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**COVER ILLUSTRATION**

*Leptoglossus occidentalis* (Hemiptera: Coreidae) on cone of *Pinus nigra*.
Photograph by Lincoln P. Nutting.
THE MICHIGAN ENTOMOLOGICAL SOCIETY

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A KEY TO CONTAINER-BREEDING MOSQUITOES OF MICHIGAN
(DIPTERA: CULICIDAE), WITH NOTES ON THEIR BIOLOGY

Thomas R. Wilmot¹, Deborah S. Zeller² and Richard W. Merritt³

ABSTRACT

An illustrated key to larvae and notes on the biology of container-breeding mosquitoes of Michigan are presented. Two species included in the key, *Aedes aegypti* and *Aedes albopictus*, are not endemic in Michigan, but occasional introductions could occur with commercial shipments of scrap tires or other containers.

Many container-breeding mosquito species are potential vectors of human disease agents in Michigan. *Aedes triseriatus* (Say), the most important vector of La Crosse Encephalitis virus, and *Culex pipiens* L. and *Culex restuans* Theobald, potential vectors of St. Louis Encephalitis virus, develop in natural and artificial containers.

Discarded tires may produce large populations of mosquitoes and are particularly important as a risk factor for mosquito-borne disease. Accumulations of tires have been directly and specifically associated with human cases of La Crosse Encephalitis in Wisconsin (Parry 1983), Minnesota (Hedberg et al. 1985) and other states. Reiter and Sprenger (1987) demonstrated that the used tire trade has been a major factor in the establishment and dispersal in the United States of *Aedes albopictus* (Skuse), a potential vector of several disease agents.

Public health and mosquito control personnel in Michigan are developing expanded programs of surveillance of tires for mosquito larvae. Identification keys for mosquito larvae are available (Darsie and Ward 1981), however, these include species not commonly found in Michigan containers and do not include *A. albopictus*. This report presents an illustrated key to larvae of mosquitoes known to inhabit artificial containers in Michigan plus two exotic species of potential concern, *Aedes aegypti* (L.) and *A. albopictus*, *Wyeomyia smithii* (Coquillett), which is found only in leaves of pitcher plants, and *Toxorhynchites rutilus septentrionalis* (Dyar and Knab), which occurs through the southeastern United States to as far north as Indiana and Ohio, are not included in the key. The key is designed specifically for Michigan, but could be used throughout much of the north central U.S.

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MORPHOLOGY

The terminology used here follows that of Harbach and Knight (1980). The body of a mosquito larva is divided into three distinct regions: head, thorax and abdomen (Figure 1). The thorax is composed of fused pro-, meso- and metathorax which are distinguished by series of bilaterally paired setae. The abdomen is composed of ten segments, of which nine are apparent. The first seven abdominal segments are similar and unmodified. The posterior segments are functionally specialized and provide many useful taxonomic characters (Figure 1). The eighth segment of most mosquito larvae bears a series of projections known as the comb scales laterally and an elongate siphon dorsally. At the base of the siphon is a small lateral sclerite, the siphon acus. In most species the siphon bears a comb-like row of spines, the pecten. The final segment, referred to as the tenth abdominal segment or the anal segment, possesses a sclerotized saddle dorsally. The anal papillae are soft elongate structures surrounding the anus. Setae of mosquito larvae are numbered sequentially for each body region. For example, seta number 5 on the head capsule (cranium) is designated 5-C and seta number 1 on the tenth abdominal segment is designated 1-X. The abbreviations used in setal designation are as follows:

- Cranium: C
- Prothorax: P
- Mesothorax: M
- Metathorax: T
- Siphon: S
- Abdominal Segments: I, II, ..., X

KEY TO THE MOSQUITO LARVAE (FOURTH INSTAR) OF MICHIGAN CONTAINERS

1. Siphon absent (Fig. 2) (Genus *Anopheles*) ........................................ 2
2. Siphon present (Fig. 1) .............................................................. 3
3. Siphon without pecten spines (Figs. 5, 6) (Genus *Orthopodomyia*) .... 4
4. Siphon with pecten spines (Figs. 7, 8b) ........................................ 5
5. Siphon with pair of setae arising near base (with or without setae beyond base) (Fig. 7) (Genus *Culiseta*) .... *Culiseta inornata* ........................................................................ 6
6. Siphon with several pairs of setae (Figs. 8b, 9b, 10) (Genus *Culex*) ........................................ 7
7. Siphon with a single pair of setae, setae arising near midsiphon (Figs. 11–15) (Genus *Aedes*) ........................................ 9
8. Siphon long and slender (Fig. 8b) .............................................. *Culex territans*
9. Siphon 5-C and 6-C single or double (Fig. 8a); Siphon long and slender (Fig. 8b) .............................................. 
10. Siphon 5-C and 6-C with three or more branches (Fig. 9a) .... 8
8(7) Siphon usually with 4 pair of setal tufts, tufts generally in a line but with apical or subapical pair out of line; Seta 2-X usually with two or three branches (Fig. 9b) .......................... Culex pipiens

8' Siphon with several irregularly-placed single hairs, perhaps one or two pair of setae tufted; Seta 2-X usually single (Fig. 10) ........

9(6') Seta 1-S inserted within pecten; Comb scales 24 to 90 (usually more than 34) in a patch, individual comb scale short with subequal spinules; siphon short and blunt (Fig. 11) .......................... Aedes atropalpus

9' Seta 1-S beyond pecten; Comb scales 6-15 in a single or irregular double row; Individual comb scales variable (Figs. 12-15) .......................... 10

10(9') Comb scale blunt apically, evenly fringed with short spinules; siphon acus present (Figs. 12, 13) .......................... 11

10' Comb scale thorn-like, with pointed median spine; siphon without acus (Figs. 14, 15) .......................... 12

11(10) Siphon acus attached or near to main sclerite; anal papillae relatively short and tapered, ventral pair shorter than dorsal; Seta 1-X usually with four or more branches (Fig. 12) .......................... Aedes triseriatus

11' Siphon acus detached from main sclerite; Anal papillae bulbous, subequal in size; Seta 1-X usually with one to three branches (Fig. 13) .......................... Aedes hendersoni

12(10') Comb scale with strong subapical spinules (Fig. 14) .......................... Aedes aegypti

12' Comb scale with fringe of fine spinules basally (Fig. 15) .......................... Aedes albopictus

BIological notes

Aedes (Ochlerotatus) atropalpus (Coquillett)
Aedes atropalpus occurs from southern Canada through the eastern United States. In Michigan, it is most commonly taken along the upper peninsula shores of Lakes Superior and Michigan. Eggs may be deposited on the sides of cavities or singly on the surface of the water, thus this species is able to survive winter and periods of drought in the egg stage and to quickly colonize new habitats (Berry and Craig 1984). Larvae are usually found in rock crevices and rock-filled pools but may inhabit tires and other artificial containers. Adults are autogenous and have been maintained in culture for several generations without a blood meal. This species is seldom abundant but may be of concern locally. Aedes atropalpus is a potential vector of La Crosse virus (Craig 1983) and it is capable of transmitting Eastern Equine Encephalomyelitis and Western Equine Encephalomyelitis viruses (Zavortink 1972).

Aedes (Protomacleaya) hendersoni Cockerell
Aedes hendersoni is the most widespread treehole-breeding mosquito in North America (Zavortink 1972), however, it is much less common in tires than is Aedes triseriatus. Adults of these sibling species are difficult to separate morphologically, but larvae are distinctive. Live A. hendersoni larvae are easily distinguished from those of A. triseriatus by their lighter color. Eggs are the overwintering stage and are deposited on the sides of containers just above the water line. Aedes hendersoni is biologically capable of transmitting the nematode Dirofilaria immitis (Rogers and Newson 1979), but its definitive role in the transmission of dog heartworm in Michigan is unknown. It is probably not an effective vector of La Crosse Encephalitis virus (DeFoliart et al. 1986).
Figure 1. *Culex pipiens* larva; dorsal view.
Figures 6–8: 6. Orthopodomyia alba; lateral view of terminal abdominal segments. 7. Culiseta inornata; lateral view of siphon. 8a. Culex tiritans; dorsal view of head; 8b. lateral view of terminal abdominal segments.

*Aedes (Protomacleaya) triseriatus* (Say)

*Aedes triseriatus* is distributed throughout the eastern United States. It is one of the most common species seen in tires and other artificial containers in Michigan. Eggs are deposited on the sides of containers, just above the water line, and the winter is passed in the egg stage. Larvae are most common in treeholes with decaying vegetation (i.e. leaf litter) (Walker et al. 1991) and in shaded areas. *Aedes triseriatus* is the most important vector of La Crosse Encephalitis virus in the midwest and may be an important vector of dog heartworm in Michigan (Rogers and Newson 1979). DeFoliart (1983) and Craig

(1983) have recently reviewed the biology of this species as it relates to disease transmission and control.

*Aedes (Stegomyia) aegypti* (Linnaeus)

*Aedes aegypti* is a highly domestic mosquito found throughout the tropical regions of the world and extending into temperate areas seasonally. It is not endemic in Michigan, but it could be introduced and survive the summer months. Eggs are laid singly just above the water line and can withstand
desiccation for several months with little if any reduction in vigor. Larvae are commonly seen in fairly clean water. They are unable to survive prolonged exposure to temperatures above 40° or below 10° C. *Aedes aegypti* is the most important vector of dengue and urban yellow fever throughout much of the world. Christophers (1960) presented an extensive review of the biology of this species.

*Aedes (Stegomyia) albopictus* (Skuse)

*Aedes albopictus* is found throughout the Oriental Region and in parts of the United States, Mexico and Brazil. It is not yet known from Michigan, but it has been found in Illinois, Indiana and Ohio. *Aedes albopictus* has been well studied in Asia and considerable variation in biology with different strains has been observed. Hawley et al. (1987) suggest that the strains which have been introduced into the U.S. are probably from Japan.

*Aedes albopictus* colonizes a wider range of containers than does *A. aegypti*, and is therefore less susceptible to source reduction programs. Eggs are deposited on the sides of containers just above the water line. This species is an important vector of dengue virus in Southeast Asia. It can transmit dog heartworm and could potentially become involved in the transmission of La Crosse Encephalitis virus in the United States. Hawley (1988) has recently reviewed the biology of this species.

*Anopheles (Anopheles) barberi* Coquillett

*Anopheles barberi* is widespread throughout the eastern United States. In Michigan, it occurs at least as far north as the central lower peninsula (Wilmot et al. 1987). *Anopheles barberi* prefers large permanent treeholes, but it may be collected from tires. Eggs are laid singly on the surface of the water. Larvae are facultative predators and are seldom taken in large numbers. This species overwinters as larvae in Michigan (Allen and Wilmot 1988), and the first adults emerge during late May or early June. Adults will feed on humans, but populations are seldom large and this species is not an important disease vector.

*Anopheles (Anopheles) punctipennis* Say

*Anopheles punctipennis* is the most widely distributed anopheline in the U.S. and is found throughout Michigan. Hibernation is by adult females, and oviposition begins in early spring. Eggs are laid singly on the surface of the water. *Anopheles punctipennis* larvae are found in a variety of habitats including streams, ponds and marshes. They prefer cool, unpolluted water and are less commonly taken from tires than are those of *A. quadrimaculatus*. *Anopheles punctipennis* is capable of transmitting dog heartworm and malaria, but is seldom seen in large enough numbers to be of serious concern. In Michigan, this species may be an important vector of Jamestown Canyon virus (DeFoliart et al. 1986).

*Anopheles (Anopheles) quadrimaculatus* Say

*Anopheles quadrimaculatus* is widespread throughout the eastern U.S. and is the most common anopheline in Michigan containers. However, it is uncommon in tires. Hibernation is by adult females, and eggs are laid singly on the water surface. Larvae are found primarily in impounded water habitats with floating debris and vegetation. *Anopheles quadrimaculatus* was the primary vector of human malaria when that disease was endemic in the eastern U.S. This species also may be involved in the transmission of Jamestown Canyon virus in Michigan (DeFoliart et al. 1986). Larvae of *A. quadrimaculatus* and *A. punctipennis* are difficult to distinguish morphologically.
**Culex (Culex) pipiens** Linnaeus

*Culex pipiens* is the most widely distributed of all mosquitoes and it is one of the most common species in Michigan tires. Hibernation is as adult females, and eggs are laid together as rafts on the water surface. Larvae thrive in water of high organic content. Significant variation has been observed in adult feeding preference with different strains and subspecies and it is unknown if this species will feed on humans in Michigan. Autogeny has been reported from many temperate areas and avian hosts are usually preferred by those females seeking a blood meal. In areas where it will feed on humans, this species is a potential vector of St. Louis Encephalitis virus, Western Equine Encephalomyelitis virus and dog heartworm.

**Culex (Culex) restuans** Theobald

*Culex restuans* is widely distributed in North America and very common in Michigan tires. Hibernation is as adult females. Eggs are laid together as rafts on the surface of the water. Larvae are found in a wide variety of habitats including ditches, flooded fields, ponds and containers. There is some question concerning adult feeding preferences and vector capacity of this species which may be due, in part, to the difficulty in separation of field collected adults of the subgenus *Culex*. However, this species should be considered a potential vector of St. Louis Encephalitis virus, Western Equine Encephalomyelitis virus and dog heartworm.

**Culex (Neoculex) territans** Walker

*Culex territans* is widely distributed across Canada, the United States and Mexico. This species can be found throughout Michigan, but it is not commonly seen in tires. Larvae prefer cool clear water and are found predominantly in streams, swamps and marshes. Eggs are laid in rafts along the edge or on the surface of the water. Adults are very resistant to cold and winter is passed in this stage. Adults feed primarily on cold-blooded animals and are not important vectors of human disease.

**Culiseta (Culiseta) inornata** (Williston)

*Culiseta inornata* is found in much of the Nearctic Region from Canada to northern Mexico. This is the most abundant species of the genus *Culiseta* in Michigan, but it is rarely seen in tires. Larvae prefer cold water and are more commonly found in swamps, marshes and flooded fields. Eggs are laid in rafts on the water surface. Adults feed primarily on large animals. *Culiseta inornata* has been found infected with Western Equine Encephalomyelitis virus, Eastern Equine Encephalomyelitis virus and Jamestown Canyon virus, but it seldom occurs in sufficient numbers to be considered an important disease vector.

**Orthopodomyia alba** Baker and **Orthopodomyia signifera** (Coquillet)

*Orthopodomyia alba* and *O. signifera* are found throughout the eastern United States. Scattered populations of *O. signifera* occur in southwestern states. *Orthopodomyia alba* was the predominant mosquito species in a survey of treeholes in northern Indiana (Copeland 1984), but larvae primarily inhabit treeholes and wooden containers and neither species is common in Michigan tires. Live *O. alba* larvae are easily distinguished from those of *O. signifera* by their lighter color. Eggs are laid singly on the edge of containers or onto the water surface. Larvae are extremely tolerant of cold (Copeland and Craig 1990), and hibernation is in the larval stage. Adults prefer to feed on birds and are not known to attack man. *Orthopodomyia signifera* may play some role in enzootic maintenance of Eastern Equine Encephalomyelitis virus.
ACKNOWLEDGMENTS

We thank Edward Walker, Randall Knepper and Elizabeth Waffle for review and comments on this manuscript. Dr. George B. Craig, Jr. very kindly provided specimens of *Aedes atropalpus* and *Aedes albopictus*. Cindy A. Plant typed the manuscript. This work was supported by a grant from the Michigan Mosquito Control Association, and supported, in part, by National Institutes of Health Grant AI-21884, awarded to R.W.M.

LITERATURE CITED


THE FOOD PLANTS AND DISTRIBUTION OF THE
AMERICAN PLUM BORER (LEPIDOPTERA: PYRALIDAE)1

David J. Biddinger2 and Angus J. Howitt3

ABSTRACT

The North American geographical and host plant distributions for the American plum borer, *Euzophera semifuneralis*, are reported. Literature and curatorial surveys found the plum borer to be present in 34 states in the U. S. as well as parts of Canada, Mexico, and South America. Pheromone surveys and direct observation found it to be present in high numbers in most cherry and plum orchards in Michigan and in 28 counties of the lower peninsula. A very wide host range representing 15 plant families was found, with most host species in the Rosaceae.

The American plum borer, *Euzophera semifuneralis* (Walker) has been a major pest in cherry and plum orchards in Michigan only since the early 1970's (Brunner & Howitt 1981). The rapid spread of this moth from relative obscurity to economic importance in Michigan has been due almost entirely to the increase in tree wounding associated with the extensive use of mechanical harvesting of tart and sweet cherries in nearly all commercial plantings during this same period. The larva is a cambium feeder and is unusual among lepidopteran fruit tree borers in that it is a pyralid (Subfamily: Phycitinae) and not a sesiid clearwing borer (Fig. 1).

The American plum borer is presently a much more serious pest on cherry and plum in Michigan than the main sesiid pest, the lesser peachtree borer, *Synanthedon pictipes* (Grote & Robinson). Lesser peachtree borer larvae tend to feed randomly up and down the entire tree including the upper scaffold limbs, occasionally girdling individual limbs, but almost never completely girdling the trunks of older trees. Plum borer larvae concentrate around the damaged tissue where they enter and feed around the trunk or limb until it is completely girdled (Fig. 2). On trees that have been mechanically harvested, 90% of the larvae will be found in the trunk and lower scaffold limbs. Damage is most severe on young trees, but high populations of plum borer larvae are capable of girdling and killing full grown trees in less than 10 years (Biddinger 1989). Full-grown larvae of the plum borer are 18-25 mm long at normal distension and the color varies from a dusky, greenish-white to a grayish, red-purple with a head capsule, cervical shield and anal plate that are dark brown (Fig. 3). Most sesiids associated with the same hosts are more pure white with light yellowish-brown head capsules.

1Salaries and research support provided by Michigan State University, Department of Entomology, E. Lansing, Mf.
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37731 Mariah, Brookbridge Sub, Brooksville, FL 33573.
The wide geographical distribution and extreme diversity in foodplants of the American plum borer has allowed it to take advantage of relatively recent horticultural practices such as the pruning and grafting of fruit, nut and ornamental trees and the use of clonal rootstocks. The larvae are unable to bore into the cambium without some sort of existing wound. In nature, this generally consists of sun-scald, winter injury, cankers and black knot growths from diseases (Biddinger 1989, Blakeslee 1915). Horticultural practices such as those already mentioned, have greatly increased wounds on trees and thereby provide a means of entry to the cambium. Other means of entry to the cambium include scrapes on trunks from orchard mowers, adventitious root growths or burr knots on the trunks of some dwarfing rootstocks, and physiological incompatibilities at the union of a rootstock and its scion (Biddinger 1989). Mechanical trunk or limb shakers used for harvesting cherries have hydraulic clamps that may exert pressures of over 1,000 psi which crack the bark and crush underlying cambium, thus creating ideal entry sites for plum borer larvae.

Little work was done on the biology of this pest until 1985, when populations were reaching epidemic proportions in some of the cherry growing areas of Michigan. A survey of cherry orchards in western Michigan found this borer to be present in most cherry orchards, averaging as high as 5 to 12 borers per tree in some commercial orchards in Oceana and Leelanau Counties (Biddinger 1989). An estimated statewide reduction in the life of cherry orchards of about a third has been largely attributed to direct girdling damage and indirect damage such as disease introduction from this borer (Biddinger 1989).

Figure 1. American plum borer, *Euzophera semifuneralis*, adult
Figure 2. Tart cherry tree with bark peeled away to reveal underlying American plum borer girdling damage to the cambium.

1989). Weiner and Norris (1983) also found the plum borer to be a serious widespread pest of tart cherries in Wisconsin, but they worked only on control methods and not the biology of the borer. Little was known about the biology and distribution of the plum borer until recently, and the following study is the most comprehensive listing of hostplants and geographical distribution to date.
Figure 3. American plum borer larva.

MATERIALS AND METHODS

The literature, especially economic, was reviewed to determine host and North American distribution records for the American plum borer. The last major review was by Heinrich (1956) and several foodplants and localities not previously recorded were found by the authors. These additional records on fruit and ornamental trees were taken in Michigan by excavating larvae and pupae from the cambium of borer infested trees. Additional distribution records for North America were found in a general review of the more recent literature and from a survey of curators of entomological collections from selected states.

The distribution of the American plum borer throughout the state of Michigan was determined through the use of a newly developed pheromone and through direct observation of larvae in suspected hosts. In 1985-86, a direct damage survey of 30 cherry and plum orchards in 12 Michigan counties was undertaken. Larvae were excavated from the cambium using long-handled screwdrivers and hammers to pry away the overlying areas of dead bark. Black light trap records by Mr. John Newman and specimens from the holdings of the Michigan State University Entomological collection were noted. In 1985, the pheromone for the American plum borer was isolated by Dr. Wendell Roeloffs at Cornell University (Biddinger 1989) and became commercially available the following year. From 1985-86, the plum borer pheromone was used in Phercon II sticky traps to survey most of the counties of the Michigan's lower peninsula.
Figure 4. North American distribution of the American plum borer, *Euzophera semifuneralis*. 
RESULTS

_Euzophera semifuneralis_ was first noted as a pest of plum by S. A. Forbes in 1890 and was given its now accepted common name. It was noted as a serious pest in the pruning wounds of pecans (Pierce & Nichols 1941), and has been known as a pest of walnut under the synonym of _Euzophera aglaella_ which was commonly known as the "Walnut Girdler" (Essig 1929). The plum borer has been noted as a minor pest of apple, pear, and peach (Blackslee 1915, Kelsey & Stearns 1957, Sanderson 1901, Slingerland & Crosby 1914, Brunner & Howitt 1981), almonds (Van Steenwyk 1986, Anonymous 1985, Moller & DeVay 1968), mountain ash (Kellicott 1891), olive (Essig 1917), London plane trees and sycamore (Johnson & Lyon 1988).

As noted in the economic literature, _E. semifuneralis_ has been found on a very diverse range of forest, ornamental, and fruit trees across Canada and the United States. Although a native insect, it clearly prefers the imported varieties of plum and cherry as its favorite hosts over the native species (Lockhead 1918). Originally described from specimens from Columbia, South America (Walker 1863), records for its foodplants in the Mexican and South American part of its range are lacking. While generally a cambium feeder, it can be found feeding in various growths such as cankers, callouses, and burr knots caused by diseases and physiological disorders of trees as previously noted. Although it has been found in dead wood and stumps of its various
foodplants (Rhoads 1924, Biddinger 1989), the plum borer cannot live in dry materials. It can also be found in stored materials such as sweet potatoes (Westcott 1973). It has infrequently been found in stems of plants such as cotton and cornstalks in the southern part of its range (Bottimer 1926, Heinrich 1956). A list of foodplants compiled from the literature and personal observations for *E. semifuneralis* in various regions of the U. S. can be found in Table 1. Most of the host species reside in the family Rosaceae, but 15 families are represented. Larvae were reared on a pinto bean diet under laboratory conditions (Biddinger 1989).

