. "verecondum"* (Fig. 4). Discharge also declined and the stream ceased to flow by mid June.

Figures 5 and 6 illustrate the succession of simulid species in Mud Creek (Site 15) during the 1975-76 and 1976-77 seasons, respectively. Although quantitative sampling did not begin until mid-February, 1976, preliminary collections were made in January and in November, 1975. Data indicated that *Prosimulium mixtum/fuscum* larvae hatched in early to mid-November and were the only black flies present in Mud Creek until January, when *Stegoptera mutata* first appeared (Fig. 6). The latter species was less abundant in 1977 than 1976, possibly due to the microsporidian parasite *Caudospora brevicauda*, which infected 20% of the larvae in 1976, preventing pupation and decreasing egg production. Since the parthenogenetic (triploid) form of *Stegoptera mutata* is more common than the diploid (sexual) form (Davies and Peterson, 1956; Basrur and Rothfels, 1959), a 20%
reduction in egg-laying females could have resulted in a smaller population the following year.

The time period that Prosimulium mixtum/fuscum and Stegopterna mutata populations remained in Mud Creek also varied during the two year study. Larvae of these species were still present in May, 1977, while they had all pupated by early April, 1976 (Figs. 5 and 6). This difference was due to the occurrence of second cohorts of each species during 1977 (Ross and Merritt, 1978). Larvae of the second cohorts did not hatch until early March (1977) and they pupated from mid-April through May (Fig. 6). Data indicated that in lower Michigan, Prosimulium mixtum/fuscum and Stegopterna mutata usually pupate in late March and early April, respectively.

The succession of Prosimulium spp. and Stegopterna mutata by Cnephia and Simulium spp. was similar at Site 13 (Fig. 4) and in Mud Creek (Figs. 5 and 6). Early instars of Cnephia and Simulium spp. hatched when larvae of the other two genera neared pupation, thus possibly reducing competition for food and suitable habitat. The successional pattern of Cnephia and Simulium spp. may also be related to other factors. Following ice-out in spring, temperate-zone lakes experience phytoplankton blooms which result in the production of large quantities of diatoms and other algae (Ruttner, 1973). Larval black flies which inhabit lake outlets (e.g., Fig. 2; Site 13 and Mud Creek) would be exposed to a rich food supply (Carlsson, 1967), and may receive some selective advantage over larvae occurring at other times of the year or further downstream. Recently, Carlsson et al. (1977) examined factors influencing black flies inhabiting lake outlets in Sweden and concluded that food quality rather than quantity was responsible for supporting huge larval aggregations of certain species immediately below these areas. Cnephia dacotensis has frequently been found in large numbers in lake and pond outlets (Anderson and Dicke, 1960; Davies et al., 1962; Stone, 1964; Gersabeck, 1978), and may
have evolved a life cycle to exploit these food resources. Some species of net-spinning Trichoptera also occur in great abundance at lake outlets and below impoundments (e.g., Chutter, 1963; Wallace and Sherberger, 1974) and different species successfully share habitats and food through different adaptive strategies, such as temporally asynchronous life cycles, different feeding habits (e.g., particle size differences) and/or different microdistributional patterns (Eddington, 1968; Wallace, 1975; Wallace et al., 1977; Malas and Wallace, 1977). Further studies are currently underway on the size, type, and quality of particulate materials ingested by different instars and species of Simuliidae to clarify some of these interspecific relationships.

PHYSICAL CHARACTERISTICS OF STREAMS

In a concurrent study the most important physical factor regulating black fly larval development was stream temperature (Ross and Merritt, 1978). It played the major role in determining hatching, pupation, and emergence, and was responsible for the timing and duration of the life cycles of each species. In other areas, temperature has been shown to also affect the number of simulid species in a stream and the life cycles of their parasites and predators (Ezenwa, 1974; Lewis and Bennett, 1975). Variations in temperature among streams in the study area were negligible and of little use in explaining black fly distribution differences.

Stream discharge also influenced immature Simuliidae. Following prolonged dry conditions, rising water levels flooded unhatched eggs, producing second cohorts of some

![Graph showing seasonal succession of black fly species at Site 15, Mud Creek (1976).]

Fig. 5. Seasonal succession of black fly species at Site 15, Mud Creek (1976).
univoltine species which typically have only one cohort per generation (Ross and Merritt, 1978). Changes in discharge also affected rates of larval colonization and detachment from artificial substrates, thus influencing estimates of black fly abundance (Disney, 1972; Pegel and Ruhm, 1976; Gersabeck, 1978; Ross and Merritt, 1978). Yearly variations in discharge determined the number of generations of some multivoltine Simulium spp. during the summer and early autumn. The nature of stream flow also had important implications, with permanent creeks generally having more species of simulids than temporary streams (Table 2, Fig. 3).

The number of black fly species inhabiting a stream did not appear to be related to the stream's origin (Figs. 1 and 3, Table 2). For example, Mud Creek and Sites 9 and 10 both drain lakes, yet the former stream contained 14 species of simulids while the latter had only five (Fig. 3). Contrary to studies by Anderson and Dicke (1960) and Davies et al. (1962) which found substrate preferences among larvae of different species, gravel, stones, wood, and vegetation were utilized by all species collected in the present study. All of these materials were colonized if water velocity was suitable and their surfaces were free of periphyton. Stream depth and width were not related to species distribution, since Prosimulium mixtum, P. fuscom, Stegopterna mutata and other species occurred in both large and small creeks (Fig. 3, Table 2).

**CHEMICAL CHARACTERISTICS OF STREAMS**

Data on the chemical properties of the seven streams showed minor variation between them. All tests for phenolphthalein alkalinity were negative, while methyl orange (bicar-
bonate) alkalinity was generally high (<200 mg/l CaCO₃). Water in all streams was hard (150-300 mg/l CaCO₃) (Kevern, 1973), and differences among streams were insignificant. Melting snow and rainfall reduced alkalinity and hardness by dilution, as well as nitrate (NO₃) and orthophosphate (PO₄) concentrations. Nitrate and orthophosphate were consistently present at low levels (<1.1 and <0.02 mg/l, respectively), indicating a lack of organic enrichment (Kevern, 1973). Dissolved oxygen exceeded 10 mg/l (71% saturation) in all streams except at Sites 9 and 10, where it was less than 6 mg/l (43% saturation) during the winter. This was caused by the formation of pools of stagnating water under the ice cover. The variability of results from the free carbon dioxide tests made estimates unreliable. Other investigators (Carlsson, 1962, 1967; Chutter, 1968; Ali et al., 1974; Ezenwa, 1974; Lewis and Bennett, 1975) who have measured chemical properties were also unable to correlate differences with simuliid distribution patterns. Grunewald (1972) determined a combination of physical and chemical factors at breeding sites of *Boophthora erythrocephala* DeGeer which were quite distinct from those of other black fly species; however, such success has not been achieved with other simuliids. Chemicals indicative of organic pollution (e.g., NO₃ and PO₄) are capable of affecting black fly population abundance and distribution by increasing food supplies. Such enriched streams were found to contain significant quantities of microplankton on which large populations of *Simulium* spp. fed (Chutter, 1968; Ali et al., 1974). More recent studies by Chance (1970, 1977), Kurtak (1973) and Ladle et al. (1977) suggested that the sizes of particulate matter available to filter-feeding black fly larvae in different streams may affect species distribution. Habitat preference and oviposition behavior could also influence species distribution (Rhum, 1971; Lewis and Bennett, 1975).

ASSOCIATED AQUATIC INSECTS

The insects collected in association with immature simuliids from seven streams in the study area are listed in Table 3. With the exception of one stream (Sites 13, 20 and 21), the fauna of temporary streams was not as diverse as that of permanent ones (Table 2 and 3, Fig. 3). Although these collections were not complete, equal effort was expended in each stream, and all samples were taken at the same time of year. Thus, some comparisons can be made among creeks. The number of black fly species occurring in each stream showed a significant positive correlation (r = .70) with the number of other insect species in the same stream (Fig. 7). This suggested that factors which influence simuliid distribution may also affect the diversity of abundance of other aquatic insects.

To make general comparisons of species differences between permanent and temporary streams in the study area, we have categorized various combinations of taxa into similar functional groups based on feeding mechanisms (Merritt and Cummins, 1978) (Fig. 8). As shown, in both permanent and temporary streams the largest percent of the species recorded were collectors, those groups which are filter or suspension feeders (filterers; e.g., Simuliidae, Hydropsychidae) or sediment and deposit feeders (gatherers; e.g., Ephemeridae, Chironomini). Shredders (i.e., herbivores and large particle detritivores) were fewer in number, although more abundant in permanent streams. Predators were equally represented in both types of streams and consisted mainly of Odonata, Hemiptera, and Plecoptera (Table 3). Scrapers of mineral and organic surfaces made up the smallest percent in each stream type, consisting of two genera of heptageniid mayflies (Table 3). Contrary to small first order or headwater woodland streams, which are heavily dependent upon terrestrial contributions of coarse particulate organic matter (particularly leaf litter) (Sedell et al., 1974; Cummins, 1977), streams in this study area were primarily of small lake origin (Fig. 1) and less dependent on direct terrestrial inputs and more on nutrient and detrital input from the lakes. This would account for the predominance of collectors and fewer shredders (Fig. 8). Functional group differences between temporary and permanent streams were not significant except for the greater number of shredders in permanent streams, which could be attributed to a requirement for year-round flow by the dominant species of shredders which were all univoltine. This factor most likely accounted for the greater number of species also found in permanent streams.
It is presumed that those readers interested in the identification of immature black flies are familiar with current character terminology. For those not familiar with this terminology the labels on the accompanying illustrations will be of help. For a discussion of larval black fly terminology see Crosskey (1960), Chance (1970), and Wood et al. (1963).
Table 3. Aquatic insect fauna associated with immature black flies in the Rose Lake Wildlife Research Area.

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<th>Site 12</th>
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**Permanent Streams**

**Temporary Streams**

Fig. 8. The relative dominance of different functional groups (% species composition) of aquatic insects in permanent and temporary streams in the study area.
KEY TO GENERA AND SPECIES OF SIMULIIDAE

LARVAE

1. Head capsule with postocciput nearly complete dorsally, enclosing cervical sclerites (Fig. 3). Basal two segments of antenna pale, contrasting with darkly pigmented distal segments (Figs. 1-5). Median tooth of hypostomium distinctly trifid (Figs. 20-24). Anal gill with three simple finger-like lobes (Fig. 30). Genus Prosimulium .......................... 2

1'. Head capsule with postocciput usually with a broad gap dorsally, not enclosing cervical sclerites (Fig. 6). Basal two segments of antenna at least partially pigmented, not contrasting in color with distal segments (Figs. 6, 8, 11-19). Median tooth of hypostomium single (Figs. 25-27). Anal gill with three simple or compound lobes (Figs. 30-31) ....................... 6

2(1). Lateral plate of proleg a narrow horizontal bar lying parallel to bases of apical ring of hooks (Fig. 9). Anal sclerite subrectangular, anterodorsal and posterodorsal arms only weakly developed (Fig. 34). Outer lateral and sublateral teeth of hypostomium of nearly equal height, median tooth lower than lateral teeth (Fig. 20). (Subgenus Parahelodon) ........................... gibsoni Twinn

2'. Lateral plate of proleg broader, with a well developed vertical portion (Fig. 10). Anal sclerite X-shaped (Fig. 30). Teeth of hypostomium variable, but not exactly as above (Subgenus Prosimulium) .......................... 3

3(2'). Antenna conspicuously shorter than stalk of cephalic fan (Fig. 1). Hypostomial teeth as in Figure 21; median tooth rather broad. Maxillary palpus (Fig. 7) about 2.0 times as long as width at base. Abdomen gradually expanding posteriorly .......................... multi dentatum Twinn

3'. Antenna subequal to (at most only slightly shorter) or longer than stalk of cephalic fan (Figs. 2-4). Hypostomial teeth as in Figures 22-24; median tooth rather slender. Maxillary palpus 2.5-3.0 times as long as width at base. Abdomen rather abruptly expanding at segment 5 .......................... 4

4(3'). Outer lateral teeth of hypostomium higher than sublateral teeth (Fig. 22). First posterolateral head spot usually present; anterolateral head spots relatively small (Fig. 2). Anterodorsal arms of anal sclerite nearly equal in length or only slightly longer than posterodorsal arms. Cephalic fan with about 37-46 rays (av. 41) .......................... fuscum Syme and Davies

4'. Outer lateral teeth and sublateral teeth of hypostomium nearly equal in height, or outer lateral teeth often lower than highest of sublateral teeth (Figs. 23-24). First posterolateral head spot usually absent; anterolateral head spots relatively large (Figs. 3-4). Anterodorsal arms of anal sclerite considerably longer than posterodorsal arms. Cephalic fan with about 27-40 rays (av. 33) .......................... 5

5(4'). Outer lateral teeth and sublateral teeth of hypostomium of nearly equal height; median tooth only slightly higher than outer lateral teeth (Fig. 23). Head capsule yellowish-brown to dark brown, head spots more pale and less distinct (Fig. 3) .......................... mixtum Syme & Davies

5'. Outer lateral teeth of hypostomium often lower than highest sublateral teeth; median tooth distinctly higher than outer lateral teeth (Fig. 24). Head capsule pale yellow to medium yellowish brown, head spots darker and more distinct (Fig. 4) .......................... mysticum Peterson

6(1'). Hypostomium either with rather uniformly small teeth (Fig. 26), or with teeth clustered in three prominent groups (Fig. 25). Anterodorsal portion of head capsule often strongly convex (Fig. 7). Anal gill with three simple lobes .......................... 7

6'. Hypostomium with median tooth and outer lateral teeth moderately large and subequal in height, and with three smaller sublateral teeth on each side (Fig. 27). Anterodorsal portion of head capsule not noticeably arched nor strongly convex. Anal gill with three simple or compound lobes. Genus Simulium .......................... 9

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5 Figures illustrating the key are contained in Plates I-VIII.
7(6). Postgenal cleft narrow, shallow, acutely pointed, an inverted V-shape (Fig. 6). Hypostomial teeth clustered in three prominent groups (Fig. 25). Abdominal segment 9 with a single transverse midventral bulge (Fig. 32)................... 

