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SYSTEMATICS OF ANEPEORUS
(EPHEMEROPTERA: HEPTAGENIIDAE)

W. P. McCafferty and A. V. Provonsa

ABSTRACT

The enigmatic genus *Anepeorus* has a confused and complex taxonomic history that is discussed and clarified. The genus is redefined and described in the adult stage. Although larvae have been assigned to *Anepeorus*, these larvae cannot be shown at the present to be *Anepeorus*. Two North American species are known from a total of 10 adult specimens: *A. rusticus* McDunnough and *A. simplex* (Walsh) are redescribed, and a neotype is designated for the latter species. Genitalic differences are diagnostic, but the penes may be found in different states of inflation and rotation that should not be interpreted as taxonomic differences.

The genus *Anepeorus* was established by McDunnough (1925) to accommodate a new species of Heptageniidae from Saskatchewan, *A. rusticus* McDunnough (genotype by original designation). The genus was significantly characterized for adult males by fore leg and genitalic characteristics, which continue to make *Anepeorus* a clearly recognizable taxon. Systematics of the species has been obscured by a rarity of specimens, nebulous treatments, and a rather intricate nomenclatural history that requires clarification.

Walsh (1863) described *Heptagenia simplex* from Rock Island, Illinois, and in 1869 deposited the types in the Chicago Academy of Sciences. Walsh sent duplicate specimens that he identified as *H. simplex*, including some collected subsequently in 1864 from the type locality, to Hermann Hagen in Prussia. Hagen deposited these specimens in the Museum of Comparative Zoology (MCZ) at Harvard in 1870. In 1871, all of Walsh's types were destroyed in the Chicago fire. Eaton (1871 and 1885) treated *H. simplex* but added nothing to Walsh's original description, evidently not having studied the MCZ material. Nathan Banks sometime later designated a number of lectotypes at the MCZ for Walsh's species, including one for *H. simplex*. These lectotype designations were not published.

McDunnough (1929) indicated that the specimens sent by Walsh to Hagen under the name *H. simplex* did not agree with Walsh's description, and he identified them as *Heptagenia persimplex* McDunnough, a species he described from material at the Canadian National Collection (CNC) that had been collected in 1928 from Iowa near Rock Island, Illinois. (This species has recently been placed in the genus *Macdunnova* Lehmkuhl by Flowers [1982]). At the same time, McDunnough indicated that fore leg traits described by Walsh (1863) for *H. simplex* corresponded to the generic concept of *Anepeorus* and therefore transferred *H. simplex* to *Anepeorus*. He identified one male specimen in the CNC collected near Davenport, Iowa, as *A. simplex* and figured its genitalic. McDunnough evidently believed this to be the only existent specimen verifiable as *A. simplex* at the time, and he made no mention of the type status for the species.

Burks (1953), after studying the MCZ material in 1942, indicated that Bank's designated lectotype of *A. simplex* (Walsh) should be disregarded; and a note initialed by George F. Edmunds, Jr. in 1960 and residing with the MCZ material concurs. Burks (1955) believed that there was one specimen at the MCZ that agreed with Walsh's
simplex, but could not fully study it because the abdomen was missing. This specimen (labeled 35 / Heptagenia simplex), even though it does conform with Walsh’s description, is not available as a lectotype because it was collected in 1864 subsequent to the original description. A neotype for A. simplex is formally designated below in the treatment of that species.

A third species of Anepeorus was described from China by Ulmer (1936) as A. hummeli. Since this description was made with stated reservation by Ulmer and was based on two adult females, and since there are presently no known female characteristics to distinguish the genus, we agree with Edmunds et al. (1976) that the generic assignment of this species is extremely questionable. The females of several species (and genera) of Heptageniidae, including those of Macdunnoa persimplex, presently would conform with Walsh’s brief original description of the female A. simplex; Walsh’s females could not have been positively correlated with males in any case; and females of A. rusticus remain unknown. We must defer further taxonomic treatment of A. hummeli until female generic traits for Anepeorus can be established.

Larvae that have been historically assigned to Anepeorus have received considerable attention in the literature due to their intriguing and unusual habitus and habitat. Paradoxically, these larvae have never been definitively associated with the genus by rearing, and all references to “larvae of Anepeorus” are to larvae that are only provisionally assigned to the genus based on circumstantial evidence. Edmunds et al. (1976) were convinced that the adult-larval associations have been correct, and Edmunds (1962) recognized a separate subfamily Anepeorinae for the genus, probably based on the relatively aberrant nature of the supposed larvae. Accounts of these interesting, carnivorous larvae may be found in Burks (1953) and Edmunds et al. (1976). We do not treat them here because we are not convinced of an association with Anepeorus.

We can account for 10 male adults of Anepeorus in collections. The three from the type series of A. rusticus are at the CNC, along with one additional male from Alberta and a possible female. Traver (1935) reported seeing “specimens” of A. rusticus taken in Utah in 1911 and located in the Carnegie Museum. We and G. F. Edmunds, Jr. (pers. comm., 1984) have been unable to locate the Carnegie Museum Anepeorus. We have, however, been able to locate slide-mounted wings, legs, and genitalia of one of these Utah specimens that Traver studied and deposited in the Cornell University Collection. One specimen of A. simplex is located at the CNC and one broken one at the MCZ as explained above. There is also a male specimen from Georgia at Cornell that Traver (1935) identified as A. simplex. Burks (1953) reported studying a male adult from Rock River in Illinois, deposited in the Illinois Natural History Survey (INHS); the only material we can find from that location in the INHS are females identified as A. simplex, and these cannot be verified. The INHS adult male has evidently been lost; specimens bearing Burk’s code numbers for Anepeorus are Rhithrogena. Burks may not have actually seen an adult male because the male genitalia he figured is an incorrect reproduction of McDunnough’s (1929) figure (the ventral penes cleft was transposed dorsally). In addition to the above, we have two male adults collected from the White River, Indiana, in 1974. Our examination of all existent adult specimens from eastern and western North America has led us to the following redescription and analysis of the genus and its species.

Genus Anepeorus McDunnough

**Adult (Male).** Body 6.0–8.2 mm long. Fore legs 0.68–0.76 × body length; femur 0.71–0.89 × tibia length; tarsus 0.46–1.13 × femur length, 0.46–0.82 × tibia length; tarsal segment 2 longest or subequal to longest segment and always longer than segment 1; tarsal claws blunt and subequal. Hind legs with tibia 0.78–0.90 × femur length; tarsus 0.37–0.44 × tibia length. Fore wing (Fig. 1) 7.4–9.0 mm; 0–3 costal crossveins in basal fourth; 0–3 forked crossveins among stigmatic crossveins. Hind wing (Fig. 2) ca. one-third fore wing length; costal projection reduced and rounded, without acute or obtuse point; Rs forks attached to stem; MA forked; few free marginal intercalaries in major-vein interspaces, with one such intercalary in fork of MA and two between CuA and CuP.
Genitalia with four-segmented forceps (Fig. 3); basal segment very weakly demarked; posterior margin of subgenital plate roundly or sub-conically produced medially, and abruptly and more extensively produced laterally into distinct bases of forceps (Fig. 3); penes (Figs. 3–7) divided nearly to base by narrow, ventrally open cleft; transparent, medially notched septum extending between divided penes lobes dorsally (margin of septum in apical fourth of penes); each penes lobe appearing bi- or trilobular apically; toothed titillators arising medially on penes lobes at about midlength of penes; in unrotated and unseparated penes (Figs. 4 and 6) titillators remaining within ventral cleft, and titillator teeth ventrally projecting; in penes with ventral aspect subjected to ventral and outward rotation (Figs. 5 and 7) titillators appearing to originate ventrally on penes lobes, and titillator teeth laterally projecting.

**Discussion.** Genitalic and fore leg characteristics allow adult males of *Anepeorus* to be distinguished from other known adult male heptageniids. Comparably well-developed forceps bases together with a produced median margin of the subgenital plate are present only in *Afronurus* Lestage, *Epeorella* Ulmer, and to a lesser degree *Cinygmina* Kimmins, and *Pseudiron* McDunnough. These genera differ from *Anepeorus* in almost all other generic characters. The relative length of the fore tarsus of *Anepeorus* is the shortest among the Heptageniidae, ranging from about one-half to four-fifths the length of the fore tibia. Only in *Rhithrogeniella* Ulmer, *Afghanurus* Demoulin, and *Afronurus* do fore tarsi of some species even approach this ratio.

The recent discovery of the adult of *Spinadis* Edmunds and Jensen (McCafferty and Provonsha, 1984) indicates that *Anepeorus* and *Spinadis* may be quite similar in the adult stage even though only males of *Anepeorus* and females of *Spinadis* can presently be compared. There is even a remote possibility that *Spinadis* and *A. simplex* are one in the same. The following differences are based on a very small number of known specimens. If genitalia and fore legs are eventually found to be similar in males of both genera, they may be tentatively diagnosed by the hind wings if intercalary venation proves not to be sexually dimorphic. Short, free marginal intercalaries are present in almost every major-vein interspace in *Spinadas*, whereas in *Anepeorus* (Fig. 2) such intercalaries have been seen only in the MA fork. Both genera possess two long cubital intercalaries, but *Spinadis* possesses a short intercalary in this region also.

*Anepeorus* was thought to have been derived independently from “near the base of the proto-Heptageniidae,” by Jensen and Edmunds (1973), but no evidence for this conclusion was given. We cannot determine the phylogenetic origin of *Anepeorus* at this time, but have data that indicate a relationship closer to *Spinadis* and *Pseudiron* than any other heptageniids, and thus would also suggest at least a strong possibility that these taxa as presently recognized were commonly derived. The adults of the three genera have several common characteristics, among which are hind wings with a costal projection that is reduced and rounded, and a head that has a straight frontal shelf (except *A. rusticus*).

*Anepeorus rusticus* McDunnough

**Adult (Male).** Body 8.0 mm long. Fore wing 9.0 mm long. Head brown; thorax dull to shiny pale brown, with mesothorax slightly darker than pro- and metathorax, sometimes mesonotum creamy white anteromedially; fore legs medium brown; middle and hind legs pale yellow-brown; abdominal terga pale brown, darker in posterior half, with pair of submedian and sublateral spots on each tergum (only sublateral marks evident on some); abdominal sterna paler than terga, with pair of submedian spots and sublateral oblique lines on each sternum. Head (Fig. 8) with eyes convergent dorsally; margin of frontal shelf distinctly produced ventromedially. Fore tarsus subequal to or slightly longer than fore femur, 0.76–0.82 × fore tibia length. Lateral margins of penes (Figs. 4 and 5) not expanded apically, more-or-less parallel sided from base of titillators; titillator teeth oriented apically and restricted to apical third of titillator (Figs. 4 and 5).
Anepeorus simplex (Walsh)

Adult (Male). Body 6.0–8.0 mm long. Fore wing 7.4–9.5 mm long. Body generally devoid of maculations, and colorless except for yellowish head, thorax, and sometimes posterior abdominal segments, all of which appear gray or grayish yellow in alcohol preserved specimens. Head (Fig. 9) with eyes widely separated dorsally; margin of frontal shelf more-or-less straight, not produced ventromedially. Fore tarsus 0.48–0.59 × fore femur, 0.46–0.50 × fore tibia. Lateral margins of penes (Figs. 3, 6, and 7) expanded apically; titillator teeth oriented outwardly along distal one-third to two-thirds of titillators.