The American plum borer is widely distributed throughout the North American continent (Heinrich 1956, Blakeslee 1915, Kimball 1915, Van Steenwyk et al. 1986, Forbes 1891, Hulst 1890, Forbes 1923, Leonard 1926, Kellicot 1891, Brimley 1938, Pierce and Nichols 1941, Weiner and Norris 1983, Bottimer 1926). It has been recorded on the west coast of Canada and there have been unpublished reports of this moth from areas of southern Canada adjacent to the Great Lakes and southern Quebec. It appears to be absent in the northern and central provinces. A survey of selected state entomological collections, as well as reports in the literature, place *E. semifuneralis* in 34 states (Fig. 4). Its range does not seem to reach into some of the north-central states such as the Dakotas and Montana or the far north-eastern states such as Vermont and Maine. Other states which lack records such as Alabama, Iowa, Louisiana, Oklahoma, and Rhode Island are most probably included in its geographical range considering records from surrounding states, but specimens haven’t yet been identified. Other states such as Idaho, Minnesota, and Nevada in which the plum borer has not been recorded, may also be part of its range, but seem less likely. It has not been found in Hawaii or Alaska.

A survey of the distribution of *E. semifuneralis* in the state of Michigan has shown it to be present in about 85% of all plum and cherry orchards in western Michigan (Biddinger 1989). Damage surveys in these areas have shown Allegan, Atrim, Benzie, Cass, Charlevoix, Grand Traverse, Leelenau, Manistee, Mason, and Oceana counties to be the most heavily infested. Holdings from the Michigan State University entomology museum, black light traps records from Dr. John Newman, and recent pheromone trapping surveys, indicate *E. semifuneralis* is found in 29 counties in the lower peninsula (Fig. 5). Because of its wide host plant distribution, however, it is probably found in all counties of the lower peninsula with its range extending up into parts of the upper peninsula.

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Table 1.—Foodplants of the American Plum Borer in North America

<table>
<thead>
<tr>
<th>Family</th>
<th>Plant Name</th>
<th>Common Name</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONVOLVULACEAE</td>
<td>Ipomoea batatas Lam.</td>
<td>Sweet potato (stored tubers only)</td>
<td>North Carolina</td>
</tr>
<tr>
<td>EBENACEAE</td>
<td>Diospyros virginiana L.</td>
<td>Persimmon</td>
<td>Ohio</td>
</tr>
<tr>
<td>FAGACEAE</td>
<td>Quercus palustris Muench.</td>
<td>Pin Oak</td>
<td>Texas</td>
</tr>
<tr>
<td></td>
<td>Quercus virginiana Mill</td>
<td>Southern Live Oak</td>
<td>Texas</td>
</tr>
<tr>
<td>GINKGOACEAE</td>
<td>Ginkgo biloba L.</td>
<td>Ginkgo</td>
<td></td>
</tr>
<tr>
<td>GRAMINEAE</td>
<td>Zea mays L.</td>
<td>Corn stalks</td>
<td>Texas</td>
</tr>
<tr>
<td>HAMAMELIDACEAE</td>
<td>Liquidambar styraciflua L.</td>
<td>Sweetgum</td>
<td></td>
</tr>
<tr>
<td>JUGLANDACEAE</td>
<td>Carya illinoensis C. Koch</td>
<td>Pecan</td>
<td>California, Texas</td>
</tr>
<tr>
<td></td>
<td>Carya sp.</td>
<td>Hickory</td>
<td>New York</td>
</tr>
<tr>
<td></td>
<td>Juglans nigra L.</td>
<td>Black Walnut</td>
<td></td>
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<tr>
<td></td>
<td>Juglans microcarpa</td>
<td>River Walnut</td>
<td>New Mexico, Arizona, Utah</td>
</tr>
<tr>
<td>MALVACEAE</td>
<td>Gossypium hirsutum L.</td>
<td>Cotton stems</td>
<td>Mississippi</td>
</tr>
<tr>
<td>MORACEAE</td>
<td>Morus alba L.</td>
<td>Mulberry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Morus spp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLEACEAE</td>
<td>Olea europea L.</td>
<td>Olive</td>
<td>California</td>
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<tr>
<td>PLATANACEAE</td>
<td>Platanus occidentalis L.</td>
<td>Sycamore</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Platanus acerifolia Willd</td>
<td>London Plane Tree</td>
<td>Eastern U.S.</td>
</tr>
<tr>
<td>ROSACEAE</td>
<td>Prunus dulcis (Mill)</td>
<td>Almonds</td>
<td>California</td>
</tr>
<tr>
<td></td>
<td>Malus domestica L.</td>
<td>Apple</td>
<td>Delaware, Michigan, New York, Virginia</td>
</tr>
<tr>
<td></td>
<td>Prunus armeniaca L.</td>
<td>Apricot</td>
<td>Michigan, California</td>
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<tr>
<td></td>
<td>Malus spp.</td>
<td>Flowering Crab</td>
<td>Michigan</td>
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<td>Pyrus communis L.</td>
<td>Common Pear</td>
<td>Delaware</td>
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<td>Sorbus americana Marsh.</td>
<td>Mountain Ash</td>
<td>Michigan, New York</td>
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<td></td>
<td>Prunus persica Batsch</td>
<td>Peach</td>
<td>Michigan, Wisconsin, California, British Columbia, Ontario, New York</td>
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<td></td>
<td>Prunus domestica L.</td>
<td>Plum</td>
<td>Michigan, Wisconsin, California</td>
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<tr>
<td></td>
<td>Prunus avium L.</td>
<td>Sweet Cherry</td>
<td>California</td>
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Table 1.—Food plants of the American Plum Borer in North America (Continued)

<table>
<thead>
<tr>
<th>Food plants</th>
<th>Genus</th>
<th>Hosts</th>
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<tbody>
<tr>
<td>Tart Cherry</td>
<td>Prunus cerasus L.</td>
<td>Michigan, Wisconsin, California</td>
</tr>
<tr>
<td>Pin &amp; Wild Cherries</td>
<td>Prunus spp.</td>
<td>Michigan, Ontario</td>
</tr>
<tr>
<td>Wild Plums</td>
<td>Prunus spp.</td>
<td>British Columbia, Ontario, Michigan</td>
</tr>
<tr>
<td>&quot;June Drop&quot; Apple</td>
<td>Malus domestica L.</td>
<td>Pennsylvania</td>
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<tr>
<td>SALICACEAE</td>
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<td></td>
</tr>
<tr>
<td>Willow</td>
<td>Salix spp.</td>
<td>Illinois</td>
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<tr>
<td>Poplar</td>
<td>Populus spp.</td>
<td></td>
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<tr>
<td>TILIACEAE</td>
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<td></td>
</tr>
<tr>
<td>Basswood</td>
<td>Tilia spp.</td>
<td>New Jersey</td>
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<tr>
<td>ULMACEAE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elm</td>
<td>Ulmus spp.</td>
<td>Texas</td>
</tr>
<tr>
<td>CANKERS ON HOSTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black-knot of plum</td>
<td>Dibotryon morbosum</td>
<td>Michigan, California</td>
</tr>
<tr>
<td>Olive-knot</td>
<td>Pseudomonas savastanoi</td>
<td>California</td>
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</table>

LITERATURE CITED

_____. 1929. Insects of Western North America. 710 pp.
FURTHER EASTERN RANGE EXTENSION AND HOST RECORDS FOR
LEPTOGLOSSUS OCCIDENTALIS (HETEROPTERA: COREIDAE):
WELL-DOCUMENTED DISPER Sal OF A HOUSEHOLD NUISANCE

Wayne K. Gall

ABSTRACT

Leptoglossus occidentalis is reported for the first time from Connecticut, New York, Ontario, Pennsylvania, and Wyoming, representing an eastern range extension from Indiana and Michigan. Tsuga canadensis and Pinus mugo are added to the long list of coniferous hosts of this coreid. Approximately 233 of 316 northeastern specimens were collected inside or on the outside of buildings from August-May, confirming previous observations that L. occidentalis uses buildings for overwintering. Isolated records from Connecticut and eastern Pennsylvania suggest human-mediated dispersal may augment its natural dispersal. The pattern of distribution records on a map of North America identifies L. occidentalis as one of the best documented examples of a native insect expanding its range eastward in North America. Striking differences in the color pattern of the abdominal dorsum facilitates separation of the closely related L. occidentalis and L. corculus.

McPherson et al. (1990) reported new distribution records for Leptoglossus occidentalis Heidemann (Heteroptera: Coreidae) from Illinois, Michigan, and confirmed one previous record from Indiana. They cited previously published records which suggest that this coreid, originally perceived as an element of the western fauna, has been expanding its range eastward.

This paper reports new distribution and host records for L. occidentalis, historically documents the eastward expansion of its range on a map, proposes the use of color pattern of the abdominal dorsum as a diagnostic character to differentiate the morphologically similar L. occidentalis and L. corculus (Say), and discusses the aesthetic nuisance which this bug causes when it enters homes seeking overwintering sites.

In western North America, L. occidentalis has been reported to feed on the seeds of cones (especially developing cones) of at least ten species of conifers, as well as some hybrids of these species (Koerber 1963, Krugman and Koerber 1969, Hedlin et al. 1980). Five additional species of native or introduced conifers have been reported as food plants in central and eastern North America (Schaffner 1967, Katovich and Kulman 1987, McPherson et al. 1990). Its direct economic impact results from reducing the quality and/or viability of conifer seed crops, since feeding tests in western North America indicate it has the potential of feeding on the seeds of most commercially important conifers there (Hedlin et al. 1980, Koerber 1963, Krugman and Koerber 1969).

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Here I report first records of *L. occidentalis* feeding on *Tsuga canadensis* and *Pinus mugo* (both Pinaceae), thus adding to the already lengthy list of coniferous hosts of *L. occidentalis*. On 28 July 1991, I collected 18 adults and 2 nymphs of *L. occidentalis* feeding on *T. canadensis* in a suburban yard in western New York (Town of Orchard Park, Erie County). The proboscis of these bugs was directed ventrad, perpendicular to the long axis of the body, and with one exception, penetrated the developing (i.e., green, unopened) cones; the one exception appeared to have its proboscis inserted into a branchlet of the new year's growth. At the same site on the same day, I also observed two adults of *L. occidentalis* similarly feeding on developing cones of *P. mugo*. Further details of the feeding habits and life history of this species are provided by Koerber (1963), Krugman and Koerber (1969), Hedlin et al. (1980), and McPherson et al. (1990).

**METHODS**

During the period January, 1990 to March, 1992, I collected or examined approximately 300 specimens of *L. occidentalis* from western and central New York, and southern Ontario. They were submitted for identification to the Buffalo Museum of Science, Cornell Insect and Plant Disease Diagnostic Laboratory (Ithaca, NY), Genesee County Cooperative Extension (Batavia, NY), Niagara County Cooperative Extension (Lockport, NY), Royal Ontario Museum (Toronto), and University of Guelph (Ontario), by concerned persons who found these relatively large, conspicuous bugs (length 16–20 mm) inside or congregating on the outside of their homes from late summer to early spring. These specimens represent the first distribution records for New York and Ontario, and indicate that this bug is continuing to expand its range eastward.

S.A. Marshall and J.E. Swann loaned me 48 specimens of *L. occidentalis* from the University of Guelph Insect Collection, including the earliest record (November, 1985) of this species from Ontario. Marshall (1992) postulates that this bug moved into southern Ontario from adjacent southeastern Michigan, where the earliest published records are from 1983 (McPherson et al. 1990). The loan from Guelph also included one *L. occidentalis* from Wyoming, the first record for that state.

A.G. Wheeler, Jr. (pers. comm.) provided two unpublished records of *L. occidentalis* from Pennsylvania, representing the first records for that state. The single specimen from York Co. in eastern Pennsylvania is especially interesting, since it was intercepted in a rail shipment of corn from Mendota, Illinois. The new records for *L. occidentalis* in New York, Ontario, and Pennsylvania, known to me through March, 1992, are shown in Figure 1.

A first record for Connecticut was also provided by R.J. Packauskas (pers. comm.), who reported a single specimen collected on a Christmas tree [Douglas fir, *Pseudotsuga menziesii* (Pinaceae)] in a house in December, 1985.

Ironically, I also discovered in my personal collection one *L. occidentalis* which I had collected in south central Wisconsin in October, 1979, while I was a graduate student at the University of Wisconsin at Madison. This record is six years earlier than the only published record for Wisconsin of which I am aware (Katovich and Kulman 1987). The distribution of *L. occidentalis* in North America, including the records reported here, is shown in Figure 2.

Specimens were identified using the key to species of *Leptoglossus* north of Mexico provided by McPherson et al. (1990). Unless specified otherwise, specimens were identified by the author, and deposited at the Buffalo Museum of Science, Buffalo, NY. Specimens have also been deposited at the
Figure 1. Records of *Leptoglossus occidentalis* by county or regional municipality in New York, Ontario, and Pennsylvania.

Canadian National Collection, Biosystematics Research Centre, Ottawa (CNC); collection of the Insect and Plant Disease Diagnostic Laboratory, Cornell Cooperative Extension, Ithaca, NY (IPDDL); Cornell University Insect Collection, Ithaca, NY (CUIC, Voucher Specimens Lot #1208); Bureau of Plant Protection, Pennsylvania Department of Agriculture, Harrisburg (PDA); Royal Ontario Museum, Toronto (ROM); the University of Guelph Insect Collection, Guelph, Ontario (UGIC); and the Yale Peabody Museum, New Haven, Connecticut (YPM).

COLLECTION RECORDS

outside of house, 16 Nov. 1990 (5 $\delta$, 7 $\varphi$), coll. T and L Stewart; on outside of house (11 $\varphi$, 6 $\delta$), in attic (1 dead/sprayed $\delta$), on outside of outbuilding (1 nymph), 26 Nov. 1990, coll. WK Gall et al., CUIC (1 $\delta$, 1 $\varphi$ voucher specimens); on outside wall or inside house, 3–17 Dec. 1990 (5 $\delta$, 8 $\varphi$), coll. D Brassel; on head of guest arriving at house, 8 Dec. 1990 (1 $\delta$), coll. J Goldfarb. Town of Amherst, North Campus, State University of NY at Buffalo, on Pinus nigra (Pinaceae), 12 Sept. 1991 (7 $\delta$, 14 $\varphi$), coll. WK Gall, CUIC (1 $\delta$, 1 $\varphi$ voucher specimens). Town of Amherst, in house, late Dec. 1991 (1 $\varphi$), coll. K Tarbell. Town of Aurora, on outside of screen door of house, 1 Nov. 1990, coll. P Matlock, CUIC (1 $\delta$ voucher specimen); on wooden siding of outbuilding (4 $\delta$), on cedar shingle siding of home (1 $\delta$, 1 $\varphi$), in spider webs outside windows of homes (2 $\delta$ dead), 2 Nov. 1990, coll. WK Gall; on kitchen stove in house, 9 Nov. 1990 (1 $\delta$), coll. P Matlock; in second floor bathroom of house, 15 Nov. 1990 (1 $\delta$), coll. J Hagner; between storm and inner windows of house, 15 Nov. 1990 (1 $\varphi$ dead), on outside of house and outbuilding (1 $\varphi$, 4 $\varphi$), coll. WK Gall, CUIC (1 $\varphi$ voucher specimen); on davenport in house, 14 Aug. 1991 (1 $\varphi$), on living room floor near fireplace, 17 Aug. 1991 (1 $\varphi$), on outside of overhead garage door, 22 Aug. 1991 (1 $\varphi$), on floor of living or dining room of house, Sept.–Oct. 1991 (7 $\delta$, 5 $\varphi$), in bedroom of house, 6 Oct. 1991 (1 $\delta$), in living room of house, 14 Oct. 1991 (1 $\varphi$), on inside of screen door, dining room of house, 22 Oct. 1991 (1 $\delta$), in living room and kitchen of house, 7–8 Nov. 1991 (1 $\delta$, 2 $\varphi$), coll. PY Matlock, CUIC (1 $\delta$, 1 $\varphi$ voucher specimens); in house around first floor window, 23 Oct. 1991 (1 $\varphi$), coll. R Ogorek. City of Buffalo, Tifft Nature Preserve, in log cabin visitor center, 7 Apr. 1990 (1 $\delta$), coll. K

Figure 2. First published records of Leptoglossus occidentalis in North America by state or province. Dates of first collection are indicated on the map when available in the respective publications.
Alexander-Thomson; Martin Luther King Park, feeding on green cones of *Pinus nigra*, 8-9 Aug. 1991 (2 $\sigma$, 2 $\delta$), on unripened cone of *Pinus nigra*, 3 Sept. 1991 (1 $\gamma$), reared ex. nymph coll. on unripened cone of *Pinus nigra*, 12 Sept. 1991 (1 $\gamma$), coll. WK Gall. Town of Colden, inside house, S Irish Road, 2 Nov. 1991 (2 $\delta$, 4 $\sigma$), 29 Nov. 1991 (2 $\delta$, 4 $\sigma$), coll. TW Gavin; in basement of house on wooden bureau, Rt. 240, 1 Dec. 1991 (1 $\gamma$), coll. C Gavin. Town of Concord, in house on lampshade, mid-Nov. 1991 (1 $\gamma$), coll. A Edmunds. Town of Eden, found dead in sun porch of house, Fall 1991 (1 $\delta$, 1 $\gamma$), coll. HL Bosworth. Town of Holland, in house, 18 Dec. 1991 (1 $\gamma$), coll. MT Dann. Village of Lancaster, in kitchen cupboard of house, 3 Feb. 1992 (1 $\delta$), coll. HM Graves. Town of North Collins, stuck to tape of fruit basket in house, 24 Dec. 1991 (1 $\gamma$), coll. EE Both. Town of Orchard Park, in house, 1 Oct. 1990 (1 $\delta$), early Oct. 1990-early Jan. 1991 (6 $\delta$, 6 $\sigma$, 6 $\gamma$), CUIC (1 $\delta$, 1 $\delta$ voucher specimens), early Jan.-late Apr. 1991 (13 $\delta$, 11 $\sigma$), CUIC (1 $\delta$, 1 $\sigma$ voucher specimens), in dining room, 28 Apr. 1991 (1 $\delta$), inside terrace window, 27 Apr. 1991 (2 $\delta$, 2 $\sigma$), 30 Apr. 1991 (1 $\delta$), 1 May 1991 (2 $\sigma$), on fence, 11 July 1991 (1 nymph), coll. E Gugino; feeding on green cones or branchlet of *Tsuga canadensis* (12 $\delta$, 6 $\sigma$, 2 nymphs), feeding on green cones of *Pinus mugo* (1 $\delta$, 1 $\gamma$), feeding on green cone of *Pinus nigra* (1 $\delta$), 28 July 1991, coll. WK Gall, C & E Gugino; on inside of window of second floor bathroom of house, Oct. 1991 (1 $\gamma$), coll. J Norcross; in house on shirt which had been dried outside on clothesline, 2 Nov. 1991 (1 $\delta$), in living room of house, 11-12 Nov. 1991 (2 $\sigma$), coll. H MacMurray. Village of Orchard Park, at picture window in converted carriage house, 20 Jan. 1990 (1 $\delta$), coll. J Norcross. Town of West Seneca, in kitchen of house, 18 Nov. 1991 (1 $\delta$), outside house on porch, 5 Mar. 1992 (1 $\delta$), coll. R Seivert. Genesee Co.: Town or City of Batavia (in house?), 20 Oct. 1991 (2 $\delta$, 31 Oct. 1991 (1 $\delta$), submitted to R Twichell, Genesee County Cooperative Extension. Monroe Co.: Penfield, 18 Mar. 1991 (1 $\delta$, 1 $\sigma$), submitted to C Klass, Cornell Cooperative Extension, IPDDL. Niagara Co.: Village of Lewiston, in house, 14 Feb. 1992 (1 $\delta$, 1 $\sigma$), coll. T Dexter, submitted to J Farfaglia, Niagara County Cooperative Extension. Ontario Co.: Victor, 14 Jan. 1992 (1 $\delta$, 1 $\gamma$), coll. M Woods, submitted to C Klass, Cornell Cooperative Extension, IPDDL. Tompkins Co.: Town of Danby, in home, 27 Jan. 1991 (1 $\delta$), coll. and det. C Klass, IPDDL. Town of Ithaca, in kitchen and living room of house, 2-4 Dec. 1991 (1 $\delta$, 1 $\gamma$), coll. ML Thayer. Town of Ulysses, Taughannock Falls State Park, reared ex. nymph coll. on unripened cone of *Pinus nigra*, 8 Sept. 1991 (1 $\gamma$), coll. WK Gall. Wyoming Co.: Town of Wethersfield, in house(?), late Nov. 1991 (1 $\delta$), D. Junkin; Town of Java, on kitchen floor in house, 8 Feb. 1992 (2 $\delta$, 2 $\sigma$), S. Burton. ONTARIO, Essex Co.: Kingsville, on pine needle, 25 Sept. 1987 (1 $\gamma$), coll. K Petrie, GUIC. Halton Regional Municipality: Oakville, 11 Apr. 1991 (1 $\delta$), coll. JP Haynes, GUIC. Middlesex Co.: London, 10 Sept. 1989 (1 $\delta$), coll. R Rea, GUIC. Hamilton-Wentworth Regional Municipality: Binbrook, 13 Oct. (1 $\gamma$), L Craig, GUIC. Metropolitan Toronto: City of Etobicoke, between sliding windows of home, 29 Jan. 1991 (1 $\delta$ dead), JD Kerr; in house, 8 Dec. 1991 (1 $\delta$), coll. A Wright, ROM; in house, 10 Dec. 1991 (2 $\delta$, 2 $\gamma$), in firewood brought into house, 16 Dec. 1991 (1 $\delta$), crawling on wastebasket in house, 16-20 Dec. 1991 (1 $\delta$), coll. SW Beke, ROM. City of North York, at window of house, 14 Mar. 1991 (1 $\delta$), coll. EC Wiggins, ROM; in house behind drapes, 18 Nov. 1991 (1 $\delta$), AL Pearce, ROM. City of Scarborough, on outside wall of fourth floor balcony of apartment building, 9 Oct. 1991 (1 $\delta$, 1 $\gamma$), coll. AE Copping, ROM; in house, 13 Feb. 1991 (1 $\delta$), coll. SR Hatt, ROM. Norfolk Co.: Delhi (inside buildings, Delhi Research Station), 9 Oct. 1990 (3 $\delta$, 3 $\gamma$), coll. HH Cheng and JJ Hanlon, det. MD Schwartz, CNC; 22 Apr. 1991 (1 $\delta$), 4 Oct.-21 Nov. 1991 (8 $\delta$, 2 $\sigma$), coll. JJ Hanlon, CUIC (1 $\sigma$ voucher specimen). Simcoe, in house, 20 Oct. 1991 (1 $\delta$), coll. JJ Hanlon. Oxford Co.: Tillsonburg, on outside of house, 7-8 Oct. 1991 (1 $\delta$, 1 $\gamma$), coll. JJ Hanlon, CUIC (1 $\delta$ voucher speci-

DISCUSSION

Approximately 233 (232 adults, 1 nymph) of the 316 specimens reported above from Connecticut, New York, Ontario, and Pennsylvania were collected inside or on the outside of buildings from mid-August to early May, the majority collected during October and November. This well-documented association of *L. occidentalis* with buildings in northeastern North America supports the previously published observations in central (McPherson et al. 1990, Schaffner 1967) and western North America (Spencer 1942) that *L. occidentalis* will enter buildings while seeking protected overwintering sites at the onset of cold weather. Other overwintering sites reported for this bug are under pine
bark (Downes 1927), in dead, dry Douglas firs (Dennys 1927), and in the nests of a hawk and rodent (Hussey 1953). In the new records reported above, the latest date *L. occidentalis* was collected inside a building was 1 May. This is reasonably consistent with published observations in California, where adults emerge from overwintering sites from mid-May to early June to feed, mate, and oviposit on needles of the host tree (Hedlin et al. 1980, Koerber 1963, McPherson et al. 1990).