7'. Postgenal cleft moderately deep, its anterior margin usually rounded (Fig. 8). Hypostomial teeth rather uniformly small (Fig. 26). Abdominal segment 8 simple, without a transverse midventral bulge. Genus *Cnephia* ................. 8

8(7'). Both rather uniformly and darker greyish-brown to moderately dark brown, with only narrow inconspicuously lighter intersegmental bands. Head capsule darker brown, less contrasting with dark head spots; dorsal head spots surrounded by a distinct fulvous area (Fig. 8). Overall size smaller and more slender ............

8'. Body distinctly bicolored, overall more pale, with distinct and rather wide greyish intersegmental bands contrasting with bands of greyish brown to reddish brown. Head capsule lighter brownish yellow, strongly contrasting with dark head spots; dorsal head spots surrounded by at most a faint fulvous area. Overall size larger and broader ............ *dacotensis* (Dyar and Shannon)

8(7'). Both rather uniformly and darker greyish-brown to moderately dark brown, with only narrow inconspicuously lighter intersegmental bands. Head capsule darker brown, less contrasting with dark head spots; dorsal head spots surrounded by a distinct fulvous area (Fig. 8). Overall size smaller and more slender ............

9(6'). Abdominal segment 8 with two large ventral tubercles equal to about one-third to one-half depth of abdomen (Fig. 33). Antenna usually distinctly longer than stalk of cephalic fan. Postgenal cleft short, anterior margin subtruncate or rounded but without an anteriorly directed point (Figs. 11-14) (Subgenus *Eusirnulium*) ...................................... 10

9'. Abdominal segment 8 without ventral tubercles, or these inconspicuous and equal to less than about one-sixth depth of abdomen (Fig. 35). Length of antenna variable, Postgenal cleft rather long, either an inverted U-shape, pointed apically or long and bulbous (Figs. 16-19) ........................................ 13

10(9). Hypostomial teeth clustered in three slightly elevated groups. Antennae pale, almost transparent. Head capsule pale, head spot pattern as in Figure 11. Body pigment unicolorous, reddish- or pinkish-brown ....................

10'. Hypostomial teeth more regular, not clustered in three slightly elevated groups. Antenna and head capsule darker with more distinct head spot pattern. Body pigment of two contrasting colors .................. 11

11(10'). Postgenal cleft widest basally, tapering distally to a rounded or pointed apex (Fig. 12). Toothed margin of hypostomium relatively narrow, the teeth relatively uniform in size. Pigmented area anteroventral to eye absent. Head spot pattern as in Figure 12 ................... *pugetense* (Dyar and Shannon)

11'. Postgenal cleft smaller, square and of nearly uniform width or widest at about the mid-point of its length, with a straight, broadly V-shaped, or rounded anterior margin (Figs. 13-14). Toothed margin of hypostomium relatively wide, the median and outer lateral teeth distinctly longer than sublateral teeth. Pigmented area anteroventral to eye present but varying in intensity. Head spot pattern as in Figures 13-14 .................. 12

12(11'). Anteromedian and postero median head spots often nearly confluent or with a narrower or less distinct gap between them; a faint but usually distinct infuscation present around head spots extending to slightly beyond outer edge of anterolateral spots (Fig. 13); pigmented area anteroventral to eye usually smaller and more pale. Labrum with setal pattern as in Figure 28. Anal gill consisting of three simple, digitiform lobes .................. *aureum* Fries complex

12'. Anteromedian and postero median head spots with a distinct pale gap between them; infuscation darker and more apparent around lateral head spots resulting in a pale stripe on each side of median spots (Fig. 14); pigmented area anteroventral to eye usually larger and darker. Labrum with setal pattern as in Figure 29. Anal gill consisting of three lobes, each with several small accessory lobes ..................... *vernurn* Macquart complex

13(9'). Postgenal cleft subquadrate, apical margin straight or rounded (Fig. 15). Second segment of antenna with a ventral whitish band or spot. Head spot pattern as in
Figure 15. Anal gill with three simple lobes, these occasionally with minute, secondary bumps (Fig. 30) (Subgenus Psilozia) ............ vittatum Zetterstedt

13'. Postgenal cleft either long and bulbous, narrowly rounded or sharply pointed apically (Figs. 16-19). Second segment of antenna more uniformly colored, without a contrasting white band or spot ventrally. Head spot pattern not exactly as above. Anal gill with three compound lobes (Fig. 31) ............ 14

14(13'). Postgenal cleft long and bulbous in outline, length and width near middle subequal. Antenna conspicuously longer than stalk of cephalic fan (Subgenus Phosterodoros) ................................................ 15

14'. Postgenal cleft variable in length, but length usually greater than width; an inverted U- or V-shape (Figs. 16-19). Antennal length variable (Subgenus Simulium) ................................................ 16

15(14'). Respiratory histoblast (Fig. 35) with 12 filaments 6 luggeri Nicholson and Mickel

15'. Respiratory histoblast with 10 filaments ....................... jenningsi Malloch

16(14'). Suboesophageal ganglion and sometimes epidermis in postgenal cleft blackish. Dorsal head spots dark but rather obscure, fulvous area around spots broad (Fig. 16). Cephalic fan usually with fewer than 40 rays. Abdomen blackish .................. tuberosum (Lundström) complex

16'. Suboesophageal ganglion and epidermis in postgenal cleft pale, not blackish. Dorsal head spots pale, fulvous area around spots variable (Figs. 17-19). Cephalic fan usually with approximately 50 rays. Abdomen brownish ............. 17

17(16'). Infuscation around head spots narrow, not extending beyond inner edge of anterolateral spots, forming an H-shaped pattern (Fig. 17). Antenna not extending beyond tip of stalk of cephalic fan. Arms of anal sclerite narrowly fused medially ....................... decorum Walker

17'. Infuscation around head spots wider, extending beyond outer edge of anterolateral spots (Figs. 18-19). Antenna slightly longer than stalk of cephalic fan. Arms of anal sclerite broadly fused medially ....................... 18

18(17'). Lateral plate of proleg lightly sclerotized, faintly visible. Postgenal cleft not bordered by a fulvous band (Fig. 18). Head spot pattern as in Figure 18. Posterior circket with approximately 66 rows of hooks ....................... verecundum Stone and Jamnback complex

18'. Lateral plate of proleg heavily sclerotized, conspicuous. Postgenal cleft bordered by a narrow fulvous band (Fig. 19). Head spot pattern as in Figure 19. Posterior circket with over 70 rows of hooks (Fig. 35) ............ venustum Say complex

PUPAE

1. Cocoon an irregular, shapeless sleeve, without a well defined anterior margin (Fig. 36). Terminal abdominal segment with two long dorsal spines ............. 2

1'. Cocoon usually well developed, variously shaped but with a well defined anterior margin (Figs. 37-39). Terminal abdominal segment with two short dorsal spines or none ............. 9

2(1). Respiratory filaments 12-14, rarely 16; if 16, dorsal trunk not usually branching 3+5 nor 3+2+3 (Figs. 40, 45) ............. 3

2'. Respiratory filaments 16 or more, if 16, dorsal trunk branching 3+5 or 3+2+3 (Figs. 41-44) ....................... 4

3(2). Respiratory filaments 12, occasionally 14, arising from two long main trunks which diverge from each other (Fig. 45) ....................... Stegopterna mutata

3'. Respiratory filaments usually 14 but sometimes 16, arising from three main trunks that are not strongly divergent (Fig. 40) ....................... Prosimulium gibsoni

4(2'). Respiratory filaments 16 ....................... 5

4'. Respiratory filaments more than 16, usually more than 20 ....................... 7

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6Character must be observed in late or final instar when respiratory histoblasts are well developed.
5(4). Primary trunks of respiratory organ short, noticeably thickened; filaments tapering distally, innermost secondary trunk arising from dorsal primary trunk distinctly longer and more remote from other two secondary trunks (Fig. 41) ... P. mysticum

5'. Primary trunks of respiratory organ variable but usually longer and not noticeably thickened; filaments more uniformly slender; secondary trunks arising from dorsal primary trunk variable but usually subequal in length and separating from base at subequal distances (Figs. 42-43) 6

6(5'). Respiratory organ, in lateral view, usually broad, often as wide or wider than long; three primary trunks separating from base so that all are equally visible, lateral trunk not obscuring other two; secondary trunks generally longer than in following species (Fig. 42) P. fuscum

6'. Respiratory organ, in lateral view, usually rather narrow and longer than wide; lateral primary trunk usually more divergent from dorsal trunk than from ventral trunk so that it tends to obscure ventral trunk usually resulting in a distinct >-shaped space between dorsal trunk and other two primary trunks; secondary trunks variable but generally shorter than in above species (Fig. 43) P. mixtum

7(4'). Respiratory filaments 20-28 (av 24), arising from a short base that immediately divides into three short primary trunks or groups of filaments; entire clump of filaments, viewed laterally, distinctly longer than wide (Fig. 44). Lateral margins of segments 8 and 9 without short curved hook-like setae ... P. multidentatum

7'. Respiratory filaments variable in number but filaments arising in at least five main groups from a short rounded knob-like base. Lateral margins of at least segments 8 and 9 with short, curved single or sometimes double hook-like setae

8

8(7'). Respiratory organ, in lateral view, usually broad, often as wide or wider than long; filaments about as long as head and thorax Cnephia dacotentisis

8'. Respiratory organ, in lateral view, usually narrower and longer than wide; filaments conspicuously longer than head and thorax C. ornithophilia

9(1'). Anterodorsal margin or cocoon with a long, median projection (this may be broken off, but base is usually evident) (Fig. 38) 10

9'. Anterodorsal margin of cocoon without a long, median projection, but a short convex protrusion may be present (Figs. 37, 39) 11

10(9). Respiratory filaments six Simulium excisum

10'. Respiratory filaments four S. vernum complex

11(9'). Respiratory filaments six or more S. aureum complex

11'. Respiratory filaments four S. pugetense

12(11). Dorsal respiratory filament strongly divergent at base from other three; dorsal pair of filaments on a short petiole, ventral pair with almost no petiole (Fig. 39) S. tuberosum complex S. verecundum complex

12'. Dorsal respiratory filament not strongly divergent at base from other three; filaments in two petiolate pairs S. pugetense

13(11'). Respiratory filaments six S. tuberosum complex S. verecundum complex

13'. Respiratory filaments eight or more S. luggeri

14(13'). Respiratory filaments eight, thickened, in three short petiolate pairs, plus two singly. Cocoon, especially anteriorly, loosely woven S. decorum

14'. Respiratory filaments 10 or more. Cocoon tightly woven S. venustum complex

15(14'). Cocoon with one-three lateral openings on each side near anterior margin. Respiratory filaments 10 or 12 S. vittatum

16(15'). Cocoon without lateral openings on each side anteriorly. Respiratory filaments usually 16 but varying from 14 to 17 (Fig. 37) S. jenningsi

16'. Respiratory filaments 10 S. luggeri

7At present, these species complexes cannot be separated from each other based on pupal characteristics.
PLATE IV
PLATE VIII

40 P. GIBSONI
41 P. MYSTICUM
42 P. FUSCUM
43 P. MIXTUM
44 P. MULTIDENTATUM
45 ST. MUTATA
ACKNOWLEDGMENTS

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THE LIFE CYCLE OF THE MAYFLY STENACRON INTERPUNCTATUM (EPHEMEROPTERA: HEPTAGENIIDAE)

W. P. McCafferty\(^2\) and B. L. Huff, Jr.\(^3\)

**ABSTRACT**

Larval growth and development of *Stenacron interpunctatum* was studied for a one year period at Wildcat Creek, Indiana. Analysis of developmental stages and size classes revealed three broods at different degrees of maturation at any one time of year. Broods emerged in early spring, mid-summer, and late summer-early fall, respectively; the former two overwintering in different stages of larval development, and the latter completing development in one growing season in warm temperatures and maturing at relatively smaller sizes. The population possessed a complex life cycle ranging from one generation per year to three generations every two years. General sampling over three growing seasons and controlled laboratory rearing support the conclusions.

*Stenacron interpunctatum* (Say) is often an abundant mayfly in streams and rivers in the eastern half of North America. Larvae graze on the undersides of rocks and large detritus during the daytime, and range freely over the upper surface of substrate at night (Wodsadalek, 1912; Lyman, 1945). The species may be an important fish food (Caucci and Nastasi, 1975), and may be useful in water quality assessment (Lewis, 1974).

Needham, et al. (1935) described postembryonic development in the laboratory, but no field data have previously been available. We describe the life cycle of *S. interpunctatum* primarily on the basis of its growth and development in a natural environment.

**METHODS AND MATERIALS**

Field studies were conducted from March, 1972, through September, 1974, on Wildcat Creek, a river in west central Indiana which drains a watershed of approximately 800 sq. mi. This river flows westerly and lies entirely within the Tipton Till Plain, emptying into the Wabash River at Lafayette. Regular benthic sampling was undertaken on its north fork upstream from the Kokomo Reservoir at Jerome, Howard County. Mean monthly discharge for the north fork ranges from less than 100 cfs in September and October to more than 1300 cfs during January (U.S.G.S. data).

Field rearing and collecting techniques were after Provonsha and McCafferty (1975). Laboratory rearing methods were after Huff and McCafferty (1974). Larvae were maintained at 22-24°C during transport and in the laboratory.

We studied larval development by regular, periodic sampling with artificial substrate samplers (Beak, et al., 1973), consisting of limestone filled 9×9×9 inch wire baskets left in the river for at least four weeks to ensure adequate colonization (Weber, 1973). Nine samples were taken between 21 July, 1973 and 13 July, 1974 (Fig. 1). Samplers were retrieved under water by capturing the entire rock basket in a canvas bag. Contents were washed, fixed in Pample’s solution, and after sorting, transferred to 70% ethanol. A total of 531 larvae were sampled, measured, and categorized into developmental stages and size classes.