Neotype. Adult male: Indiana, Martin County, East Fork White River at Hindostan Falls, VI-21-1974, A. V. Provonsha and L. Dersch; in alcohol with ‘neotype’ label in the Purdue University Entomological Research Collection, West Lafayette, Indiana. The neotype is the best undissected specimen of the species available at this time, and it is typical of Walsh’s original description of the species.

Discussion. The two species of Anepeorus are easily differentiated from each other as male adults. Anepeorus rusticus is a darker species with at least some slight abdominal maculation. It has dorsally convergent eyes, a medially produced frontal shelf (Fig. 8), a longer fore tarsus relative to both the fore femur and tibia, non-bulbous penes lobes, and apical titillator teeth (Figs. 4 and 5). Anepeorus simplex is a pale, unmarked species that has widely separated eyes, a straight frontal shelf (Fig. 9), a shorter fore tarsus that is about half the length of both the fore femur and the fore tibia, apically bulbous penes lobes, and titillator teeth more scattered along the titillator.

The penes of Anepeorus (and many other heptageniids) are heavily muscled, allowing them to be variously expanded, extruded, separated, and partially rotated. For this reason, the penes of one individual may appear superficially quite different than another individual of the same species (note especially the titillator positions in Figs. 4–7). The appearance depends on such things as the state of the penes at death, the method of preservation, and the amount of pressure applied in slide mounting. Our discovery of this phenomenon in Anepeorus should serve as a caveat to others relying on heptageniid penes morphology for identification or descriptive purposes.

Biology. Based on all adult collections, the emergence period of A. simplex is early June in Georgia and southern Illinois and late June in Indiana, northern Illinois, and Iowa. The emergence period for A. rusticus is mid to late July in Utah and Alberta and mid September in Saskatchewan. Both species apparently develop in large rivers.

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We thank the following individuals for assisting us in this study by providing previously unpublished information or specimens for examination: A. F. Bednarik, Yale University; G. F. Edmunds, Jr., University of Utah; K. G. A. Hamilton, CNC, Biosystematics Research Institute; J. K. Liebherr, Cornell University; J. F. H. Martin, CNC, Biosystematics Research Institute; M. K. Thayer, MCZ, Harvard University; R. D. Waltz, Purdue University; D. W. Webb, INHS; and C. W. Young, Carnegie Museum.

LITERATURE CITED


STATE RECORDS AND CONFIRMATIONS OF ODONATA FROM ILLINOIS AND MISSOURI

T. E. Vogt and J. E. McPherson

ABSTRACT

The occurrence of several species of Odonata in Illinois and Missouri is reported for the first time including *Telebasis byersi* Westfall, *Tachopteryx thoreyi* (Hagen), *Aeshna mutata* Hagen, *Celithemis fasciata* Kirby, *Ladona deplanata* (Rambur), and *Dythemis fugax* Hagen for Illinois; and *Cordulegaster obliqua* (Say), *Gomphus quadricolor* Walsh, *Helocordulia uhleri* (Selys), *C. fasciata*, and *C. verna* Pritchard for Missouri. Also, the presence of several species is confirmed including *Archilestes grandis* (Rambur), *C. obliqua*, *Hagenius brevistylus* Selys, and *Anax longipes* Hagen for Illinois; and *Lestes eurinus* Say, *H. brevistylus*, *Stylogomphus albitylus* (Hagen), *Arigomphus villosipes* (Selys), *A. longipes*, and *L. deplanata* for Missouri.

The literature on the Odonata of Illinois and Missouri is limited and scattered. The most recent comprehensive faunal lists of these states are found in Needham and Westfall's 1955 manual on the dragonflies of North America and Montgomery's 1967 paper on the Odonata of the north central states. Only a few species have been added since publication of these lists including *Dromogomphus spliolatus* (Hagen) (Westfall and Tennessen 1979), *Epitheca costalis* (Selys) (Dunkle 1983), *Anax longipes* Hagen, and *Neurocordulia xanthosoma* (Williamson) (Brigham and Brigham 1979) for Illinois; and *Nasiaeschna peruacamha* (Rambur) (Roback and Westfall 1967), *A. longipes*, *Aeshna mutata* Hagen, *Arigomphus villosipes* (Selys), *E. costalis*, and *Ladona deplanata* Rambur (Dunkle 1983) for Missouri.

Since 1979, we have collected several specimens of Odonata in southern Illinois and in southeastern and east central Missouri. Included among these are state records and others that confirm reports of earlier investigators. Presented here is information on some of these specimens selected because they represent the extremes of the flight season of our specimens or because they were observed in tandem. This information is supplemented with data from specimens taken by other collectors. All specimens are housed in the Southern Illinois University Entomology Collection (SIUEC) and were collected by T. E. Vogt, unless stated otherwise. Data added to label information are in parentheses. The sequence of Anisoptera taxa follows that of Needham and Westfall (1955).

LESTIDAE

*Archilestes grandis* (Rambur) ranges from Pennsylvania (Beatty and Beatty 1971a, b), Maryland (Donnelly 1961), and Virginia (Kennedy 1977) south to the Carolinas (Huggins and Brigham 1982) and Alabama (Tennessen 1979), and west through South Dakota (Bick et al. 1977), Nebraska (Montgomery 1967), Oklahoma (Bick and Bick 1957, 1970) and Texas (Gloyd 1958, Johnson 1971, Tinkham 1934) to California (Needham and Heywood 1929, Smith and Pritchard 1956) and Arizona (Bick 1978). It also occurs south through Central America into South America (Paulson 1982). Needham and Heywood (1929) reported it from Washington but Paulson (1970) stated that the species occurring in Washington is *A. californica* MacLachlan. Huggins and Brigham (1982) reported

1Department of Zoology, Southern Illinois University, Carbondale, IL 62901.
observations of tandem flights in southern Illinois as early as 4 June, and adult flight in central Illinois as late as 20 October, but provided no further information.

Label information for some Illinois specimens is given below; the watershed referred to extends across the common Williamson and Saline County line.

Jackson County, Little Grand Canyon, 8 August 1984 (1 ♀).
Randolph County, Piney Creek, T7S, R5W, Sec 27, NE ¼, NE ¼, 3 September 1984 (1 ♂).
Williamson County, Bankston Fork watershed, 13 September 1975 (1 ♀), R. P. Urbanek, coll.

*Lestes eurinus* Say ranges from Quebec (Caron 1978, 1979; Larochelle 1978; Rousseau 1978; Walker 1953) south to the Carolinas (Huggins and Brigham 1982), and west to Ontario (Montgomery 1967, Walker 1953), Iowa (Hummel 1978, Hummel and Haman 1975, Montgomery 1967), and Missouri (Dunkle 1983, Walker 1953). Walker presented no data with his Missouri record, and Dunkle’s record was mentioned only in passing in a discussion of *A. longipes* and *A. mutata*; Montgomery (1967) did not list *L. eurinus* from the state. We here confirm the presence of this damselfly in Missouri.

Christian County, Peckout Hollow, 3 June 1975 (1 ♂), S. W. Wilson, coll.
Lincoln County, Cuivre River State Park, pond, 16 June 1980 (10 ♂, 3 ♀ ♀, including 2 pairs in tandem), 17 August 1984 (1 ♀ and 1 ♀ ♀ in tandem), 20 September 1984 (1 ♂).

COENAGRIONIDAE

*Telebasis byersi* Westfall has been reported from North Carolina, Florida, and Alabama (Westfall 1957). We here report it from southern Illinois, a significant northwestern extension of its known range.

Union County, Pine Hills, 6 July 1984 (5 adults; 3 ♂, 2 ♀ ♀, including 2 pairs in tandem), 17 August 1984 (1 ♂ and 1 ♀ ♀ in tandem), 20 September 1984 (1 ♂).

PETALURIDAE

*Tachopteryx thoreyi* (Hagen) ranges from Quebec (Hutchinson 1976, 1977, 1978; Walker and Corbet 1975), New Hampshire, and New York south to Florida, and west to Michigan, Missouri (Needham and Westfall 1955), Oklahoma (Bick and Bick 1957), and Texas (Needham and Westfall 1955). Although it has been collected in Indiana, Kentucky, Missouri (Needham and Westfall 1955, Montgomery 1967), and Arkansas (Bick 1959, Farris and Harp 1982, Harp and Rickett 1977), it has not previously been reported from Illinois.

Pope County, Cretaceous Hills, nr. acid seep spring, 12 July 1983 (1 ♂), 2 June 1984 (1 teneral ♂), 7 June 1984 (1 ♀), 12 July 1984 (3 ♂ ♀).

CORDULEGASTRIDAE

*Cordulegaster obliqua* (Say) ranges from Quebec and Maine south through Virginia (Needham and Westfall 1955) to North (Cuyler 1968) and South Carolina (White et al.
and west to Wisconsin, Kansas, Oklahoma (Needham and Westfall 1955), and Texas (Dunkle 1975). Needham and Westfall (1955) reported it from Illinois but its presence in the state was questioned by Montgomery (1967). It has not previously been reported from Missouri.

Illinois: Pope County, Cretaceous Hills, 7 July 1983 (3 ♂♂, 2 ♀♀), 2 June 1984 (4 adults; 3 ♂♂, 1 ♀♀, including 1 pair in tandem).

Union County, Giant City State Park, 29 May 1959 (1 ♀♀), L. D. Moehn, coll.

Missouri: Bollinger County, Blue Pond, outflow stream, 29 July 1984 (1 ♂♂).

Stoddard County, Holly Ridge State Forest, 28 July 1984 (2 ♂♂, 2 ♀♀).

GOMPHIDAE

_Hagenius brevistylus_ Selys ranges from Quebec, Nova Scotia, and Maine south to Florida, and west to Manitoba, Minnesota, Kansas, and Texas (Needham and Westfall 1955). Needham and Westfall (1955) reported it from Illinois and Missouri, but both localities were questioned by Montgomery (1967).

Four adults and three nymphs from southeastern Missouri are housed in the SIUEC. In addition, an adult and a cast skin from Illinois are housed in the Illinois Natural History Survey (INHS) collection, Champaign.

Illinois: (Piatt County), White Heath, 13 June 1939 (1 adult ♂), J. C. Dirks, coll.

(Vermilion County), Oakwood, Salt Fork River, 6 July 1936 (cast skin), Mohr, Burks, coll.

Missouri: Douglas County, Noblett Lake spillway, 21 August 1979 (4 adult ♂♂). Greene County, James River, 28 June 1975 (1 nymph), S. W. Wilson, coll.

Shannon County, Current River, 3.2 km N Round Spring, 14 April 1979 (1 nymph), J. K. Buttner, coll.