All *L. occidentalis* collected inside or on the outside of buildings in western and central New York were surrounded by, or in close proximity to, one or more species of conifers. For example, in Erie County, New York, large numbers of *L. occidentalis* were found inside or on the outside of homes in Orchard Park and Aurora situated near stands of mature specimens of *Pinus nigra*, *Pinus resinosa*, *Pinus strobus*, and *Pinus sylvestris*, and smaller numbers of at least some of the following conifers: *Pinus mugo*, *Thuja occidentalis* (Cupressaceae), *Picea glauca*, *Picea abies*, *Tsuga canadensis*, and *Abies concolor* (all Pinaceae unless otherwise indicated). Forty-three *L. occidentalis* were collected inside or on the outside of an Amherst home which was adjacent to a dense stand of several dozen mature *Pinus strobus*; at the time of collection in November, 1990, the ground was littered by fallen cones, indicating a good cone crop that year.

Interestingly, only one specimen of the closely related *Leptoglossus corculus* was collected in association with buildings during this study, compared with the 233 specimens of *L. occidentalis* found in similar circumstances: an adult female (Figs. 3 c, d) on the outside (cedar shingle siding) of a home in the Town of Aurora, Erie County, NY, 2 November 1990, in the company of several *L. occidentalis*. The only other specimen of *L. corculus* that I have collected in western and central New York was an adult female (Fig. 3 e, f) on *Pinus nigra* in Sampson State Park, Seneca County, 31 Aug. 1991, where I checked dozens of cone-bearing *Pinus nigra* planted along roadways and the campground. These trees harbored several early instar nymphs of an unidentified species of *Leptoglossus*, but no adults of *L. occidentalis* were observed. The relative rarity of *L. corculus* in western and central New York most likely results from it being at the northern limit of its range in New York State (Allen 1969, Henry and Froeschner 1988, Hedlin et al. 1980). In fact, the range map of Hedlin et al. (1980) shows this species, a pest of several pines in the southeastern U.S., penetrating New York State only in the extreme southeastern corner. Although Hedlin et al. (1980) report adults of *L. corculus* hibernating in various protected spots, I have not seen any published records of this species hibernating in buildings. Since populations of *L. occidentalis* and *L. corculus* are probably coming into contact for the first time as a result of the eastward spread of *L. occidentalis*, this recently established sympatry may provide ecologists, ethologists and systematists with interesting opportunities to investigate competitive interactions, partitioning of food resources, and interbreeding or maintenance of reproductive isolation between these closely related species. Allen (1969) placed these two species together in the *corculus* group with *L. clypealis* Heidemann, although he did not provide an explicit phylogeny of the genus.

ABDOMINAL COLOR PATTERN

In couplet 8 of the key to species of *Leptoglossus* north of Mexico provided by McPherson et al. (1990), *L. occidentalis* and *L. corculus* are separated on the basis of the relative lengths of the inner vs. outer dilation of the hind tibia (nearly equal in *occidentalis*, outer distinctly longer than inner in *corcu-
Figure 3. Color pattern of the abdominal dorsum and closeups of the right hind tibiae of *Leptoglossus* spp. a,b: *L. occidentalis*, Erie County, NY; c,d: *L. corculus*, Erie County, NY; e,f: *L. corculus*, Seneca Co., NY.
lus), and the shape of the median notch in the posterior margin of the genital capsule (subrectangular in *occidentalis*, roundly V-shaped in *corculus*). During this study, some specimens referable to *L. occidentalis* (mostly females) had the outer dilation noticeably longer than the inner (compare Fig. 3b, with Figs. 3d and 3f), and conversely, one specimen referable to *L. corculus* (identified by E.R. Hoebeke) had a less pronounced difference in lengths of the inner and outer dilations (Fig. 3d). In regard to the second character, after comparing over 140 males of *L. occidentalis* with 4 males of *L. corculus*, I found intraspecific variation in the shape of the posterior notch of the genital capsule in *L. occidentalis* to be at least as great as interspecific differences, thus rendering this character unreliable for separating the two species (also compare Figs. 46 and 47 in Allen 1969). Although I did not compare the shape of the male claspers of the two species (see Figs. 26 and 27 in Allen 1969), differences in shape may be consistent and important for species identification, but require careful dissection of the genitalia (Allen 1969). After spreading the wings of nine specimens of *L. corculus*, and comparing them with several dozen *L. occidentalis*, interspecific differences in the color pattern of the abdominal dorsum were so consistently and strikingly different, that it appears to provide a reliable and easy way of differentiating the two species (compare Fig. 3a with Figs. 3c and 3e). It is therefore surprising to me that Heidemann (1910), in his description of *L. occidentalis*, and Allen (1969), in his revision of the species of *Leptoglossus*, made no mention of the color pattern of the abdominal dorsum. The only reference I could find to this pattern in *L. occidentalis* adults was that of Koerber (1963): “The dorsal side of the abdomen is yellow or light orange with five transverse black patches,” and “The adults are strong flyers and fly readily if disturbed. In flight the adults produce a loud buzz which, together with their size, manner of flight, and the orange and black pattern of the abdomen, is strongly suggestive of a bumble bee.”

The striking orangish-yellow pattern on the abdominal dorsum of *L. occidentalis* (Fig. 3a is typical) includes the posterior margin of tergite 3; a trapezoidal-shaped area (widest anteriorly) covering the full lengths of tergites 4 and 5, interrupted medially by a black spindle or diamond-shaped marking that abruptly widens posteriorly to cover the postero-median projections of tergites 4 and 5; and a complete transverse band along the anterior one-third to one-half of tergite 6, this band shortened postero-medially by a dark, triangular projection of the posterior dark area of that tergite. The abdominal tergites of *L. corculus* (Fig. 3e is typical) are predominantly black, with small, indistinct, white or cream-colored markings antero-medially on tergite 4, and bordering the lateral portions of the postero-median projections of tergites 4 and 5. Fig. 3c illustrates the greatest development of these white or cream-colored markings in the nine specimens of *L. corculus* available to me, but this specimen was atypical. No sexual dimorphism in color pattern was evident in either species. It will be interesting to see if other workers find these differences in color pattern between *L. corculus* and *L. occidentalis* to hold up after examining a larger sample size of *L. corculus*, and also whether there may be distinctive differences in color pattern of the abdominal dorsum between other species of *Leptoglossus*.

The only drawback to use of this character is that it requires spreading specimens for complete visualization. Spreading is easy with fresh material, but first requires relaxing in the case of dried specimens. However, enough of the striking orangish-yellow color pattern of *L. occidentalis* can be visualized to permit identification by using forceps to slightly lift the postero-lateral margins of the folded wings of even dried specimens. The key to species of *Leptoglossus* north of Mexico provided by McPherson et al. (1990) can be modified as follows:

8. Outer hind tibial dilation nearly equal in length to inner dilation; abdom-
inal tergites 4 and 5 with striking orangish-yellow markings, each interrupted medially by a black, spindle or diamond-shaped marking. ................................................................. L. occidentalis Heidemann 8'. Outer hind tibial dilation distinctly longer than inner tibial dilation; abdominal tergites entirely dark or nearly so, striking orangish-yellow markings absent ........................................... L. corculus (Say)

DISPERsal

First records of L. occidentalis for southern Ontario (November, 1985) and western New York (January, 1990) provide conservative estimates for arrival times in these areas. McPherson et al. (1990) inferred that the pattern of eastward spread of L. occidentalis was associated with the ability of this species to utilize several native or introduced species of conifers in the east as food plants. In the last few decades, several of these conifers (particularly Pinus nigra) have been increasingly planted in the northeast in parks, on college campuses, along highways, and in landscaping commercial and residential properties. While collecting in the field, I have been impressed with the strong and rapid flight of L. occidentalis, as was Koerber (1963). Given the intrinsic dispersal capabilities of L. occidentalis, and its propensity to wander in search of overwintering sites, it is plausible that this bug has 'hop-scotched' east between the increasingly available islands or patches of host conifers. Its catholic feeding habits are also an advantage in dispersal, permitting it to shift to hosts with available cone crops. For example, published records for intervals between large seed crops are: 2-5 years for Pinus nigra, 3-7 years for Pinus resinosa, 3-10 years for Pinus strobus, and 4-6 years for Pinus sylvestris (USDA 1974).

Data for the two apparently disjunct northeastern records, in Connecticut and eastern Pennsylvania, suggest that human-mediated dispersal may supplement the direct dispersal of L. occidentalis. The lone Connecticut record is from a douglas fir Christmas tree in a house on 27 Dec. 1985. It seems doubtful that establishment of a bonafide population in Connecticut would have long escaped the notice of heteropterists James Slater, Carl Schaefer and their students at the University of Connecticut, Storrs. Yet as of March, 1991, no other specimens had been collected there (R.J. Packauskas, pers. comm.). Assuming the bug did indeed enter the Connecticut home on the Christmas tree, the interesting possibility arises that the eastward spread of L. occidentalis may be facilitated by the commercial Christmas tree trade from the western states. Michael Pochan, Secretary of the Connecticut Christmas Tree Growers Association, has advised me (pers. comm. 22 Feb. 1992) that douglas fir Christmas trees have unquestionably been trucked into Connecticut from Washington and Oregon for sale during the last 4-10 years. Alfred G. Wheeler, Jr. (pers. comm. 5 Feb. 1992) provided precise documentation for eastward commercial transport of L. occidentalis: a single male intercepted by the Pennsylvania Department of Agriculture at York, Pennsylvania, in a rail shipment of corn originating from Mendota, Illinois. These records provide compelling evidence that L. occidentalis is indiscriminate in its selection of overwintering sites, even opportunistically entering commercial loads, in which it can effectively hitchhike.

Figure 2 graphically illustrates the eastward expansion of the range of L. occidentalis over time. The chronology of some records may be artifacts of lack of collecting effort or lack of reporting to extension or university entomologists, e.g., years of first records for Washington, Oregon, and Wyoming. But in the relatively more populated central and eastern states and provinces,
where there is a higher probability of human-bug contacts (and probably a greater concentration of entomologists and extension agents to report such contacts to), the trends in records probably more closely reflect expansion of range. The habit of *L. occidentalis* coming into buildings for overwintering, and its large size and conspicuousness, facilitate its detection and hence awareness of newly established populations in an area (Marshall 1992, Shaffner 1967). Shaffner (1967) convincingly argues that 1956 is a reasonably reliable first record for Iowa, given the historic collecting effort by heteropterists at Iowa State University, Ames. He also presents a first record of 1961 for Indiana, based on a single specimen collected by a student, but there are no additional records for Indiana until 1980 (McPherson et al. 1990). Collection records suggest that *L. occidentalis* became established in Illinois and Wisconsin by the mid to late 1970’s, in southern Michigan and southern Ontario by the mid-1980’s, western New York by early 1990, and western Pennsylvania by 1991. Thus it appears that *L. occidentalis* provides one of the best documented cases of a native insect expanding its range eastward in North America [see McPherson et al. (1990) for examples of other Heteroptera].

It also appears that Van Duzee (1917) mistakenly substituted Idaho for Utah as a locality for *L. occidentalis*, an error perpetuated by Torre-Bueno (1941). Heidemann’s (1910) male syntype was from Utah (chosen as lectotype by Allen 1969), and he did not report examining any specimens from Idaho in his description, while Van Duzee (1917) and Torre-Bueno (1941) list Idaho but not Utah as a locality for this coreid. The first bonafide record for Idaho appears to be that of Harris and Shull (1944).

Extension agents and pest control operators in New York, Ontario (Canada), and elsewhere in northeastern North America should be aware of the range extension of this coreid, and the potential for nuisance complaints from homeowners during autumn and winter. At the onset of cold weather in late summer and early autumn, *L. occidentalis* frequently congregates on the outside walls of buildings, especially south-facing exposures, where they seem to bask in the sun. The high incidence of individuals collected around or between windows and doors, suggests these to be a common point of entry; conversely, this bug may be attracted to the light at windows and doors seeking an exit from buildings. For example, Deborah Brassel carefully recorded the location of 12 *L. occidentalis* collected inside her Amherst, NY, home between 3-17 Dec. 1990. She found them in 7 different rooms on 2 floors, and 8 of the 12 specimens were found at windows. Elizabeth Gugino collected 12 specimens in her Orchard Park, NY, home between October and January in an estimated 7 rooms and the basement; she noted 4 specimens between a loose screen and window on one occasion. Where *L. occidentalis* is a persistent nuisance in homes, the best method of control therefore appears to be mechanical exclusion: weather-stripping or replacing loosely fitting screens, windows and doors; caulking gaps around door frames, window frames, and soffits; and tightly screening attic and wall vents. Consideration should also be given to appropriately screening fireplace chimneys, as one homeowner in the Town of Aurora, NY, collected several *L. occidentalis* on the floor near his fireplace before the heating season began. In December, 1991, a homeowner in Metropolitan Toronto, Ontario, also found one male *L. occidentalis* overwintering in a crevice of a piece of firewood that he brought inside from his wood pile. Whatever the point of entry into homes, nuisance complaints followed a pattern of this coreid becoming active and conspicuous on mild (often unseasonally mild) days when the ambient temperature rose above freezing from autumn to spring.
ACKNOWLEDGMENTS

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LITERATURE CITED


extension of Leptoglossus occidentalis with a key to Leptoglossus species of America north of Mexico (Heteroptera: Coreidae). Great Lakes Entomol. 23:99–104.


Ontogeny and Systematics of the Genus Cerophagus (Acari: Gaudiellidae), Mites Associated with Bumblebees

Barry M. O'Connor

Abstract

Nymphs and adults of Cerophagus nearcticus n. sp. are described from the nest of Bombus terricola occidentalis in California and phoretic associations with B. impatiens in Michigan and New York. On the basis of adult morphology, the genus Cerophagopsis is removed from synonymy with Cerophagus and retained in the family Acaridae, while Cerophagus is transferred to the family Gaudiellidae. The genus Rhypoglyphus is considered a junior subjective synonym of Cerophagopsis. The genera of Gaudiellidae are noted and the genus Trigonacoptes is considered a junior subjective synonym of Gaudiella.

Descriptive taxonomy, systematics and phylogeny reconstruction for many groups of astigmatid mites have been hampered by their dimorphic life cycles. Deutonymphs are specialized for dispersal and/or surviving adverse conditions and typically have a morphology quite unlike that of the other instars. Taxa have usually been based on only the adult or the deutonymph but not often both. In order to positively correlate the heteromorphic life stages, it is best to rear the species in pure culture. A second method of absolute correlation is to obtain all instars of a species as pharate individuals through collection methods such as hand sorting or flotation of substrate materials. Simple association in the same habitat is not usually deemed sufficient to prove conspecificity following the experiences of early workers who incorrectly associated deutonymphs and adults in this fashion (e.g. Michael 1886, corrected by Fain 1969). Often, once one species in a genus has been positively associated through rearing or collection of pharate instars, subsequent associations of related taxa may be assumed through simple co-occurrence in the same habitat sample, however, these still do not prove conspecificity.

A second difficulty in studying the phylogeny of the Astigmata is the problem of convergent evolution. Most commonly, deutonymphs of unrelated taxa may converge in both progressive and regressive characters when they use similar hosts or other dispersal means (e.g. "inert" forms). The case described in this paper contains elements of all of these difficulties in dealing with systematics of the Astigmata.

The genus Cerophagus was established by Oudemans (1904) for the species Glycyphagus bomborum Oudemans, 1902, which had been described from deutonymphs collected from Bombus terrestris L. in the Netherlands. Vitzthum (1912) described Cerophagus gracilis, also from B. terrestris, in Germany. Zakhvatkin (1941) placed both nominal species names in synonymy.
with *Hypopus granulatus* Dujardin, 1849, originally described from *Bombus lapidarius* L. in France. He also reported specimens of this species from *Bombus argilaceus* (Scopoli), but without specific locality information. All of these descriptions dealt only with deutonymphal morphology; the post-deutonymphal instars have not been described for this species.

Fain and Heard (1987) described *Cerophagus trigona* from the nest of a meliponine bee, *Trigona carbonaria* Smith, in Australia. Numerous adults and nymphs were recovered along with one deutonymph that was assumed to belong to this species by association in the same habitat. This deutonymph was similar to those of the two species previously described in the genus *Cerophagopsis* Zakhvatkin, 1941: the type species, *C. skorikovi* Zakhvatkin, 1941, described from *Megachile doderleini* Friese (= *Chalicodoma sculpturalis* (Smith)) from Japan, and *C. furcata* Fain, 1974, described from a single specimen collected from *Bembex borrei* Handlirsch and later a second specimen from *Megachile sp.*, both from Vietnam (Fain and Heard, 1987). On the basis of similarities in the deutonymphal morphology of their new species with *C. granulatus*, Fain and Heard placed *Cerophagopsis* in synonymy with *Cerophagus*.

Contemporaneous with the publication of Fain and Heard (1987), Potter and Olson (1987) described a new genus and species, *Rhypoglyphus indicus*, from adult mites collected in stored food products imported from India into the United States. On the basis of the similar adult morphologies of *R. indicus* and *C. trigona*, Fain (1988) placed *Rhypoglyphus* in synonymy with *Cerophagus*.

Over the past few years, I have examined a number of specimens which shed light on the ontogeny and systematics of this group of mites. Of particular importance are two collections which include pharate individuals belonging to a new species whose deutonymphal morphology is very close to *Cerophagus granulatus*, the type species of the genus. This positive correlation between adult and deutonymphal morphologies led me to hypothesize on the basis of the adult morphology, that the genus *Cerophagus* (*sensu stricto*) is more closely related to the family Gaudiellidae than the Acaridae (O'Connor, 1988). The purpose of this paper is to describe the known ontogeny of this new species, use detailed morphological comparisons to test the hypothesis of a relationship between *Cerophagus* (*s.s.*) and *Cerophagopsis*, and to discuss the phylogenetic relationships of these taxa. In the following description, signatures for idiosomal setae follow Griffiths et al. (1990). All measurements are given in micrometers (μm).

### Cerophagus nearcticus new species

**Female:** (Figs. 1–12) Dorsum (Fig. 1). Body of single known female almost circular in outline, idiosomal length excluding copulatory tube 427, width 380. Except for prodorsal and supracoxal sclerites, cuticle unsclerotized, mammilated with raised rounded protuberances over entire surface except on and lateral to prodorsal sclerite. Prodorsal sclerite about as long as wide, with heavy ridges in posterior half. Sejugal furrow absent. Dorsal setae of moderate length, strongly bipectinate, on elevated tubercles bearing rounded mammillations, except setae *ve* evenly barbed and not elevated, and *sex* deeply bifurcate, with each fork bearing relatively long basal barb. Setae *ve* on anterior lateral corners of prodorsum, *vi* on anterior edge of prodorsal sclerite. External scapular setae (*sce*) somewhat more anterior than internal scapulars (*sci*). Notogastral setation complete; setae *he* situated on lateral margins of sclerotized copulatory tube. Measurements of idiosomal setae given in Table
Figure 1. *Cerophagus nearcticus*, female, dorsum.

1. Due to complex cuticular structure, cupules could not be observed. Opisthonal gland openings (gla) ventro-lateral to setae $e_v$.

Venter (Fig. 2). Ventral surface partially obscured by folded posterior legs (legs reconstructed in lateral view in Fig. 2). Cuticle mammilated laterally and posteriorly, smooth in coxal area and between legs IV and anus. Coxal apodemes I broadly fused medially; anterior apodemes of coxal fields II broad, posterior apodemes more narrow, fused medially with transverse sejugal apodemes; apodemes of coxal fields III-IV arched. All ventral body setae of coxal (1a, 3a, 3b, 4a) and genital (g) origin strongly barbed. Ovipore positioned between coxal fields II-IV; due to obscuring structures, genital papillae were not observed. Notogastral setae $c_2$ similar in form to dorsal setae and likewise with elevated alveoli, positioned between and lateral to coxal fields II-III. Anus displaced anteriorly from posterior edge of body by a distance greater than the length of the anus. Paraproctal setation consisting of six pairs of
Table 1. — Measurements (in mm) of idiosomal setae in Cerophagus nearcticus.

<table>
<thead>
<tr>
<th>Seta</th>
<th>Female</th>
<th>Protonymph</th>
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<tr>
<td>vi</td>
<td>49</td>
<td>33</td>
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<tr>
<td>ve</td>
<td>30</td>
<td>18</td>
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<tr>
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<td>40</td>
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<tr>
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<td>103</td>
<td>40</td>
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<tr>
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<td>3b</td>
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<td>4a</td>
<td>27</td>
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<td>g</td>
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setae, four pairs of thin, bipectinate setae flanking anus (ps₃ and ad₁,₂,₃), and two pairs of setae (ps₁,₂) similar in form to dorsal setae positioned on mammilated tubercles posteriorly and laterally from anus. Posterior end of body with a sclerotized copulatory tube bearing copulatory opening subapically on ventral surface.

Gnathosoma. Chelicerae (Fig. 3) chelate, fixed digit with three teeth, moveable digit with one median and one apical tooth; paraxial face with globose seta above base of moveable digit and short, pointed process and broadly rounded process more proximal on cheliceral shaft. Subcapitulum (Fig. 4) broadly trapezoidal, ventral subcapitular setae filiform; palpal supracoxal setae short and somewhat spinelike. Rutella rounded apically, dorsoapical teeth not visible. Palps (Fig. 4) with unique structure: basal palpal segment very wide basally, bearing 1 dorsal and 1 ventral filiform setae; distal palpal segment attenuated into blunt process bearing 1 dorsal seta and very elongate solenidion. The elongate process may be hollow and possibly homologous with button-shaped ventral eupathidium at apex of palp in other acaroid mites.

Legs (Figs. 5-12). All legs stout, well-sclerotized; legs I-II with sclerotized ridges on femora, genua and tibiae. Setation as follows: Trochanters I-III each with a strongly barbed seta (pR, sR); femora I, II and IV with a strongly bipectinate seta (vF, wF), vF I-II situated on tubercles; genua I-II with setae cG and mG and genu III with seta nG bipectinate; tibiae I-II with setae gT and hT and tibiae III-IV with setae kT bipectinate; tarsi with 12-12-10-10
setae respectively, seta $aa$ absent from tarsus I; setae of tarsi I-II generally similar in form and position, setae $wa$ and $ba$ bipectinate, other setae filiform or spine-like; tectal setae ($e$ and $f$) similar in length and form; proral setae ($p$ and $q$) larger than unguinal setae ($u$ and $v$); seta $ba$ II stouter than $ba$ I; setae of tarsi III-IV generally similar in form and position except setae $r$ and $w$ IV stouter, bearing few barbs while those of tarsus III thinner, smooth. Soleni-
Cerophagus nearcticus, female. 3. Chelicera. 4. Gnathosoma, ventral.


ing of deeply cleft subcapitulum bearing palpal supracoxal setae dorsally; palps distinct, each bearing dorsal seta and elongate, terminal solenidion.