Since the number of instars in mayflies varies and the relationships of size and physiological development possibly vary with environmental conditions, developmental

\(^1\)Purdue University Agricultural Experiment Station No. 6656.
\(^2\)Department of Entomology, Purdue University, West Lafayette, IN 47907.
\(^3\)WAPORA, 5700 Hillside Ave., Cincinnati, OH 45233.
Fig. 1. Percent composition of *S. intermedium* larvae in millimeter size classes.

[Diagram showing size distribution of larvae over time with dates and body lengths indicated.]
stages advocated by Pleskot (1962) rather than instars were used to determine larval development. The stages as defined below are somewhat arbitrary but are consistent and comparatively useful in ascertaining the relative degree of development toward maturation of the larvae. Instars were virtually impossible to determine from field samples. Since total length has previously been a useful measurement when sexes were treated separately (Clifford, 1970a, 1970b), body lengths exclusive of caudal filaments and antennae were measured and correlated with development.

Criteria for developmental stage classification were as follows: Stage I larvae possessed either thread-like gills or no gills at all; Stage II larvae possessed thickened gills but no wing pads; Stage III larvae possessed wing pads but the mesothoracic wing pads did not cover the metathoracic wing pads; Stage IV larvae possessed mesothoracic wing pads covering the metathoracic wing pads but not exceeding beyond abdominal segment 1; Stage V larvae possessed longer wing pads than the latter but shorter than the distance between the pads and not exceeding beyond abdominal segment 2; Stage VI larvae possessed mesothoracic wing pads longer than the distance between them and extended beyond abdominal segment 2; Stage VII larvae possessed dark wing pads indicative of impending emergence. The presence or absence of developing male genitalia were used for sexing larvae. Sex could not be confidently determined for Stages I, II, and sometimes III.

Fig. 2. Percent composition of male and female *S. interpunctatum* larvae in size classes (with developmental stages indicated at their mean size).
RESULTS AND DISCUSSION

Field data are summarized in Figures 1-5. There was no overall increase in size of larvae sampled from January through April (Fig. 2). Following adult emergence which began in May, the size class distribution varied considerably through July. Size became more evenly distributed as the emergence season progressed, especially in June and July.

When males and females were differentiated (Fig. 2), the distribution of size classes became skewed to varying degrees. The largest larvae were females. By indicating (Fig. 2) the distribution of developmental stages for each sex at points representing their mean size, it became apparent that females were also larger for each stage and exhibited a greater difference between successive stages. It was noted also that the mean size of mature larvae in May, June, and July, was greater than in late August. These relationships between sexes, and the size differences of mature larvae over the emergence period, have been reported for other aquatic insects (Hynes, 1970); and in mayflies somewhat similar size distributions have been found for *Leptophlebia cupida* (Clifford, 1970b), two species of *Epeorus* (Ide, 1935), and *Hexagenia bilineata* (Fremling, 1973).

Outlined areas (Figs. 3 and 4) are superimposed on the temporal distribution of developmental stages (including adults) and approximate three developing broods inferred from the data as follows. A group of very small larvae were found in the fall and winter, and represent progeny of adults emerging late in the emergence season. This brood (designated A), after overwintering as early developmental stages, began development at a rapid rate throughout spring and part of summer and emerged in late June, July, and early August. Another brood (B) began its larval development in June and early July, overwintered as Stage IV females and Stages IV to V males, continued larval development through the spring, and emerged from mid-May until July. A third brood (C) began larval development in May. These larvae developed rapidly throughout the summer and emerged...
in late August and September as relatively small adults. We assume the above sequences to be similar from year to year. The fit between the last sample in July, 1974, and the first sample in August, 1973, would seem to substantiate this. Little growth apparently took place during periods of depressed winter temperatures, and from October through April no mature or Stage VI larvae were found. This population evidently does not overwinter as well developed larvae.

Broods A, B, and C were compared (Table 1) in terms of the mean time of development for Stage II to Stage VII larvae, the mean monthly water temperature for the period of this development, and the mean size of male and female Stage VII larvae. Brood C larvae were exposed to a longer continual period of relatively warmer water, and completed development in much less time than the other broods. Also, mature larvae were smaller, the females markedly so, in these "fast developers."

When reared from Stage II or III larvae at 22-24°C, individuals were consistently smaller than field samples as mature larvae and adults, and completed this development in 38-71 days. Fremling (1967 and personal communication) found that he could rear Hexagenia bilineata from eggs to adults in 79 days, and that these adults were always relatively very small.

Adult females were maintained in our laboratory for periods up to eight days; no data are available on adult longevity in the field. Needham, et al. (1935) reported eggs of S. interpunctatum hatching 13 to 15 days from time of oviposition in the laboratory. Ide (1935) found that eggs of three females of S. interpunctatum, all deposited at the same time and maintained under identical laboratory conditions, continued to hatch over a period of six weeks. Incubation time from 7 to 32 days at 18°C was recorded in our laboratory. Incubation time in the field is unknown.

The field and laboratory data suggest a complex life cycle (Fig. 5): The presence of three generations every two years at Wildcat Creek is indicated by Figures 3 and 4 since adults of Brood A would give rise to Brood B which subsequently overwinters; and Brood B would give rise to Brood C; and Brood C would give rise, at least in part, to Brood A.

Fig. 4. Distribution of mean size of developmental stages of male S. interpunctatum larvae (with diagonal areas representing developing broods).
Fig. 5. Diagrammatic representation of the life cycle of *S. interpunctatum* at Wildcat Cr., Indiana.

Table 1. A Comparison of Developing Larval Broods of *S. interpunctatum* in Wildcat Creek, Indiana.

<table>
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<th>Brood</th>
<th>X Length of Development (Stage II to Stage VII)</th>
<th>X Monthly Water Temperature During Development</th>
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<td>A</td>
<td>272 days</td>
<td>10.2 C (0.8-24.5 C)</td>
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<td>10.24 mm</td>
</tr>
<tr>
<td>B</td>
<td>355 days</td>
<td>11.9 C (0.8-24.5 C)</td>
<td>8.06 mm</td>
<td>10.66 mm</td>
</tr>
<tr>
<td>C</td>
<td>86 days</td>
<td>21.7 C (7.6-24.5 C)</td>
<td>7.56 mm</td>
<td>8.85 mm</td>
</tr>
</tbody>
</table>
which subsequently overwinters, etc. This is the type "D" life cycle of Landa (1968) and
is similar to that described for *Baetis vagans* in New York by Murphy (1922). This
classification may not be entirely satisfactory, however, because generation time estima-
tion is complicated by factors of variable adult life span, length of egg incubation, and
possible differential larval growth within broods. For example, it appears that the later
maturing individuals of a brood (Figs. 3, 4, and 5) may also have some potential to give
rise to individuals of the same brood the next year (see especially brood C). Also, there is
evidently some potential for crossmating between broods (see adult overlap in Figs. 3, 4,
and 5).

In conclusion, within the same geographic population there are population com-
ponents contributing to three generations every two years, and concurrently, population
components potentially contributing to one generation per year. This complex, inter-
woven life cycle would apparently guarantee considerable genetic mixing within the
population over time. Any resource partitioning by different developmental stages being
distributed in time throughout the year would theoretically reduce intraspecific competi-
tion. If length of brood development and water temperature are correlated, as data
suggest, then the life cycle of *S. interpunctatum* populations may be expected to vary
somewhat with climate and stream temperature regime within the broad latitudinal range
of the species.

An interesting and potentially biosystematically significant by-product of this investi-
gation was the preliminary observation that adult color variation is also apparently
affected by length of brood development. This would tend to suggest that the previous
use of historically typological color variants in recognizing several species or sympatric
subspecies for *S. interpunctatum* is invalid. It also would help explain the preponderance
of intermediate or "non-typical" color variants present in this and other North American
populations of the species. We hope to test these hypotheses with controlled rearings and
quantification of adult variability.

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This account is the result of efforts by Drs. Kenneth Christiansen and Peter Bellinger to amass and examine the major collections of North American Collembola. Their work will culminate in a descriptive monograph on the Collembola-fauna of North America. The author agreed to describe part of the new species of Sminthuridae extracted from those collections. The analysis of specimens justifies erection of 17 species new to science.

**Sminthurinus (Polykatianna) polygonius** n.sp.
Plate I: Figs. 1-13

Antennae light purple, darkest distally. Head with purple polygons of pigment strongly expressed from the bases of the antennae to the apex; with a dark inter-antennal spot and light dusting of purple on the genae. In some specimens only the inter-antennal spot and genal pigmentation occurs. Thorax and abdomen with purple pigment in an irregular pattern of polygons on a light yellow background; some specimens lack purple pigment entirely.

Eyes 8+8; ocellus C smaller than H. Antennal segments in the ratio of 1:2:3:6. ANT IV subannulated into 12-13 intermediates; median apical bulb not present, but with lateral apical papilla. ANT III with subapical sense rods lying in shallow depressions; lateral sensory papilla may or may not be visible. Thoracic segmentation evident. Metatrochanter with D₂ modified into a trochanteral organ. Inner margins of the metatibiae with 11-12 heavy setae; tibotarsi with 10-11 strongly clavate tenent hairs; pretarsus with an anterior inner and posterior setula. Unguis with an distinct inner corner tooth and short apical needle. Sacs of the ventral tube smooth. Rami of the tenaculum quadridentate; anterior corpus with one subapical and one apical setula. Manubrium with 10 dorsal setae. Dens with 3+3 ventral subapical setae; dorsally with seven and laterally with five subapical setae. Micro with rachi obliquely recurved, inner lamella serrate, outer lamella smooth. Dorsal anal lobe without a median, bifid seta. Unguiculus with a distinct inner corner tooth and short apical needle. Sacs of the ventral tube smooth. Rami of the tenaculum quadridentate; anterior corpus with one subapical and one apical setula. Manubrium with 10 dorsal setae. Dens with 3+3 ventral subapical setae; dorsally with seven and laterally with five subapical setae. Micro with rachi obliquely recurved, inner lamella serrate, outer lamella smooth. Dorsal anal lobe without a median, bifid seta. Female subanal appendage fimbriate. Bothriotrix D situated on a low papilla; body setae on the posterior half of the abdomen twice as long as those on the thorax. Maximum length 1.4 mm.

**Sminthurinus (Polykatianna) intermedius** n.sp.
Plate I: Figs. 14-27

Antennae purple, darker distally. The rest of the body is yellow overlaid with purple (sometimes blackish-purple). The head has slightly more dusting of pigment from the
apex, down the frons, to the mouthparts; the inter-antennal spot may be faint or darker than the rest of the pigment, but never blackish and well demarcated. Purple pigment appears as a wash over the thorax and abdomen; in some specimens the pigment is concentrated slightly more on the posterior-lateral regions of the abdomen; the pigment surrounding bothriotrix A, B, C, and D appears almost black. The legs and furcula, in all cases, are yellow.

Eyes 8+8; ocelli C and D reduced in diameter, C .66 to .75 as large as ocellus H. Antennal segments in the ratio of 1:1.5:2:4; ANT IV not subannulated; median apical bulb not present, but with a lateral apical papilla. ANT III with subapical sense rods lying in shallow depressions; with a lateral sensory papilla. Thoracic segmentation evident. Metatrochanters with seta D2 modified into a trochanteral organ. Inner margins of the metatibia with 11-12 heavy setae; tibiotarsi with two strongly clavate tenent hairs; pretarsus with an anterior and posterior setula. Unguis curving lanceolate with an inner tooth (sometimes not well developed) two-thirds of the distance from the base; a tunica is usually present. Unguiculus with a distinct corner tooth and short apical needle (however, on the proleg, the needle is half the length of the unguculus). Sacs of the ventral tube smooth. Rami of the tenaculum quadridentate; anterior corpus with a single apical setula. Manubrium with 14 dorsal setae. Dens with 2+2 ventral subapical setae; dorsally with six and laterally with three subapical setae. Micro with rachis obliquely recurved, inner lamella finely serrate, outer lamella smooth, ventral surface curved rather than straight. Dorsal anal lobe without a median, bifid seta. Female subanal appendage fimbriate. Bothriotrix D located on a prominent papilla (very clear on specimens in alcohol); body setae uniformly short and curving. Maximum size 0.75 mm.


This species is questionable in its placement. It displays a papilla on ANT III and has the ventral surface of the mucro curved. In many respects, it resembles the subgenus *Sminthurius*. However, it clearly lacks the bifid seta of the anal lobe common to that subgenus.

*Sminthurius (Sminthurius) atrapallidus* n.sp.

Plate II: Figs. 28-38

Antennae white with a light dusting of blue, ANT I dark blue-black, ANT II-IV with dark blue-black pigmentation distally. The head and trunk black with dark blue highlights; ventrally with posterior light area. Legs and furcula with a dusting of blue over white.

Eyes 8+8; ocellus C half the diameter of H. Antennal segments in the ratio of 1:2:3:6. ANT IV not subannulated, with setae whorled, and apical bulb present. ANT III with subapical sense rods lying in shallow depressions; with a lateral sensory papilla; setae not outstanding. Thoracic segmentation evident. Metatrochanters with seta D2 modified into a trochanteral organ. Inner margins of metatibia with 9-11 heavy setae; tibiotarsi with five-six clavate tenent hairs; pretarsus with an anterior and posterior setula. Unguis curving lanceolate with a small inner tooth two-thirds distance from the base, an inner and outer pseudonymchium is present, a tightly appressed tunica present (seen in some
mounting media better than others). Unguiculus with a corner tooth and apical needle (somewhat longer in the proleg). Sacs of the ventral tube smooth. Rami of the tenaculum quadridentate, anterior corpus with a single apical setula. Manubrium with 14 dorsal setae. Dens with 0+0 ventral subapical setae; dorsally with five and laterally with six subapical setae. Mucro with rachis distally upturned, inner lamella finely denticate, outer lamella smooth. Median bifid seta present on dorsum of anal lobe. Female subanal appendage palmate, Bothriotrix D short, on a low papilla; body setae very short and curving. Maximum size 1.25-1.5 mm.