Wayne County, St. Francis River, 15 April 1978 (1 nymph), M. S. Rathke, coll.

_Syrogonomphus albistylus_ (Hagen) ranges from Quebec, Nova Scotia, and Maine south to North Carolina and Alabama, and west to Michigan (Needham and Westfall 1955), and Oklahoma (Kormondy 1960). Needham and Westfall (1955) reported it from Missouri but its presence in the state was questioned by Montgomery (1967).


Oregon County, Eleven Point River, Thomasville, 11 April 1981, T. Bonace, coll.

Shannon County, Current River, 3.2 km N Round Spring, 14 April 1979, J. K. Buttner, coll.

_Arigomphus illinoensis_ (Selys) ranges from New Hampshire (White and Morse 1973), New York, and Massachusetts south to North Carolina, and west to Ontario, Minnesota (Needham and Westfall 1955), Missouri (Dunkle 1983), and Arkansas (Rickett 1976). Dunkle's Missouri record was based on an adult male collected in Shannon County at Lewis Lake 3 km N of Winona on 8 June 1981. We here confirm his record.

Oregon County, McCormack Lake, 22 June 1979 (1 ♂♂).

Shannon County, 6.5 km S Birch Tree, pond, 26 June 1984 (1 ♂♂).

_Gomphus quadricolor_ Walsh is presently known to range from Ontario, New York, and New Hampshire south to Virginia (Needham and Westfall 1955), and west to Minnesota (Hamrum et al. 1971). Illinois (Needham and Westfall 1955, Montgomery 1967), and Arkansas (Ham and Rickett 1977).

Franklin County, Meramec River, 1.6 km S Piney Park, 8 June 1980.
AESHNIDAE

Anax longipes Hagen ranges from Ontario (Montgomery 1967, Walker and Corbet 1975), New York, and Massachusetts south to Florida (Needham and Westfall 1955), and south and southwest to Missouri (Dunkle 1983), Oklahoma (Bick and Bick 1957, Ries and Cruden 1966), Louisiana (Bick 1957), and eastern Texas (Geijskes 1968). Geijskes, (1968) listed it from the Bahamas, Haiti, and Mexico, but its presence there is not universally accepted (Dunkle, pers. comm.).

Brigham and Brigham (1979) reported the occurrence of A. longipes in Illinois based on an adult male collected at Lake Shelbyville in Moultrie County on 8 June 1970 and a sight record at the same locality the following day; their specimen is housed in the INHS collection. Dunkle (1983) reported its presence in Missouri based on a male exuviae and a sight record of a mature male, both found on 7 June 1981 in Oregon County, at a pond 0.3 km W of MO 19 on Mark Twain National Forest Road 3174. We here confirm both state records.

Illinois: Pope County, 8 km W Delwood, pond, 1 June 1982 (5 adults, 4 ♂♂, 1 ♀, including 1 pair in tandem); 3 km W Delwood, pond, 9 August 1983 (1 ♂).
Missouri: Oregon County, 6.5 km N Greer, pond, 27 June 1984 (2 ♂♂).
Shannon County, Elbow Pond, 15 June 1979 (1 ♀).

Aeschna mutata Hagen ranges from Ontario, Michigan, and Massachusetts (Needham and Westfall 1955) south to West Virginia (Beatty and Beatty 1969), Kentucky (Needham and Westfall 1955), and Missouri (Dunkle 1983). It has not previously been reported from Illinois.

Pope County, 8 km W Delwood, pond, 28 June 1984 (1 ♂), J. E. McPherson, coll.; 22 May 1983 (1 ♂).

CORDULIIDAE

Helocordulia uhleri (Selys) ranges from Nova Scotia and New Brunswick south to North Carolina and Alabama (Needham and Westfall 1955) and west to Ontario (Needham and Westfall 1955, Montgomery 1967). Ohio (Montgomery 1967), Kentucky (Needham and Westfall 1955, Montgomery 1967), Oklahoma (Bick and Bick 1957), Arkansas (Harp and Rickett 1977), and Louisiana (Needham and Westfall 1955). It has not previously been reported from Missouri.

Ste. Genevieve County, Hawn State Park, Pickle Creek, 26 May 1984 (1 ♂).

LIBELLULIDAE

Celithemis fasciata Kirby ranges from West Virginia (Cruden 1962, Kormondy 1960) and Indiana (Needham and Westfall 1955, Montgomery 1967), south to Florida and Texas (Needham and Westfall 1955). It has not previously been reported from Illinois or Missouri.

It should be noted that Needham and Westfall (1955) and Montgomery (1967) listed C. monomelaena Williamson from Missouri and it is possible that this species is conspecific with C. fasciata (Dunkle, pers. comm.).

Six adults collected in southern Illinois and six in southeastern Missouri are housed in the SIUEC and Illinois State Museum (ISM).

Illinois: Jackson County, Carbondale, 29 May 1982 (2 teneral 2 ♀), V. V. Voyles, coll.
Pope County, Lake Glendale, 3 October 1983 (1 ♂), W. J. Webb, coll. (ISM).
Union County, Giant City State Park, pond, 9 July 1979 (3 ♂♂).
Missouri: Oregon County, Camp Five Pond, 27 June 1984 (1 ♂ and 1 ♀ in tandem); McCormack Lake, 26 June 1984 (4 ♂ ♂).

_Celithemis verna_ Pritchard ranges from North Carolina (Needham and Westfall 1955) and Indiana (Montgomery 1967) south and southwest to Florida and Oklahoma (Needham and Westfall 1955). We here report it from Missouri, but its presence in the state is not surprising because it has previously been reported from Kentucky (Needham and Westfall 1955, Montgomery 1967), Tennessee (Johnson et al. 1980, Tennessen 1979), and Arkansas (Bick 1959, Harp and Rickett 1977).

Shannon County, 6.5 km S Birch Tree, pond, 22 June 1979 (2 ♂), 26 June 1984 (1 ♂).

_Ladona deplanata_ (Rambur) ranges from Florida and Texas (Needham and Westfall 1955) north to Massachusetts (Gibbs and Gibbs 1954), New Jersey (Beatty and Beatty 1968), Indiana (Montgomery 1967, 1970), and Missouri (Dunkle 1983). We here report it for the first time from Illinois. We also confirm Dunkle's Missouri records, which were based on an adult male and female collected in Oregon County at McCormack Lake on 7 June 1981, and an adult male collected in Wayne County at Upalika Pond 11.7 km E of Ellsinore on 9 June 1981.

Illinois: Pope County, 3 km E Eddyville, 25 April 1984 (1 teneral ♀); Teal pond, 1 June 1982 (1 ♂).

Union County, Shawnee National Forest, T11S, R2W, Sec 35, SW ¼, pond, 2 May 1981 (4 ♂ ♂).

Missouri: Oregon County, Falling Springs, mill pond, 25 May 1980 (1 ♀); McCormack Lake, 26 May 1980 (7 ♂ ♂, 1 ♀).

_Dythemis fugax_ Hagen has been reported from New Mexico, Texas, and Oklahoma (Needham and Westfall 1955). We here report it from southern Illinois, a considerable northeastern extension of its known range.

Jackson County, Carbondale, 4 September 1983 (1 teneral ♀), B. Simon, coll.


ACKNOWLEDGMENTS

We wish to thank Drs. M. J. Westfall and S. W. Dunkle, University of Florida, for confirming or correcting our identifications of representative specimens of each species and for reviewing the manuscript. We also thank Drs. E. D. Cashatt, Illinois State Museum, Springfield, and D. W. Webb, Illinois Natural History Survey, Champaign, for the loan of specimens. We are grateful to Mr. K. S. Cummings, Illinois Natural History Survey, for providing us photocopies of many of the papers cited herein.

LITERATURE CITED


INTERSPECIFIC INTERACTIONS BETWEEN
ORCHELIMUM NIGRIPES AND ORCHELIMUM VOLANTUM
(ORTHOPTERA: TETTIGONIIDAE)

Marianne Niedzlek Feaver

Interspecific interactions are relatively rare among coinhabiting Orthoptera. Most records are of overzealous males courting females not of their species or, for that matter, inanimate objects. Less frequent are reports of two signalling males interacting, yet these are of interest. Calling songs are used to distinguish species (Alexander 1956). The possibility then exists that the "interference" or, more correctly, the competition for broadcast space that occurs when two closely related species with similar songs interact, may have been influential in shaping aspects of song delivery or pattern.

This report treats interactions between signalling males belonging to two different species of *Orchelimum* (meadow grasshoppers) found on the E. S. George Reserve, Livingston County, Michigan. *Orchelimum nigripes* (Scudder), the black-legged meadow grasshopper, was fairly widespread on the Reserve even during the period from 1936 to 1939 when the first intensive collections were made (Cantrall 1943). *Orchelimum volantum* (McNeill), the nimble meadow grasshopper, is the newcomer, not recorded in Livingston County until this study.

*Orchelimum volantum* was relatively scarce on the Reserve, found in 1978 and 1979 only along the outer margins of one swamp (Big Swamp). Six interactions involving two different *O. volantum* and four different *O. nigripes* males were observed. Two of these interactions were taped (Scotch Brand #306, magnetic recording tape, using an Uher tape recorder, model 400L), and subjected to sonograph analysis (Kay Electric Co. Sonograph, model 7030A).

All interactions observed were initiated when an *O. nigripes* male started stridulating near an already stridulating *O. volantum* male. The first visible sign that an interaction was imminent was the orientation of an *O. volantum* male to an *O. nigripes* male. The *O. volantum* male then proceeded to shorten the interval between calling songs (Fig. 1, A and B). Such interval shortening has already been described by Feaver (1977) in three species of *Orchelimum* (*O. nigripes*, *O. gladiator* (Bruner) and *O. vulgare* (Harris)) as the first acoustical sign of an interaction that may terminate in physical combat, and so designated by her as aggressive or defensive signalling. Unlike interactions occurring between conspecifics, however, only one participant in the interspecific interactions being treated here, the *O. volantum* male, exhibited such interval shortening.

Then as is typical for the genus, one participant, in all these interactions the *O. volantum* male, slowly decreased the distance between himself and the other, here the *O. nigripes* male (Feaver 1983). The *O. volantum* male, silent when moving, stopped at intervals to stridulate and then signalled aggressively. As the *O. volantum* male got closer (3–1 m), he paused while stridulating and oriented to the *O. nigripes* male. In all cases, while orienting to the *O. nigripes* male and sometimes just after, stridulation in the *O. volantum* male was noticeably interrupted. It appeared as if the *O. volantum* male's stridulation (be it the calling song or aggressive signalling) was inhibited by that of the *O. nigripes* male. In one instance, in an interaction of more than 45 min, such inhibition was very pronounced because the *O. nigripes* male's own stridulation was interrupted, first by the presence of a conspecific female and then his own feeding activities. The *O. volantum* male, when from 2 to 0.2 m from the *O. nigripes* male, only stridulated when the *O. nigripes* male was silent. Yet up to this point, in all the interactions observed, the *O.
Fig. 1. Selected sonographs from an interaction between the same *O. nigripes* and *O. volantum* males: (A) the calling song of *O. volantum*, (B) defensive signalling by the same *O. volantum* male in A. Sonograph B was recorded less than 30 sec after A. (C and D) Arrows denote ticking by the *O. volantum* male. The ticks follow the buzz of *O. nigripes*, the end of which can be seen in both sonographs. After ticking, the *O. volantum* male buzzes. In D, after the buzz of the *O. volantum* male, starting ticks of another song by the *O. nigripes* male can also be seen.
The male of *O. nigripes* gave no visible indication that he was in any way responding to the approaching *O. volantum* male. The song of *O. nigripes* is much more intense than that of *O. volantum* and perhaps the *O. nigripes* did not "hear" the softer male's defensive signalling while he himself was singing or otherwise preoccupied (i.e. such as when interacting with a conspecific).