Dorsum (Fig. 13). Propodosoma and hysterosoma each covered by large sclerite bearing pattern of deep punctations; sclerites separated by sejugal furrow. Propodosoma bearing short, filiform scapular setae (*sci*, *sce*); vertical setae not on sclerite, visible ventrally. Supracoxal setae (*scx*) of legs I similar to other dorsal setae. Hysterosomal sclerite with complete set of short, filiform, notogastral setae (except *cs*, positioned ventrally). Cupules *ia* visible between setae *c₁* and *cp*, other cupules ventrally positioned. A strong longitudinal dorsal apodeme underlies hysterosomal sclerite posteriorly.

Venter (Fig. 14). Cuticle unsclerotized except where dorsal hysterosomal sclerite extends ventrally along posterior margin. Coxal apodemes well developed, all connected except posterior apodemes of coxal fields IV. Anterior apodemes of coxal fields I extend dorsally around gnathosoma to body apex. Internal vertical setae (vi) positioned apically, external vertical setae (ve) positioned lateral to gnathosoma, above extensions of coxal apodemes I. Coxal setae 1a and 3b filiform; setae 3a and 4a absent, represented by vestigial alveoli. Genital setae g short and filiform, flanking genital opening. Genital papillae two segmented, apical segment attenuate. Attachment organ relatively small, bearing well developed anterior and median suckers, two pairs of conoidal setae and five weakly developed cuticular suckers; pair of vestigial alveoli visible anterior to median suckers. Pair of cupules (probably im) positioned laterally between bases of legs III-IV; cupules ih positioned on lateral margins of attachment organ.

Legs (Figs. 15–22). Legs I-IV equally developed, segmental proportions similar to other stages. Setation unusual in that tarsal setae s I-II and ba I are retained. Setae: tarsi 9–9–8–8, setae of tarsi I-II similar in form and position: ba filiform, anterior dorsal in middle of segment; d relatively short and filiform, posterior dorsal in apical third of segment; pair e and f foliate, dorso-apical; wa filiform, midventral in proximal third of segment; la and ra foliate,
somewhat anterior to \( wa \); seta \( q \) short and foliate, anterior ventral at apex of segment; seta \( p \) represented by vestigial alveolus paired with seta \( q \); seta \( s \) filiform, midventral, slightly subapical. Tarsus III with 3 dorsal setae: \( d \) filiform, \( e \) and \( f \) foliate; ventrally with five setae: foliate setae \( r \) and \( w \) in basal half of segment, foliate setae \( p \) and \( q \) apical, and filiform seta \( s \) subapical. Tarsus IV similar to tarsus III except setae \( r \) and \( w \) filiform. Tibiae 2-2-1-1, setae \( gT \) and \( hT \) I-II and \( kT \) III-IV filiform. Genua 2-2-1-0, setae \( mG \) and \( cG \) I-II and \( nG \) III filiform. Femora 1-1-0-1, setae \( vF \) I-II and \( wF \) IV filiform. Trochanters 1-1-1-0, setae \( pR \) I-II and \( sR \) III filiform. Solenidia: tarsi 3-1-0-0, tarsus I with \( \omega_1 \) basal, \( \omega_2 \) and \( \omega_3 \) in apical half of segment; tibiae 1-1-1-1, \( \phi \) I greatly elongate, \( \phi \) II-IV much shorter; genua 1-1-1-0, solenidia \( \sigma \) becoming progressively shorter posteriorly. Famulus \( \varepsilon \) short, spine-like, adjacent to solenidion \( \omega_1 \) on tarsus I.

Pretarsi with empodial claws strongly hooked, base of claw with flattened medial expansion; ambulacral stalks relatively short but distinct, no obvious ambulacral discs; paired condyliophores short and strongly developed, visible within each ambulacrum.

**Protonymph:** Two specimens observed, one in poor condition, containing a pharate deutonymph. Body form, cuticle and notogastral setae (except \( h_3 \)) as in female. Setae \( h_3 \) positioned ventrally, shorter and thinner than in female

Figure 13. *Cerophagus nearcticus*, deutonymph, dorsum.
Figure 14. *Cerophagus nearcticus*, deutonymph, venter.

and tritonymph. Paraproctal setation consisting of 3 pairs of PS setae, all thin, bipectinate and flanking anus. Coxal setae *la* and *3a* and genital setae *g* filiform. Measurements of idiosomal setae given in Table 1. Legs generally similar to those of female and tritonymph, but setae and solenidia having typical protonymphal pattern (i.e. lacking setae *pR* I-II and *sR* III; *wF*, *kT*, *s*, *e* and *f* IV; and solenidia *ωg* I and *ϕ* IV).

**Larva:** Not observed.

**Material Examined:** Holotype and five paratype deutonymphs (one containing a pharate tritonymph) from *Bombus (Pyrobombus) impatiens* Cresson, 1863 (*Hymenoptera: Apidae*); USA, MICHIGAN, Washtenaw Co., 23 May 1935. Mite specimens labelled: "BMOC #86-0131-1". Host bee in collection of University of Michigan Museum of Zoology (UMMZ) labelled: "Mites

removed, B. M. O'Connor #86-0131-1". One paratype deutonymph from _B. impatiens_; USA, NEW YORK, Tompkins Co., Ithaca, Cornell University Campus, 21 May 1974, B. M. O'Connor; slide labelled: "BMOC 74-0521-1a". One paratype female, one paratype male, two paratype protonymphs (one containing a pharate deutonymph) from nest of _Bombus (Bombus) terricola occidentalis_ Greene, 1858; USA, CALIFORNIA, San Mateo Co., San Bruno Mts., 9 July 1960, R. W. Thorp (slides labelled "Bombus occid. nigroscutatus", a junior synonym of _B. terricola occidentalis_ [Hurd, 1979]), these specimens from the Canadian National Collection of Insects, Ottawa.

_Type Deposition:_ Holotype and 4 paratype deutonymphs deposited in the University of Michigan Museum of Zoology; 1 paratype deutonymph deposited in the Cornell University Insect Collection, Ithaca, New York; adults,
protonymphs and one deutonymph deposited in the Canadian National Collection of Insects, Ottawa, Ontario.

SYSTEMATIC RELATIONSHIP OF CEROPHAGUS NEARCTICUS

The three collections of Cerophagus nearcticus described above appear to be conspecific based upon the essentially identical morphology of the deutonymphs in each series. The deutonymph collected along with the adults and protonymphs in the nest of Bombus terricola is pharate within a protonymphal cuticle and is broken and somewhat distorted. However, I was able to locate and compare all structures with those in the free, undistorted deutonymphs collected from B. impatiens. Correlation of protonymph and adult is based only upon their similar morphologies and collection in the same habitat. The one tritonymph obtained was surprisingly pharate within the deutonymphal cuticle while still attached to the host bee. I have also observed this phenomenon of tritonymphal development within the deutonymphal cuticle on a host in several collections of the chaetodactylid genus Sennertia associated with carpenter bees, Xylocopa spp.

Deutonymphs of Cerophagus nearcticus share a large suite of character states with C. granulatus as most recently redescribed and figured by Zakhvatkin (1941). The deeply pitted dorsal sclerites, configuration of coxal apodemes, form and position of the attachment organ structures, general form of the legs and pretarsi are all identical in the two species. I have not been able to examine specimens of the European species to check the accuracy of the earlier descriptions. Some differences were noted between C. nearcticus and Zakhvatkin's description and figures of C. granulatus. Zakhvatkin mentioned 13 setae on tarsus I of which 5 were noted as foliate. This number agrees with the total number of sensilla (setae, solenidia and famulus) and foliate setae on tarsus I of C. nearcticus. However, in his figure 695, Zakhvatkin illustrated seta wa I as foliate, whereas it is filiform in C. nearcticus. He also illustrated three non-foliate setae at the ventral apex of tarsus I. In C. nearcticus, only setae s and q are present in this region (p is absent) and q is foliate. In C. granulatus, solenidion ϕ I was illustrated as only slightly longer than ϕ II, while in C. nearcticus, ϕ I is approximately 7 times longer than ϕ II. Although the fine details of the tarsal chaetotaxy should be checked in C. granulatus to determine if the above differences are real, I regard the differences in tibial solenidial length in the two species as distinctive and not likely to have been figured incorrectly by Zakhvatkin (1941).

PHYLOGENETIC RELATIONSHIPS OF THE GENUS CEROPHAGUS

Testing hypotheses of phylogenetic relationships of the genus Cerophagus is complicated by prior nomenclature. For the sake of clarity in the following discussion, I will use the following generic names in their original conception: Cerophagus, to include the deutonymphal characters of C. granulatus and C. nearcticus and adult characters of C. nearcticus; Cerophagopsis to include the deutonymphal characters of C. skorikovi, C. furcata, Cerophagus trigona and three undescribed species I have examined; and Rhypoglyphus to include adult characteristics of R. indicus, C. trigona and one undescribed species.

In placing the genus Cerophagopsis in synonymy with Cerophagus, Fain and Heard (1987) diagnosed the taxon with the following character states of the deutonymphs: "(1) Dorsum either pitted or striated. (2) Claws of tarsi I-IV
equal, rather long, non-pedunculate and strongly modified in shape, they are abruptly bent in their middle at 90 to 110°, the basal part being inflated while the apical half is narrow and blade-like. These claws are not twisted spirally. (3) Condylophores relatively long, especially the posterior ones. (4) Tarsi I-IV with 10-9-8-8 setae of which 7-7-6-4 are foliate, most of them very narrowly so. (5) Palposoma strongly reduced, the palpi being either very short or completely lacking."

Of these characters, (1) is not diagnostic, with the two states mentioned being characteristic of *Cerophagus* and *Cerophagopsis* respectively. Character state (2) is an apparent synapomorphy; the form of the pretarsus in the two nominal taxa is essentially identical; I have observed a similar but smaller basal flange in the empodial claw in an undescribed genus associated with certain euglossine Apidae. The form of the condylophores (3) is similar in the two taxa, however, a similar form also occurs in other bee-associated Acaridae such as *Megachilopus*, *Sennertionyx* and an unnamed genus. Character (4) requires more detailed analysis as follows. In *Cerophagus nearcticus*, the tarsal setation is 9-9-8-8, while in *Cerophagopsis* it is 10-9-8-8 as stated or 9-8-8-8 in one unnamed species. However, all of the setae of tarsi I-II are not homologous in the two taxa. In *Cerophagus*, setae aa I and p I-II are absent while s I-II are present. In *Cerophagopsis*, aa is present on tarsus I and p is usually present on tarsi I-II (absent in one unnamed species) while s I-II are absent. Seta ba is present on both tarsi I and II in both taxa. Some differences in form and position of tarsal setae and solenidia are also apparent: setae d of tarsi I-II are foliate in *Cerophagopsis*, filiform in *Cerophagus*; solenidion ω3 is positioned in the distal half of tarsus I more apically than seta ba in *Cerophagus*, while in *Cerophagopsis*, ω3 is in the basal half of the segment, more basal than seta ba. Character (5) also requires more detailed analysis. The gnathosomal remnants (=palposoma) of *C. nearcticus* are much more developed than those of *Cerophagopsis*. Both taxa retain all three pairs of sensilla ancestrally present in acaroid mites (the palpal tarsal solenidion, distal dorsal palpal seta and palpal supracoxal seta). In *C. nearcticus*, the palpi themselves are conspicuously present although short and are borne on a short, medially cleft subcapitular remnant. Zakhrvatkin (1941) also mentioned the presence of palpal remnants in *C. granulatus* although he did not mention setae other than what are clearly the solenidia. In *Cerophagopsis*, the gnathosoma is reduced to a sclerotized plate bearing the setae and solenidia. Distinct palpal remnants are not discernable.

Of the character states mentioned by Fain and Heard (1987), I regard only one as a potential unique synapomorphy of *Cerophagus* and *Cerophagopsis*: the form of the pretarsal empodial claws. Certain other deutonymphal character states, however, are shared between *Cerophagus*, *Cerophagopsis* and three genera of bee-associated Acaridae belonging to the subfamily Horstiinae sensu O'Connor (1988), *Megachilopus*, *Sennertionyx* and an unnamed genus. These include the form of the pretarsal condylophores, loss of coxal setae 3a and 4a and the presence of seta ba on tarsus I. Tarsal setae p I-II are also absent in all of these genera except *Cerophagopsis* where they are present in some but not all species. The presence of seta ba I in these taxa is an example of paedomorphism. Early in the evolution of the Astigmata, an ontogenetic modification evolved in that seta ba of tarsus I, which was ancestrally present throughout ontogeny, was not expressed in the deutonymphal instar. This first derived pattern occurs in most Astigmata in which the deutonymph is retained in the life cycle. The failure of this seta to regress in the deutonymph is here interpreted as a further derivative condition resulting from the reversal of the earlier ontogenetic pattern of deletion and reappearance. A simpler paedomorphic condition involves coxal seta 4a. This seta ancestrally appears first in the deutonymphal instar in acariform mites. Its delayed appearance
until the tritonymphal instar in these mites is a case of simple ontogenetic retardation. Using only deutonymphal characters, a case can be made for a relationship between Cerophagus and certain genera of Horstiinae, notably Cerophagopsis.

Adult morphology is potentially more informative in formulating hypotheses of relationship for these taxa. Positive correlation of the deutonymph with the protonymph and tritonymph in C. nearticus has been accomplished, with the adult collected with the protonymphs so similar as to invite little question of conspecificity. The case of Cerophagus trigona is much less certain, with the correlation made only by the collection of a single deutonymph in the same habitat as the adults. However, I have recently received a series of specimens from Dr. Lynn Royce of Oregon State University that had been collected from a nest of Apis mellifera L. in Thailand. Like the collection of C. trigona, this material contains a number of males and females and a single deutonymph. Both the adults and deutonymph strongly resemble C. trigona although minor differences suggest they are not conspecific. This second habitat association between a Cerophagopsis type deutonymph with a Rhypoglyphus type adult is still not conclusive evidence, but I will accept the proposed correlation of ontogenetic stages until more definitive evidence can be obtained.

Adults of both the Cerophagus and Rhypoglyphus types belong to the superfamly Acaroidea as diagnosed by O'Connor (1982) in that they possess ventral sejugal apodemes and modified sucker-like setae on tarsi IV of the male. Adults with the Rhypoglyphus morphology possess the two diagnostic characteristics of the family Acaridae: asymmetry of setae e and f of the tarsi, with f longer than e (although only slightly in these species), and enlargement of ventral tarsal setae u and v such that they are larger than the more lateral setae p and q (O'Connor, 1982). Adults of C. nearticus do not possess these two diagnostic character states of the Acaridae; setae e and f are the same length and setae p and q are larger than u and v. Thus, there is no direct evidence that Cerophagus belongs to the family Acaridae.

On the other hand, Cerophagus adults share a number of derived character states with taxa comprising the family Gaudiellidae. This family had been proposed for a single species, Gaudiella minuta, collected from a nest of Melipona quadrifasciata Lep. in Brazil (Athey et al., 1974). Two other small families, Platyglyphidae and Partamonacoptidae, species of which had also been collected from the nests of social bees, were placed in synonymy with Gaudiellidae by O'Connor (1988). The monospecific family Platyglyphidae (Platygly­ phus malayanus) was described by Kurosa (1976) from an unidentified bee nest from Malaysia. Possibly unaware of the description of Gaudiella minuta, Fain and Rosa (1983) proposed the new family Partamonacoptidae for two species placed in two new genera (Partamonacoptes and Trigonacoptes) from neotropical meliponine nests. Trigonacoptes and Gaudiella are morphologically very similar, and I have previously indicated their probable synonymy (O'Connor, 1988). I have had the opportunity to study the holotype of Gaudiella minuta and observed that in addition to the very similar overall morphology, it shares a similar pattern of enlarged, barbed dorsal setae with Trigonacoptes camargoi that is not apparent from the original figures of G. minuta. The two pairs of longer simple setae in the posterior central quarter of the body are actually barbed rather than smooth as originally illustrated.

2Setae e 1-11 are not mentioned or illustrated for C. trigona; I have verified the presence of these setae on paratypes kindly provided by Dr. Fain. The adult tarsal setal counts for this species should thus be 13-12-10-10 as in R. indicus.
(Atyeo et al, 1974, fig. 1). The two species are clearly distinct but I consider *Trigonacoptes* to be a junior subjective synonym of *Gaudiella* (NEW SYNONYMY).

Although it is beyond the scope of this paper to provide a complete phylogenetic analysis of relationships among the gaudiellid genera, certain derived character states shared among *Cerophagus* and the Gaudiellidae suggest a closer relationship than either has with the Acaridae. The most conspicuous of these are the round body form and loss of the sejugal furrow shared among all taxa. *Cerophagus* also shares the heavily barbed form of some dorsal setae with the New World Gaudiellidae (not *Platyglyphus*) and the cuticular mamililation with *Partamonacoptes*. Unlike *Gaudiella* and *Partamonacoptes*, however, the opisthosoma is not as abbreviated in *Cerophagus* and the female ovipore is more anterior in position, ancestral states also retained in *Platyglyphus*. Among the Gaudiellidae, *Cerophagus* is unique in the form of the palpi, the bipectinate dorsal setae, ridged leg segments and the presence of a sclerotized copulatory tube in the female.

Deutonymphal morphology cannot be used to test this hypothesis of relationship since deutonymphs have not been positively correlated with species in the Gaudiellidae. Fain and Flechtmann (1985) described an unusual deutonymph, *Meliponopus palpifer*, from a single damaged specimen collected from *Melipona seminigra* and suggested the possibility that it could represent the deutonymph of one of the previously described nidicolous species. Those authors conservatively declined to assign this taxon to a family. O'Connor (1988) noted similarities in the gnathosomal structures of *Meliponopus* and *Cerophagus* deutonymphs and considered both in the Gaudiellidae. Closer inspection of the gnathosoma in *Cerophagus* indicates that the subcapitular remnant is much more reduced in this taxon (although not as reduced as in *Cerophagopsis* and related Acaridae). *Meliponopus* retains a more pleiomorphic form of the deutonymphal gnathosoma. As I have not examined the specimen of *M. palpifer*, I now believe it was premature to assign this taxon to the Gaudiellidae.

In summary, the evidence from the adult morphology of *Cerophagus* nearcticus suggests that *Cerophagus* is more closely related to the Gaudiellidae than to the Acaridae. The genus *Cerophagopsis* is removed from synonymy with *Cerophagus*, and the generic name *Rhypoglyphus* is considered a junior subjective synonym of *Cerophagopsis* rather than *Cerophagus*. The character states which originally suggested a close phylogenetic relationship between deutonymphs of these taxa are presumed to be convergent. It is worth noting that another, even more extreme modification of deutonymphal pretarsal empodia has arisen independently in several different taxa. The enlarged, spirally twisted claws which characterize deutonymphs of the family Chaetodactylidae also occur in the genera *Sennertionyx* (Acaridae) and *Macroharpa* (Winterschmidtiiidae). Similarly, paedomorphic modifications of leg setation occur sporadically throughout the Astigmata, such as in the Carpglyphidae and Lardoglyphidae. With the description and correlation of ontogenetic stages of additional taxa in the Acaroidea, a thorough analysis of morphological and ontogenetic characters using a parsimony approach may be possible. At that point, relationships among the families and genera in this large group may be hypothesized with more confidence.

On the basis of the above arguments, I present the following diagnosis for the genus *Cerophagus*:

*Cerophagus* Oudemans, 1904

Family Gaudiellidae. Adults with circular body outline; dorsal, lateroventral and posterio-ventral cuticle with raised mamilations; sejugal furrow absent. Gnathosoma triangular, palpi attenuated distally. Body chaetome complete. Dorsal setae bipectinate, borne on tubercles. Prodorsal sclerite well
developed. Supracoxal seta of leg I bifurcate with basal barbs. Legs strongly sclerotized, bearing longitudinal and transverse ridges on segments. Leg setation complete except seta aa absent from tarsus I. Solenidion W2 distally positioned on tarsus I. Female with ovipore between coxal fields III-IV, and a terminal sclerotized copulatory tube bearing setae k3. Male more strongly sclerotized than female, setae d and e of tarsus IV modified into suckers.

Deutonymph with gnathosomal remnant well developed. Dorsal propodosomal and hysterosomal sclerites strongly pitted. Dorsal setation complete, ventral setation lacking coxal field setae 3a and 4a. Leg setation complete for astigmatid mite deutonymph except tarsal setae aa I, p I-II absent, and setae s I-II and 6a I present. Pretarsal empodia consisting of a strongly hooked claw bearing a flattened basal projection.

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LITERATURE CITED


RIFFLE BEETLES OF WISCONSIN (COLEOPTERA: DRYOPIDAE, ELMIDAE, LUTROCHIDAE, PSEPHENIDAE) WITH NOTES ON DISTRIBUTION, HABITAT, AND IDENTIFICATION

William L. Hilsenhoff2 and Kurt L. Schmude2,3

ABSTRACT

Twenty-four species of Elmidae, three species of Psephenidae, two species of Dryopidae, and one species of Lutrochidae were represented among 33,351 riffle beetles that were identified from Wisconsin. Almost all were found in streams, but some inhabited wave-swept lake margins and spring-ponds. Adults and larvae of eight species were collected almost exclusively from submerged, decaying wood, while those of most other species inhabited rock or gravel substrates, especially in stream riffles, and only occasionally were found in wood; adults of three species of Dubiraphia were found also on macrophytes. The presence of Stenelmis antennalis, S. fuscata, and S. knobeli in Wisconsin represents significant range extensions.

Members of the coleopteran families Dryopidae, Elmidae, Lutrochidae, and Psephenidae are commonly called “riffle beetles” or “dryopoid beetles” in North America (Brown 1972, 1987a), although the latter term is no longer appropriate because Lawrence and Britton (1991) recently placed these families in the superfamily Byrrhoidea instead of Dryopoidea. Aquatic adults and larvae of riffle beetles in Wisconsin were thoroughly studied because of their importance in biological monitoring of streams and as part of an ongoing revision of the elmid genus Stenelmis. Both larvae and adults of Elmidae are aquatic, only adults of Dryopidae are aquatic, and in Lutrochidae and Psephenidae only larvae are aquatic. The purpose of this publication is to document the riffle beetle fauna of Wisconsin, to provide information about the occurrence of each species within the state, and to include keys and descriptions that will permit aquatic biologists to identify them.

Over the past 37 years 29,230 adult and larval riffle beetles were collected from throughout Wisconsin and identified to species, along with about 21,000 additional larvae in three genera of Elmidae, which could be identified only to genus. All are preserved in 70% ethanol and housed in the University of Wisconsin Aquatic Insect Collection. These specimens, along with those in Kurt Schmude’s private collection, the University of Wisconsin Insect Research Collection, and some other collections (see acknowledgments) are the basis for this study. We found 24 species of Elmidae, three species of

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Table 1. — Numbers of Dryopidae, Elmidae, Lutrochidae, and Psephenidae collected in nine areas of Wisconsin (Fig. 1). A = adults, L = larvae.