**HOLOTYPE** and one **PARATYPE** on a single slide from Tangipahoa Parish, Louisiana, 16 March, 1951, Cockerham and Harrison, under mulch. Holotype slide deposited at the U.S. National Museum. **ADDITIONAL LOCALITIES**: Louisiana, Ouachita Parish, slides 0006.001, 0012.001, 115.001, 003.001, J. Cancellare; Baton Rouge Parish, Baton Rouge, 21 February, 1963. Mississippi, Adams County, 5 mi S. Natchez, 5 March, 1957, on vetch; Jackson County, 5 mi. N. Ocean Springs, 21 February, 1956, on rye grass and Ocean Springs, same date, on white clover, George Decker.

This species is one of the largest of the genus. *S. (Sminthurinus) atrapallidus* keys out to *S. mime* Börner in Stach (1956). The brief description given refers to the pseudo-nychiun as finely serrate for *mime*. This is not the case for *atrapallidus* which has coarse serrations.

*Sminthurinus (Sminthurinus) conchyliatus* n.sp.

**Plate II: Figs. 39-51**

Antennae uniformly purple. Head and trunk purple-brown with scattered dots and lines of lighter pigment. Frons darker than genal areas, interantennal spot present with a small colorless bar-like line beneath it, light areas occur around the inner dorsal edge of the eye patches. Abdomen with many light spots and polygons of pigment; anal papilla with two dorsal pale spots in the shape of a comma. Legs dusted with purple, becoming lighter distally.

Eyes 8+8; ocellus C and H subequal, ocellus D half the diameter of the others. Antennal segments in the ratio of 1:2:3:6. ANT IV not subannulated, with setae whorled, and apical bulb present. ANT III with subapical sense rods lying in shallow depressions; with four lobed lateral sensory papilla; setae not outstanding; Thoracic segmentation evident. Metatrochanters with seta D1 modified into a trochanteral organ. Inner margins of metatibia with 10-11 heavy setae; pro- and mesotibiotarsi with five clavate tenent hairs, metatibiotarsus with four; pretarsus with an anterior and posterior setula. Unguis curving lanceolate with a small inner tooth two-thirds distance from the base, an anterior and posterior pseudonychiun is weakly developed, a tightly appressed tunica is present. Unguiculus with a corner tooth and apical needle (the proleg apical needle is slightly over half the length of the unguis). Sacs of the ventral tube smooth. Rami of the tenaculum quadridentate, anterior corpus with two apical setulae. Manubrium with 16 dorsal setae. Dens with 1+1 ventral subapical setae; dorsally with five and laterally with four subapical setae. Mucro tapering with both lamellae serrate. Median bifid seta present on dorsum of anal lobe; circumanal setae expanded basally and irregularly serrate. Female subanal appendage fimbriate. Maximum size 1.2 mm.

**HOLOTYPE** and three **PARATYPES** on a single slide from Illinois, Burksville Cave, 4 January, 1958, on wood, Mockford and Bouseman. Additional four paratypes in alcohol, same location. Holotype slide and paratypes deposited at the Illinois Natural History Survey.

*S. (Sminthurinus) conchyliatus* keys out to *S. quadrimaculatus* (Ryder) in Stach (1956). It differs from that species with respect to the ANT III lateral sense papilla; *quadrimaculatus* is simple, *conchyliatus* is four-lobed. Also *quadrimaculatus* may have as many as two to three teeth on the inner margin of the unguis, while *conchyliatus* has one.
This species varies in color from the west to the east coast. Specimens from Oregon and California are mottled with bluish-purple pigment. Antennae light purple, becoming darker distally. Head dorsally darker than lower frons and genae. Inter-antennal spot clearly visible. Dorsum of the thorax and abdomen generally darker than lateral areas; California specimens with pale area surrounding manubrium; two dorsal pale spots on the anal papilla in some individuals. Legs pigmented basally, becoming lighter distally. The Louisiana specimens are uniformly pale yellow, except for purple dusting on the last two segments of the antennae. Sometimes a very light dusting of purple occurs laterally on the body in these individuals.

Eyes 8+8; ocelli C and D half the diameter of the others, B and H widely separated. Antennal segments in the ratio of 1:1.5:2:5. ANT IV not subannulated, setae whorled, apical bulb not present, latero-apical papilla present. ANT III with subapical sense rods lying in shallow depressions; lateral sensory papilla very low or absent; setae not outstanding. Thoracic segmentation evident. Metatrochanters with seta D2 modified into a trochanteral organ. Inner margins of metatibia with 10-11 heavy setae; tibiotarsi with six-seven weakly clavate tenent hairs; pretarsus with an anterior and posterior setula. Unguis lanceolate with a weak tooth two-thirds distance from the base, tunica present. Unguiculus with a weak corner tooth and apical needle (longer on the proleg). Sacs of the ventral tube smooth. Rami of the tenaculum quadridentate, anterior corpus with a single apical setula. Manubrium with 12 dorsal setae. Dens with 6+6 ventral subapical setae; dorsally with six and laterally with six subapical setae. Mucro with inner lamella finely denticulate, outer lamella smooth. Median bifid seta present on dorsum of anal lobe; circumanal setae expanded basally; female subanal appendage fimbriate. Body sparsely clothed with short curved setae. Maximum size 1 mm.

**Holotype and Paratype** on a single slide from Oregon, Jackson County, Griffin Creek, 5 December, 1950, on water and debris of an irrigation canal, H. H. White. Additional paratypes on two slides from the same date. A vial containing 40 additional specimens from the type locality of the same date was examined. However, all of the specimens mounted were identified as S. elegans. Therefore, the 40 specimens in addition to the holotype and one paratype slide, are deposited at the Illinois Natural History Survey. It is hoped that future investigators will mount and determine these dubious specimens when the need arises. A paratype slide is deposited in the Entomology Museum, Michigan State University.


This species keys out in Stach (1956) closest to S. megoculatus Maynard. Upon examination of megoculatus we find that it is a synonym of Sminthurinus henshawi (Folsom). Sminthurinus (Sminthurinus) maculosus appears closely related to henshawi. However, it can be separated from that species by the differences in ventral subapical setae of the dens; lack of the pseudonychium; 12 dorsal setae on the manubrium (specimens of henshawi from Michigan have 14); and possibly the female subanal appendage (henshawi is greatly dissected, while maculosus has few branches).

**Bourletiella (Bourletiella) christianseni** n.sp.

Antennae blue, becoming darker distally. Inter-antennal spot present; below the eye patches and midway between the vertex of the head and mouthparts is a broken blue band that extends across the frons and extends over the genae to the posterior. Body with blue pigment on light yellow, forming a broad lateral band on each side of the abdomen and a narrower dorsolateral band which runs from the head to the posterior of the great abdomen, where these bands join together dorsally on the anal papilla; sometimes with a median dorsal line. Legs and furcula without markings.
PLATE III. Figs. 52-65. Sminthurinus (Sminthurinus) maculosus n.sp. 52. Right eyepatch (holotype, Ore.); 53. ANT III, distal portion (Stanislaus Co., Calif.); 54. Metatrochanter (Stanislaus Co., Calif.); 55. Metatibia, posterior view (Stanislaus Co., Calif.); 56. Tenaculum (Stanislaus Co., Calif.); 57. Manubrium, right dorsal-lateral view (Stanislaus Co., Calif.); 58. Ventral surface of dens (Tallalah, La.); 59. Dorsal surface of dens (Tallalah, La.); 60. Mucro (holotype, Ore.); 61. Fore foot complex (holotype, Ore.); 62. Hind foot complex (holotype, Ore.); 63. Female anal papilla (Stanislaus Co., Calif.); 64-65. Female subanal appendage (Stanislaus Co., Calif.). Figs. 66-71. Bourletiella (Bourletiella) christianseni n.sp. (All illustrations from holotype, Ill., except where indicated) 66. Left eyepatch; 67. Hind foot complex; 68. Tenaculum; 69. Dorsal-lateral view of dens and mucro; 70. Female anal papilla; 71. Female subanal appendage, dorsal view; 72. Male dorsal organ (paratype, Ill.).
Eyes 8+8; ocellus C smaller than H. Specimens so shriveled that the ratio between segments of the antenna cannot be determined. ANT IV subannulated into seven-eight intermediates; apical bulb present. ANT III with subapical sense rods lying in shallow depressions; setae normal. Thoracic segmentation not distinct. Metatrochanters with oval organs. Tibiotarsus of the pro- and mesotibia with three appressed clavate tenent hairs, metibia with two. Pretarsus with an anterior setula. Unguis lanceolate with lateral teeth and an inner tooth two-thirds distance from the base; first pair of legs with an outer tooth one-third the distance from the base. Unguiculus tapering, without a corner tooth, with a short apical needle. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with two apical setae. Dens with seven dorsal and nine lateral setae. Mucro with rachis fused with lateral lamellae into a spoon-shape. Anal papilla with upper valve bearing two large setae with expanded bases on either side, lower valve with three; female subanal appendage truncate with apical fringe. Male dorsal organ with short subovate setae. Maximum size 1 mm.

**HOLOTYPE** and eight **PARATYPES** on one slide from Illinois, Champaign County, Illinois State University campus, 8 August, 1951, grass sweeping, W. R. Richards. An additional slide with three paratypes taken on the same day. The type and paratypes are deposited at the Illinois Natural History Survey. **ADDITIONAL LOCALITY:** Illinois, Williamson County, Carterville, 2 August, 1952, grass sweeping, L. Stannard and W. R. Richards.

*B. christianseni* appears to be unique among the members of the subgenus for North America by having the male dorsal organ with subovate spines. This characteristic alone separates it from other species. It gives me great pleasure to name this species for Dr. Kenneth Christiansen of Grinnell College.

**BourletieNa** (*Deuteromimthurus*) *lippsoni* n.sp.

**Plate IV: Figs. 73-92**

**FEMALE:** Antennae light brown, segments I and II with dark purple pigment. Head with mosaics of pigment forming patches and bands; midway between antennae and mouthparts an alternating light and dark brown band extends to the genae; lower frons to mouthparts dusted with yellow-orange; deep orange interantennal spot surrounded with yellow, brown "?" mark lines connect the interantennal spot with the bases of the antennae; brown mosaic patches posterior to eyepatches extend to occiput; the rest of the head white. Body with a brown-purple lateral band becoming darker as it extends and converges over the base of the anal papilla; dorso-lateral band of orange and brown mosaics extending half the length of the abdomen before becoming dark blackish-purple and converging with the lateral band at the base of the anal papilla; parafurcular lobes with two dark purple maculae; and papilla with dorsal blackish-purple pigment with a white macula on either side. The rest of the body and appendages white.

**MALE:** The same as for the female except that the ground color is more yellow; the lateral bands are expanded both to the anterior and dorsum, leaving only the dorso-lateral bands free for half their length, forming a blackish-purple pattern over three-quarters of the great abdomen. It should be noted that in both male and female, at the apex of the great abdomen, white enamel-like patches appear between the two bands. These are formed from deposition of ureate by-products and are best seen in adult specimens.

Eyes 8+8; ocelli D and G reduced to half the diameter of H. Antennal segments in the ratio of 1:1.5:2:5. ANT IV subannulated into five intermediates; apical bulb present. ANT III with subapical sense rods lying in shallow depressions; an accessory sense rod lies slightly oblique and posterior to the pair of sense rods; setae normal. Thoracic segmentation not distinct. Metatrochanters with oval organs; five anterior and one posterior setae. Metasternum with two posterior setae. Tibiotarsi of the pro- and mesolegs with three heavy, appressed, clavate tenent hairs; meta-tibiotarsi with two tenent hairs. Pretarsus with an anterior setula. Unguis lanceolate with a basal outer tooth and a weak inner tooth one-half to three-quarters the distance from the base. Unguiculus of the prolegs shaped like a strong bristle, tapering to a strong knob; meso- and metalega with lamellae developed, with stout apical filament, ending in a knob. Sacs of the ventral tube...
PLATE IV. Figs. 73-92. Bourletiella (Deuterosminthurus) lippsoni n.sp. (All illustrations from holotype, Md., except where indicated) 73. Right eyepatch; 74. ANT I; 75. ANT III, distal portion; 76. Antennal segments III and IV; 77. Metatrochanter; 78. Metafemur; 79. Metatibia; 80. Fore foot complex; 81. Hind foot complex; 82. Tenaculum; 83. Dorsum of manubrium; 84. Ventral surface of dens; 85. Dorsal surface of dens; 86. Mucro; 87. Female anal papilla; 88. Anal papilla of male (allotype, Md.); 89. Female subanal appendage, dorsal view; 90. Female subanal appendage, lateral view; 91. Bothriotrix D complex; 92. Setal pattern of head.
tuberculate. Rami of the tenaculum tridentate; anterior corpus with three apical setulae. Manubrium with 16 dorsal setae. Dens with six ventral setae; six lateral setae and 16 dorsal setae. Mucro with rachis fused with lateral lamellae into a spoon-shape. Anal papilla with normal curving setae; female subanal appendage setiform. Setae of the head and body, short and curving; heavily concentrated between the eye patches and sparsely distributed on the abdomen. Maximum size of female 0.7 mm and male 0.5 mm.

**HOLOTYPE** (female) and **ALLOTYPE** (male) from Maryland, Talbot County, Easton, 5 September, 1975, grass sweepings, R. J Snider. **PARATYPES:** 29 in alcohol taken on the same date. The types and paratypes are deposited in the Entomology Museum, Michigan State University. **ADDITIONAL LOCALITIES:** Maryland, Talbot County, Oxford, 5 September, 1975, dry basin grass sweepings, R. J. Snider. Florida, Dade County, Miami, 27 December, 1956, grass lawn, G. C. Decker.