Four of the interactions terminated at this point with the *O. volantum* male after such inhibition was noticed, eventually increasing not decreasing the distance between himself and the *O. nigripes* male. The *O. volantum* male in every case, paused while moving away, stridulated, gave evidence of some inhibition, and then continued to move. In one case, a male relocated and resumed "calling" 5 m away from the *O. nigripes* male he had interacted with. In the other three cases, the males moved toward the center of the swamp (unfortunately in the direction of open water where they could not be pursued on foot).

In the other two interactions, the *O. volantum* male continued to decrease the distance between himself and the *O. nigripes* male, until the two males faced each other less than 30 cm apart. Only at this point did the *O. nigripes* male visibly respond, by orienting, to the approaching *O. volantum* male. What evoked these orientations is difficult to say, but males do typically orient to conspecifics approaching them even at distances of a few meters. Also while the two males were orienting to each other, the *O. volantum* male appeared to "tick" (Fig. 1, C and D).

The basic unit of sound in the calling song is termed the phonatome (Alexander 1960, Morris and Walker 1976), or the syllable (Nielsen 1978). In any case, it is a unit corresponding to one wingstroke. Calling songs then consist of complex and long recognized species specific groupings of such basic units of sound (Alexander 1956, Morris and Walker 1976). Units delivered at a rate that can be distinguished by human ears are known as "ticks." Wingstrokes delivered at a faster rate form what appears to be a sustained pulse of sound or a "buzz" (after Alexander 1956). Sequences of ticks are found in the calling song of various *Orchelimum*, including *O. nigripes*. Alexander (1956) however, described the calling song of *O. volantum* as a sustained short pulse or buzz. That *O. volantum* would modify its song so as to add a new component, a short preceding sequence of ticks, while interacting with *O. nigripes* is of interest.

For some time ticking has been associated with aggression. This is because various investigators have noted that in those *Orchelimum* with two-part songs (consisting of a sequence of ticks plus a buzz), larger number of ticks are produced when males are in close proximity than when they are far apart (Alexander 1956, 1960; Cantrall 1943; Feaver 1977). In fact, in three *Orchelimum* species (*O. nigripes*, *O. vulgare*, *O. gladiator*) treated by Feaver (1977), males only ticked (the buzz was dropped) when they were in close visual proximity (usually less than 25 cm away). The modification of a calling song by these *O. volantum* males to include ticking when they were interacting with the *O. nigripes* males serves to further substantiate claims of primarily a male-male communicative function or, since most male-male interactions are aggressive in nature, an agonistic signal function for ticking. Perhaps the two-part songs that typify many *Orchelimum* species were derived by fusing what was primatively two signals with different functions. As males of some species encountered higher conspecific densities, the close-range male-oriented tick was added to the buzz or what has been described as the more effective long range, and so assumed female attracting, signal. Morris and Walker (1976) presented evidence that the basic units, in this case termed phonatomes, of the buzz and tick differ in type. In the tick phonatome, the insect lodges its scraper behind a tooth and exerts force without scraper displacement prior to generating sound so that sound is generated with maximum intensity from the start. In the buzz, intensity builds more slowly over successive phonatomes.

Missing from these interspecific interactions were the bouts of synchrony and alternation of song that occur as conspecific males move toward each other (Feaver 1977). Perhaps that is what the *O. volantum* was in fact doing, attempting to alternate songs by only singing when the *O. nigripes* male was silent.

The inhibition of one male's singing by another is more pronounced in the interspecific interaction observed here than in intraspecific interactions reported earlier (Feaver 1977). Interestingly such inhibition characterizes all the interspecific interactions recorded to date.
for katydids (Latimer 1981, Samways 1977). Latimer (1981) offered evidence that by such inhibition or “jamming” and the negative phonotaxis that results, Platycleis albopunctata (Goeze) can even exclude Metrioptera roeselii (Hagenbach) from favored habitat. Perhaps, as indicated by Samways (1977) and other previous works discussed by him, interspecific interactions have in the past, by such jamming, influenced habitat preferences, and many sympatric species today are acoustically isolated from each other because they occur in different microhabitats. Evidence seems to be accumulating, not as much for a role for past interspecific interactions in shaping song pattern as aspects of song delivery. Where a species sings today, or when a species sings during a 24-h period (if inhibition is not accompanied by negative phonotaxis) may have been influenced by selection in the past to avoid “jamming” of that species signals by a once sympatric species.

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I would like to thank R. D. Alexander and G. K. Morris for previewing the sonagrams; also, R. D. Alexander and I. J. Cantrall for confirming my species identifications.

LITERATURE CITED


VULNERABILITY OF HYBRID POPULUS NURSERY STOCK TO INJURY BY THE TARNISHED PLANT BUG, LYGUS LINEOLARIS (HEMIPTERA: MIRIDAE)

Louis F. Wilson and Lincoln M. Moore

ABSTRACT

The tarnished plant bug injured 21 Populus clones in the clonal nursery of the Packaging Corporation of America in Michigan. Degree of injury ranged from 0.5 to 82.0%. Clone 'Wisconsin 5' sustained the heaviest attack, followed by Imperial Carolina poplar. 'Wisconsin 5' was salvaged by changing the standard and accepting shorter cutting stock for outplanting.

The tarnished plant bug, Lygus lineolaris (Palisot de Beauvois), normally a pest of agricultural crops, was recognized as an injurious pest of hybrid Populus in Wisconsin in 1978 (Sapia 1982). Since then, its injury has been found in various Populus plantings in the Lake States and Canada. The tarnished plant bug (TPB) makes split-stem lesions up to 5.0 cm long that deform the stems and branches of young trees. Stems and branches often break at the lesion.

Numerous lesions were found in 1983 at a nursery near Freesoil in Mason County, Michigan, owned by the Packaging Corporation of America (PCA). TPB lesions had been found in the nursery in 1982, but the injury then was light and widely scattered. In the 1983 infestation some clones were heavily injured and others were not. Because of this apparently wide range of host susceptibility or tolerance, we set out to qualify and quantify the injury for the various Populus clones planted in the PCA nursery.

MATERIALS AND METHODS

The study was conducted at the PCA nursery. The nursery has both rooting beds and cutting or stool beds.

Three rooting beds were planted in spring 1983, with 18-cm hardwood cuttings of 21 hybrid Populus clones cut the previous fall from the stool beds (Table 1). Single, and occasionally double or triple, shoots (whips) grew from these cuttings. By fall, the whips were 0.3–1.5 m tall and ready for lifting as rooted stock.

On 18 and 31 October 1983, TPB lesions were counted on 200 whips of each clone just before lifting. Whips were examined in groups of 30–40, and then 5–15 m of the row were skipped before counting again in order to cover most of a row. Whips shorter than 0.3 m were not examined because these normally are culled during sorting. Fifty lesions were selected from injured whips of all clones and then examined in detail and characterized by size and form.

After the most heavily injured clone had been lifted, the rooted whips of that clone were sorted into three classes: (1) suitable for fall planting, (2) suitable for spring planting, and (3) culs. Sorting was based on standards for fall and spring stock as well as on TPB injury. Fall planting stock differs from spring stock by size and treatment. Fall stock, which is mostly 0.6 m tall, is field planted immediately after lifting from the nursery.

1USDA Forest Service, North Central Forest Experiment Station, 1407 S. Harrison Rd., East Lansing, MI 48823.
Table 1. Susceptibility of 21 *Populus* clones to tarnished plant bug (TPB) feeding injury, Packaging Corporation of America clonal nursery, Freesoil, MI, 1983

<table>
<thead>
<tr>
<th>Clone</th>
<th>Parentage</th>
<th>Number lesions (200 trees)</th>
<th>Percent trees with lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Wis. 5'</td>
<td><em>Populus × euramericana</em> 'Wisconsin 5'</td>
<td>311</td>
<td>82.0</td>
</tr>
<tr>
<td>DN-34</td>
<td><em>P. × euramericana</em> 'Eugenei'</td>
<td>96</td>
<td>37.5</td>
</tr>
<tr>
<td>FRS-2*a</td>
<td>--</td>
<td>66</td>
<td>25.0</td>
</tr>
<tr>
<td>DN-31</td>
<td><em>P. × euramericana</em> 'Negrito de Granada'</td>
<td>44</td>
<td>22.0</td>
</tr>
<tr>
<td>DN-55</td>
<td><em>P. × euramericana</em></td>
<td>50</td>
<td>21.5</td>
</tr>
<tr>
<td>DN-21</td>
<td><em>P. × euramericana</em> 'Jacometti'</td>
<td>38</td>
<td>17.0</td>
</tr>
<tr>
<td>NE-308</td>
<td><em>P. nigra var. charkowiensis × P. nigra</em> 'Incassata'</td>
<td>37</td>
<td>16.5</td>
</tr>
<tr>
<td>DN-1</td>
<td><em>P. × euramericana</em> 'Allenstein'</td>
<td>22</td>
<td>11.0</td>
</tr>
<tr>
<td>I 45/51</td>
<td><em>P. × euramericana</em> '45/51'</td>
<td>32</td>
<td>10.0</td>
</tr>
<tr>
<td>Rav</td>
<td><em>P. × euramericana</em> 'Raverdeau'</td>
<td>11</td>
<td>5.5</td>
</tr>
<tr>
<td>DN-34b</td>
<td><em>P. × euramericana</em> 'Eugenei'</td>
<td>8</td>
<td>4.0</td>
</tr>
<tr>
<td>NC-5258</td>
<td><em>Populus sp.</em></td>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>DN-9</td>
<td><em>P. × euramericana</em> 'Lons'</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>DN-30</td>
<td><em>P. × euramericana</em> 'Canada Blanc'</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>FRS-1a</td>
<td>--</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>NC-238</td>
<td><em>P. deltoides × P. nigra</em> 'Volga'</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>NE-19</td>
<td>*P. nigra var. charkowiensis × P. nigra var. caudina</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>NE-20</td>
<td>*P. nigra var. charkowiensis × P. nigra var. caudina</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>DN-18</td>
<td><em>P. × euramericana</em> 'Tardif de Champagne'</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>DN-22</td>
<td><em>P. × euramericana</em></td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>NE-359</td>
<td><em>P. deltoides × P. nigra var. caudina</em></td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*aUnidentified clones from Fry Nursery.