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Psephenidae, two species of Dryopidae, and one species of Lutrochidae; we believe the occurrence of additional species in Wisconsin is unlikely. Riffle beetles were predominantly found in streams, but some were also collected from spring-ponds and wave-swept shallow areas of lakes. Rarely, adults of Elmidae were found in other lentic habitats; some were undoubtedly transients on dispersal flights.

Generic and species keys are provided below for all aquatic adults and identifiable aquatic larvae; they are intended for use by biologists who are familiar with riffle beetles and other aquatic beetles, at least at the family level. The keys are followed by information on the distribution, abundance, habitat, and identification of each species; distribution maps are appended. Table 1 shows the relative abundance of each species in different areas of Wisconsin.
Figure 1. Map of Wisconsin showing locations of counties and the nine areas into which the state was divided (NW = northwest, NC = north-central, NE = northeast, WC = west-central, C = central, EC = east-central, SW = southwest, SC = south-central, and SE = southeast).

Wisconsin, except for larvae of Dubiraphia, Optioservus, and Stenelmis, most of which cannot be identified to species. Distribution of species in North America north of Mexico, along with synonymies and references to pertinent literature, appears in catalogues by Brown (1983a,b,c) and Wooldridge (1986). Keys to larvae and adults of all North American riffle beetle genera appear in Brown (1972), and White, Brigham, and Doyen (1984), with Brown also keying adults of species known at that time. Brown (1987a) also reviewed the biology of riffle beetles.

MATERIALS AND METHODS

Adults and larvae were routinely collected from rock and gravel riffles or vegetation in streams by using a kick-sampling technique and a D-frame aquatic net. They were similarly collected from shallow areas of lakes by
disturbing substrates and immediately sweeping a net through the water above the disturbed area. Examination and hand picking of large rocks and wood yielded numerous specimens, many of which represented rarer species. Wood-inhabiting beetles were collected as they crawled from interstices after wood was removed from the water and had begun to dry. Light traps were infrequently used to collect adults; five species of _Stenelmis_ were obtained by this method. No special effort was made to collect the riparian adults of Lutrochidae or Psephenidae, although some are included in this study. No larvae of Dryopidae or terrestrial pupae of any family were collected.

Individually measured lengths of the pronotum and elytra were summed (PE length) and used in keys as a measure of length, which is important in identification of several species. Total length was not used because of frequent partial separation of body segments and partial retraction of the head into the thorax. Measurements were made at 72X or 144X using an ocular reticle in a Leitz dissecting microscope. A range of PE lengths is provided for all species in the keys; few individuals will be encountered that are near the extremes of the range and rarely an individual shorter or longer than the stated range may be found. In all species the average length of females was greater than that of males.

Riffle beetles, especially adults of _Stenelmis_, are often coated with dirt, sand, or mineral deposits and must be cleaned before identification, or before being pinned. We cleaned encrusted beetles with concentrated hydrochloric acid for 0.5–2.0 minutes, which either loosened or dissolved encrustations. After a thorough rinsing in alcohol, specimens were placed in a 1-dram vial of fresh alcohol, held in the water of an ultrasonic cleaner, and sonicated for 3–15 seconds. Beetles that were covered only with loose dirt or sand were not treated with acid before sonication. This method worked extremely well for beetles preserved in alcohol, and most pinned beetles on points can be held firmly (by the pin) in a wide-mouthed vial of alcohol and similarly cleaned.

**KEY TO GENERA OF ADULT RIFFLE BEETLES IN WISCONSIN**

1. Larger, PE length > 4.4 mm; antenna short with pectinate club (Fig 2) ....................................... DRYOPIDAE, *Helichus*
   
   Smaller, PE length < 4.1 mm; antenna slender, filiform (Figs. 3–6) .......................... ELIMIDAE 2

2(1). ELMIDAE — Elytra with conspicuous orange, crescent-shaped markings (Fig. 3); PE length 2.42–3.00 mm ... *Ancyronyx variegata*  
   
   Elytra without orange, crescent-shaped markings .................. 3

3(2). Unicolorous dark brown with no pale markings on elytra; antenna short, 7-segmented, curled under eye; legs very long (as in Fig. 3); PE length 2.85–3.63 mm ................. *Macronychus glabratus*  
   
   Usually with pale marks or stripes on elytra (Figs. 4–6); antenna long, 11-segmented, projecting from head; legs shorter (Figs. 4–6) ... 4

4(3). Surface of pronotum smooth, except for basal carinae and/or punctures (Figs. 4–5) ....................................... 5  
   
   Surface of pronotum rough, with costae, granules, sulci, and tubercles (Fig. 6) .................. 6

5(4). Pronotal surface smooth, except for punctures; lateral margin of pronotum smooth; elongate beetles (Fig. 4) ........... *Dubiraphia*  
   
   Pronotal surface with basal carinae (Fig. 5); lateral margin of pronotum weakly serrate; ovate beetles (Fig. 5) ........... *Optioservus*  

6(4). Larger, PE length 2.4–4.1 mm; tomentum absent from protibia ...  
   
   Smaller, PE length 1.75–2.14 mm; tomentum present on protibia (Fig. 7) .................. *Microcylloepus pusillus*
KEY TO GENERA OF LARVAL RIFFLE BEETLES IN WISCONSIN

1. Body oval and extremely flat (Figs. 8–9); head concealed from dorsal view .................................................. PSEPHENIDAE 2
Body elongate, round or triangular in cross section; head exposed (Fig. 10) .................................................. 3

2(1). PSEPHENIDAE—Abdominal pleura separated from each other (Fig. 8); no gills ventrally on abdominal segments 2–6 Ectopria Abdominal pleura contiguous (Fig. 9); gills ventrally on abdominal segments 2–6 .......................... Psephenus herricki

3(1). Last abdominal tergum broadly rounded (Fig. 11); one ventral ocellus below base of antenna in addition to group of 5 posterior to base of antenna ............... LUTROCHIDAE, Lutrochus laticeps
Last abdominal tergum apically notched (Fig. 12); a group of 5 ocelli posterior to base of antenna .......................... ELMIDAE 4

4(3). ELMIDAE—Posterior angles of anterior abdominal segments produced (Fig. 13) .................... Ancyronyx variegata
Posterior angles of abdominal segments not produced ........ 5

5(4). Prothorax with a posterior sternum (Fig. 14) ..................... Stenelmis Prothorax without a posterior sternum (Fig. 15) .................. 6

6(5). Dorsum of abdomen covered with granules; head with a distinct tooth mesad of each antenna (Fig. 16) .......... Stenelmis Dorsum of abdomen with granules in longitudinal rows; head without a distinct tooth mesad of each antenna Microcylwepus pusillus

7(5). Last abdominal segment about 5 times longer than wide ...

DUBIRAPHIA
Last abdominal segment less than 3 times longer than wide .... 8

8(7). Mesopleuron divided (Fig. 17) .................... Macronychus glabratus
Mesopleuron undivided (Fig. 18) .............................. Optioservus

DRYOPIDAE ADULTS

Helichus Erichson, 1847

Adults resemble Elmidae, but are much larger and have pectinate antennae (Fig. 2). Only two species have been collected in Wisconsin, but H. fastigatus, which occurs in Illinois, may also occur in the state (Musgrave 1935, Brown 1972). Larvae are riparian.

Key to Adults of Helichus in Wisconsin

1. Elytra completely covered with a fine, uniform, silky pubescence; scutellum projecting distinctly forward; PE length 4.76–6.08 mm .......................... Lithophilus Silky pubescence absent from mesal third of elytra, where only coarse setae occur; scutellum only slightly arcuate anteriorly; PE length 4.48–6.33 mm .......................... Striatus

Helichus fastigatus (Say, 1824)

Distribution: It is possible, but unlikely, that this species occurs in extreme southern Wisconsin.

Identification: Adults are much broader, especially across the pronotum, than those of H. lithophilus and H. striatus of the same length. They have a forward-projecting scutellum like H. lithophilus, but like H. striatus lack pubescence on the middle of the elytra. The area of the elytra not covered by pubescence is wider than in H. striatus, covering the middle half instead of the
middle third; it is also distinctly sinuate laterally, not linear as in *H. striatus*. Males have a mesal pair of prominent denticles on the metacoxae.

**Helichus lithophilus** (Germar, 1824)

*Distribution and Habitat:* Uncommon from northeast to southwest (Map 1). Most adults were found in decaying wood in small to large streams, although its name (stone-loving) suggests otherwise.

*Identification:* The dense, even pubescence that covers the beetle is distinctive.

**Helichus striatus** LeConte, 1852

*Distribution and Habitat:* Common, especially in unglaciated southwest quarter and Lake Superior drainage (Map 2). Adults were found on rocks and among debris in riffles of cold to warm, small to very small streams and spring-fed brooks; they were uncommon in larger streams. Many streams in which they occurred received significant organic enrichment from agricultural sources.

*Identification:* The linear shiny area on the middle third of the elytra and the weakly convex anterior margin of the scutellum are diagnostic.

**Elmidae Adults and Larvae**

*Ancyronyx* Erichson, 1847

*Only one species is known from North America.*

*Ancyronyx variegata* (Germar, 1824)

*Distribution and Habitat:* Fairly common, especially in western two-thirds (Map 12). Adults and larvae occurred in decaying wood, usually in larger streams and occasionally in smaller streams.

*Identification:* The long-legged adults are easily identified by the orange, crescent-shaped marks on the elytra (Fig. 3). Larvae have produced posterolateral angles on anterior abdominal segments (Fig. 14).

**Dubiraphia** Sanderson, 1954

The genus is widespread in North America, but it has not been thoroughly studied throughout its range and needs revision. Adults are recognized by their smooth pronotum, which is devoid of bumps and carinae, and by their elongate shape. Larvae are easily recognized by an elongate last abdominal segment that is about five times as long as wide.

The most recent study of adults was by Hilsenhoff (1973). In that study genitalia were slide-mounted, causing the penis (“aedeagus”) to be widened, especially toward the base, and lengthened up to 7% in all species except *D. quadrinotata*. The penis, as described and illustrated below for each species, was not slide-mounted and differs from illustrations and descriptions in Hilsenhoff (1973). While the male genitalia are distinctive, size and color patterns must be relied upon to identify females. Because color patterns vary somewhat, it may not be possible to reliably identify some females that are near extremes of their size range. Larvae cannot be identified to species.

**Key to Adults of Dubiraphia in Wisconsin**

1. Large, PE length 2.85–3.19 mm; vittae broad, not constricted in basal third; penis 524–582 µm long, and at mid-length > 2 times as wide as parameres (Fig. 19) ....................... *bivittata*

Smaller, PE length < 2.75 mm; vittae often constricted in basal third; penis shorter, and at mid-length < 2 times as wide as para-
2(1). Usually quadrinotate, if vittate, vittae darkened at basal third, except on third strial interval; penis thin, sword-shaped for entire length and gradually curved ventrally, 402–470 μm long (Fig. 20); PE length 2.06–2.75 mm, females > 2.25 mm. ... quadrinotata 
Vittate, if vittae clouded at basal third, then PE length < 2.18 mm; penis < 375 μm long, wider in basal third, not distinctly curved ventrally. ............................................. 3 

3(2). Very small, PE length 1.77–2.17 mm; vittae at basal third narrow and sometimes obscure, conspicuously widened near middle to include intervals 3–7; penis narrower than parameres and nearly parallel-sided in apical two-thirds, 316–371 μm long (Fig. 21) ... minima 
Larger, PE length in 98% of females > 2.20 mm; vittae at basal third not substantially narrower than in posterior two thirds; penis at mid-length distinctly wider than parameres and tapered in apical third ................. 4 

4(3). Robust species, width of pronotum > 0.67 mm in males and > 0.70 mm in females; penis 305–332 μm long, nearly parallel-sided in basal half, except at base (Fig. 22); PE length 2.26–2.65 mm ... robusta 
Usually smaller and narrower, width of pronotum infrequently > 0.67 mm in males or > 0.70 mm in females; penis 244–300 μm long, gradually tapered from base to near apex (Fig. 23); PE length 2.00–2.44 mm. ................................... vittata

Dubiraphia bivittata (LeConte, 1852)

Distribution and Habitat: Uncommon, most found in southern half (Map 7). Adults inhabited plants and decaying wood in medium to large rivers and adjacent sloughs, marshes, and ponds.

Identification: The beetle's large size is distinctive, as is the very large aedeagus (Fig. 19). The smallest males are still larger than very large females of D. robusta, which they most closely resemble. The elytral vittae are not at all constricted in the basal third and are much broader than in adults of D. quadrinotata, which may be almost as long.

Dubiraphia minima Hilsenhoff, 1973

Distribution and Habitat: Common in most areas (Map 8). Adults were found on rocks, plants, roots, and decaying wood in streams of all sizes, but were more common in larger streams; occasionally they were found in wave-swept shallows of lakes.

Identification: The small size is usually distinctive. Some females are the size of very small males of D. quadrinotata, the only other species in which adults may have very constricted vittae basally, but the size-range of females does not overlap. Rarely, D. vittata are as small as D. minima, but in D. vittata the vittae are not as constricted in the basal third and the penis is shorter and much broader than in D. minima (Figs 21, 23). Identification of some females with a PE length of 2.1–2.2 mm may not be possible.

Dubiraphia quadrinotata (Say, 1825)

Distribution and Habitat: Common in most areas (Map 9). Adults occurred in rocky riffles, vegetation, and decaying wood, mostly in small to medium-sized streams; rarely, they were found in ponds.

Identification: The beetle's rather large size, along with quadrinotate elytra or greatly constricted elytral vittae, is usually distinctive. Unusually small females that are not distinctly quadrinotate could be confused with D. minima, but there apparently is no overlap in size. The pronotum is more convex

anteriorly and has more distance between punctures than in other species. The relatively long, ventrally curved, sword-shaped penis of males is distinctive (Fig. 20).

*Dubiraphia robusta* Hilsenhoff, 1973

Distribution and Habitat: Apparently rare, which may be due to inadequate sampling of lakes; most found in northwest (Map 10). Adults inhabited decaying wood in wave-swept shallows of lakes; a few were collected from larger streams.

Identification: While shorter than *D. bivittata*, adults are much longer than *D. minima* and almost always longer and broader than adults of *D.*
The broad, parallel-sided vittae immediately separate adults from those of large *D. quadrinotata*. Adults most closely resemble unusually large adults of *D. vittata*, but the pronotum is normally wider than in adults of *D. vittata* of the same length, and the vittae lack a slight constriction in the basal third that is usually found in *D. vittata*. The pronotum normally is about 6% wider anterior to the base than at the base; it is rarely more than 3% wider in *D. vittata*. The penis is always longer than in *D. vittata*, in which the penis is rather evenly tapered from the base to near the apex (Fig. 23).

**Dubiraphia vittata** (Melsheimer, 1844)

**Distribution and Habitat:** Very common in eastern two-thirds (Map 11). Adults were collected mostly from rocks, travertine, vegetation, and decaying wood in streams of all sizes; rarely, they were found in ponds.

**Identification:** The nearly parallel-sided vittae with little constriction usually separate adults from those of *D. minima* and *D. quadrinotata*; their smaller size separates adults from those of *D. bivittata* and most *D. robusta*. In Wisconsin they are almost always larger than adults of *D. minima* of the same sex. Separation from *D. robusta* and *D. minima* is discussed under those species.

**Macronychus Miller, 1806**

One species occurs in North America.

**Macronychus glabratus** Say, 1825

**Distribution and habitat:** Very common in most areas (Map 3). Adults and larvae were found on decaying wood and roots, and rarely on rocky substrates. They inhabited medium to large streams and wave-swept shallow areas of lakes. They were collected infrequently from small streams, and rarely from ponds.

**Identification:** Like *Ancyronyx variegata* (Fig 3), adults have very long legs and are readily identified by characters in the generic key. Larvae resemble larvae of *Optioservus*, but the mesepimeron is divided into two sclerites (Fig. 17).

**Microcyloleopus Hinton, 1935**

Several subspecies of *M. pusillus* have been designated (Brown 1983a). We agree with Barr and Chapin (1988) and Shepard (1990) that subspecies are merely color morphs.

**Microcyloleopus pusillus** (LeConte, 1852)

**Distribution and Habitat:** Rare in central and northwest areas (Map 4). Adults and larvae inhabited rocky riffles of clear, medium-sized streams, and wood in sand-bottomed streams.

**Identification:** The extremely small size separates adults from all other elmids except small specimens of *Dubiraphia* and *Optioservus trivittatus*, all of which have a smooth pronotum that lacks the distinct bumps and sulci found on adults of *M. pusillus*. Two color morphs are present in Wisconsin; they key to *M. pusillus pusillus* and *M. pusillus aptus* in Brown (1972). The only apparent difference between them is the bimaculate vs. vittate color pattern on each elytron. The degree of coloration varies in adults of many other elmids, with bimaculate and vittate specimens frequently occurring within species of *Optioservus* and *Stenelmis*. Although we saw limited elytral color variation between adults within a local population, variation in adults between local populations formed a continuum that encompassed short and narrowly bimaculate to broadly vittate color patterns. Larvae resemble those of *Stenelmis*, but are readily identified by characters in the key.
Optioservus Sanderson, 1954

This genus was revised by White in 1978. Two species occur in Wisconsin; no others are likely to be found. Adults have an oval shape, and can be distinguished by their smooth pronotum with a pair of basal longitudinal carinae. Larvae lack a posterior sternum (Fig. 15) and resemble those of Macronychus, but have only a single mesopleural sclerite (Fig. 18). Last instar larvae of both species were associated with adults based on distribution and the significant difference in size; no larvae were reared. Only final instar larvae, which are distinguished by the presence of spiracles on the mesothorax and abdominal segments 1–8, can be identified. Since collections of adults of both species are extensive, no effort was made to find and identify final instar larvae in the collection.

Key to Adults of Optioservus in Wisconsin

1. Smaller, PE length 1.90–2.40 mm; a vitta on each elytron with a third vitta overlapping the elytral suture ................. trivittatus

Larger, PE length 2.90–3.50 mm; each elytron vittate or bimaculate, with no vitta on elytral suture ................. fastiditus

Optioservus fastiditus (LeConte, 1850)

Distribution and Habitat: Abundant in almost all areas (Map 5). Adults and larvae were collected in rocky riffles of streams of all sizes, and uncommonly from submerged wood; a few were found in Lake Michigan's Green Bay.

Identification: The much larger size distinguishes adults and final instar larvae from those of O. trivittatus.

Optioservus trivittatus (Brown, 1930)

Distribution and Habitat: Very common in northern third, fairly common in central third (Map 6). Adults and larvae were found in rocky riffle areas or decaying wood in streams of all sizes.

Identification: The small size and trivittate appearance of adults is diagnostic. The sutural vitta may be obscured in dark specimens, but it is revealed when an elytron is lifted above the abdomen.

Stenelmis Dufour, 1835

Sanderson revised Stenelmis in 1938; another revision by Kurt Schmude is in progress. Fourteen species were collected in Wisconsin. Larvae of six of them were included in Shepard's key (1980), but because larvae of six of the remaining species remain unassociated with adults, larvae cannot be reliably identified to species. Adults are readily recognized by their relatively large size and the tubercles, sulci, and costae on the pronotum. Each elytron in most species has a longitudinal pale vitta or is bimaculate. Adults of two species have an additional lateral and mesal vitta on each elytron, and adults of another species may be immaculate. Various structures on the pronotum of adults are important in identification; they are shown in Figure 24 and will be referred to in the key and frequently in the identification section under each species. A lateral process on the penis (Figs 25, 27) is helpful in identifying some species, but it often cannot be seen on specimens that were preserved in formalin, which apparently distorts this structure. Unlike other elmid genera
Figures 24-27. 24. Pronotum of *Stenelmis* showing anterolateral tubercle (ALT), posterolateral tubercle (PLT), median sulcus (MS), median costae (MC), oblique lateral depression (OLD), and basomesal area (BMA) including basomesal triangle. 25. Penis of *Stenelmis bicarinata*. 26. Penis of *S. decorata*. 27. Penis of *S. grossa*.

in which genitalia must be observed to sex adults, male *Stenelmis* in Wisconsin can be recognized by having a low, short, medial spinous ridge on the inner margin of the mesotibia. Larvae are most similar to those of *Microclytloespus*, but are readily identified by characters in the key.

**Key to Adults of *Stenelmis* in Wisconsin**

1. Each elytron with anterior testaceous mark overlapping umbone (anterolateral angle); each elytron bimaculate to univittate ... 2
   Anterior light mark, if present, not overlapping umbone; elytral markings variable ........................................ 5

2(1). Larger, pronotal width > 0.98 mm in males and > 1.00 mm in females; elytral width ≥ 1.29 mm; pronotum wider than long, with width/length (W/L) ratio ≥ 1.05; apicoventral margin of tarsomere 5 produced into pointed process; PE length 3.05-3.63 mm. ...  
   Smaller, pronotal width < than 0.98 mm in males and <1.00 mm in females; elytral width ≤ 1.31 mm; pronotal W/L ratio 0.91-1.05; apicoventral margin of tarsomere 5 truncate or slightly convex.  
   ................................................................. 3

3(2). Elytron vittate, vitta confined to striae 3-5 and uniform in width; posterolateral tubercle on pronotum only slightly raised and not costiform; longer, PE length 2.85-3.39 mm ............ *cheryl*
   Elytron bimaculate, or with vitta medially clouded or widened beyond stria 3; posterolateral tubercle on pronotum variable; shorter, PE length 2.44-3.10 mm ........................ 4

4(3). Length/width (L/W) ratio of elytra > 1.85; posterolateral tubercle on pronotum only slightly raised and not costiform; PE length 2.53-3.10 mm ........................................... *knobeli*
   L/W ratio of elytra < 1.85; posterolateral tubercle on pronotum dis-
distinctly raised and costiform; PE length 2.44–2.91 mm. ... mera

5(1). Apex of antenna and/or palpi, dusky to piceous ............... 6
Antenna and palpi completely flavous to testaceous ............. 8

6(5). Palpi flavous to testaceous; apical antennomeres piceous, rarely dusky; PE length 2.88–3.34 mm .................. antennalis
Palpi fuscous to piceous; apical antennomeres testaceous to piceous ....................................................... 7

7(6). Larger, PE length of males 2.83–3.18 mm, females 3.04–3.26 mm; mostly lentic ........................................ 9

8(5). Elytron trivittate, with one vitta near lateral margin (may be faint), another occupying interval 4 to stria 5, and a shorter vitta on interval 2, which may be obscure ......................... 9

9(8). Legs and dorsum of pronotum densely granulate; tarsomere 5 shorter than or equal to preceding four tarsomeres combined; PE length 3.20–4.03 mm .................................. sexlineata
Legs and dorsum of pronotum apparently without granules; tarsomere 5 distinctly longer than preceding four tarsomeres combined; PE length 3.25–3.71 mm ....................... douglasensis

10(8). Tarsomere 5 shorter than, equal to, or at most just barely longer than preceding four tarsomeres combined; posterolateral tubercle on pronotum prominently raised, elongate, and nearly carinate; PE length 2.98–3.64 mm ................. crenata
Tarsomere 5 distinctly longer than preceding four tarsomeres combined; posterolateral tubercle on pronotum weakly raised and at most barely costiform ........................................ 11

11(10). Larger, PE length of males 3.56–3.84 mm, females 3.60–3.99 mm; elytron very narrow and confined to interval 5 (sometimes also part of 4). ........................................ fuscata
Smaller, PE length of males 3.00–3.54 mm, females 2.88–3.73 mm; elytron vittate, infrequently bimaculate, with markings wider ...................................................... 12

12(11). L/W ratio of elytra ≤ 1.87; elytron most often with medially narrowed vitta, less frequently bimaculate or with vitta uniform in width; pronotum relatively convex and smooth with weakly raised median costae and tubercles, a very shallow median sulcus and weak oblique lateral depressions; pronotal granules numerous, evenly distributed, and at least as large as largest femoral granules; penis with an arcuate lateral process (Fig. 25); PE length of males 3.06–3.40 mm, females 3.14–3.61 mm ........ bicarinata
L/W ratio of elytra ≥ 1.82; combination of other characters not as above ............................... 13

13(12). Smaller, PE length of males 3.00–3.24 mm, females 3.11–3.49 mm; elytral width 1.05–1.24 mm; interocular width 0.31–0.39 mm; pronotal granules larger on basomesal area and clustered in females, with most separated by less than twice their diameter; penis without a lateral process (Fig. 26) ............... decorata
Larger, PE length of males 3.11–3.54 mm, females 3.25–3.73 mm; elytral width 1.16–1.38 mm; interocular width 0.36–0.44 mm; pronotal granules on basomesal area small, evenly scattered, with most separated by more than three times their diameter; penis with a subangulate lateral process giving it an arrow-shaped appearance (Fig. 27) .................................................................. grossa
Stenelmis antennalis Sanderson, 1938

Distribution and Habitat: Fairly common in northwest area and central third (Map 13). Previously reported only from South Carolina to Louisiana (Sanderson 1938, Brown 1983a, Barr and Chapin 1988). Adults were found exclusively on decaying wood in sandy, warm rivers of medium to large size.