*B. (Deuterosminthurus) lipposoni* may be easily recognized by the unique heavily knobbed unguiculus. Other members of the subgenus, while exhibiting this feature, do not have such a thick filament. It gives me pleasure to name this species for my friend and colleague, Dr. Robert L. Lippson, Research Coordinator, National Marine Fisheries Service, Oxford, Maryland, in whose backyard I first made its acquaintance.

**Bourletiella (Deuterosminthurus) lurida** n.sp.
Plate V: Figs. 93-111

Uniformly pale yellow; appendages almost colorless; the only outstanding color is the black pigment surrounding the ocelli. In some large adults, very faint purple markings occur on the dorsum of the abdomen.

Eyes 8+8; ocelli C and H subequal, D slightly reduced in diameter. Antennal segments in the ratio of 1:2:3:6. ANT IV subannulated into six-nine intermediates; apical bulb present. ANT III with subapical sense rods lying in shallow depressions; an accessory sense rod lies slightly oblique and posterior to the pair of sense rods; setae normal. Thoracic segmentation not evident. Metatrochanters with oval organs; five anterior and one posterior setae. Metafemora with two posterior setulae. Tibiotarsi of the pro- and mesolegs with three heavy, appressed clavate tenent hairs; meta-tibiotarsi with two tenent hairs. Pretarsus with an anterior setula. Unguis lanceolate with a weak outer tooth half the distance from the base; inner tooth one-third the distance from the apex. Unguiculus of the proleg shaped like a strong bristle; meso- and metalegs with lamellae developed, tapering to a sharp filament. Sac of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with two setulae. Manubrium with 20 dorsal setae. Dens with six subapical ventral setae. Mucro with rachis fused to lateral lamellae forming a spoon-shape. Anal papilla with normal curving setae; female subanal appendage spatulate (appearing setiform in lateral view). Setae of the head and body normal curving; heaviest concentration between the eye patches and frons, and posterior half of the abdomen. Maximum size of female 1 mm and male 0.7 mm.

**HOLOTYPE** (female) and **ALLOTYPE** (male) from California, Monterey County, Monterey, Linsdale #64. **PARATYPES:** from the same location and date, a single slide of ten specimens and 37 in alcohol. Types and 25 paratypes are deposited at the Illinois Natural History Survey; six paratypes at the Museum of Comparative Zoology, Harvard University; six paratypes at the Entomology Museum, Michigan State University. **ADDITIONAL LOCALITIES:** California, Fresno County, Coalinga, ex. *Erodium cicutarium*, 26 February; *Monalopium major*, 25 March; juniper leaf mould, 30 April, 1957, H. L. Wilson. Modoc County, Knox Mountain, 1 and 2 July, 1964, drop cloth collections, Don Dahlster.

*B. (Deuterosminthurus) lurida* keys out in Stach (1956) to *D. russata* Maynard based on the length and shape of the unguiculus. While the two species are close, they can be separated by the number of ventral subapical setae on the dens; *russata* has three, and *lurida* has six.
The condition of the specimens, in all of the material, is so poor that a valid color description is impossible. Based on examination of four individuals preserved in alcohol, the following pattern is offered. Frons and lower genae with pigment; bands of pigment behind each eye patch leading to the occiput. The body has lateral and dorsal bands converging at the anal papilla; the dorsal band has a lighter line running through the middle from anterior to posterior. This pattern is best seen in the male. The female appears to have a confluence of the pigment bands over much of the abdomen, leaving a light area at the anterior apex of the dorsum. Legs with blotches of color on the tibia, femur, and trochanter. Manubrium with dorsal and ventral blotches of pigment; dens with basal blotches on proximal to the integumentary ridges. From slide material, it is possible to see the pigment laid down as mosaics. Some individuals have a scattering of pigment, while others have heavy concentrations. The slide material registers the pigment color as blue.

Eyes 8+8; ocellus C is three-quarters the diameter of H. Antennal segments in the ratio of 1:2:2.5:5.5. ANT IV subannulated into 9-10 intermediates; apical bulb present. ANT II with subapical sense rods lying in shallow depressions; an accessory sense rod lies slightly oblique and posterior to the pair of sense rods; setae numerous, normal. Thoracic segmentation not evident. Metatrochanters with oval organs; five anterior and one posterior setae. Meta"cmora with two posterior setae. Tibiotarsi of the pro- and meselegs with three heavily appressed, clavate tenent hairs; meta-tibiotarsi with two tenent hairs. Pretarsus with an anterior setula. Unguis curving lanceolate with strong inner tooth one-quarter the distance from the apex; an outer tooth occurs one-half the distance from the base. Unguiculus setiform with a heavy subapical needle tapering into a knob. Sacs of the ventral tube tuberculate. Rami of tenaculum tridentate; anterior corpus with three apical setae. Manubrium with 14 dorsal setae. Dens with six subapical ventral setae. Manubrium with 14 dorsal setae. Dens with six subapical ventral setae. Mucro with rachis fused to lateral lamellae forming a paddle. Anal papilla with 14 heavy, broad based circumanal setae and normal curving setae; female subanl appendage spatulate (blunt setiform in lateral view). Setae of the head and body short and curving, most heavily concentrated between the eyes and lower frons, and posterior half of the abdomen. Maximum size for female 1.25 mm and male 0.8 mm.

**HOLOTYPE** (female) and **ALLOTYP** (male) from Arizona, Pima County, Quijotoa, 28 August, 1927, J. D. Hood. Holotype and allotype in alcohol, four paratypes of same date deposited at the Illinois Natural History Survey, one paratype deposited at the Entomology Museum, Michigan State University. **ADDITIONAL LOCALITIES**: Oklahoma, Pawnee County, 9 May, 1971, on cow pats, slide #2855. Texas, Presidio County, Presidio, 22 April, 1928, on greasewood; West Texas, October 1961, E. Huddleston.

This species can be recognized by the large inner tooth of the unguis. The unguiculus has a shape that is very similar to that of Bourletiella (Prorastropes) coalingaensis n.sp.

**Bourletiella (Deuterosminthurus) xeromorphus n.sp.**

Plate VI, VII; Figs. 128-130, 131-146

Antennae light purple, darkest distally on segments I-III, segment IV uniformly darker. Head with a purple band of pigment extending between the eye patches to behind the head; dorsum of head without purple pigment between the eyes; pigment does not extend below the eye patches onto the genae or frons. Thorax and great abdomen with purple pigment extending halfway down, laterally lighter on the dorsal area of the first two to three abdominal segments, a light “V” sometimes appears clearly in that region; anal papilla purple dorsally with a lateral spot on either side, papilla of bothriotrix D surrounded by purple pigment. The rest of the body and legs bright yellow to pigmentless.

Eyes 8+8; ocellus C smaller in diameter than H. ANT IV segmented in the ratio 1:2:2.8:5.2 in females and 1:2:2.5:4.4 in males; subannulated into seven-eight intermediates with the basal portion elongate, intermediates ringed with eight curved setae;
apical retractile bulb present along with three-four rods. ANT III with subapical sense rods situated in shallow depressions; situated slightly below and posterior to the primary sense organ is a second sense organ consistency of a simple rod-shaped papilla in a depression; setae of the third antennal segment numerous and evenly distributed from base to apex. Segmentation of the thorax not evident. Metatrochanters with oval organs; five anterior and one posterior setae present. Femora with two posterior setulae. Tibiotarsi with heavy spine-like setae on the posterior margin, most evident in the distal half of the segment; pro- and mesotibiotarsi with three appressed; strongly clavate and two nonclavate tenent hairs; metatibiotarsi with two appressed, strongly clavate and two nonclavate tenent hairs; pretarsus with an anterior setula. Unguis of all legs curving lanceolate, with one outer tooth midway between base and apex, and an inner tooth midway between base and apex. Unguiculus lanceolate with a narrow outer lamella and broad inner lamella, with a strong subapical filament ending in a knob. Rami of the tenaculum tridentate; anterior lobe of corpus with three setulae. Sacs of the ventral tube tuberculate. Manubrium with 14 dorsal setae. Dens with 14 dorsal setae and six ventrally. Mucro with rachis fused to lateral lamellae forming a spoon-shape. Anal papilla with numerous setae, female subanal appendages smooth and curving. Body setae short, curving and serrate, concentrated from mid-dorsum to posterior. Maximum size for female 0.75 mm and male 0.60 mm.

HOLOTYPE (female) and ALLOTYPE (male) from Michigan, Shiawassee County, T.5N, R.1W, S.21, Rose Lake State Game Area, pet trap, 21-28 May, 1967, R. T. Schuh. Holotype and allotype slides deposited in the Entomology Museum, Michigan State University. PARATYPES taken on the same date deposited as follows: 10 alcohol and three slide specimens, Michigan State University; 10 alcohol specimens, Illinois Natural History Survey; four alcohol and three slide specimens, Museum of Comparative Zoology, Harvard University; seven slide specimens undesignated.

This species is in many ways very similar to B. (Deuterosminthurus) wexfordensis Snider. It can be separated from that species on the basis of circumanal setae; ocellus C is smaller than H, in wexfordensis, they are subequal; finally the setae pattern of the dens is in a different configuration, the dorsal setae of wexfordensis is more uniform.

Bourletiella (Deuterosminthurus) nonfasciata n.sp.
Plate VII, VIII: Figs. 147-153, 154-169

Head and body entirely white except for the black pigment surrounding the ocelli and a very light dusting of purple pigment on the distal segments of the antennae. Eyes 8+8; ocellus C with a diameter slightly less than H. Antennal segments in the ratio of 1.5:3:4:9. ANT IV subannulated into 14-15 intermediates, distal intermediates have a subapical setula, basal portion with two setulae, apical bulb present. ANT III with subapical sense rods lying in shallow depressions; an accessory sense rod lies slightly oblique and posterior to the pair of sense rods; setae numerous and normal. Thoracic segmentation not evident. Metatrochanters with oval organs; five anterior and one posterior setae. Metafemora with two posterior setulae. Tibiotarsi of the pro- and mesolegs with three heavily, appressed, clavate tenent hairs; metatibiotarsi with two tenent hairs; inner margin with heavy but not outstanding setae. Pretarsus with an anterior setula. Unguis lanceolate with a weak inner tooth one-quarter the distance from the apex; an outer tooth is sometimes evident half way between the base and apex. Unguiculus of the proleg setiform; meso- and metaleg have an apical needle. Sacs of the ventral tube tuberculate. Rami of tenaculum tridentate; anterior corpus with three setulae. Manubrium with 12 dorsal setae. Dens with six subapical ventral setae. Mucro with rachis fused to lateral lamellae forming a spoon-shape. Anal papilla with normal curving circumanal setae; female subanal appendage spatulate (setiform in lateral view). Setae of head and body short and curving; heaviest concentration between the eye patches and posterior half of abdomen. Maximum size for female 1 mm and male 0.8 mm.

HOLOTYPE (female) and ALLOTYPE (male) from California, Modoc County, Manzanita Mountain, 24 June, 1974. Holotype and allotype on slides deposited in the
Museum of Comparative Zoology, Harvard University. PARATYPES on the same date: two slides and three alcohol specimens deposited in the Museum of Comparative Zoology, Harvard University, two slides and three alcohol specimens deposited in the Entomology Museum, Michigan State University; one slide and two alcohol specimens deposited at the Illinois Natural History Survey.

This species keys out in Stach (1956) to *Heterosminthurus cornutus* Stach. It differs from that species by having a tooth on the unguis; three instead of two setae on the corpus of the tenaculum; lacking a four bristle complex on the frons of the male.

*Bourletiella (Prorastropes) coalingaensis* n.sp.
Plate IX: Figs. 170-183

All specimens were cleared before mounting, making it impossible to provide a color description at this time.

Eyes 8+8; ocellus C is smaller in diameter than H. Antennal segments in the ratio of 1:3:4:8. ANT IV subannulated into eight-nine intermediates, apical bulb present. ANT III with subapical sense rods lying in shallow depressions an accessory sense rod lies slightly oblique and posterior to the pair of sense rods; setae numerous and normal. Thoracic segmentation not evident. Metatrochanters with oval organs; five anterior and one posterior setae. Metamesa with two posterior setulae. Tibiotarsi of the pro- and mesolegs with three heavy, appressed, clavate tenent hairs; metatibiotarsi with two tenent hairs; tibiae with inner setae differentiated and truncate. Pretarsus with an anterior setula. Unguis curving lanceolate with an inner tooth? Unguiculus setiform lamella not developed, apical needle tapering to a knob. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with three setulae. Dens with six subapical ventral setae. Urotrichia of the proleg.

*Sphyrotheca confusus* n.sp.
Plate IX, X: Figs. 184-196, 197

The small series of specimens available do not allow an accurate color description. However, the slides examined indicate that the antennae are blue; an interantennal spot is present; with pigment posterior to the eye patch and vertex of the head. Body with blue pigment in irregular oblique bands with many dots and lines; legs with blue mottlings on the femur and tibia.

Eyes 8+8; ocellus C and H subequal, one-half the diameter of other ocelli. ANT IV subannulated with 11-12 intermediates; apical bulb not present, with a slightly subapical papilla. ANT III with subapical sense rods lying in a shallow depression; with five-six straight, strong setae, others curving and normal. Thoracic segmentation not evident. Metatrochanters with oval organs; five anterior setae and posterior trochanteral spine. Tibiotarsal tenent hairs acuminate. Pretarsus with an anterior and posterior setula. Unguis lanceolate, with an inner tooth one-quarter the distance from the apex, tunica present. Unguiculus with well developed lamellae and corner tooth; subapical needle of proleg.
almost as long as unguiculus, short on the meso- and metalegs. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with two setulae. Dens with nine subapical ventral setae. Micro with both lamellae serrate; spine present. Anal papilla numerous long curved setae; female subanal appendage curved, setiform. A single interocular spine-like seta associated with each eye patch. Dorsal body setae heavy, spine-like; posterior with short curving setae. Maximum length 1 mm.