*bCuttings taken from a large windbreak on Milarch Road near Manistee, MI.

*cCommonly called Imperial Carolina poplar or Carolina poplar.

Spring stock, 0.6–1.5 m tall, is stored overwinter in bundles in healing beds. Before planting, the tops of the whips are removed above 0.6 m.

The lesion's size and location on the whip were also criteria used in sorting the fall and spring planting stock. Stock with large lesions was not accepted for planting because of the good chance of breakage. Stock with small, healed-over lesions was acceptable.

Each winter whips are cut from the stool beds and sawed into hardwood cuttings for nursery and planting stock for the next season. The lower part of each whip over 1.3 cm dia. is cut into 33-cm-long cuttings; the smaller top, 0.6–1.3 cm dia., is cut into 18-cm cuttings. The 33-cm stock is outplanted; the 18-cm material replenishes the nursery and becomes the rooted stock lifted after the first growing season.

The stool beds were also injured by TPB in 1983. When the stool bed whips were cut, 100–300 were selected from three clones, sawed into 18- and 33-cm cuttings, and sorted. Cuttings with medium or large galls were culled. The three clones sampled were 'Wisconsin 5,' Imperial Carolina Poplar (=DN-34), and 'Raverdeau.'

RESULTS AND DISCUSSION

TPB lesions occurred anywhere along the length of the whips above 0.3 m. Short whips usually were injured more on the upper half. Depending on the duration of feeding, and
perhaps also on the ability of the tree to withstand the enzymatic activity of the TPB saliva. lesion formation and its consequences for the tree varied considerably. Whatever the cause, at the end of the growing season some lesions remained small and were nearly imperceptible except for a slight swelling. Lesions that were swollen enough for easy detection measured about 1.5 cm long with a small slit or scar on the surface. Internally these showed only minor necrosis in the xylem (Fig. 1A), which varied little from the uninjured stem (Fig. 1B). Unless possibly acting as an infection court, such small healed-over lesions did not seem to affect the strength of the whip, and were accepted for planting stock.

Other lesions were larger, more extensively necrotic, and structurally weaker. One type was about 1.5–2.0 cm long and swollen into an ovoid gall. Outwardly the gall had ribs
and slits and was heavily calloused (Fig. 1C). Internally the gall was hollow or honeycombed and any remaining xylem was generally necrotic and punky (Fig. 1C). The largest lesions were up to 5.0 cm long and flattened into an elongate flared area of blasted tissue, which from both the front and back resembled the hood of a cobra (Fig. 1D). Slits through the tissue sometimes occurred in the flattened area. In cross-section the damaged area was mostly a veneer of necrotic xylem backed by bark and callous tissue. Often the stems bent over at the lesion and in some instances they bent nearly into a right angle. The stem above this lesion sometimes died and often it broke.

All 21 clones in this study, which were mostly of \( P. \times euramerica \) parentage, were injured by the TPB, but incidence of injury differed widely among the clones (Table 1). Location in the nursery rooting beds apparently did not affect the degree of injury because both the most heavily and most lightly attacked clones were side by side. ‘Wisconsin 5’ was the most heavily injured clone with 311 lesions on the 200 sample trees (1.6 lesions / tree, range 0-6) and 82% of the trees had at least one lesion. Four other clones (DN-34, FRS-2, DN-31, and DN-55) were moderately injured with 21.5–37.5% of the trees infested. About half of the clones were less than 10% affected, and NE-359 was only 0.5% injured (one lesion). Imperial Carolina poplar (DN-34), stocked from two sources, showed both moderate and light incidence of injury. The most injured (37.5%) Carolina poplar stock was the purchased source; the other (4% injured) was taken as cuttings from a large windbreak on Milarch Road near Manistee, Michigan. Two FRS clones (FRS-1 and FRS-2) also showed wide differences in lesion incidence. These two unidentified clones were from stock shipped by the Fry Nursery in Pennsylvania.

Sorting ‘Wisconsin 5’ rooted stock yielded a 60% loss as culls because of the numerous lesions on the upper stems. If 10% is set as maximum allowable cull, this injury to ‘Wisconsin 5’ would be unacceptable. However, by cutting the culls back to 0.3 m, which is still tall enough for spring planting stock, 87% of the culls were salvaged.

Table 2. Hardwood stoolbed cuttings acceptable for planting and culled because of lesions caused by tarnished plant bug for three \( P. \) clones from the PCA nursery

<table>
<thead>
<tr>
<th>Clone</th>
<th>Cuttings per 100 whips</th>
<th>18-cm cuttings</th>
<th>33-cm cuttings</th>
<th>Both</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Accept</td>
<td>Cull</td>
<td>Accept</td>
</tr>
<tr>
<td>‘Wisconsin 5’</td>
<td>635</td>
<td>81.9%</td>
<td>18.1%</td>
<td>88.4%</td>
</tr>
<tr>
<td>Carolina Poplar</td>
<td>653</td>
<td>96.2%</td>
<td>3.8%</td>
<td>97.8%</td>
</tr>
<tr>
<td>‘Raverdeau’</td>
<td>689</td>
<td>97.4%</td>
<td>2.6%</td>
<td>91.7%</td>
</tr>
</tbody>
</table>
contrast to the light attacks in Wisconsin. Clones DN-30 and NC-5258 differed little between the two locations.

The reasons for the differences are unclear. One reason may be due to differences between the nursery situation and the study plot layout. Also, the study plots in Wisconsin had more weeds nearby and that may have been important. Sapio et al. (1982) demonstrated some differences in resistance or tolerance of Populus to the TPB, but found they were only partially clonal and tempered by the presence of other food sources including weeds. The PCA nursery was particularly free of weeds, with only an occasional small patch of quackgrass (Agropyron repans (L.) Beauv.) or wild carrot (Daucus carota L.). Populus appears to be more vulnerable to attack in areas free from vegetation (Sapio et al. 1982), but this does not fully explain the great differences in attack of clones planted side by side in rows only 0.7–1 m apart.

The growth in TPB populations from 1982 to 1983 at the PCA nursery may have been due in part to a change in utilization of land surrounding the nursery. In 1983, fields on four sides were planted to field corn, a host of the TPB. Before then, corn was not planted entirely around the nursery and the TPB had not been a problem. Also, the unusually mild winter of 1982–1983 may have contributed to better survival by overwintering adults and subsequent population increase. The insect is trivoltine in Michigan and an increase in survival could increase the size of the second and third generations which cause most of the lesions. Lack of lesions in the first 0.3 m of stem suggests that the first generation causes little or no injury to Populus.

LITERATURE CITED

CONTROL OF HYADAPHIS TATARICAЕ (HOMOPTERA: APHIDIDAE) ON HONEYSUCKLE INCLUDING OBSERVATIONS ON HOST PLANT RESISTANCE

Philip L. Nixon¹, Carolyn Peet Nixon², and James E. Schuster³

ABSTRACT

Hyadaphis tataricae causes witches-brooming to the growing tips of Zabelii and other large bush-type honeysuckles in the north central states. Insecticide tests show that acephate (Orthene), dimethoate (Cygon), or oxydemeton-methyl (Metasystox-R) sprayed monthly in June and July will reduce witches-brooming. Malathion was not effective in reducing damage. Host plant resistance observations indicate that Lonicera × notha, L. × muendeniensis, L. × amoena 'Alba', L. × xylosteoides, and L. tatarica 'Arnold Red' are H. tataricae resistant. These large bush-type honeysuckles would appear to be good replacements for Zabelii and other susceptible honeysuckles in ornamental plantings.

Damage caused by Hyadaphis tataricae (Aizenberg) was discovered in northern Illinois in 1979; however the aphid was not identified until 1980 (Voegtlín 1981). By 1981 it had spread into Michigan, Ohio, Indiana, Wisconsin, Minnesota, Iowa, and Nebraska (Voegtlín 1982). It has been present in Canada since 1975 or 1976 (Boisvert et al. 1981). Prior to that time, H. tataricae appears to have been limited to eastern Europe and northwestern Asia (Voegtlín 1981, 1982; Boisvert et al. 1981).

H. tataricae eggs hatch in the early spring at honeysuckle bud break, which can be in early April in the north central states (Voegtlín 1984). The aphid feeds on the succulent new growth at the top of the plant. In northern Illinois, the aphid population can increase to high enough levels in early June to cause damage in the form of red streaking on the leaves and leaf folding.

Feeding by H. tataricae on the upper side of expanding leaves results in the upward folding of the leaves at the midvein, completely enclosing the aphids. As the leaves are damaged, lateral buds produce new stems with leaves that are subsequently attacked. This process continues throughout the summer, resulting in twiggy growth with small, underdeveloped leaves called witches-brooming. Most of the witches-brooms are dead by late summer and the rest die during the fall and winter. Eggs are laid in the fall in these dead witches brooms.

Of those honeysuckles used commonly in landscape plantings, Zabelii honeysuckle (Lonicera tatarica L. 'Zabelii') and Tatarian honeysuckle (L. tatarica), both large bush forms, exhibit the most damage from feeding by H. tataricae. Vining, ground cover, and smaller bush forms such as Clavey's Dwarf honeysuckle (L. xylosteum L. 'Claveyi') appear to be resistant to H. tataricae.

Insecticide tests were conducted on H. tataricae during 1982 and 1983 to identify a means to prevent the witches-brooming damage to honeysuckle. Observations of host plant resistance were also made from 1980 through 1983.

¹University of Illinois Cooperative Extension Service, 1010 Jorie Blvd., Suite 300, Oak Brook, IL 60521.
²4751 St. Joseph Creek Rd. #104, Lisle, IL 60532.
³University of Illinois Cooperative Extension Service, 421 N. County Farm Rd., Wheaton, IL 60187.
METHODS

Insecticide Tests. Insecticides were tested during the summers of 1982 and 1983 to determine their efficacy against *H. tataricae*. A stand of Zabelii honeysuckle planted as a three-row snowfence along a 404-m section on the north side of a highway in DuPage County, Illinois, was selected as a test area.

The stand of honeysuckle was mature, ca. 1.5 m tall. Plots 12 m long were established, with the insecticide treatments being assigned randomly in 1982 and 1983. Each insecticide plot was sprayed with a hand-compression sprayer in 1982 on 21 June and 21 July, and on 22 June and 21 July in 1983 to coincide with damaging populations of *H. tataricae*. In 1983, only the east 4 m of each plot were treated to reduce time costs. In both years, control plots received no treatment.

Malathion was applied at the labeled rate of 1 lb/100 gal of water. Acephate (Orthene) and dimethoate (Cygon) were applied at the labeled rate of 0.5 lb/100 gal of water. Oxydemeton-methyl (Metasystox-R) was applied at the labeled rate of 0.37 lb/100 gal of water.

Due to the large size of the honeysuckle bushes, only the south row of honeysuckle was sprayed, with the two north rows receiving very little insecticide. This provided a constant source of reinfestation.