Identification: Adults have a distinctive combination of piceous terminal antennomeres, testaceous palpi, and quadrimaculate elytra (each elytron narrowly vittate in some individuals). Our collections represent a considerable range extension, but based on comparison with the holotype and southern specimens, including some from Arkansas and Missouri (unpublished records), along with the similarity of habitats, we conclude that specimens from Wisconsin and the southern United States are conspecific.

Stenelmis bicarinata LeConte, 1852

Distribution and Habitat: Fairly common in northern half, especially in northwest area (Map 14). Adults occurred mostly on submerged wood, but were also collected in rocky riffles and runs of moderately warm, medium to large rivers.

Identification: Schmude and Hilsenhoff (1991) recently clarified the status of this species. Adults are most similar to those of S. decorata and S. grossa, but are more ovate and have an elytral L/W ratio of 1.64–1.87; in S. decorata this ratio is 1.87–2.09 and in S. grossa it is 1.82–1.96. Elytral vittae are between interval 4 and stria 5 anteriorly and posteriorly, but are narrower medially (interval 5) in most specimens; some beetles appear quadrimaculate while a few have vittae that are uniform in width. The pronotum is more convex than in S. decorata and S. grossa because the lateral tubercles and median costae are broadly and weakly raised, and the median sulcus and oblique lateral depressions are very shallow. Pronotal granules are at least as large as the largest femoral granules, and are evenly distributed over the surface. Also, the pronotum of most specimens has three dark areas that are as dark as pronotal granules, one in the median sulcus, and two basomesal triangular areas that are bordered by the median costa, lateral tubercles, and posterior margin; dark basomesal triangles do not occur on the pronotum of S. decorata and S. grossa. This species would be identified as S. maerkelii Motschulsky, 1854, in Sanderson (1938) and Brown (1972).

Stenelmis cheryl Brown, 1987

Distribution and Habitat: Uncommon in northern half (Map 15). Adults lived in gravel to boulder riffles in fast, clear, moderately warm streams of all sizes; they rarely were collected from submerged wood.

Identification: Adults of four species found in Wisconsin have elytral markings that overlap the umbone. All adults of S. cheryl from Wisconsin are vittate; the vittae are uniform in width, cover striae 3–5, and overlap only the posterolateral portion of each umbone, a portion equal in width to the width of a vitta. Adults of the three other species are mostly bimaculate on each elytron, with the anterior macula overlapping a greater portion of the umbone. In Sanderson (1938) and Brown (1972) adults are referred to as S. bicarinata (Brown 1987b, Schmude and Hilsenhoff 1991).

Stenelmis crenata (Say), 1824

Distribution and Habitat: Abundant statewide (Map 16). Adults were collected from rocky riffles and runs, wood, travertine, and debris in most streams in the state, except for those that are either very cold, very small, heavily shaded, or heavily polluted; they also occurred on these substrates in wave-swept shallow areas of lakes.

Identification: The rough and densely granulate pronotum with its deep
median sulcus, pronounced anterolateral tubercles, and elongate and nearly carinate posterolateral tubercles, is distinctive. Pale markings on each elytron vary in intensity and shape, from bimaculate to vittate. The penis has an arcuate lateral process similar to that of *S. bicarinata* (Fig. 25).

*Stenelmis decorata* Sanderson, 1938  
**Distribution and Habitat:** Common in south-central and southwest areas, uncommon farther north (Map 17). Adults occurred on rocks and submerged wood in medium to very large, warm, sandy streams.

**Identification:** Males and females are generally shorter and narrower than those of *S. bicarinata* and *S. grossa*, but some females are difficult to distinguish from those of *S. grossa*. The ratio of elytral length to width is 1.87–2.09. In females, a clustering of relatively large pronotal granules occurs basomedially on either side of the median costae; these granules are not as clustered and slightly less numerous on males. Granules in this area are more evenly distributed on adults of *S. bicarinata* and very small and sparse on adults of *S. grossa*. Elytral vittae are most often uniform in width, but some specimens have medially narrowed vittae; a few beetles appear quadrimaculate and similar to adults of *S. bicarinata*. Males are easily separated from those of *S. grossa* and *S. bicarinata* by the absence of a lateral process on the penis (Fig. 26).

*Stenelmis douglasensis* Sanderson, 1938  
**Distribution and Habitat:** Very rare in southern third (Map 18). Only Sanderson (1938) reported collections of this species, finding it on submerged wood in two different lakes in Michigan. We collected 15 adults, all from submerged wood in warm, medium-sized, sand-bottomed streams, and from near the mouths of small streams that empty into the lower Wisconsin River.

**Identification:** Adults lack the numerous granules found on legs and pronota of all other species in Wisconsin; only tiny inconspicuous granules occur on the legs. The short, mesal elytral vitta that is confined to interval 2 may be obscure.

*Stenelmis fuscata* Blatchley, 1925  
**Distribution and Habitat:** Uncommon in a limited area (Map 20). Previously reported only from Alabama and Florida (Sanderson 1938, Brown 1983a). Adults were found only on submerged wood in medium to very large, warm, sand-bottomed rivers.

**Identification:** Based on comparisons with the holotype and many specimens of *S. fuscata* from North Carolina to Texas, and from the Mississippi River drainage basin north to Iowa (unpublished records), we conclude that the distinctive adults we collected in Wisconsin are conspecific with *S. fuscata*. Adults are most similar to those of *S. bicarinata*, but size ranges of corresponding sexes are almost disjunct. Most individuals are larger than nearly all adults of other species in Wisconsin. The color pattern of each elytron as described in the key is diagnostic.

*Stenelmis grossa* Sanderson, 1938  
**Distribution and Habitat:** Fairly common, especially in southern third and northwest area (Map 19). Adults were collected from rocks and submerged wood in medium to large, warm, sandy rivers, and occasionally in smaller streams.

**Identification:** Schmude and Hilsenhoff (1991) synonymized *S. vittipennis* Zimmermann, 1869 with *S. bicarinata*, and stated that Sanderson’s (1938) concept of *S. vittipennis* should be referred to as *S. grossa*. Adults are similar to those of *S. decorata* and *S. bicarinata*, but are larger and have wider elytral
vittae that are more uniform in width (L/W ratio is 1.82-1.96); quadrimaculate specimens are rare. Pronotal granules are very small, smaller than the largest femoral granules, and frequently less numerous and more scattered than on aforementioned species.

*Stenelmis knobeli* Sanderson, 1938

**Distribution and Habitat:** Rare, found only in the lower Wisconsin River (Map 15). The only published records are from Arkansas (Sanderson 1938). Adults were collected from under or on sides (at the rock/substrate interface) of large sandstone rocks and slabs in fast, shallow, rocky riffles and runs at three sites in the lower Wisconsin River, a very large, warm river with a shifting sand bottom; much of the substrate at these sites was sandstone bedrock. This species was placed on the Wisconsin Department of Natural Resources’ list of endangered species in 1989.

**Identification:** Based on comparisons with the holotype and other specimens, we conclude that Arkansas and Wisconsin beetles are conspecific. Each elytron is bimaculate to vittate, with the vitta or anterior macula overlapping the umbone. Testaceous markings extend mesally beyond stria 3 in vittate specimens. The narrow elytra (≤1.08 mm wide) make adults appear much more elongate than adults of the three other species with elytral markings that overlap the umbone.

*Stenelmis mera* Sanderson, 1938

**Distribution and Habitat:** Common in northern half, especially in northwest (Map 21). Adults inhabited rocks in riffle areas of fast, medium to large, clear, moderately warm streams; they rarely occurred on submerged wood.

**Identification:** Adults are smaller than those of *S. sandersoni* and most *S. cheryl*. Each elytron is usually bimaculate with the anterior macula covering the entire umbone; if vittate, the vitta is at least partially clouded medially. The posterolateral tubercles on the pronotum are elongate and costiform, unlike those on specimens of *S. cheryl* and *S. knobeli*, but similar to those on adults of *S. sandersoni*. Many adults have a pair of dark basomesal triangles on the pronotum (described for *S. bicarinata*), which are absent on the three aforementioned species.

*Stenelmis musgravei* Sanderson, 1938

**Distribution and Habitat:** Uncommon in southeastern rivers that empty into Lake Michigan, and in the Little Platte River drainage basin (Map 21). Adults and larvae inhabited travertine on rocks in shallow, medium-sized, warm, hardwater streams. Adults were exceedingly difficult to dislodge by kick-sampling, but more than 100 individuals per rock could be obtained by picking them from drying rocks. Both larvae and adults were deep in the interstices of the hardened, microcavernous travertine.

**Identification:** Like adults of *S. quadrimaculata*, which occur mostly in lakes, adults of *S. musgravei* have fuscous to piceous palpi and testaceous to piceous terminal antennomeres, but they are distinctly smaller. Each elytron is bimaculate in most specimens; sometimes it is vittate. Dark basomesal triangles on the pronotum are present on many adults of this species and *S. quadrimaculata*.

*Stenelmis quadrimaculata* Horn, 1870

**Distribution and Habitat:** Very rare, records from only three sites (Map 21), which may be due to inadequate sampling of lakes. An inhabitant of marl deposits in lakes (Blatchley 1910) and lake outlets; we found specimens on submerged wood and in soft marl deposits on rocks in a single northwestern lake. Other records were from Lake Mendota in Dane Co. and the ‘Lower Fox
River" in Winnebago Co., which is either in or associated with Little Lake Butte des Morts.

**Identification:** While larger than specimens of the lotic *S. musgravei*, adults are otherwise very similar. The palpi are fuscous to piceous; apical antennomeres are dusky to fuscous, or occasionally testaceous. Elytra are usually quadrimaculate, but if vittate, vittae are narrowed or clouded medially.

*Stenelmis sandersoni* Musgrave, 1940

**Distribution and Habitat:** Fairly common in northern half, especially in northwest area (Map 18). Some adults were found on rocks, but most were collected from smaller substrates within fast, rocky areas of clear, moderately warm streams of variable size; they rarely occurred on submerged wood.

**Identification:** The large size separates adults from those of other species that have vittae or maculae that cover each umbone. The pronotum is wider than long; its surface is densely granulate and rough in appearance with a deep median sulcus, and prominent median costae and lateral tubercles. Posterolateral tubercles are distinctly elongate and costiform.

*Stenelmis sexlineata* Sanderson, 1938

**Distribution and Habitat:** Very rare in east-central area (Map 18); common south of Wisconsin. We are uncertain of its habitat since only a few adults were collected from rocky riffles in Waukau Creek, a small, warm stream that becomes dry periodically.

**Identification:** Adults are easily identified by their short tarsomere 5, wide pronotum (W/L ratio > 1.00), and trivittate elytron; the lateral and/or mesal vitta may be obscure. A few of our specimens are the largest *Stenelmis* in the state, and among the largest reported from North America (Schmude and Brown 1991).

**LUTROCHIDAE LARVAE**

*Lutrochus* Erichson, 1847

Only one species is known to occur in the northern United States.

*Lutrochus laticeps* Casey, 1893

**Distribution and Habitat:** Very rare in southeast (Map 24). Larvae and adults were collected from small to large, warm, calcareous streams that contained nearly equal percentages of cobbles, pebbles, gravel, and sand. Ovipositing adults were found on submerged wood and on travertine on rocks in shallow riffles; larvae were collected from rocks.

**Identification:** Larvae are similar to those of Elmidae, but the last tergum is broadly rounded apically (Fig. 11). The riparian adults can be identified by using the key in Brown (1972).

**PSEPHENIDAE LARVAE**

*Ectopria* LeConte, 1853

Brigham (1981) recognized adults of three species in North America, *E. leechi* Brigham, 1981, *E. nervosa* (Melsheimer, 1845), and *E. thoracica* (Ziegler, 1845). The only adults in our collection are five *E. leechi*, which were collected from Dane Co. in the early 1900's. We have not associated larvae with adults, but we recognize larvae of two species in Wisconsin and a third species from Louisiana. Based on reliable distribution records of adults of the three species (Brigham 1981, Barr and Chapin 1988, Brigham pers. comm.), we believe that only two species occur in Wisconsin. After comparing the distribution of the
two larval forms in Wisconsin with the known distribution of adults, we con­
clude that larvae of species 1 are probably *E. leechi* and larvae of species 2 are
probably *E. nervosa*. *Ectopria thoracica* is apparently a southern and eastern
species; larvae from Louisiana lack asperities (dark, dot-like elevations) and
are likely this species. The riparian adults can be identified by using
Brigham’s key (1981).

**Key to Larvae of *Ectopria* in Wisconsin**

1. Numerous dark asperities on all lateral abdominal projections and
   between dorsal longitudinal rows of asperities; setae on posterior
   margin of thoracic and abdominal terga clear and inconspicuous
   ................................................................. *Ectopria* species 1

   Dark asperities mostly absent from lateral abdominal projections
   and from between dorsal longitudinal rows of asperities; conspicu­
   ous, dark, brush-like setae arising from posterior margins of terga
   on thorax and abdominal segments 1–7  . . . . *Ectopria* species 2

**Ectopria species 1**

Distribution and Habitat: Fairly common statewide, especially in south­
eastern area (Map 23). Larvae were found on cobbles and boulders in streams
of all sizes and wave-swept shallows of lakes; some were found on submerged
wood. Many were collected from sandy, hardwater streams where they
occurred on and underneath sand and travertine deposits on rocks. Larvae of
the two species were collected together in only two rivers in the northwest.

Identification: The key readily separates larvae of the two species.

**Ectopria species 2**

Distribution and Habitat: Rare in northern half (Map 24). Larvae occurred
on cobbles and boulders in medium to large streams; a few were found on
submerged wood. None were collected from lakes.

Identification: Larvae are easily identified by the key.

**Psephenus Haldeman, 1853**

Only one species occurs in eastern North America (Brown and Murvosh
1974).

**Psephenus herricki** (DeKay, 1844)

Distribution and Habitat: Common in eastern half (Map 22). Larvae were
found on cobbles and boulders in riffles and runs of streams and wave-swept
shallows of lakes, including Lake Michigan’s Green Bay.

Identification: Characters in the key readily separate larvae from those of
*Ectopria*. The riparian adults, which enter the water to oviposit, can be identi­
fied by using the key in Brown and Murvosh (1974).

**ACKNOWLEDGMENTS**

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trips.
LITERATURE CITED


DETECTION OF PROLONGED DIAPAUSE OF NORTHERN CORN ROOTWORM IN MICHIGAN (COLEOPTERA: CHRYSOMELIDAE)

D. A. Landis1, E. Levine2, M. J. Haas1 and V. Meints3

ABSTRACT

Prolonged diapause of northern corn rootworm, while known from other Midwestern states, has not previously been reported in Michigan. Populations of northern corn rootworm, (Diabrotica barberi) from two first-year corn fields in Genesee County, Michigan were examined for prolonged egg diapause. Prolonged diapause was suspected in these populations due to an unusually high proportion of northern versus western corn rootworms in these fields. Eggs obtained from females collected at these sites were reared in the laboratory for two years. The presence of the prolonged diapause trait was confirmed in one population by eggs which hatched following two simulated winters (7.3%). None of the eggs in the second population hatched following the second chill period, however, some eggs in this population remained in apparent diapause at the end of two years. The potential for using observed population shifts in favor of D. barberi as an early warning of the expansion of prolonged diapause in a population is discussed.

Northern corn rootworm (NCR), Diabrotica barberi Smith and Lawrence, and western corn rootworm (WCR), Diabrotica virgifera virgifera LeConte, are the most serious insect pests of corn in the Midwest, accounting for approximately 1 billion dollars annually through lost yield and costs of control (Metcalf 1986). Rootworm eggs are laid in the soil of corn fields in late summer, overwinter in diapause and typically hatch the following spring (Branson and Krysan 1981). Larval feeding on corn root systems is usually confined to fields which have been in corn for two or more years. Management of corn rootworms includes the use of adult monitoring and thresholds to predict the need to control rootworms where corn follows corn as well as, crop rotation, tillage, host plant resistance, cultural, biological and insecticidal controls (Levine and Oloumi-Sadeghi 1991). In Michigan, rootworm management is usually accomplished by crop rotation, i.e. planting corn following a non-host crop (soybeans, dry beans, alfalfa, sugar beets or small grains), or by use of insecticides where fields are not rotated (Landis and Giebink 1992a). Scouting for adults to predict the potential for damage in the following year is becoming more prevalent as a decision tool.

Rootworm management is complicated by the occurrence of prolonged (extended) diapause in some NCR populations (Levine and Oloumi-Sadeghi

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Prolonged diapause occurs when eggs pass through more than one winter (chill period) before hatching. This allows for the possibility of damage in first year corn (e.g. corn, soybean, corn rotation) and makes prediction of appropriate management tactics more difficult. Chiang (1965) reported that a small percentage (0.3%) of NCR eggs collected from a Minn. corn field hatched after passing through two winters. More recently, prolonged diapause of NCR has been confirmed from Minn. (Krysan et al. 1986), S. Dak. (Krysan et al. 1984, 1986), N. Dak. and Ill. (Levine et al. 1992). The maximum reported percentage of eggs hatching following more than one chill period (simulated winter) is 51% from east central Ill. (Levine et al. 1992). Damage to first year corn, suggesting the occurrence of the prolonged diapause trait, has occurred in Iowa (Tollefson 1988). Prolonged diapause of NCR has not previously been reported from Michigan.

In many cases, the occurrence of prolonged diapause is detected only after reports of damage (lodged plants) in first-year corn fields. For first-year damage to occur, two criteria must be met. The prolonged diapause trait must be present and there must be sufficiently high numbers of NCR in a field so that the population that diapause for two winters is adequate to cause lodging. In Michigan, NCR are at present relatively uncommon, with 95% or greater of the rootworm population made up of WCR. This situation would tend to lead to minimal damage to first-year corn even if the prolonged diapause trait were present in NCR and may complicate or delay the detection of the phenomenon.

Beginning in 1987, unusually high proportions of NCR beetles were observed in a localized area of Richfield township in Genesee County, Michigan. In August, 1989, an exceptionally high proportion of NCR (> 85%) was observed in two first-year corn fields (following winter wheat) in this area. Prolonged diapause of NCR was one possible explanation for these observations and the following studies were conducted to determine if the trait was present in these populations.

METHODS AND MATERIALS

Two first-year corn fields in Genesee Co., MI (DeWitt and Fisher) with similar cropping histories (Table 1) and high proportions of NCR adults were selected. The soil type of the DeWitt field was a Celina loam (fine, mixed, mesic Aquic Hapludalf), and in Fisher a Conover loam (fine-loamy, mixed, mesic Udollic Ochraqualf). Numbers of adult corn rootworm beetles per plant and proportion of NCR versus WCR were determined by counting beetles on sixty plants in each of three areas of the two fields in early August 1989 (Landis and Giebink 1992b). Corn root systems from these fields were sampled on 24 August 1989, to determine if rootworm larvae had fed on the current year's plants. Five representative areas of the field were selected and four plants chosen at random from each area. Plants were excavated and root systems returned to the lab for washing and rating of corn rootworm larval damage. Root damage was rated on a 1-6 scale (Hills and Peters 1971). Adult beetle counts on the Fisher field and four additional sites in the same township were conducted on 1-2 Aug. 1991 to assess corn rootworm density and proportions of NCR in the populations. The DeWitt field was not in corn in 1991.

Adult NCR beetles were collected from the DeWitt and Fisher fields on 28 Aug. 1989 by tapping infested silks over a funnel placed in a 3.8 l plastic jug. Beetles were also collected from the flowers of Daucus carota, Solidago spp. and Setaria spp. in the immediate field borders. Approximately 100 females
Table 1. — Cropping histories, mean number of corn rootworm beetles (D. virgifera virgifera and D. barberi) per plant and percentage D. barberi of total number of beetles observed for the study fields (Fisher and DeWitt) and other locations in Genesee Co., MI.

<table>
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<tr>
<th>Field</th>
<th>Year</th>
<th>Crop</th>
<th>Planting date</th>
<th>Insecticide</th>
<th>Mean No. adults per plant ± SEM</th>
<th>% D. barberi (N total)</th>
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<td>1991</td>
<td>Corn</td>
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<tr>
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<td>Corn (&gt;3 yr)</td>
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<td>-</td>
<td>2.9±0.7</td>
<td>52.0 (258)</td>
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</tbody>
</table>


bEstimated by crop scout.

were collected from DeWitt and 50 from the Fisher site along with equivalent numbers of males. Beetles from each population were placed in separate 30 cm³ screen cages (21 ± 2°C) and supplied with fresh corn silks and 3 cm sections of milk-stage corn ear with the kernels lacerated. Oviposition dishes (Krysan et al. 1984) were presented to the beetles from 29 Aug. through 2 Oct. and changed weekly. Soil which passed through a 6.25 mm but not through a 3.13 mm mesh screen was used as the oviposition media. Two loam soils (Colwood-Brookston and Capac) were placed in separate oviposition dishes in each cage and kept moist but not wet with distilled water.