**HOLOTYPE** (female) from California, Three Rivers, #3611. **PARATYPES:** one on same slide as holotype; Lakeside, 11 October, 1969; Sequoia National Park, Tulare County, Rt. 0198, 6 mi. above wood level, 16 April, 1974, P. Bellinger. Holotype and paratypes are deposited at the Museum of Comparative Zoology, Harvard University.

This species has many characteristics common to the genus *Sminthus*. The stout setae of the body are smooth; the head lacks spines; both edges of the mucro are serrate; and the ventral setae of the dens are similar. However, it does exhibit a trochanteral organ and has exposed sense rods on ANT III.

*Sphyrotheca mucroserratus* n.sp.
Plate X: Figs. 198-213

Antennae purple, uniform throughout. Head with purple on lower frons, with purple band between bases of the antennae; a band from the frons, extends across the genea to the occiput. The body with weak purple bands extending laterally to the posterior; most of the posterior of the abdomen purple; legs and furcula with purple pigment. Background color yellow.

Eyes 8+8; ocellus C smaller in diameter than H. ANT IV subannulated with 9-10 intermediates; apical bulb weakly developed. ANT III with subapical sense rods lying in shallow depressions; with six spine-like setae, others curving and normal. Thoracic segmentation not evident. Metatrochanters with oval organs; five anterior setae and posterior spine. Tibiotarsal tenent hairs acuminate. Pretarsus with an anterior and posterior setula. Unguis lanceolate, with an inner tooth half the distance from the base, tunica present. Unguiculus with lamellae developed and lacking a corner tooth; apical needle of proleg as long as unguiculus, short on meso- and metalegs. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with four setulae. Dens with three subapical ventral setae. Micro with outer lamella smooth, inner serrate; mucronal seta absent. Anal papilla with normal setae; female subanal appendage truncate, weakly serrate apically. Interocular setae spine-like, uniform in size and shape, serrate. Body with stout, spine-like serrate setae, interspersed with curving, normal setae. Maximum size of female 0.85 mm and male 0.75 mm.


This species resembles *S. minnesotensis*, but lacks that species' definite color pattern. The cephalic spines of *mucroserratus* are uniform in size and shape, whereas *minnesotensis* varies in size and shape.

*Neosminthurus bakeri* n.sp.
Plate X, XI: Figs. 214-220, 221-234

Antennae with blue pigment, darkest on apical regions of each segment. Head dark blue to purple with light areas near the inner margins of the ocellar patches, mouthparts
white. Body generally dark blue to purple, numerous pale spots and lines occur throughout, especially between segments. Legs and furcula with light blue pigment.

Eyes 8+8; ocelli C and H subequal, smaller in diameter than others. ANT IV not annulated, without an apical bulb, 1.1-1.4 times as long as ANT III. ANT III with subapical sense rods lying in deep depressions; setae short and stout. Thoracic segmentation evident. Metatrochanters with oval organs; posterior spine and 15 anterior setae. Metafemora (and mesofemora) with a posterior "finger-like" process, and two setulae. Profemora with two appressed posterior spines. Metatibia with six short setae on the posterior surface, outer edges with four; inner surface with four-five long setae; outer tenent hair acuminate, curving laterally around apex. Pretarsus with an anterior and posterior setula. Unguis curving lanceolate, with an inner tooth one-third the distance from the base; tunica present, with lateral serrations. Unguiculus lamellate, with a minute corner tooth or absent; apical needle tapers and then widens into a lanceolate form. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with four setulae. Dens without ventral setae, with five inner lateral setae. Mucro trough-shaped, appearing bifid; inner lamella with low serrations. Female subanal appendage finely serrated apically. Intercocular setulae short smooth, acuminate and spine-like. Body setae in the anterior half cylindrical, scaled; in the posterior half the cylindrical setae appear shorter and are mixed smooth acuminate setae. Maximum length 1.2 mm


This species is easily recognized from Neosminthurus clavatus and Neosminthurus richardsi n.sp. on the basis body setae shape, and the number and position of dorsal setae on the dens. It gives me pleasure to name this species for Dr. Rollin H. Baker, Director of The Museum, Michigan State University.

Neosminthurus richardsi n.sp.
Plate XI, XII: Figs. 235-242, 243-250

Head and body blue to blue-black. Pigment laid down in mottlings separated by pale spots. Antennae blue, darkest distally on each segment. Legs and furcula with blue pigment in irregular mottlings.

Eyes 8+8; ocellus C smaller in diameter than H. ANT IV without an apical bulb; 1.25-1.35 times as long as ANT III. ANT III with subapical sense rods lying in deep depressions; setae short and stout. Thoracic segmentation evident. Metatrochanters with oval organs; posterior spine and five anterior setae. Metafemora (and mesofemora) with a posterior "finger-like" process, and five short setae. Profemora with two appressed posterior spines. Metatibia with four short setae on the posterior surface, outer edge with five; outer tenent hair acuminate, curving laterally around apex. Pretarsus with an anterior and posterior setula. Unguis curving lanceolate, with an inner tooth half the distance from the base; tunica present, with lateral serrations. Unguiculus lamellae, without a corner tooth; apical needle longer than unguiculus. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with four setulae. Dens without ventral setae, with four inner lateral setae. Mucro trough-like, inner lamella with low serrations, outer smooth or with an indentation. Female subanal appendage curved, with lateral cilia, apex blunt with fine fringe. Intercocular setulae smooth, short and blunt,
arranged in two rows of five. Body setae short, palmate scaled or serrate interspersed with short curving types. Maximum size 1.2 mm.


This species is very similar to *N. clavatus* but differs in the shape of the body setae as well as claw and leg features. It is my pleasure to name this species for Dr. W. Robin Richards, whose work has helped clarify many systematic problems associated with the Sminthuridae.

*Sminthurus incisa* n.sp.

Plate XII, XIII: Figs. 251-261, 262-269

Antennae purple, becoming darker distally. Background color yellow with brownish-purple or purple pigment. Head in some specimens without purple or sometimes a light dusting; others with broken lines on the frons, forming a circle below the bases of the antennae. Body with light dusting of purple to lines and irregular mottled bands; sometimes very dark pigmentation broken by spots and light lines.

Eyes 8+8; ocellus D about half the diameter of B. ANT IV subannulated into 17-18 intermediates; apical bulb present; as well as a small lateral apical papilla. ANT III with subapical sense rods lying in an invaginated pocket; with five outstanding heavy setae on the basal half. ANT II with subapical ring of eight setae. ANT I with two posterior subapical setae. Metatrochanters with oval organs; posterior seta normal and five anterior setae. Metatibia with long outer and heavy inner setae; a single acuminate tenent hair (proleg of similar structure). Pretarsus with an anterior and posterior setula. Unguis lanceolate, with a large inner tooth, pseudonychium and tunica. Unguiculus with a corner tooth and lamellae developed; apical needle of the proleg as long as the unguiculus; metaleg with needle only one-third as long. Sacs of the ventral tube tuberculate. Rami of the tenaculum tridentate; anterior corpus with five setae. Manubrium with 12 dorsal and one ventral setae. Dens with 17 subapical ventral setae. Mucro with rachis fused to lamellae forming spoon-shape, edges of lamellae smooth (in older mounts the edges

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PLATE XIII. Figs. 262-269. *Sminthurus incisa* n.sp. (Illustrations from paratype, Chandler Lk., Alaska, except where indicated.) 262. Hind foot complex (Footprint Lk., Alaska); 263. Fore foot complex; 264. Mucro, newly mounted; 265-266. Mucro, older mounts showing crenulations; 267. Female anal papilla; 268. Female subanal appendage, lateral view; 269. Female SAA, dorsal view.
become crenulated or indented); mucronal setae present. Anal papilla with long, fine setae; female subanal appendage curving acuminate. Setae of the head and body moderately long; a short spine-like seta between the eye patch and base of the antenna. Maximum length 2 mm.

**HOLOTYPE** (female) from Alaska, Utrikok River, 1-7 August, 1952, driftwood, P. F. Bellinger. **PARATYPES:** four specimens on same slide as holotype; 21 specimens in alcohol from Alaska, Chandler Lake, Brooks Mountains, 21 July, 1952, P. F. Bellinger. Holotype and four paratypes deposited at the Museum of Comparative Zoology, Harvard University; five paratypes at the Entomology Museum, Michigan State University; five paratypes at the Illinois Natural History Survey; seven paratypes to K. Christiansen, Grinnell College, Iowa. **ADDITIONAL LOCALITIES:** Alaska, Umiat, Colville River, 31 July, 1952, P. F. Bellinger; Footprint Lake.

This species keys out to *S. viridis* (L.) in Stach (1956). It differs from that species in lacking a strong rib supporting the female subanal appendage; by having five setae on the tenacular corpus, *viridis* has three; the pseudonychium of the metalegs extends almost to the apex, and is double.

**ACKNOWLEDGMENTS**

I wish to offer thanks to Dr. Kenneth Christiansen for providing so many specimens from which to work; to my wife, Renate Machan Snider, for inking in all of the pencil sketches; and to Judy DeJaegher for typing the manuscript.

**LITERATURE CITED**

ALTERNATIVES TO THE GYPSY MOTH ERADICATION PROGRAM IN MICHIGAN

Joseph G. Morse and Gary A. Simmons

ABSTRACT

Responding to questions of what the gypsy moth, *Porthetria dispar*, would do in Michigan forests, a computer simulation model was constructed. The model consisted of three subunits: a submodel of gypsy moth population dynamics, a submodel of forest growth and a submodel of tree defoliation and mortality. Several different policies were simulated for an 80 year period. The eradication policy now employed in Michigan failed due to survival of small portions of the population. Allowing the gypsy moth to become established in Michigan forests and then responding by spraying when defoliation is visible provided a policy with the least economic and environmental cost.

The gypsy moth, *Porthetria dispar* (Linnaeus) (Lepidoptera: Lymantriidae) is not yet a serious pest in Michigan forests. Pheromone trappings in 1973, however, indicated that males were present in 22 counties and that at least 600,000 acres in Michigan were lightly infested (Wallner, 1974). Dense populations such as those experienced in East Coast forests have not yet been observed. In fact, defoliation has not yet been discovered. If outbreaks should occur in Michigan, however, action may have to be taken to preserve oak forests for their high recreational value as well as for the harvestable products they represent.

Control of the insect pest has, in the past, centered around chemical control means. Eradication has been attempted in Michigan during two periods, 1954-1967 and 1973-present. Either low density survival or subsequent reinestation has left us with widespread, low density populations. The present control strategy of eradication has probably slowed the spread of the gypsy moth, but is only postponing a solution to the problem.

Since 1973, approximately 73,000 acres have been treated in attempts to eradicate the gypsy moth from Michigan. Future plans call for treating larger acreages yearly until the job is completed. For such a program to be successful two assumptions must be met: (1) 100% mortality must be obtained throughout the acreages sprayed and (2) no additional gypsy moths can be introduced from outside the state. Many experienced entomologists feel such assumptions cannot be met, yet Michigan, with its millions of acres of mixed oak forests, is not willing to chance allowing gypsy moth populations to become established because the results are unknown.

Response to resource management problems of this nature has and continues to be largely trial-and-error. The potential for large-scale error is far greater, however, than the potential for problem solution. As Holling et al. (1976) have stated, "The past history of resource management, and indeed applied sciences in general has been essentially one of trial-and-error approaches to the unknown... but we now find increasingly that the extensive and intensive nature of our trials can generate errors larger and more costly than society can afford."

METHODS

One alternative to trial-and-error is computer simulation to examine a range of alternatives without risk. Computer simulation, modeling, and the use of system analysis
techniques has recently come into increasing use in ecological problems (Conway, 1976; Ruesink, 1975). Benefits of the modeling technique are not only the finished model, but also useful information derived from the methodology. The initial phases of modeling require a pooling and organization of existing information relevant to the study. Perhaps even more importantly, data holes are indicated where further research is needed.

Alternative control strategies may be simulated in order to compare short and long-range consequences. User-interaction models can be useful learning and teaching tools in which the outcomes of decision alternatives may be analyzed quickly and efficiently. Models also lend themselves to graphic and visual aids useful in public relations displays, discussions, and conflict resolution.

With all of the uses of models, of whatever form, there are limitations to the modeling technique. Models are only as accurate and as complete as the data base upon which they are built. Conversely, models which accurately represent complex ecological systems are usually very difficult to analyze and comprehend (not to mention build) because of their complexity.

A schematic diagram of the model is given in Figure 1. The model is composed of three sub-units: a submodel of gypsy moth population dynamics, a submodel of forest growth, and a third submodel interacting with the first two in which tree defoliation and mortality caused by the gypsy moth are simulated.

Any modeling effort must begin with a number of basic assumptions upon which model validity and generality are based. In building the model, we tried to maintain model generality. Instead of accurately modeling within-year fluctuations of the gypsy moth we attempted to capture year to year population dynamics as they influence forest growth and mortality.

The site modeling technique of Holling et al. (1976) was used to model small sub-units of a typical Michigan forest which later were combined to represent the whole forest area of interest. We chose as our site size a 1 square mile (640 acres) area of forest. Trees within the site were divided into susceptible (mainly oak varieties) and non-susceptible species. Trees under 20 years of age were assumed somewhat resilient to gypsy moth attack because of their rapid growth rate (this is not a bad assumption since natural mortality due to crowding is high for this age group). The equation of Gingrich

![Figure 1. Submodel interactions for the gypsy moth/forest simulation model.](image-url)
(1971) was used to compute yearly increments in tree growth from which tree leaf surface was calculated. Forest sites were sub-classified as to site quality (poor-medium-good) using the criteria of Gysel and Arend (1953). Poor sites were assumed to support less trees/unit area and to be less resilient to defoliation.