Plots were monitored between sprayings for the presence of aphids and damage. Each plot was evaluated on 8 October 1982 and on 14 October 1983 for evidence of aphid damage. Assuming that the ends of the plots might have received drift during the insecticide sprayings, only the center 10 m and 3 m were analyzed in 1982 and 1983 respectively for damage.

Each shoot that was at least 30 cm long in the evaluated area of each plot was checked for signs of the leaf distortion and witches-brooming characteristic of *H. tataricae* induced damage. At least 10% of the current year’s growth per shoot had to be distorted for the shoot to be counted as damaged.

Host Plant Resistance. A contiguous planting of ca. 50 cultivars of bush-type honeysuckles at the Morton Arboretum, Lisle, Illinois, was monitored for signs of host plant resistance during the summers of 1980-1983. The planting originally consisted of three specimens of each cultivar, although some of the bushes had died or had been relocated to other parts of the arboretum over the years.

Plants were rated into four general damage categories: (1) no damage, (2) less than 1/4 of shoots damaged, (3) 1/4-3/4 of shoots damaged, (4) more than 3/4 of shoots damaged. Ratings were also made as to the length of the witches-brooming, since many short witches-brooms tend to be less noticeable, particularly from a distance, than do a few long ones.

Due to the difficulty of the taxonomy of the genus *Lonicera*, most of the cultivars had not been identified. Several of the cultivars that consistently were placed into the No Damage category were subsequently identified.

RESULTS AND DISCUSSION

Insecticide Tests. The plots sprayed with the systemic insecticides, acephate, dimethoate, and oxydemeton-methyl, (Table 1) showed significantly less damage than the control or malathion plots in both 1982 and 1983. Damage in the control and malathion plots continued to progress from leaf folding to witches-brooming and dieback throughout the test periods.

In both years, *H. tataricae* and its subsequent damage in the form of leaf folding and streaking appeared in the acephate, dimethoate, and oxydemeton-methyl plots ca. 4 weeks after spraying. Although *H. tataricae* reappeared in large numbers in these plots in late August of both years, witches-brooming was not produced, probably due to the maturity of the attacked shoots.

Host Plant Resistance. Five varieties that have consistently shown resistance to damage by *H. tataricae* are listed in Table 2. All of these varieties have shown a growth
Table 1. Average number of shoots at least 10% damaged by *Hyadaphis tataricae* per insecticide test plot in 1982 and 1983.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>1982a</th>
<th>1983a</th>
</tr>
</thead>
<tbody>
<tr>
<td>acephate</td>
<td>3.4 A</td>
<td>0.4 A</td>
</tr>
<tr>
<td>dimethoate</td>
<td>8.4 A</td>
<td>1.0 A</td>
</tr>
<tr>
<td>oxydemeton-methyl</td>
<td>5.4 A</td>
<td>1.0 A</td>
</tr>
<tr>
<td>malathion</td>
<td>105.0 B</td>
<td>19.4 B</td>
</tr>
<tr>
<td>control</td>
<td>98.6 B</td>
<td>28.4 B</td>
</tr>
</tbody>
</table>

Values followed by the same letter are not significantly different at \( \alpha = 0.05 \) for each corresponding year.

Table 2. Large bush-type honeysuckles that are apparently resistant to damage by *Hyadaphis tataricae*.

<table>
<thead>
<tr>
<th>Lonicera × notha Zabel</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. × muendeniensis Rehder</td>
</tr>
<tr>
<td>L. × amoena Zabel ‘Alba’</td>
</tr>
<tr>
<td>L. × xylosteoides Tausch</td>
</tr>
<tr>
<td>L. tatarica L. ‘Arnold Red’</td>
</tr>
</tbody>
</table>

habit, size, and hardiness that is comparable to Zabelii honeysuckle at the Morton Arboretum. These appear to be good candidates for replacement of Zabelii and Tatarian honeysuckle in landscape plantings.

ACKNOWLEDGMENTS

We wish to thank the Illinois Tollway Authority and the Morton Arboretum for the use of their honeysuckle plantings and facilities. We also wish to thank Mr. R. Klatt of the Illinois Tollway Authority and Drs. T. Green, C. Lewis, and G. Ware of the Morton Arboretum, Dr. D. Voegtlin of the Illinois Natural History Survey, and Dr. R. Randell of the University of Illinois Cooperative Extension Service for their assistance throughout this project. We also thank Dr. W. Hess, Morton Arboretum, for his identifications of the resistant honeysuckles.

LITERATURE CITED


WINTER WHEAT COLD HARDINESS AND FRUCTAN RESERVES AFFECTED BY RHOPALOSIPHUM PADI (HOMOPTERA: APHIDIDAE) FEEDING

S. G. Wells1, C. R. Olien3, and R. P. Hoxie2

ABSTRACT

The cold hardiness of 'Winoka' and 'Genesee' winter wheats was each significantly less ($P = 0.05$) when fed upon by bird-cherry oat aphids, *Rhopalosiphum padi*, than non-infested seedlings. Aphid feeding also reduced the amount of fructans in crown tissue ca. 20% compared to extracts from crowns of non-infested seedlings. It appears that the cold hardiness of these wheat cultivars may have been reduced because of fructan depletion by insect feeding.

Phytophagous insect damage is typically related to yield or biomass loss. Entomologists have been generally unsuccessful in establishing a direct relationship of insect numbers or the amount of feeding to yield and (or) biomass loss. In general, this loss depends on the plant's physiological condition and results from all physical, biological, and environmental factors and stresses that impinge on the plant. In some years a plant may tolerate feeding damage because of its physiological condition, while in other years the same amount of damage may cause a significantly greater loss. It is this variability of plant response to insect feeding that has caused low accuracy in estimating yield and biomass losses.

Insect damage has also been related to the reduction in plant cold hardiness. Harper and Freyman (1979, 1983) found that pea aphids, *Acyrthosiphon pisum* (Harris), reduced the cold hardiness of alfalfa, and they noted that the height and weight of top growth was less, but not the percent dry matter. Sakoi (1960), Levitt (1981), and Olien and Smith (1981) all noted that carbohydrates and other root reserves played an important role in the cold hardiness of plants. Harper and Freyman (1983) reported that the aphids did not reduce the total carbohydrates in the roots, and suggested that the lack of carbohydrate loss was due to leaf cells collapsing after feeding, concurrently disrupting the translocation of reserves to and from the lower parts of the plant.

This study investigated whether feeding by bird-cherry oat aphids decreased the cold hardiness of two winter wheat cultivars. The amount of fructans in damaged and undamaged plants was determined to gain additional information about the relationship of insect feeding to fructan reserves.

MATERIALS AND METHODS

**Test plants.** Two commercial winter wheat cultivars, 'Genesee' (C.I. 12653) and 'Winoka' (C.I. 14000), were planted in sand in separate pots (10-cm d.) and maintained at $20 \pm 5^\circ$C, LD 16:8 and 50 $\pm$ 20% RH in a greenhouse. The pots were watered on even

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1Michigan Agricultural Experiment Station Journal Article 11265.
2USDA, ARS, Department of Entomology, Michigan State University, East Lansing, MI 48824-1115.
3USDA, ARS, Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824-1114.
days and provided nutrient solution on odd days, and after two weeks from planting were thinned to 10 seedlings per pot. After three weeks from planting, the pots for each cultivar were divided into three groups of 33 pots each and subsequently infested with insects as described below. Tests were initiated on 6, 24, and 31 May, and 6 and 13 June 1983.

**Test insects.** The bird-cherry oat aphids, *Rhopalosiphum padi* (L.), were collected from field populations in Michigan and reared on ‘Augusta’ wheat in growth cabinets. The three groups of potted plants of both cultivars were placed in screen cages (214 [L] by 95 [W] by 31 [H] cm). The first group of plants was infested with 3–5 aphids per seedling. The second group was uninfested (control). The plants were maintained for two weeks to allow insect feeding and plant injury to occur, after which 10 seedlings from each group were removed and prepared for sugar extraction and the number of insects present was recorded. The remaining plants were used in the freeze tests.

**Freeze test.** Five freeze tests were conducted as described by Gullard et al. (1975). The seedlings were hardened at 1°C with continuous light at 200 microeinsteins m$^{-2}$ sec$^{-1}$ for three weeks. From each pot, eight of the seedlings were washed free of sand in ice water, trimmed to 5-cm crown sections having 1 cm of roots and 4 cm of shoots, and placed in slots cut into wet cellulose sponges. The temperature was lowered to $-3°C$ for 24 h prior to freezing. Test freezing involved lowering the temperature of prefrozen plants 1°C/h to $-10°C$, maintained at $-10°C$ for 3 h, and then thawed slowly. The cut plants were repotted in moist sand and plant recovery recorded two weeks later. The crowns were visually rated for peripheral meristem survival on a 0 (dead) to 5 (undamaged) scale (a rating based on root development), and evaluated statistically (ANOVA).

**Sugar extraction.** The crowns were trimmed to 1-cm sections devoid of roots. Ten crowns were split longitudinally, then immediately dropped into 15 ml, 60°C, 80% ethanol and macerated for 4 min to pulp. The samples were agitated for 15 min in a 60°C shaker bath and centrifuged for 5 min at 700 G. The supernatant solution was decanted into a 60°C porcelain evaporating dish and the pellet was extracted an additional time with 15 ml of 80% ethanol and two times with 15 ml of 60°C distilled water. The combined supernatant solutions were removed from heat when the sample was free of alcohol vapors. The supernatant solution was frozen at $-30°C$ and lyophilized. Lyophilized samples were weighed, dissolved in 6 ml of glass-distilled water. The wet and dry weights of each sample plus one internal standard were prepared for two of the five freeze tests.

**Chromatography.** Plant carbohydrates were detected by high pressure liquid chromatography utilizing a Bio-Rad Aminex HPX-87P Column heated to 85°C, with a mobile phase of degassed glass distilled water at a flow rate of 0.4 ml/min. The refractive index of the carbohydrates was determined and quantified by comparison with pure sugars with the same retention time (fructosan, 10.75 min; sucrose, 14.75 min; glucose, 17.5 min; and fructose, 23.5 min). Peak area was determined by triangulation. Fructosan collected from the HPLC separation of rye crown sugars was analyzed and subsequently used as a reference. When hydrolized and chromatogrammed, fructosan hydrolysate yielded 11 moles of fructose per mole of glucose. This ratio is in keeping with fructosans previously reported to occur in cereals (Olien and Lester, in press).

**RESULTS**

Bird-cherry oat aphid feeding on ‘Genesee’ or ‘Winoka’ winter wheat seedlings under controlled conditions relative to crown tissue ratings were compared with values for uninfested control seedlings (Table 1). ‘Winoka’ is typically more winter hardy than ‘Genesee’ wheat and this was true in this study. More aphids were present on plants on 6 June (26.4 aphids/plant) and 13 June (50.3 aphids/plant) two weeks after infestation than on plants from the other test dates, and these more heavily infested plants were less cold hardy than plants with fewer aphids. Within ‘Genesee’ or ‘Winoka’ wheats, average crown ratings from the aphid treatments were significantly different ($P = 0.05$, LSD) from the uninfested control (Table 1).