On 2 Oct. all dishes were sent to Illinois for egg extraction and determination of diapause length using methods from Levine et al. (1992). Upon arrival, ca. one half of the dishes were examined to confirm that successful oviposition had occurred. Eggs were removed from the soil by washing through a 0.25 mm mesh sieve with 20°C tap water, counted, placed on and covered by moistened silty clay loam soil (sieved through a 0.18 mm screen) in 60 mm petri dishes (± 50 eggs per dish). Eggs in the remaining dishes were not removed from the oviposition soil before storage. All dishes were then placed in a dark environmental chamber (5 Oct.) set to simulate average monthly soil temperatures (1981–1984) at the 10 cm depth in Urbana, IL. (Table 2). Temperatures were adjusted monthly to mimic field conditions and distilled water was added as necessary to keep soil moist. In May 1990, all eggs were separated from the soil by washing through a 0.25 mm mesh sieve and placed on moistened filter paper in 60 mm petri dishes and returned to the chamber. Six drops of 1000 ppm benomyl was added to each filter paper at the outset to retard fungal growth (Oloumi-Sadeghi and Levine 1989). Egg hatch was monitored and recorded daily and distilled water added as needed to keep the filter paper moist. Hatched eggs, larvae, collapsed eggs and those heavily infested with fungi were removed with a camel hair brush (sterilized in alcohol and rinsed with distilled water between each use). In Sept. 1990, unhatched eggs were
Table 2.—Mean monthly soil temperature (1981–1984) at the 10 cm depth, Urbana, IL, used to mimic corn rootworm egg diapause and hatch conditions. Simulated monthly temperature equals average monthly mean (N = 4 years) and is actual temperature (±0.5 °C) of chamber used for the experiment. Minimum and maximum monthly soil temperatures show the warmest and coldest monthly averages in data set.

<table>
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<tr>
<td>February</td>
<td>6.8</td>
<td>-1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>March</td>
<td>11.3</td>
<td>0.0</td>
<td>4.4</td>
</tr>
<tr>
<td>April</td>
<td>18.3</td>
<td>3.9</td>
<td>10.6</td>
</tr>
<tr>
<td>May</td>
<td>22.5</td>
<td>10.1</td>
<td>16.7</td>
</tr>
<tr>
<td>June</td>
<td>26.9</td>
<td>17.2</td>
<td>22.2</td>
</tr>
<tr>
<td>July</td>
<td>29.1</td>
<td>20.2</td>
<td>24.4</td>
</tr>
<tr>
<td>August</td>
<td>28.2</td>
<td>20.0</td>
<td>24.4</td>
</tr>
<tr>
<td>September</td>
<td>26.3</td>
<td>14.2</td>
<td>20.6</td>
</tr>
<tr>
<td>October</td>
<td>21.8</td>
<td>8.6</td>
<td>15.0</td>
</tr>
<tr>
<td>November</td>
<td>15.3</td>
<td>2.9</td>
<td>8.9</td>
</tr>
<tr>
<td>December</td>
<td>9.4</td>
<td>-1.5</td>
<td>3.3</td>
</tr>
</tbody>
</table>

RESULTS

In the DeWitt field, 63% of the plant roots sampled in 1989 were fed upon by corn rootworm larvae, however, no root systems had damage ratings greater than 2, indicating minimal damage. The mean root rating for the field was 1.6 (N=19, SEM = 0.11). In the Fisher field, 86% of the plant roots had detectable rootworm damage. Most damaged plants (76.2%) had root ratings of 2, however, single plants with root ratings of 4 and 5 were recorded and both were lodged. The mean root rating for the Fisher field was 2.1 (N=21, SEM=0.19). Yield losses from rootworm damage depend on the biological, environmental and agronomic factors which occur prior to and following damage, however, a root rating of 2.75–3.0 (1–6 scale) is considered by many entomologists to be the minimum level at which the potential for economic damage exists (Mayo 1986).

A total of 101 viable eggs laid by NCR from the DeWitt population, were recovered in May 1990 following the first chill period. During the first observation (hatching) period (May-Sept. 1990) 8 of these eggs died and 76 hatched. At the end of the period, 17 viable (diapausing) eggs were returned to a soil dish for a second chill period. Following the second chill period, (May 1991) 6 had died, 1 was lost and 10 remained viable. During the second observation period, 4 eggs died and 6 hatched. When calculated as a percentage of the eggs which hatched in two years, 92.7% of the eggs in the DeWitt population exhibited a one year diapause and 7.3% had a two year diapause.

In the Fisher population, 41 viable eggs were recovered following the first chill period. In the first observation period, 6 of these eggs died and 18 hatched. At the end of the period, 17 viable eggs remained. In May 1991, 4 eggs were recovered: 12 had died and 1 was lost. Two eggs died in the subsequent observation period and none hatched. The two remaining viable eggs
were placed back into soil for a third chill period. All of the eggs which hatched from the Fisher population exhibited a one year diapause. None showed a two year diapause, however, two eggs remained in diapause at the end of the study.

DISCUSSION

The unusually large percentage of NCR adults in first-year corn fields combined with the presence of root damage was strongly indicative of prolonged diapause in these populations. However, it could not be ruled out that wheat residue or weeds had stimulated egg laying by NCR following wheat harvest in 1988. The subsequent egg diapause studies confirmed that the prolonged diapause trait is present in at least one and perhaps both of these populations.

In the Fisher population, all of the eggs which hatched within two years did so in the first summer, however, two eggs remained in diapause at the end of the study. In other studies (Levine et al. 1992), between 25 and 100% of the eggs which remained in diapause after two years hatched in year three (Mean=49.3%, SEM=9.2%, N=7) with a much smaller percentage hatching in year four. Thus, it is possible that the remaining eggs in this study are exhibiting a three year or longer diapause. If both of the remaining eggs hatched in a subsequent year they would represent a prolonged diapause in 10% of the Fisher population.

The DeWitt population, had a significant proportion of the individuals with a two year diapause (7.3%). This supports the hypothesis that root damage observed in the DeWitt field in 1989 was due to eggs laid in 1987 when the field was last in corn. Failure to detect a two year diapause from the Fisher population suggests that damage in 1989 was either due to eggs laid in 1986 (three year diapause) or that oviposition occurred in the wheat stubble or weeds in 1988. However, it is possible that the smaller initial egg sample size (N=41 for Fisher, N=101 for DeWitt) may have inhibited our ability to detect a low level of two year diapause in the Fisher population. While oviposition by rootworm adults in crops preceding corn has been proposed as an explanation for damage to first-year corn (Branson and Krysan 1981, Hill and Mayo 1980), studies examining oviposition in soybeans (Shaw et al. 1978) and small grain stubble (Gustin 1984) indicate that non-corn oviposition is minimal.

Prolonged diapause is believed to be an adaptation of the NCR to the cultural practice of crop rotation (Krysan et al. 1986). There is a greater incidence of two year diapause in areas where corn is commonly grown in a two year rotations (e.g. corn, soybeans, corn) than in areas of continuous corn production (Krysan et al. 1986, Ostlie 1987). Levine et al. (1992) provide evidence that NCR may also adapt to longer rotations. A population from a South Dakota site where various two to four year rotations prevail, had 20.6, 20.9 and 9.6% of the eggs hatching after two, three and four winters respectively. Among Michigan cash grain producers, corn is typically grown in a two year (31% of acres) or three year rotation (23% of acres) with small grains, beans or sugar beets. This includes some rotations which have corn following corn (e.g. corn, corn, soybeans). A smaller amount (10%) is planted as continuous corn with four year or longer and "other" rotations making up the remainder of the acreage (Chase et al. 1990).

In our study area of Genesee County, numerous rotational patterns exist, including continuous corn as well as three and four year rotations with corn, wheat and soybeans. Although two year crop rotations are practiced on some farms, they not particularly common in this area and are not used on the
farms where we conducted our studies (DeWitt was corn in four out of six years and Fisher five out of six). While it may not be immediately clear from these rotational patterns why prolonged diapause is occurring, it should be noted that development of the trait must be viewed at the population rather than individual field level. As long as a substantial number of fields in an area have rotations which include corn on a two to four year basis, then selection for prolonged diapause can occur particularly since interfield movement of adult beetles is well known (Lance et al. 1989, Naranjo 1991). Eggs laid in corn in the DeWitt or Fisher fields in 1987 were subjected to a wheat, corn sequence in the next two years. Any individuals previously selected for prolonged diapause would have increased fitness under these conditions.

A unique feature of this study is that the presence of prolonged diapause was detected primarily from the presence of a high proportion of NCR versus WCR beetles in these fields, not from observation of damage in first-year corn. Several farms in this area have been scouted regularly since 1985 by employees of a crop consulting firm. Experience indicated that in this area of the state, WCR made up > 95% of the corn rootworm population, with NCR typically < 5%. A high proportion of NCR was first recorded in 1987 from one field in this immediate area. In 1989, observations of several fields with very high proportions of NCR (> 85% Fisher, and 89% DeWitt) indicated a very unusual situation and prompted these investigations. The 1991 adult survey data (Table 1) indicate that four out of the five fields sampled in this area continue to have a greater than expected proportion of NCR versus WCR beetles. The Fisher field had 60% NCR with a density of 2.8 beetles per plant (Table 1). The Soper, Zelco and Cullen fields also had elevated proportions of NCR ranging from 16 to 52% of the total population. All of these are unusually high in contrast to the normal level of < 5% NCR in most areas of Michigan. The Bird field had a more typical situation with 0.3 beetles per plant and 2.6% NCR.

Although individual plants in the Fisher and DeWitt fields exceeded the minimum root rating for economic damage (3 on a scale of 1-6), the field means (root ratings = 2.1 and 1.6) were well below economic levels. In Michigan, and other states where WCR predominates, a sudden unexplained shift in the species composition of a corn rootworm population towards the NCR may be an early warning signal of the expansion of the prolonged diapause trait in the population. Since this warning may be detected prior to economic damage in first-year corn (as in this study), appropriate management practices can be initiated earlier, perhaps by several years, than if lodging of first-year corn was the only symptom. Observation of a population shift towards NCR could be caused by a number of other factors and should only be used as a signal that prolonged diapause may be present. In particular, since WCR eggs are less cold hardy than NCR eggs (Palmer et al. 1977, Gustin 1983), widespread population shifts towards NCR following extremely cold winters may not be diagnostic. Increased abundance of NCR without a concomitant increase in proportion of NCR versus WCR may also simply reflect better overall survival and may not be important in signaling prolonged diapause. Rearing experiments, although tedious, are at present the only reliable method for positive confirmation of prolonged diapause and should be conducted if the trait is suspected.
ACKNOWLEDGMENTS

We thank Agri-Business Consultants for alerting us to the original situation and sharing their records with us. We also acknowledge Bill Hunt of Hunt Farms for allowing us to conduct the field portions of this study on his farm. Joe Hudecek assisted with the field evaluations, David Bott and Amy Ziegler assisted in the laboratory studies. We also thank E. Grafius and J. Miller and two anonymous reviewers who provided useful comments on an earlier version of this manuscript. This study was supported in part by the Michigan and Illinois Agricultural Experiment Stations.

LITERATURE CITED


CONTROL OF APHIDS ON SPRING OATS AND WINTER WHEAT WITH SLOW RELEASE GRANULAR SYSTEMIC INSECTICIDES

Jaime E. Araya and Sue E. Cambron

ABSTRACT

Aphid infestations (Homoptera: Aphididae) on spring oat (Avena sativa) cv. 'Ogle', and during the fall on winter wheat (Triticum aestivum) cv. 'Clark', composed mainly of Rhopalosiphum padi and Macrosiphum avenae, were reduced with applications at the 2-3 leaf stage of slow release granular formulations of acephate, carbofuran, and disulfoton, compared with carbofuran 15G and untreated controls, in field trials during 1990-1991 in northwestern Indiana. These field results corroborated those obtained by previous studies with the same formulations and dosages in the laboratory.

In oat, all insecticide treatments reduced aphid populations and percentage aphid-infested plants, with a residual action of ca. 25 d. Barley yellow dwarf virus-like visual symptoms were reduced with disulfoton. In winter wheat, the residual action of all insecticide treatments in the fall lasted up to 19 d. The carbofuran treatment on winter wheat seedlings caused earthworms to move out of the soil, where they died; an effect requiring further study. Percentage of aphid-infested plants revealed relatively wider differences among treatments than total number of aphids in both test crops. Predation by Coleomegilla maculata (Coleoptera: Coccinellidae) contributed to the overall reduction of spring populations of cereal aphids in wheat and oat. Aphid mummies parasitized by micro-hymenopterans were common in oat plants.

Cereal aphids (Homoptera: Aphididae), specifically the bird cherry-oat aphid, Rhopalosiphum padi (L.), and English grain aphid, Macrosiphum (Sobion) avenae (F.), are important pests of small grains (Rabbinge and Rijsdijk 1984, Araya et al. 1986). They damage plants by direct feeding on phloem sap and are vectors of plant viruses (Hinz et al. 1979), most importantly barley yellow dwarf virus (BYDV) (Bruehl 1961, Stern 1967, Kolbe 1973). Severe losses due to BYDV infection have been reported (Caldwell et al. 1959, Tothman et al. 1959, Palmer and Sill 1966, Gill 1980, Carrigan et al. 1981). Damage may be severe when winged migrants colonize winter wheat in the fall (Endo and Brown 1963) or in early spring (Arretz and Araya 1978).

Economic infestations of cereal aphids can be controlled easily with foliage sprays of various insecticides. Araya et al. (1990a) summarized that the
most important advantages of using granular formulations of systemic insecticides applied to the soil, compared with foliage sprays, are the protection of natural enemies of aphids and the reduced exposure of toxicants and effective placement of formulated chemicals to control the target pest.

Acephate, carbofuran, and disulfoton were selected for this study because of their acceptability and wide solubility in water (Oetting et al. 1984). Acephate has low toxicity to non-target organisms, including diverse hymenopteran parasitoids (Fitzpatrick et al. 1978, Lange et al. 1980, Flanders et al. 1984, Hsieh and Allen 1986) and predators (Whalon and Elsner 1982). Acephate residues decline rapidly in plants (Frank et al. 1984) and even faster in the soil (Szeto et al. 1979, Yamazaki et al. 1982). Soil applications of granular carbofuran and disulfoton have systemically controlled cereal aphids (DePew 1974, van Rensburg et al. 1978, Arretz and Araya 1978, 1980, Mize et al. 1980, Araya et al. 1990b). Insect predators are spared with soil incorporated carbofuran (e.g. Gholson et al. 1978, Semtner 1979, Edwards et al. 1980), while spray residues of carbofuran are highly toxic to parasitoids (Dumbre and Hower 1977).

Our research studied the effects of the slow release granular formulations of systemic insecticides tested in the laboratory by Araya et al. (1990a, 1990b) on cereal aphids on spring oat (Avena sativa), and winter wheat (Triticum aestivum) under field conditions in northwestern Indiana.

MATERIALS AND METHODS

Field trials using spring oat and winter wheat, both at the Purdue University Agronomy Farm, located northwest of West Lafayette, Tippecanoe Co., Indiana, were conducted during 1990-1991.

I. Spring oat.

The insecticide treatments listed (formulation, concentration, and g/plot) were applied on 8 May 1990, on 2–3 leaf stage ‘Ogle’ spring oat seedlings (growth stage 1–2 of Feekes scale [Large 1954]) with 23% of the plants infested (mean: 3 aphids/100 plants), using 0.5 x 1 m plots (0.5 m²) and 5 replicates. All dosages were adjusted to a standard of 10 kg/ha of carbofuran 10G. The description, preparation and effectiveness of these formulations have been described by Araya et al. (1990a, 1990b), Shasha et al. (1984), and Wing et al. (1987), respectively. The granular insecticide treatments were applied by hand with a 0.5 l plastic cylindrical container. Granular clay was used as inert carrier to facilitate an even distribution of the formulation over the respective plots.

- t1. Acephate ps (pearl starch granules; 10.1%; 0.495 g).
- t2. Acephate cf (corn flour granules; 9.7%; 0.516 g).
- t3. Carbofuran ps (pearl starch granules; 8.1%; 0.618 g).
- t4. Carbofuran cf (corn flour granules; 8.3%; 0.603 g).
- t5. Carbofuran (15G; 0.394 g).
- t6. Disulfoton ps (pearl starch granules; 2.7%; 1.853 g).
- t7. Disulfoton (wax granules; 12.9%; 0.338 g).
- t8. Control without insecticide.
II. Winter wheat.

In the winter wheat test, the cv. Clark and 0.75 x 1 m plots were used; 2-leaf seedlings (growth stage 1 of Feekes scale [Large 1954]) were treated on 2 Nov. 1990. Treatment No. 6 (t6: disulfoton) was applied at 8% AI (0.938 g/plot); all the other treatments were the same as in the spring oat test.

Periodic counts of cereal aphids and percentage aphid-infested plants in the test plots were recorded in both tests when aphids were present in the field. Results were analyzed statistically using single factor ANOVAs with repeated measures (percentage data were previously normalized with the ln(1+x) transformation); significantly different (P≤0.05) means were separated using Fisher's PLSD tests (Statview 512+ Statistical Software, Abacus Concepts, Inc. 1986).

RESULTS AND DISCUSSION

Both *R. padi* and *M. avenae* were commonly found. Bird cherry-oat aphids were usually more abundant late in the fall and early in the spring than English grain aphids, revealing a probable better adaptation to cooler temperatures of the former species; the later was more abundant later in spring, and was concentrated, but was not exclusively on the heads of maturing plants. A few greenbugs, *Schizaphis graminum* Rondani, were found in late spring, as this species may be better adapted to warmer temperatures (Araya et al. 1983).

I. Spring oat.

All insecticide treatments reduced significantly (P≤0.05) aphid populations and the percentage of aphid-infested oat plants (Table 1), with residual action lasting ca. 25 days. Rain 1 d after application may have accelerated the incorporation of the active ingredients (AI) in the soil, so the insecticide effects were noticed at the first aphid count, 6 days after application. When the effects of the insecticide treatments were averaged by AI to visualize the average effect of the AI (Table 2), carbofuran [(t3+t4+t5)/3 = average of three formulations] offered the best protection, followed by disulfoton and acephate [averages of two formulations each: (t7+t8)/2 and (t1+t2/2), respectively].

On 4 June 1990 (27 days after application), some plants at the growth stage 10 (booting) of the growth scale of Feekes (Large 1954) exhibited barley yellow dwarf virus (BYDV)-like symptoms. An ANOVA showed that both formulations of disulfoton presented less plants with these symptoms than the other treatments (Table 3). Thus, disulfoton may have prevented BYDV infection. It is unclear, however, whether these visual symptoms may have been caused by plant infection with BYDV alone or in conjunction with one or more small grain viruses. Further tests are required.

Observations of natural enemies of aphids, including counts of aphids with mycelia of *Enthomophthora*, mummified aphids, and the different stages of the ladybird beetle, *Coleomegilla maculata* DeGeer, are presented on Table 4.

Counts of dead aphids covered with *Enthomophthora* are not quantitative because and unknown number of these infected aphids fall to the ground. They provide, however, an indication of the period when this beneficial control agent was detrimental to cereal aphids.

Aphid mummies parasitized by microhymenopterans were common in the oat test, from plant growth stages 6 through 10.1 of Feekes. The maximum
Table 1. — Mean number of aphids per plant, and mean percentage of aphid-infested spring oat plants ± S.E. in field plots treated with different insecticide formulations

<table>
<thead>
<tr>
<th>Insecticides</th>
<th>Days from application – Feekes growth stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-5</td>
</tr>
<tr>
<td>a. Aphids per plant</td>
<td></td>
</tr>
<tr>
<td>1. Acephate 10.1 ps</td>
<td>0.56±0.19b</td>
</tr>
<tr>
<td>2. Acephate 9.7 cf</td>
<td>0.56±0.07b</td>
</tr>
<tr>
<td>3. Carbofuran 8.1 ps</td>
<td>0.26±0.09b</td>
</tr>
<tr>
<td>4. Carbofuran 8.3 cf</td>
<td>0.28±0.10b</td>
</tr>
<tr>
<td>5. Carbofuran 15 G</td>
<td>0.34±0.15b</td>
</tr>
<tr>
<td>6. Disulfoton 2.7 ps</td>
<td>0.50±0.08b</td>
</tr>
<tr>
<td>7. Disulfoton 12.9 wax</td>
<td>0.46±0.07b</td>
</tr>
<tr>
<td>8. Control</td>
<td>1.00±0.21a</td>
</tr>
<tr>
<td>F test/P values</td>
<td>3.340/0.0103</td>
</tr>
</tbody>
</table>

b. % aphid-infested plants

<table>
<thead>
<tr>
<th>Insecticides</th>
<th>Days from application – Feekes growth stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6-5</td>
</tr>
<tr>
<td>1. Acephate 10.1 ps</td>
<td>34.0±10.30ab</td>
</tr>
<tr>
<td>2. Acephate 9.7 cf</td>
<td>34.0±5.10ab</td>
</tr>
<tr>
<td>3. Carbofuran 8.1 ps</td>
<td>18.0±5.83b</td>
</tr>
<tr>
<td>4. Carbofuran 8.3 cf</td>
<td>24.0±9.27b</td>
</tr>
<tr>
<td>5. Carbofuran 15 G</td>
<td>20.0±7.07b</td>
</tr>
<tr>
<td>6. Disulfoton 2.7 ps</td>
<td>38.0±4.90ab</td>
</tr>
<tr>
<td>7. Disulfoton 12.9 wax</td>
<td>30.0±3.16ab</td>
</tr>
<tr>
<td>8. Control</td>
<td>60.0±10.95ab</td>
</tr>
<tr>
<td>F test/P values</td>
<td>1.894/0.1084</td>
</tr>
</tbody>
</table>

1Insecticide formulation treatment means in a column for each of the two parameters with different letters are significantly different (P ≤ 0.05), according to Fisher's PLSD tests.
2Application on 5.8.90; growth stages of Feekes (Large 1954).
3F test and P values for treatments were obtained from single factor ANOVAS with repeated measures (Statview 512™ Statistical Software; Abacus Concepts, Inc. 1986).
Table 2.—Average number of aphids per plant, and average percentage of aphid-infested spring oat plants ± S.E. in field plots treated with different insecticides (averages of 2, 3, and 2 formulations of acephate, carbofuran, and disulfoton, respectively).