In building an accurate population model for the gypsy moth in Michigan, we were faced with a nearly impossible task. At present, the only information available from Michigan on gypsy moth population dynamics is what little we know from yearly pheromone trap catches. Some life table data on both low level stable populations from Eastford, Connecticut, (Campbell, 1969, 1976) and violently fluctuating populations from Glenville, New York, (Campbell, 1976) are available. However, using statistics from two widely separated ecological regions for use in a third region can lead to somewhat invalid results. We therefore decided that instead of precisely modeling population dynamics, we would model the stability properties of the gypsy moth-forest ecosystem. We attempted to mimic the stability behavior of this system by allowing the gypsy moth population to oscillate between an observed low stability region and a high level outbreak (Campbell, 1976).

As diagrammed in Figure 1, the foliage consumed by the gypsy moth divided by the available foliage gives the percent defoliation used to determine tree condition and mortality. Mortality tables (Campbell and Valentine, 1972) were combined with site quality criteria (Gysel and Arend, 1953) in determining mortality figures. Past defoliation history was also taken into consideration. Additional details are available from the authors.

RESULTS

Results of several simulations are plotted in Figure 2. Figure 2B depicts gypsy moth population fluctuation for a poor site (most susceptible to defoliation) with an initial gypsy moth infestation of 40 adults per acre (50:50 sex ratio; 40/acre was chosen as the low level equilibrium density). The model was initiated with trees of uniform age (20 years) and 60% stocking (poor sites). Gypsy moth population levels are represented on the y-axis as the logarithm of actual levels.

As seen in Figure 2B, the gypsy moth population erupts from the low equilibrium level (40/acre = 1.60 on graph) roughly once every 10 years. Peak outbreak levels average around 10,000 moths/acre with outbreaks lasting about four years. Note in years 51 and 76 the occurrence of "mini outbreaks" which were initially controlled by gypsy moth natural enemies. Figure 2A shows tree defoliation corresponding to the population fluctuations in Figure 2B. Tree mortality occurred after several successive years of high defoliation. Near year 64, high cumulative tree mortality resulted in constant 100% defoliation of remaining trees.

Figures 2C-2F show population fluctuations for the same 80 years when gypsy moth

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Table 1. Simulations depicted in this study.

- excluded natural mortality
- defoliation curve
Fig. 2. Results of several different simulations: (A) percent defoliation when gypsy moth is not controlled, (B) population fluctuations of uncontrolled gypsy moth population, (C) population controlled with 65% efficacy when density exceeds 50 adults/acre, (D) population controlled with 95% efficacy when density exceeds 50 adults/acre, (E) population controlled with 65% efficacy when density exceeds 1000 adults/acre, (F) control imposed with 95% efficacy when density exceeds 1000 adults/acre; (G) eradication policy, 99% mortality achieved each year for the first 20 years, controls relaxed thereafter.
control practices were added. Five contrasting control policies were simulated representing tactics available with current technology.

Two tactics represent responses to slight rises in endemic populations above a low-level equilibrium point. We presumed that such rises, although not detectable by observing defoliation, could be indicated using pheromone traps. The slight rise would "release" the populations from natural enemies enough for the population to reach outbreak level within one to three years. Figure 2C represents a control response using a microbial insecticide such as Bacillus thuringiensis. We presumed such a tactic would impose an average of 65% mortality. Figure 2D, by contrast, represents a control response using a chemical insecticide that will result in a mean mortality rate of 95%. In each case, population levels of adult moths were sampled at the end of each development cycle yearly. Such information was used to determine whether a spray should be applied the next year. Population levels (at the end of year of X-1) above the spray decision threshold determined spray action (at the beginning of the year X season). Sprays were timed to affect instars I-III.

Two additional tactics represent responses after population rises sufficient enough for defoliation to be noticeable. Again, the sprays used are (Figure 2E) a microbial insecticide and (Figure 2F) a chemical insecticide. The procedure for determining spray action was similar to that depicted in Figures 2C and 2D except the population density required for response was higher.

Figure 2G shows population level fluctuations for the model run where a spray of 99% efficacy is applied for the first 20 model years regardless of population levels. This simulation represents an eradication policy using a material that would affect 99% mortality, such as a chemical insecticide.

DISCUSSION

As expected, gypsy moth populations, if uncontrolled, result in extreme tree mortality on poorer sites. When spray decisions are based on population levels in the previous year, it is seen that waiting until the population is truly in an outbreak results in fewer total sprays and reasonable tree survival. The results of our "eradication" run are quite revealing. Although model validity can be questioned at the low population levels present in this simulation, our model does suggest that if survivors are left from continuous spraying, it will be only a matter of time before outbreak populations are again present.

Based on the range of tactics we have examined, aside from no control, the eradication policy is perhaps the worst choice available. The eradication approach requires an intensive spray effort, without regard to gypsy moth population density, that inevitably fails. The cost, both economically and environmentally, is the maximum for the tactics examined. Once failure is admitted (likely much earlier in the real world due to taxpayer pressure than was represented by our simulations) another tactic must be selected. A very high economic and environmental price will have already been paid at that point.

The best tactic is given in the simulation represented by Figure 2F. This policy uses a minimum of sprays over an 80 year period and results in very slight tree mortality. The environmental and economic cost is minimum. This does, however, allow the gypsy moth to become established in Michigan forests.

LITERATURE CITED

TWO TRAPPING SYSTEMS TO DETERMINE INCIDENCE AND DURATION OF MIGRATION OF ADULT ALFALFA WEEVILS, *HYPERA POSTICA* (COLEOPTERA: CURCULIONIDAE)

S. J. Roberts, R. D. Pausch, E. J. Armbrust, and R. J. Barney

ABSTRACT

Emergence and flight traps were used to study the pre- and post-diapause movements of the alfalfa weevil, *Hypera postica*. The emergence traps proved to be an excellent tool in determining the time of diapause termination and in providing an accurate accounting of the number of weevils per unit area in aestivation sites. The flight traps showed when diapause flights to and from alfalfa fields took place. Both trapping systems can be utilized in a pest control program to locate more closely where the alfalfa weevil aestivates and when diapause related movements occur.

For the past two years our research on the alfalfa weevil, *Hypera postica* (Gyllenhal), has focused on aspects of regional populations. Adequate methods of monitoring adult migratory behavior during these studies were of primary importance. Of particular interest was the timing of adult emergence from aestivation and their departure from aestivation sites. Newly designed flight and emergence traps were used to measure these adults movements over selected periods of time. Several objectives were fulfilled by employing both flight and emergence traps. Migratory behavior, in terms of accumulative emergence/ft² (0.093 m²), emergence rate of beetles/day, and the incidence of flight activity was determined. Both traps are described herein along with their respective field data.

MATERIALS AND METHODS

The emergence traps were pyramidal in design, having a base of 1 ft² (0.093 m²) and a height of approximately 18 inches (45.7 cm) including the base (Fig. 1). Bronze screening was used in fabricating the pyramid while galvanized sheet metal was used to make the bottom frame and top plate. The screening was cut long enough to allow a 1 inch (2.5 cm) overlap for soldering to the inside of the galvanized square base and top plate. A four-sided pattern limited the soldering on the sides of the screening to only one seam. A wide mouth canning jar lid was inverted and glued to the top plate for use with a wide mouth collecting jar similar to that used by Musick and Fairchild (1970).

The collecting jar, as used by Musick and Fairchild (1970), was screwed onto the ring and examined daily for insects. This method did not provide for one-way entry. One-way entry was accomplished by cutting the apex from conical drinking cups having a 3½ inch (8.5 cm) wide mouth, placing a narrow band of Stickem Special® (Michel & Petton Co., Emeryville, CA) midway around the cup and inverting it (mouth down) into the canning jar lid.

Flight traps used in these studies were a modification of the commonly used...
window-pane trap. Our traps (Fig. 2) consisted of a shallow, rectangular box, supported by a single galvanized metal pipe screwed into an attached floor flange, and a sheet of clear plexiglas hinged to the rear of the box. The plexiglas was positioned approximately 30° forward of vertical so that any insects striking it would bounce downward into the collecting trays below. The supporting pipe, threaded at one end, was driven into the ground to the desired depth, and the trap, which was approximately 1.5 m above the ground, was threaded onto the pipe by means of the floor flange which was attached to the exact bottom center of the box.

To reduce the effect of turbulence from air currents entering the trap and rebounding from the plexiglas, triangular wooden frames covered with window screening were placed on the sides of each trap. This positioned the plexiglas at the appropriate angle and allowed incoming air currents to pass out and around the sides of the trap but still retain incoming insects. For ease of maintenance, heavy aluminum foil cooking pans were used as the collecting trays. These were placed in the box of the trap and filled to a depth of approximately 1.5 cm with ethylene glycol. Insects falling into the collecting trays became mired, quickly drowned, and sank to the bottom of the tray where they were visible enough to count and identify in situ. The transparency of the plexiglas was gradually reduced by an accumulation of dust on the surface. An occasional wiping with a damp cloth restored original clarity.

The number of alfalfa weevils captured was determined weekly. After the weekly count, the collecting trays were cleaned by passing an aquarium dip net through the ethylene glycol which removed all the collected insects.

Because we were interested in sampling only those insects coming from one particular direction, our traps were constructed so as not to rotate in the wind. If, however, wind oriented collections were desired, the trap design could possibly be altered with a bearing replacing the floor flange and a fin attached to the rear of the trap.

![Diagram of emergence trap used to study diapause termination of alfalfa weevil, Washington County, Illinois, 1977.](image)
RESULTS AND DISCUSSION

Thirty-six emergence traps were placed in the wood edge of our study area in Washington County, Illinois. Our studies have shown that alfalfa weevils are most concentrated in these wood edges during the time of aestivation, and variation in number of adults per square foot is sometimes fairly high making it desirable that the traps be placed as randomly as possible. Our results indicated, however, that our placement of traps was biased inasmuch as we obtained populations in the emergence traps that were three times higher than were measured previously during the summer by absolute densities samples. This, however, did not detract from the overall function of the emergence traps as indicators of approximate diapause termination, and did provide an accurate account of accumulative emergence of beetles/ft² (0.093 m²) and emergence rate in terms of beetles/day as given in Figure 3. The emergence traps worked equally well in obtaining adults of clover root curculio, *Sitona hispidula* (Fabricius), and the clover leaf weevil, *Hypera punctata* (Fabricius). The emergence traps were installed 18 August, 1977 and the weekly trap counts were taken thereafter and are shown as mean/ft² (0.093 m²) ± SE for all three species in Table 1. This year all three species of weevils were collected on the first observation (24 August). This was much earlier than we had anticipated. Preliminary data involved with supplementary studies in the fall of 1976 showed the first emergence of clover root curculio on 14 September, clover leaf weevil on 22 September, and the alfalfa weevil on 29 September. Traps used in these studies were placed in the field as early as 26 August, 1976. In this latitude (Washington County, IL 38°20'N) the weevil is generally thought to return to alfalfa from aestivation in late September or October (Prokopy et al., 1967). Our emergence trap data and adult sweepnet counts taken in areas bordering wood edges indicated that some weevils began
fall migration earlier than was generally thought. The majority of adults (74%) did migrate in October, however, as was evidenced by both the emergence and flight traps.

The flight traps performed well in indicating migratory flight behavior of the alfalfa weevil. Although peak migration time was established, low densities may have gone undetected because of the relatively small surface area of each trap. Using a larger number of traps would lessen this problem. In the spring of 1977 we had only eight such traps, whereas in the fall we had a total of 16. Table 2 shows the flight trap data for the spring and fall of 1977. Since flight is somewhat passive (Prokopy and Gyrisco, 1965) and dependent on wind speed, for the spring sampling we attempted to face the traps
Table 1. Mean number/ft.² (0.093 m²) ± SE of *Hypera postica*, *Sitona hispidula* and *H. punctata* captured in emergence traps. Washington County, Illinois, August-November, 1977.

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th><em>H. postica</em></th>
<th><em>S. hispidula</em></th>
<th><em>H. punctata</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>24/8</td>
<td>.25 ± .12</td>
<td>1.64 ± .43</td>
<td>.14 ± .06</td>
</tr>
<tr>
<td>31/8</td>
<td>.47 ± .14</td>
<td>3.17 ± .78</td>
<td>.11 ± .05</td>
</tr>
<tr>
<td>11/9</td>
<td>.56 ± .26</td>
<td>1.56 ± .50</td>
<td>.17 ± .08</td>
</tr>
<tr>
<td>15/9</td>
<td>.19 ± .08</td>
<td>.11 ± .07</td>
<td>.11 ± .05</td>
</tr>
<tr>
<td>21/9</td>
<td>.17 ± .08</td>
<td>.11 ± .05</td>
<td>.19 ± .09</td>
</tr>
<tr>
<td>28/9</td>
<td>.11 ± .07</td>
<td>.08 ± .05</td>
<td>.06 ± .04</td>
</tr>
<tr>
<td>4/10</td>
<td>.28 ± .12</td>
<td>.08 ± .06</td>
<td>0</td>
</tr>
<tr>
<td>12/10</td>
<td>.58 ± .17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18/10</td>
<td>1.81 ± .38</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25/10</td>
<td>1.75 ± .24</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1/11</td>
<td>.44 ± .12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8/11</td>
<td>.03 ± .03</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6.64</td>
<td>6.75</td>
<td>.78</td>
</tr>
</tbody>
</table>

Table 2. Total number of *Hypera postica* and *Sitona hispidula* captured in flight traps. Washington County, Illinois, Spring and Fall, 1977.a

<table>
<thead>
<tr>
<th>Facing alfalfa at wood edge</th>
<th>Facing wood edge in alfalfa</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>H. postica</em></td>
<td><em>S. hispidula</em></td>
</tr>
<tr>
<td>19/5</td>
<td>0</td>
</tr>
<tr>
<td>25/5</td>
<td>6</td>
</tr>
<tr>
<td>26/6</td>
<td>20</td>
</tr>
<tr>
<td>8/6</td>
<td>0</td>
</tr>
<tr>
<td>14/6</td>
<td>1</td>
</tr>
<tr>
<td>25/6</td>
<td>1</td>
</tr>
<tr>
<td>6/7</td>
<td>0</td>
</tr>
<tr>
<td>13/7</td>
<td>0</td>
</tr>
<tr>
<td>20/7</td>
<td>0</td>
</tr>
<tr>
<td>27/7</td>
<td>0</td>
</tr>
<tr>
<td>4/8</td>
<td>0</td>
</tr>
</tbody>
</table>

aFigures are trap totals for eight traps in spring, 19 May-4 August, and for 16 traps in the fall.

toward alfalfa and toward the direction of the prevailing winds south and west. In late summer, 10 September, 1977, the traps were placed in the alfalfa fields and faced toward the woods, which included all compass points except south. Peak flight from the alfalfa fields occurred between 25 May and 2 June in the spring and to the alfalfa fields between 18 October and 25 October in the fall. There were only two clover leaf weevils recovered (14 June and 21 September) from the flight trap counts.