Bird-cherry oat aphids feed on the leaf blade and remove nutritive reserves. The effect of aphid feeding on fructan depletion is presented in Table 2. These preliminary data show
Table 1. One way ANOVA of crown recovery ratings of Genesee and Winoka winter wheats with respect to each treatment date. Rating scale 0-5: 0 = dead, 5 = no damage.

<table>
<thead>
<tr>
<th>Initiated 1983</th>
<th>Control</th>
<th>Bird-cherry oat aphid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘Winoka’</td>
<td>‘Genesee’</td>
</tr>
<tr>
<td></td>
<td>Ratings</td>
<td>Ratings</td>
</tr>
<tr>
<td>6 May</td>
<td>2.4 BC^a</td>
<td>1.0 A</td>
</tr>
<tr>
<td>24 May</td>
<td>2.9 D</td>
<td>2.0 C</td>
</tr>
<tr>
<td>31 May</td>
<td>2.3 B</td>
<td>1.1 AB</td>
</tr>
<tr>
<td>6 June</td>
<td>2.7 CD</td>
<td>0.9 A</td>
</tr>
<tr>
<td>13 June</td>
<td>1.6 A</td>
<td>1.4 B</td>
</tr>
<tr>
<td>Avg^b</td>
<td>2.4 E</td>
<td>1.3 F</td>
</tr>
</tbody>
</table>

^aMean values in a column with no letter (ABCD) in common are significantly different (P = 0.05, LSD).
^bMean values in a row (Avg) with E or F are significantly different from E’ or F’, respectively (11P = 0.05, LSD).

Table 2. Fructans present in the crown tissue of ‘Winoka’ and ‘Genesee’ winter wheat seedlings fed upon by bird-cherry oat aphids compared with uninfested seedlings (control).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Test dates (1983)</th>
<th>Control (mg Fructan / gm of crown tissue)</th>
<th>Aphids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fructan / gm of crown tissue</td>
</tr>
<tr>
<td>‘Winoka’</td>
<td>31 May</td>
<td>104.0</td>
<td>64.0 (8.3)^a</td>
</tr>
<tr>
<td></td>
<td>6 June</td>
<td>122.0</td>
<td>119.0 (26.4)</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td>113.0</td>
<td>91.5</td>
</tr>
<tr>
<td>‘Genesee’</td>
<td>31 May</td>
<td>—</td>
<td>85.0 (8.3)</td>
</tr>
<tr>
<td></td>
<td>6 June</td>
<td>113.0</td>
<td>95.0 (26.4)</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td>113.0</td>
<td>90.0</td>
</tr>
</tbody>
</table>

^aAverage number of insects/plant two weeks after infestation shown in parentheses.

that about 20% less fructans were present in those seedlings damaged by the insects than in the control. Little information is available on the depletion of energy reserves in the plant or the ability of plants to recover from biological stress with depleted energy reserves. These studies indicate that insect feeding can reduce the fructans in wheat and reduce the cold hardiness of plants grown under controlled conditions. We do not understand the greater depletion of fructans in aphid group 3 than 4, as more aphids were present in group 4 (26.4 aphids/plant) than in group 3 (8.3 aphids/plant). Further studies should be done to show the relationship of insect numbers, the duration of feeding, reduction of energy reserves, and the rate of recovery of small grains exposed to insect attack to better understand some of the factors that cause yield and biomass loss in plants.
ACKNOWLEDGMENT

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LITERATURE CITED


NEARCTIC EPIBLEMA: A NEW SYNONYMY, A REVISED IDENTITY, AND TWO NEW SPECIES (LEPIDOPTERA: TORTRICIDAE)

William E. Miller

ABSTRACT

New findings are reported for four species: Epiblema naoma Clarke is a junior synonym of E. iowana McDunnough; E. numerosana (Zeller) is currently misidentified; E. chromata, currently identified as the preceding, is described from Texas and differentiated from E. grossbecki Heinrich by maculation and female genitalia; and E. arctica, recently discovered in the Alaskan tundra, is described and differentiated from the boreal E. hyalana McDunnough by maculation and male genitalia.

Nearctic Epiblema currently comprises some 40 species (Powell 1983). Before Brown's (1973) review, the genus was last revised by Heinrich (1923). The known larvae feed on Compositae, the late instars boring in host stems or roots (Brown 1973, Miller 1976).

Four species are discussed here, plus two more in passing. Of the first four, one has been going under two names, one is associated with the wrong type, and two lack valid names. One of the last is a new tundra form, representing a biome not previously known for Epiblema (Brown 1973, Downes 1966, and others).

The letter n denotes number of observations or specimens underlying a statement. Museum abbreviations are AM, American Museum of Natural History, New York; C, W. S. Craig collection, Columbia, Missouri; CN, Canadian National Collection, Ottawa; H, J. R. Heitzman collection, Independence, Missouri; IS, Illinois Natural History Survey, Urbana; MEM, Mississippi Entomological Museum, Mississippi State University; MZ, Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts; NM, National Museum of Natural History, Washington, D. C.; UCB, University of California, Berkeley; and UM, University of Minnesota, St. Paul.

Epiblema iowana McDunnough
(Figs. 1–4)

Epiblema iowana McDunnough (1935: 142) (holotype: male, Renwick, Iowa, 19 May 1928, No. 3871 in CN, forewing length 7.5 mm, wings illustrated here in Figure 1).


Forewing length 6.0–8.0 mm (25n). Maculation of the sexes is similar, but females are darker hued than males (Figs. 1–2).

Clarke (1953) did not personally compare examples of E. iowana and E. naoma. He differentiated them based on a comparison by T. N. Freeman. Freeman stated that, among lesser differences, the apex of the E. iowana uncus is truncate, whereas that of E. naoma is bilobed. Brown (1973) conjectured that the two species were synonymous, and that the alleged structural differences were artifacts of genitalia preparation. My comparison of E. iowana and E. naoma (Figs. 1–4) tends to support Brown's conclusion, in that the uncus of E. iowana is truncate, whereas that of E. naoma is bilobed.

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2Department of Entomology, University of Minnesota, St. Paul MN 55108.
iowana and E. naoma types confirms that uncus apex and some other differences are indeed artifacts of mounting, while remaining differences are merely those between populations. The uncus apex is bilobed, as close examination of properly prepared genitalia reveals (Fig. 3).

I examined specimens from Illinois, Iowa, Minnesota, and Missouri (25n) (C, CN, H, IS, NM, UM).

Capture dates range from 12 April to 30 May (21n). The larva feeds in roots of Ratibida pinnata (Clarke 1953).

Epiblema numerosana (Zeller)
(Figs. 5–8)

Paedisca numerosana Zeller (1876: 317) (holotype: male, Dallas, Texas, no date, No. 14339 in MZ, forewing length 6.5 mm).

Forewing length 6.0–8.5 mm (27n). Maculation of the illustrated example (Fig. 5) matches that of the type closely.

Heinrich (1923) did not identify specimens of true E. numerosana to species; he merely labeled them “Epiblema” (Fig. 5). What he called E. numerosana is a misidentified species to which no existing name can apparently be assigned. It is described in the next section.
Besides the type, I examined specimens from Illinois, Iowa, and Minnesota (27n) (NM, UM). Capture dates range from 24 June to 6 August (26n). The larval host is unknown.

*Epiblema chromata* new species
(Figs. 9-12)

*Epiblema numerosana* (not Zeller 1876: 317); Heinrich (1923: 141).

**Female.** Forewing length 7.5–9.0 mm (holotype 9.0 mm) (3n). **Head:** labial palpus mostly yellowish white, a spot of blackish brown on outer side near middle, apical segment blackish brown; scaling of front and crown mostly yellowish white, mid-frontal area sometimes darker; antennae ringed near base with blackish brown. **Thorax:** dorsal scaling yellowish white with occasional darker patches; ventral scaling shiny white, legs mostly white, tarsi and sometimes tibiae brown banded. **Wings:** upper side of forewings white, yellowish white, and brown, patterned as in Figure 9, under side faintly resembling upper side; upper and under sides of hindwings pale grayish brown. **Abdomen:** coloration

![Figures 5-16](image-url)
not noted before descaling for genitalia preparation. **Genitalia** (Figs. 10–11) (3n): posterior apophyses one-half as long as anterior apophyses; sterigma rounded, posterior edge trident; ductus bursae not sclerotized; corpus bursae with two large fin-like signa unequal in size.

**Male.** Forewing length 7.0–8.0 mm (3n). Similar externally to female, except that basal one-fourth of costa folded. **Genitalia** (Fig. 12) (3n): uncus rudimentary, rounded; socii separated, short; valval neck constricted to one-half dorsal-ventral cucullus dimension, clasper broad; vesica with about 20 deciduous cornuti.

**Type Data.** Holotype: female, Kerrville, Texas, July 08, H. Lacey, genit. prep. CWT 156, in AM. Five paratypes: one male and one female, same data as holotype except June 06 (Fig. 9) and June 11, genit. prep. CH 5, 13 Sept. 1919 and CWT 160 (Figs. 10, 11), respectively (NM); one female and one male, Corpus Christi State Park, 5 mi. W Mathis, Tex., 16 July 1954, genit. prep. JCL 1027831 and 1027836, respectively (CN); one male, San Benito, Tex., 16 March 1923, genit. prep. JCL 1027837 (Fig. 12), *Epiblema numerosana* Zell., det. C. H. 1925 (NM).

**Discussion.** Compared with *E. numerosana*, *E. chromata* is larger, paler, has different maculation, a differently shaped sterigma, and stouter male valvae (Figs. 5–12).

*Epiblema chromata* most resembles *E. grossbecki* Heinrich. Heinrich (1923) contrasted the males and found differences only in maculation (Figs. 9, 13). He conjectured they might differ only at the subspecies level. Had he examined female genitalia, he would have found at least three structural characters that separate them: a small sculptured sclerotized patch on the ductus bursae of *E. grossbecki* (Fig. 14, arrow) is absent in *E. chromata*; the larger of the dual signa is larger in *E. chromata* than in *E. grossbecki* (Figs. 11, 15, reproduced at the same magnification), that of the former being more than 1.8 × sterigma width, that of the latter less; and the sterigma of *E. chromata* is more rounded in outline than that of *E. grossbecki* (Figs. 10, 14) (3n each species). Both species reportedly occur at the same localities in Florida (Kimball 1965), a situation unlikely for subspecies. The larval hosts of neither are known.

Heinrich (1923) gave the distribution of the species here called *E. chromata* as Texas, Arkansas, and Louisiana, but I could not confirm the last two states.

*Epiblema arctica*, **new species**

(Figs. 17–19)

**Male.** Forewing length 7.5–9.0 mm (holotype 8.0 mm) (23n). **Head:** labial palpus grading from brownish white at base to brownish black at apex; scaling of front and crown similar. **Thorax:** dorsal scaling similar to preceding; ventral scaling paler and shiny, front and middle legs brownish white with tarsi dark and light banded, hind legs paler. **Wings:** upper side of forewings brown, blackish brown and white, patterned as in Figure 17, under side paler, basal one-third of costa folded; upper side of hindwings mostly grayish brown, usually paler in middle, under side pale. **Abdomen:** Shiny gray dorsally, paler ventrally; eighth segment with a lateroposterior pair of erectile scale patches. **Genitalia** (Fig. 18) (6n): uncus rudimentary, triangular, apex sometimes slightly cleft; socii separated, short; valva constricted slightly, neck thick, clasper pointed; vesica with about 20 deciduous cornuti.