<table>
<thead>
<tr>
<th>Insecticides</th>
<th>Days from application</th>
<th>6–5</th>
<th>10–6</th>
<th>15–7</th>
<th>21–8–9</th>
<th>27–10</th>
<th>34–10.1</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>a.</td>
<td>Aphids per plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Acephate</td>
<td>0.56±0.12a</td>
<td>0.56±0.12b</td>
<td>0.97±0.12b</td>
<td>1.07±0.26b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carbofuran</td>
<td>0.53±0.21a</td>
<td>0.21±0.04b</td>
<td>0.42±0.10b</td>
<td>0.57±0.04b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Disulfoton</td>
<td>0.56±0.06a</td>
<td>0.36±0.05b</td>
<td>0.72±0.07b</td>
<td>0.94±0.13b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control</td>
<td>1.00±0.21a</td>
<td>1.00±0.11a</td>
<td>1.92±0.41a</td>
<td>2.74±0.45a</td>
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<tr>
<td></td>
<td>F test/P values</td>
<td></td>
<td></td>
<td>1.479/0.2697</td>
<td>8.591/0.0026</td>
<td>9.008/0.0021</td>
<td>15.550/0.0002</td>
</tr>
<tr>
<td></td>
<td>b. % aphid-infested plants</td>
<td></td>
<td>Acephate</td>
<td>34.0 ± 05.79b</td>
<td>38.00±5.15b</td>
<td>58.00±3.39b</td>
<td>51.00±4.00a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carbofuran</td>
<td>20.67±3.06c</td>
<td>16.66±2.11c</td>
<td>21.33±3.59d</td>
<td>32.67±1.94a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Disulfoton</td>
<td>34.00±1.87b</td>
<td>31.00±3.32b</td>
<td>42.00±1.23c</td>
<td>48.00±2.92a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control</td>
<td>60.00±10.95a</td>
<td>64.00±6.00a</td>
<td>78.00±6.63a</td>
<td>50.00±17.03a</td>
</tr>
<tr>
<td></td>
<td>F test/P values</td>
<td></td>
<td></td>
<td>9.196/0.002</td>
<td>17.197/0.0001</td>
<td>47.436/0.0001</td>
<td>0.945/0.4494</td>
</tr>
</tbody>
</table>

1Insecticide treatment means in a column for each of the two parameters with different letters are significantly different (P≤0.05), according to Fisher’s PLSD tests.
2Application on 5.8.90; growth stages of Fookes (Large 1954).
3F test and P values for treatments were obtained from single factor ANOVAS with repeated measures (Statview 512+® Statistical Software; Abacus Concepts, Inc. 1986).
Table 3. — Percentage of spring oat plants\(^1\) with BYDV-like symptoms 27 days from application\(^2\).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>% plants with BYDV-like symptoms</th>
<th>Treatments averaged by Active Ingredient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Acephate 10.1 ps</td>
<td>14.00 ± 2.45ab</td>
<td>Acephate: ((t1 + t2)/2) 14.00 ± 1.87b</td>
</tr>
<tr>
<td>2. Acephate 9.7 cf</td>
<td>14.00 ± 2.45ab</td>
<td></td>
</tr>
<tr>
<td>3. Carbofuran 8.1 ps</td>
<td>16.00 ± 7.48ab</td>
<td>Carbofuran: ((t3 + t4 + t5)/3) 13.33 ± 2.58b</td>
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<tr>
<td>4. Carbofuran 8.3 cf</td>
<td>10.00 ± 5.48ab</td>
<td></td>
</tr>
<tr>
<td>5. Carbofuran 15 G</td>
<td>14.00 ± 4.00ab</td>
<td></td>
</tr>
<tr>
<td>6. Disulfoton 8.0 ps</td>
<td>8.00 ± 3.74b</td>
<td></td>
</tr>
<tr>
<td>7. Disulfoton 12.9 wax</td>
<td>12.00 ± 5.83b</td>
<td>Disulfoton: ((t6 + t7)/2) 10.00 ± 3.16b</td>
</tr>
<tr>
<td>8. Control</td>
<td>36.00 ± 5.10a</td>
<td>Control: ((t8)) 36.00 ± 5.10a</td>
</tr>
</tbody>
</table>

\(P\) test/\(P\) values\(^3\) 1.366/0.2579 6.969/0.0057

\(^1\)Growth stage 10 (booting) of Fekkee scale (Large 1954). Insecticide formulation treatment means in a column for each of the two parameters with different letters are significantly different (\(P \leq 0.05\)), according to Fisher's PLSD tests.

\(^2\)Application on 5.8.90.

\(^3\)\(F\) test and \(P\) values were obtained from single factor ANOVAS with repeated measures (Statview 512+ "Statistical Software; Abacus Concepts, Inc. 1986").

density of mummies occurred on plants during the growth stages 8-9, when aphid counts were greatest (Table 1), and declined gradually thereafter, following the decline in density of aphids and revealing the importance of microhymenopteran parasitoids in reducing populations of cereal aphids.

Adult \(C.\) \(maculata\) ladybird beetles were observed throughout the test, except for the last aphid count. Their greatest density also occurred when aphids were most abundant. Oviposition of these predators, occurrence of larvae, and pupation started 2, 3, and 4 wk after the first aphid count, respectively.

II. Winter wheat.

a. Fall of 1990. Insecticide treatments were applied on relatively humid soil 1 d after rain on 2 November 1990, when the population density averaged 0.19 aphids per plant. Even though the population density of aphids was low, the treatments were applied to avoid population growth and provide insecticide protection to the plants when they were most susceptible to both cereal aphids and BYDV (Endo and Brown 1963, Smith 1967). The initial aphid count, 5 d after insecticide application, revealed a statistically significant effect of disulfoton, both in the mean number of aphids per plant and percentage aphid-infested plants (Table 5). The low population density may have contributed to mask the effect of the other treatments, which were not significantly different from the control in both parameters measured. The average insecticide effect of the treatments grouped by AI (Table 6) was clear at the first aphid count, 5 d after application. The residual action of all insecticide treatments in the fall lasted up to 19 d. Aphid counts were stopped afterwards due to cold weather. Winter migrant aphids are particularly important in the fall for the transmission of BYDV (Araya et al. 1987), a virus disease that can severely damage crops when the plants are inoculated at the seedling stage (Endo and Brown 1963, Smith 1967). Thus, the protection period of at least 3 wk obtained with the insecticide treatments is a very valuable result. Overall, the lowest aphid numbers and percentage of aphid-infested wheat plants (Tables 5 and 6) were observed with the formulations of disulfoton \([t6 + t7]/2\).
Table 4. — Aphids infected with *Entomophthora* sp. and aphids mummified with parasitoids observed on 40 spring oat and winter wheat field plots (10 plants per plot), and number of *Coleomegilla maculata* present on all plots (total of 20 m² per field trial).

<table>
<thead>
<tr>
<th>Days after treatment and plant stage</th>
<th>No. aphids infected with <em>Entomophthora</em></th>
<th>No. of mummified aphids adults</th>
<th><em>Ladybird beetles</em> egg masses</th>
<th>larvae</th>
<th>pupae</th>
<th>adult mh</th>
<th>Other insects²</th>
<th>ch larvae</th>
<th>om larvae</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Spring oat, 1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10-6</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>0</td>
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<tr>
<td>15-7</td>
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<td>2</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>21-8-9</td>
<td>1</td>
<td>35</td>
<td>17</td>
<td>5</td>
<td>4</td>
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<td>3³</td>
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</tr>
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<td>27-10</td>
<td>0</td>
<td>8</td>
<td>3</td>
<td>10</td>
<td>3</td>
<td>14</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>34-10.1</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>19</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>41-10.4</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b. Winter wheat, 1990-91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>10-2-3</td>
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<td>0</td>
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<td>0</td>
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<td>0</td>
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</tr>
<tr>
<td>14-3</td>
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<td>1</td>
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<td>0</td>
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<td>19-3-4</td>
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<td>0</td>
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<td>0</td>
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</tr>
<tr>
<td>Winter recess</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>165-7</td>
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<td>0</td>
<td>3</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>173-8</td>
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<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>181-9</td>
<td>0</td>
<td>0</td>
<td>1⁵</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>188-10.1</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>195-10.5</td>
<td>4</td>
<td>0</td>
<td>32</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>202-11</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0⁶</td>
</tr>
</tbody>
</table>

¹Applied to oat and wheat on May 8, and Nov. 2, 1990, respectively. Feeked growth stages (Large 1954).
²mh = microhymenopterans observed flying near the plants; ch = chrysopid; om = *Oulema melanopus* L.
³One of these mummies was parasitized by *Prason* sp.
⁴One *Nabis* sp.
⁵This specimen was parasitized by *Perilitus* sp.
⁶One syrphid larva.
Table 5. Mean number of aphids per plant, and percentage of aphid-infested winter wheat plants ± S.E. in field plots treated with different insecticides 1

<table>
<thead>
<tr>
<th>Insecticides</th>
<th>5 - 2</th>
<th>(Fall 1990)</th>
<th>Days from application – Feekes growth-stage 2</th>
<th>(Spring 1991)</th>
<th>a. Aphids per plant</th>
<th>b. % aphid-infested plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 - 2 - 3</td>
<td>14 - 3</td>
<td>19 - 3 - 4</td>
<td>165 - 7</td>
<td>173 - 8</td>
<td>181 - 9</td>
</tr>
<tr>
<td>1. Acephate 10.1 ps</td>
<td>0.48 ± 0.11a</td>
<td>0.16 ± 0.05bc</td>
<td>0.06 ± 0.02b</td>
<td>0.12 ± 0.07bc</td>
<td>0.40 ± 0.02a</td>
<td>0.40 ± 0.02a</td>
</tr>
<tr>
<td>2. Acephate 9.7 cf</td>
<td>0.18 ± 0.07bc</td>
<td>0.26 ± 0.07ab</td>
<td>0.08 ± 0.04b</td>
<td>0.16 ± 0.05ab</td>
<td>0.02 ± 0.02a</td>
<td>0.60 ± 0.06a</td>
</tr>
<tr>
<td>3. Carbofuran 8.1 ps</td>
<td>0.32 ± 0.04ab</td>
<td>0.10 ± 0.08bc</td>
<td>0.04 ± 0.02b</td>
<td>0.02 ± 0.02c</td>
<td>0.60 ± 0.04a</td>
<td>0.00 ± 0.00a</td>
</tr>
<tr>
<td>4. Carbofuran 8.3 cf</td>
<td>0.18 ± 0.06bc</td>
<td>0.12 ± 0.04bc</td>
<td>0.02 ± 0.02b</td>
<td>0.12 ± 0.04bc</td>
<td>0.00 ± 0.00a</td>
<td>0.00 ± 0.00a</td>
</tr>
<tr>
<td>5. Carbofuran 15G</td>
<td>0.38 ± 0.05a</td>
<td>0.06 ± 0.02c</td>
<td>0.08 ± 0.06b</td>
<td>0.06 ± 0.02bc</td>
<td>0.02 ± 0.02a</td>
<td>0.02 ± 0.02a</td>
</tr>
<tr>
<td>6. Disulfoton 8.0 ps</td>
<td>0.04 ± 0.04c</td>
<td>0.02 ± 0.02c</td>
<td>0.08 ± 0.04ab</td>
<td>0.02 ± 0.02c</td>
<td>0.60 ± 0.04a</td>
<td>0.00 ± 0.00a</td>
</tr>
<tr>
<td>7. Disulfoton 12.9 wax</td>
<td>0.00 ± 0.00c</td>
<td>0.00 ± 0.00c</td>
<td>0.06 ± 0.06b</td>
<td>0.06 ± 0.04bc</td>
<td>0.00 ± 0.00a</td>
<td>0.60 ± 0.04a</td>
</tr>
<tr>
<td>8. Control</td>
<td>0.36 ± 0.09ab</td>
<td>0.38 ± 0.12a</td>
<td>0.24 ± 0.07a</td>
<td>0.24 ± 0.07a</td>
<td>0.00 ± 0.00a</td>
<td>0.20 ± 0.02a</td>
</tr>
</tbody>
</table>

F test/P values 7.274/0.0001 4.522/0.018 2.539/0.037 3.333/0.010 0.817/0.581 0.770/0.617 1.000/0.452 0.758/0.618 0.805/0.590 1.192/0.339

Insecticide treatment means in a column for each of the two parameters with different letters are significantly different (P ≤ 0.05), according to Fisher's PLSD tests.

Application on 11.2.90; growth stages of Feekes (Large 1954).

F test and P values for treatments were obtained from single factor ANOVAs with repeated measures (Statview 512+, "Statistical Software; Abacus Concepts, Inc. 1986.

1 Insecticide treatment means in a column for each of the two parameters with different letters are significantly different (P ≤ 0.05), according to Fisher's PLSD tests.
2 Application on 11.2.90; growth stages of Feekes (Large 1954).
3 F test and P values for treatments were obtained from single factor ANOVAs with repeated measures (Statview 512+, "Statistical Software; Abacus Concepts, Inc. 1986).
Table 6.—Average number of aphids per plant, and percentage of aphid-infested winter wheat plants ±S.E. in field plots treated with different insecticides (averages of 2, 3, and 2 formulations of acephate, carbofuran, and disulfoton, respectively)1

<table>
<thead>
<tr>
<th>Insecticides</th>
<th>5–2</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Fall 1990)</td>
<td>Days from application—Feekes growth stage2</td>
<td>(spring 1991)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>a. Aphids per plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Acephate</td>
<td>0.33±0.06a</td>
<td>0.21±0.04ab</td>
<td>0.07±0.02b</td>
<td>0.14±0.05ab</td>
<td>0.03±0.01a</td>
<td>0.05±0.04a</td>
<td>0.00±0.00a</td>
<td>0.00±0.00b</td>
<td>0.23±0.14a</td>
<td>0.25±0.18a</td>
<td></td>
</tr>
<tr>
<td>2. Carbofuran</td>
<td>0.29±0.02a</td>
<td>0.09±0.03bc</td>
<td>0.05±0.02bc</td>
<td>0.07±0.02b</td>
<td>0.02±0.01a</td>
<td>0.00±0.00a</td>
<td>0.00±0.00a</td>
<td>0.07±0.04ab</td>
<td>0.22±0.08a</td>
<td>0.13±0.08a</td>
<td></td>
</tr>
<tr>
<td>3. Disulfoton</td>
<td>0.00±0.02b</td>
<td>0.01±0.01c</td>
<td>0.07±0.05b</td>
<td>0.04±0.02b</td>
<td>0.06±0.06a</td>
<td>0.04±0.02a</td>
<td>0.07±0.07a</td>
<td>0.04±0.02ab</td>
<td>0.56±0.23a</td>
<td>0.05±0.02a</td>
<td></td>
</tr>
<tr>
<td>4. Control</td>
<td>0.36±0.09a</td>
<td>0.38±0.11a</td>
<td>0.24±0.07a</td>
<td>0.24±0.07a</td>
<td>0.00±0.00a</td>
<td>0.01±0.01a</td>
<td>0.00±0.00a</td>
<td>0.12±0.05a</td>
<td>0.78±0.35a</td>
<td>0.04±0.04a</td>
<td></td>
</tr>
<tr>
<td>F test/P values</td>
<td>9.065/0.0021</td>
<td>6.887/0.0060</td>
<td>5.398/0.0139</td>
<td>6.614/0.0069</td>
<td>0.573/0.6435</td>
<td>0.901/0.4693</td>
<td>1.000/0.4262</td>
<td>2.117/0.1514</td>
<td>1.358/0.3023</td>
<td>1.165/0.3636</td>
<td></td>
</tr>
</tbody>
</table>

b. % aphid-infested plants

<table>
<thead>
<tr>
<th>Insecticides</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Acephate</td>
<td>23.00±3.39a</td>
<td>15.00±1.58ab</td>
<td>7.00±2.00ab</td>
<td>14.00±4.85ab</td>
<td>3.00±1.23a</td>
<td>5.00±3.87a</td>
<td>0.00±0.00a</td>
<td>0.00±0.00b</td>
<td>10.00±3.54a</td>
</tr>
<tr>
<td>2. Carbofuran</td>
<td>21.27±3.06a</td>
<td>8.00±2.00ab</td>
<td>3.33±1.06b</td>
<td>6.00±1.25bc</td>
<td>2.00±1.33a</td>
<td>0.00±0.00a</td>
<td>0.00±0.00a</td>
<td>2.67±1.25ab</td>
<td>10.00±2.79a</td>
</tr>
<tr>
<td>3. Disulfoton</td>
<td>2.00±2.00b</td>
<td>1.00±1.00bc</td>
<td>5.00±2.74b</td>
<td>4.00±1.87c</td>
<td>6.00±6.00a</td>
<td>1.00±1.00aa</td>
<td>1.00±1.00aa</td>
<td>2.00±0.82ab</td>
<td>20.00±5.24a</td>
</tr>
<tr>
<td>4. Control</td>
<td>32.00±4.90a</td>
<td>26.00±5.10a</td>
<td>18.00±4.90a</td>
<td>24.00±6.78a</td>
<td>1.00±0.00a</td>
<td>0.00±0.00a</td>
<td>8.00±2.00a</td>
<td>14.00±2.45a</td>
<td>2.00±2.00b</td>
</tr>
<tr>
<td>F test/P values</td>
<td>27.891/0.0001</td>
<td>26.736/0.0001</td>
<td>2.313/0.1278</td>
<td>9.938/0.014</td>
<td>0.325/0.8075</td>
<td>1.445/0.2785</td>
<td>1.000/0.4262</td>
<td>3.465/0.0509</td>
<td>1.772/0.2060</td>
</tr>
</tbody>
</table>

1 Insecticide treatment means in a column for each of the two parameters with different letters are significantly different (P ≤ 0.05), according to Fisher’s PLSD tests.
2 Application on 11.2.90; growth stages of Feekes (Large 1954).
3 F test and P values for treatments were obtained from single factor ANOVAS with repeated measures (Statview 512+ Statistical Software; Abacus Concepts, Inc. 1986).
The average effect of the disulfoton treatments on the number of aphids and percentage of aphid-infested plants was noted at the first aphid count, 5 d after application (Table 6), while those of acephate \[(t_1 + t_2)/2\] and carbofuran \[(t_3 + t_4 + t_5)/3\] started to show later.

In the fall, natural enemies were almost nonexistent; a total of 3 mummified aphids and 1 adult mycrohymenopteran parasitoid were observed on the plants randomly selected for aphid counts at this time (Table 4). This low density of natural enemies may favor a rapid growth of populations of cereal aphids during the fall, at a stage when plants are most susceptible to damage by these BYDV vectors. If environmental conditions are favorable for cereal aphids, they will also be so for natural enemies, but because of the time-lag produced between the growth of populations of aphids and their natural enemies, most of the damage caused by these aphids during the fall will be done before they are controlled by beneficial arthropods.

Infestation of Hessian fly, *Mayetiola destructor* (Say), during the fall in these plots was minimal, as only two dead larvae were found 5 d after application in one of the plants sampled from the control plots.

A number of dead earthworms, *Lumbricus* sp., were counted 5 d after application (Figures 1 and 2) over the surface of the plots treated with the three formulations of carbofuran. The three formulations of this insecticide caused statistically significant earthworm mortality, with a relative greater effect of carbofuran 8.3 cf. Reduced populations of lumbricid earthworms were reported by Martin (1978) on carbofuran-treated plots of pasture in New
Zealand. It is not known whether carbofuran or the other AI caused earthworm mortality below the soil surface. Further tests are required.

b. Spring of 1991. Aphid counts were stopped during winter and resumed in spring. Aphid populations were small, with a relatively minor increase from days 188 through 202 after application (plant growth stages 10.1 and 11 of the Feekes scale [Large 1954], respectively) (Tables 5 and 6). Population density peaked on day 195, when plants were at the 10.5 Feekes growth stage.

Aphids killed by *Enthomophthora* were observed in late spring (Table 4), on maturing wheat plants. No activity of microhymenopteran parasitoids was observed, but adult *C. maculata* ladybird beetles were often observed as soon as cereal aphids were found in the field. The other stages occurred later, as observed the previous year on spring oat. This coccinellid may play an important role in reducing cereal aphid populations on winter wheat during the spring, making it unnecessary to protect the maturing plants with organosynthetic aphicides.

Using slow release formulations of acephate encapsulated in pearl corn...
starch or corn flour granules in laboratory studies, Araya et al. (1990a) achieved >50% mortality of *R. padi* from days 15 and 17 through days 31.5 and 32.8 after seeding, respectively. The corresponding granular formulations of carbofuran provided control (>50% mortality) from days 13.3 through 17.9 and 31.6 and 35.5 after seeding, respectively. Foliar sprays of acephate and carbofuran applied 12 d after seedling emergence provided control for 18.3 and 36.2 d from application, respectively. Further laboratory studies (Araya et al. (1990b), testing similar formulations and dosages of acephate and carbofuran and higher dosages of disulfoton encapsulated in pearl corn starch granules, controlled *R. padi*, the Russian wheat aphid, *Diuraphis noxia* (Mordvilko), and rose-grain aphid, *Metopolophium dirhodum* (Walker), corroborating results obtained first with *R. padi*.

ACKNOWLEDGMENTS

The authors express their appreciation to Rick Foster, John J. Roberts, and Stanley G. Wellso for critically reviewing the manuscript.

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NORTHERLY-OUTLYING RECORDS OF TWO SPECIES OF HAWKMOTHS
(LEPIDOPTERA: SPHINGIDAE) IN MICHIGAN

John F. Douglass

The Grand Traverse Region of Lower Michigan is of special interest zoo­
geographically in that it includes the northernmost known localities for vari­
ous species of organisms characteristic of the Carolinian Biotic Province
(Douglass 1977, 1983; McCann 1979).

On 5 July 1984 I found a gravid female achemon sphinx (Eumorpha ache­
mon [Drury]) dead on Figg. Rd., Benzie Co. (T26N, R16W, boundary Sec.
14–15, N of jct. Graves Rd.). The specimen (collected) is in fresh condition, and
appeared to have been rather freshly killed: greenish eggs had spilled from the
ruptured abdomen and were congealing in the sand. The most northerly previ­
ously recorded Michigan localities for E. achemon are in Oceana, Midland, and
Bay Counties (Moore 1955, M. C. Nielsen, pers. comm.).

On 21 May 1988 I collected a male Abbott's sphinx (Sphecodina abbottii­
[Swainson]) beneath a mercury vapor light at the Douglass family cottage
overlooking Green Lake, Grand Traverse Co. (T26N, R12W, SW1/4 Sec. 21).
The specimen is in fresh condition. The northernmost previously recorded
Michigan localities for this species are in Ingham, Livingston, and Bay Coun­
ties (Moore 1955, M. C. Nielsen, pers. comm.).

These new moth records extend each species' known Michigan range three
tiers of counties to the north. It is not clear whether or not the specimens at
hand come from resident populations. Average temperatures, recorded at Tra­
verse City, were not appreciably higher than normal in the two months preced­
ing either date of capture. However, southern Lower Michigan experienced an
extreme drought during June 1984 and had its driest month of May on record
in 1988 (U. S. Dept. of Commerce 1984, 1988a, b). The possibility that the
specimens captured represent strays or temporary colonists from the south
cannot be ruled out.

General amelioration of climates following the latest event of glaciation in
the Great Lakes Region is viewed as having permitted northward range
expansions by a variety of organisms (de Vos 1964). Within historic times,
northward range expansions by some species have apparently been acceler­
ated by logging and agricultural clearing (Douglass 1977). In addition,
account should be taken of the findings of Cleland (1966, 1973): During an
earlier interval or intervals, the northward 'tongue' of distribution of Carolin­
ian species in western Lower Michigan was apparently more pronounced than
at present. For example, northward range expansions by various species
occurred along the Traverse Corridor (narrow coastal strip) during a warm
climatic phase ca. 1000 yr B.P., and southward range restrictions (evident
from the relictual nature of various plant, animal, and archaeological locali­
ties) apparently accompanied a return to cool, moist conditions beginning ca.
1300 A.D. Disjunct, northern populations of some species of insects currently
found in northwestern Lower Michigan may thus be relictual.

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LITERATURE CITED

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Papers dealing with any aspect of entomology will be considered for publication in *The Great Lakes Entomologist*. Appropriate subjects are those of interest to professional and amateur entomologists in the North Central States and Canada, as well as general papers and revisions directed to a larger audience while retaining an interest to readers in our geographic area.

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