**LITERATURE CITED**


FALL TERMINATION OF AESTIVATION AND FIELD DISPERSAL OF THE ALFALFA WEEVIL (COLEOPTERA: CURCULIONIDAE) IN ILLINOIS¹


ABSTRACT

Emergence traps, flight traps, sweeping, and egg sampling were employed to determine fall termination of aestivation of the alfalfa weevil, *Hypera postica*, and patterns and timing of field reentry, and subsequent fall oviposition. Adult alfalfa weevils were found to terminate aestivation in wood edge field borders in mid-late October. Field reentry began in late October as a gradual process, starting at wooded field borders, with the field population equally dispersed by mid-November.

Attempts to control the alfalfa weevil, *Hypera postica* (Gyllenhal), with fall insecticide applications have met with varying degrees of success (Armbrust et al., 1966; Dorsey, 1966; Steinhauer and Blickerstaff, 1967). A means of determining the location of aestivating weevils, field reentry, and subsequent oviposition is needed to accurately time an insecticide application.

Prokopy et al. (1967) suggested that alfalfa weevils aestivate in woods bordering fields. This study identified the time of termination of alfalfa weevil aestivation, pattern of field reentry, and subsequent fall oviposition in Washington County, southern Illinois. This information can be integrated into a pest management program for control of the alfalfa weevil.

MATERIALS AND METHODS

This study was conducted in Washington County, southern Illinois, where there are many wooded field borders which serve as aestivation sites for alfalfa weevils. The study field was 100 m × 240 m (24 acres) and bounded on the north by soybeans, on the south by corn, on the west by a road and corn, and on the east by woods. Four sampling methods were employed: emergence traps, flight traps, sweeping, and egg samples.

The emergence traps were pyramidal in design and constructed to cover a 0.093 m² (1 ft²) area (Roberts et al., 1978). Any active organisms were collected into an inverted jar at the apex of the pyramid, as used by Musick and Fairchild (1970). The jar was fitted with an inverted paper drinking cup with a ring of Stickem Special® (Michel and Pelton Co., Emeryville, CA.) to prevent any organisms from leaving the jar. The bottoms of six emergence traps were inserted in the ground in the wooded field border along the alfalfa field. The “Stickem” was checked periodically and any alfalfa weevils caught were removed, recorded, and discarded.

The flight traps consisted of a rectangular box supported in the middle by a single galvanized metal pipe (Roberts et al., 1978). A sheet of clear plexiglas was positioned 30° forward of vertical above the box to deflect any flying organisms into a layer of ethylene.

¹This research is supported by the Illinois Natural History Survey, the Illinois Agricultural Experiment Station, National Science Foundation, and the U.S. Environmental Protection Agency, through a grant (NSF DEB 75-64223) to the University of California. The findings, opinions and recommendations expressed herein are those of the authors and not necessarily those of the University of California, the National Science Foundation or the Environmental Protection Agency.

²Illinois Natural History Survey and Illinois Agricultural Experiment Station, Urbana, IL 61801.
Fig. 1. Relationship of adult alfalfa weevil (a) emergence and flight activity, and (b) field population by sweeping, with time during fall of 1977, southern Illinois.

glycol contained in the box. Four traps were located in the alfalfa field 15.2 m (40 ft) from the wooded field border. The flight traps faced the field border to detect the movement from the aestivation sites. The traps were checked periodically and any alfalfa weevils were removed with an aquarium dip net, recorded, and discarded.

A standard 37.5 cm (15 in) diameter sweepnet was swung across the top portion of alfalfa in a pendulum type motion. One sweep was equal to one pass of the net, with the return pass counted as the second sweep. Five sets of 50 sweeps were taken at five evenly spaced intervals across the alfalfa field. The first set was near the wooded border of the field (east) with the fifth set coming at the west end near the road. The number of adult alfalfa weevils was counted for each set every sampling date.

Each egg sample consisted of a 232 cm² (0.25 ft²) area of alfalfa, removed with a knife, and placed in a plastic bag. The alfalfa was ground in a blender, and washed through a series of screens (10-30-80 U.S. Bureau of Standards) to locate the alfalfa weevil eggs. Five egg samples were collected at each of the five previously mentioned
locations where the sweeps were taken. The egg samples were collected until the average daily temperature was below the threshold of development for the alfalfa weevil, 8.89°C (48°F) (Koehler and Gyrisco, 1961).

RESULTS AND DISCUSSION

Alfalfa weevils did not terminate aestivation uniformly. Two distinct peaks of activity were indicated by the emergence traps (Fig. 1a). A small cohort of weevils appeared in the traps in early September, while the majority were found during mid-late October. There were over 300 total acres of alfalfa in the area surrounding the study field, thus forcing growers to cut much of their alfalfa before the optimum time. Poinar and Gyrisco (1962) suggested that cutting an alfalfa field in the spring, which results in much higher ground temperatures than otherwise, may initiate alfalfa weevil migration from the alfalfa into aestivation sites. This early initiation of aestivation by a minority of weevils may result in an early termination of aestivation by these same weevils, possibly explaining the emergence in early September.

The flight traps revealed alfalfa weevil dispersal from aestivation sites to follow peak emergence by one week (Fig. 1a). However, the small number of weevils trapped may indicate the flight traps were insufficient in number or placed at an incorrect height and distance from the field border. Another explanation may be that weevil field reentry consists of short flights or simply walking which would not be detected by the flight traps.

The sweeping data demonstrated a large population of adult weevils in the field three weeks after emergence in aestivation sites (Fig. 1b). Once the alfalfa weevils terminate aestivation in wooded borders and initiate field reentry, a feeding period at the edge of the alfalfa field may be necessary before complete field dispersal. Sweeping the field at five locations resolved the method of field reentry. Figure 2a shows that field reentry was indeed a gradual process beginning at the wooded field border. In late October over 50% of the alfalfa weevils were located nearest the wooded border. By mid-November the population was equally dispersed throughout the alfalfa field. Prokopy and Gyrisco (1963) in New York and Pamanes and Pienkowski (1965) in Virginia also found fall migration to occur in late October-early November.

The data retrieved from the egg samples demonstrate the same gradual method of field dispersal (Fig. 2b). On 1 November almost 60% of the weevil egg population was located along the woodedge. The egg density was uniform throughout the field by mid-November.

In summary, the majority of adult alfalfa weevils terminated aestivation in wooded field borders in mid-late October. Timing of termination may depend on time of initiation of aestivation. Field reentry began in late October nearest the wooded field border. Field dispersal was a gradual process with complete dissemination by mid-November.

Termination of adult alfalfa weevil aestivation and the pattern of field reentry may be different for various areas of the alfalfa weevil’s range due to availability of aestivation sites, timing of spring alfalfa cutting, and climatic conditions. Local information is necessary to predict accurately the time for fall application of insecticides in a pest management program.

LITERATURE CITED


Fig. 2. Gradual field reentry from wooded field border by adult alfalfa weevils as evidenced by (a) sweeping, and (b) egg samples, taken at five locations across an alfalfa field during fall of 1977, southern Illinois.
NOTES ON MAYFLY NYMPHS FROM NORTHEASTERN MINNESOTA WHICH
KEY TO *STENONEMA VICARIUM* (EPHEMEROPTERA: HEPTAGENIIDAE)

A review of the literature indicates that *Stenonema vicarium* (Walker) adults have not been collected from northeastern Minnesota. However, mayfly nymphs which key to that species, based on the descriptions in Lewis (1974), have been collected from many streams in the area which are also inhabited by nymphs of the closely related species, *Stenonema fuscum* (Clemens). The identity of *vicarium* nymphs from northeastern Minnesota has been questioned because males reared from similar *vicarium* nymphs in Wisconsin were determined to be *Stenonema fuscum rivulicolum* (McDunnough) (Flowers and Hilsenhoff, 1975). Previous records for *vicarium* are from New York, Ohio, Pennsylvania, Vermont, and West Virginia. The junior author has also seen typical *vicarium* adults from Michigan, Maine, and Ontario.

Since a *vicarium* male was reared from a stream near Kenora, Ontario, Canada, 240 km to the northwest (Lewis, 1974), it was thought these Minnesota nymphs, which appear to be *vicarium*, were *vicarium* rather than *fuscum rivulicolum*. However, nine of the typical *vicarium* male nymphs from Snake Creek, T.16N, R.10W, 5.12, Lake County, Minnesota were reared and found to be *fuscum rivulicolum*.

Diagnostic characters used to separate *fuscum* and *vicarium* nymphs are the amount of dark pigment on the ninth sternum and the number of setae on the maxilla (Lewis, 1974). These characters are sufficient to separate nymphs of these species in the eastern United States where both occur, but if *vicarium* occurs in Minnesota additional characters must be found to identify these species. Nymphs which key to *vicarium* should be reared to determine their identity.

LITERATURE CITED


Thomas M. Lager
Institute of Paper Chemistry
Appleton, WI 54911

Philip A. Lewis
Environmental Monitoring and Support Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

COLLECTING *NEOCURTILLA HEXADACTYLA*, THE NORTHERN MOLE CRICKET (ORTHOPTERA: GRYLLIDAE), IN IOWA

The northern mole cricket, *Neocurtilla hexadactyla* (Perty), is a common insect that is infrequently collected perhaps owing to its burrowing and nocturnal habits. It tunnels into moist soil and feeds on tender roots, earthworms, or various insect larvae (Blatchley, 1920). Although most general entomological collections exhibit specimens of mole crickets, these specimens are usually obtained only incidentally. Entomological textbooks often refer collectors to pond and stream banks for obtaining specimens of *hexadactyla*, but this insect is not always easily detected. In Michigan, *hexadactyla* occurs in sometimes abundant but very local populations under four general conditions: moist but not saturated soil, shoreline free from wave action, available organic food material, and a soil texture suitable for burrowing (Cantrall, 1943; 1968). In Iowa *hexadactyla* has been reported from only 20 countries (Froeschner, 1954) but is probably distributed state-
wide. This note describes two occurrences of collecting numerous specimens of *hexadactyla*.

On 21 and 23 July, 1976, *hexadactyla* was found in abundant numbers at Lost Lake in the Ledges State Park in Boone County, Iowa (a new county record). On the first date, *hexadactyla* was noted on the surface of moist soil adjacent to the water after a seine had been brought to shore. About 20 immature mole crickets were observed. The disruption of the upper surface soil near the water line by the seine apparently dislodged numerous specimens. Most were about 15 mm long and attempted to reburrow into the moist soil. On the second date, the soil near the shoreline was raked in an area of about 9 m long by 0.3 m wide to a depth of about 20 to 40 mm. More than 50 immature mole crickets were immediately detected. Mixed with the moist soil that had settled on the shoreline was decaying duckweed, *Lemna* sp., and watermeal, *Wolffia* sp.

The conditions observed at this collection site were likely typical of the general conditions required for successful development of northern mole crickets. The soil to about 1 m from the shoreline was moist but not saturated and wave action or moving water was not present. Decaying organic debris, particularly duckweed and watermeal, provided satisfactory material for some food, and soil texture was favorable for easy and rapid burrowing.

These observations may assist collectors in determining specific local collecting sites for *hexadactyla*.

LITERATURE CITED


J. R. DeWitt
Department of Entomology
Iowa State University of Science and Technology
Ames, IA 50011

TWO OBSERVATIONS OF PREDATION ON LEPIDOPTERA

During the early afternoon of 25 August, 1977, a large European mantid, *Mantis religiosa* Linnaeus, was observed feeding on an adult male monarch butterfly, *Danaus p. plexippus* Linnaeus (Danainae) while clinging to the flower head of a blazing star plant (*Liatris* sp.) on a cactus prairie at the Allegan State Game Area, Allegan County, Michigan. The mantid had apparently seized its prey as it nectared on the flower, and had the monarch firmly clutched in its foreclaws and had nearly subdued it. The butterfly was the second victim of the mantid; a set of male monarch wings lay beneath the plant.

The following morning, a few miles away in prairie habitat, I noticed a small noctuid moth, *Agrotis ducens* Walker, in an unusual position on another blazing star plant. The moth, a fresh male, was in contact with a tiny ambush bug, *Phymata enosa* Linnaeus. The moth was already dead, and apparently was about to be eaten.

I wish to thank Mogens C. Nielsen for aid in identifying the predators and the noctuid moth. All specimens are deposited in the Michigan State University Department of Entomology collection.

Irwin Leeuw
1219 Crystal Lake Road
Cary, IL 60013
INFORMATION FOR AUTHORS

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Manuscripts must be typed, double-spaced, with wide margins on white 8½" x 11" or equivalent size paper, and submitted in duplicate. Footnotes, legends, and captions for illustrations should be typed on separate sheets of paper. Titles should be concise, identifying the order and family discussed. The author of each species mentioned must be given fully at least once in the text. A common name for each species or group should be given at least once when such a name exists. The format of references should follow that used in recent issues. Photographs should be glossy and 8" x 10" size. Drawings, charts, graphs, and maps must be scaled to permit proper reduction without loss of detail. Contributors should follow the recommendations of the Style Manual for Biological Journals, available from the American Institute of Biological Sciences, 3900 Wisconsin Avenue, N.W., Washington, D.C. 20016.

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