**Female.** Forewing length 8.0–8.5 mm (5n). Similar externally to male, except that abdominal erectile scales are absent, and, on average, distal half of forewing has whiter markings. **Genitalia** (Fig. 19) (3n): posterior apophyses 0.6–0.7 as long as anterior apophyses; sterigma widening caudally; a large sclerotized patch near middle of ductus bursae; corpus bursae with two signa equal in size.

**Type Data.** Holotype: male, Anaktuvuk Pass, Alaska, 11 July 1970, K. W. Philip, genit. prep. JCL 1027839, in AM. Twenty-seven paratypes, all from Alaska: two males, same data as holotype except 9 July (Fig. 17) and 14 July, genit. prep. JCL 1027838 (Fig. 18) and KL 173, respectively (AM, CN); five males, Schrader Lake, 2–24 July 1973, K. W. Philip and J. F. G. Clarke, genit. prep. JFGC NM 24157; one female, same data as preceding except genit. prep. JFGC NM 24158 (NM); two males, 4 mi. N Cantwell, 2,000–2,200 ft., 26–27 June 1979, P. Opler and J. Powell, genit. prep. WEM
Figs. 17-21. *Epiblema arctica* and *E. lyallana*: (17) wings of *E. arctica* paratype male from Anaktuvuk Pass, Alaska; (18) genitalia of preceding (prep. JCL 1027838); (19) sternum and associated structures of *E. arctica* paratype female from Eagle Summit, Alaska (prep. WEM 298843); (20) wings of *E. lyallana* paratype male from Mt. Lyall, Quebec; (21) genitalia of preceding (prep. CH 19 Nov. 1935).

298841 and JAP 4460 (UCB); 14 males, Eagle Summit, 65 mi. SW Circle, 2 July 1979, Opler and Powell, genit. prep. WEM 298842; four females, same data as preceding, genit. preps. WEM 298843 (Fig. 19) and RLB 1144 (UCB, MEM, UM).

**Discussion.** This species resembles the boreal *E. lyallana* McDunnough (1935), but its dorsal wing spot is usually less sharply defined (Figs. 17, 20) (28n and 1n, respectively), and its valval cucullus, relative to the sacculus, is larger (Figs. 18, 21) (6n and 1n, respectively).

The type locality, Anaktuvuk Pass, lies at 68°10′N, 151°50′W, which is above the Arctic Circle.

**ACKNOWLEDGMENT**

For specimen loans and other assistance, I thank F. H. Rindge (AM), Akira Mutuura and P. T. Dang (CN), G. L. Godfrey (IS), J. M. Burns (MZ), D. R. Davis and J. F. G. Clarke (NM), J. A. Powell (UCB), P. J. Clausen (UM), as well as others named earlier. I also thank R. L. Brown (MEM) who sent 25 examples of *E. arctica* after seeing an early draft of the manuscript.

**LITERATURE CITED**


CLEPTES SPECIOSUS IN THE GREAT LAKES REGION
(HYMENOPTERA: CHRYSIDIDAE: CLEPTINAE)
Mark F. O'Brien

ABSTRACT

Cleptes (Melanocleptes) speciosus Aaron is newly recorded from Michigan, with records from five counties in the Upper and Lower peninsulas. A New York record from near Lake Ontario suggests this western species also has a Great Lakes distribution.

Primitive chrysidids of the Holarctic genus Cleptes are recorded as parasites of tenthredinid and diprionid sawflies, ovipositing on the prepupae in their cocoons (Dahlsten 1961, Gauss 1964, Smith 1962). Hence, they may be likely to occur where their hosts are common, e.g., the coniferous and transition forests of North America. In the recent treatment of North American Chrysididae, Bohart and Kimsey (1982) did not record Cleptes (Melanocleptes) speciosus Aaron from Michigan, and only a single locality ("New York") east of the 100th meridian was listed. Kimsey (1981) and Bohart and Kimsey (1982) thought C. speciosus to be restricted to states west of the 100th meridian. The records from Michigan that follow are new for the state, and another New York locality adds to the known distribution of C. speciosus. Specimens listed are deposited in the University of Michigan Museum of Zoology (UMMZ), Michigan State University entomological collections (MSU), and the State University of New York College of Environmental Science and Forestry insect collection (ESF).


The C. speciosus males listed above are very bright green on the head and thorax, with the abdomens dark with green reflections. This agrees with the diagnosis of C. speciosus by Bohart and Kimsey (1982). The females are also typical of the species, being bronzey to coppery on the head and thorax with greenish highlights.

The above localities give a distributional picture very similar to that of the sphecid wasp, Diploplectron peglowi Krombein (O'Brien 1984). The pattern of species extending from the west to the east is also present in the sphecid genus Mimesa (Finnamore 1983). The same pattern, no doubt, occurs in many other species of insects with a trans-montane and northern transition forest distribution. As collecting continues in the Upper Peninsula of Michigan, more "western" species may be found farther eastward than expected. Such studies of the fauna in the upper Great Lakes region can only enhance our knowledge of the Nearctic fauna, and provide a better understanding of biogeographical relationships.

1Insect Division, Museum of Zoology, The University of Michigan, Ann Arbor, MI 48109.
ACKNOWLEDGMENTS

I thank R. L. Fischer, Michigan State University, and F. E. Kurczewski, SUNY College of Environmental Science & Forestry, Syracuse, for the loan of the Cleptes specimens; the Huron Mountain Wildlife Foundation for its support; and L. S. Kimsey, University of California, Davis, for verifying some Cleptes determinations.

LITERATURE CITED

OBSERVATIONS ON THE NESTING AND UNIQUE CACHEMENT BEHAVIOR OF CALICURGUS HYALINATUS (HYMENOPTERA: POMPILIDAE)

Frank E. Kurczewski and Margery G. Spofford

ABSTRACT

The components of the nesting and provisioning behavior of Calicurgus hyalinatus are delineated chronologically. The unique cachement of the prey, whereby the spider is suspended from vegetation by its own silken threads, is described. The nesting and provisioning components we observed are compared with those described in the Nearctic and Palearctic literature.

Although Calicurgus hyalinatus (Fabricius) is not rare, relatively little is known about its nesting behavior in North America. Only a single observation, that by Evans and Yoshimoto (1962), is available for this species. In Europe C. hyalinatus has been studied briefly, notably by Ferton (1897), Maneval (1939), Soyer (1946), and Wahis (1949). Their behavioral observations agree remarkably well with that of Evans and Yoshimoto (1962).

On 10 September 1983, at about 1500 hr, we observed this species carrying an Araniella displicata (Hentz) female (Araneidae) slowly forward on sandy soil in an overgrown, semi-wooded portion of a sand pit near Owasco Lake, Auburn, Cayuga County, NY. The pair was collected as the wasp dragged the spider backwards up a plant, before entering dense vegetation. The wasp weighed 8 mg and its prey, 48 mg.

On 30 June 1984, at 1332 hr, a female of C. hyalinatus, weighing 8 mg, was observed transporting a female A. displicata, weighing 40 mg, across bare sand on a sandy-gravelly ridge in the town of Sennett, 3.2 km E of Auburn. The wasp grasped the spider with the mandibles by the bases of its hindlegs, and, retaining the prey head forward and ventral side upward, walked slowly forward while beating the wings for momentum. She spent 3 min in traversing 1 m of sand and then at 1335 hr released the spider, ventral side upward, on the sand just beneath a small cottonwood. The wasp returned intermittently during the next 15 min and circled this area three times. At 1354 she returned again, flew in circles, and walked on the sand circuitously while searching for her prey. After 1 min of searching she retrieved it, grasping it as before, and proceeded forward on the sand. She "hopped" (flew) to a peripheral branch of the cottonwood and began moving upward from leaf to stem and vice-versa, retaining the same grasp of the prey while holding the substrate sometimes with only a hindleg. The wasp ascended the vertical stems usually by walking forward, but occasionally she would turn and walk backwards, holding the spider in the same manner. The wasp amazingly walked across vertical leaf surfaces without sliding or faltering. At a point 50 cm above the sand surface the provisioning female walked back and forth across a dead branch several times. She then paused and malaxed the prey on the underside of its abdomen. Then, holding the prey, the wasp rapidly circled the branch while laying down rings of silk from the spider's spinnerets. She hung by both or one hindleg while manipulating this silk with the fore- and midlegs. In the process she suspended the spider tautly, 1.0 cm below the branch, by a tripod of its own silk and then flew away at 1414. Several ants were traversing nearby living branches, but they did not...

1Department of Environmental and Forest Biology, State University of New York, College of Environmental Science and Forestry, Syracuse, NY 13210.
approach the dead branch from which the spider was suspended. Upon close inspection it was noted that the spider’s third and fourth right legs anchored it via silken threads to the dead branch. In addition, there were four curled silken threads hanging loosely from the spider’s spinnerets.

At 1438 the wasp returned, presumably from feeding because we were unable to locate her in the vicinity for nearly 25 min, examined the spider from a distance of 10 cm, and flew away. She returned again at 1441 and 1447, searched for the dead branch and examined the prey from a distance the first time but checked the silken connecting threads the second time. The wasp returned again at 1500, examined the spider’s head and abdomen with her antennae, flew away, returned at 1504, examined the spider from a distance, and then flew to the shaded sand beneath the cottonwood, ca. 1 m from the cached prey. Here, at 1505, she began constructing a burrow, using the mandibles while holding the mid- and hindlegs spread almost laterally like struts; her abdomen was bent downward like an inverted C. She continued to burrow head downward, backing out to remove sand using the forelegs alternately. After 2.5 min she had disappeared entirely from sight but periodically pushed damp sand upward, using the fore- and midlegs, after which the hindlegs distributed the sand circularly around the entrance. The wasp was not seen for 24 min. Except for one sand removal during which she used the hindlegs and apex of the abdomen, the only evidence of burrow construction was the damp sand being continually pushed upward into the plugged entrance. At 1532 the wasp could be seen inside the entrance; she exited headfirst at 1535, circled the entrance, flew to the prey and examined it for 1 min. She then grasped the spider with the mandibles, as before, and tugged on it, breaking the silken connecting threads at 1539. Holding the spider she flew to a leaf below, then walked downward on it, transporting the spider forward. She “hopped” from the leaf to the sand, transported the prey forward toward the nest, released it on the surface, ventral side upward, 6 cm from the entrance, walked to the opening, returned to the spider, grasped it as before and, retaining this grasp, backed into the entrance at 1541.

At 1551 the wasp was seen inside the entrance, breaking down the sides of the burrow from all directions, using the mandibles. During the closure the female worked both head up- and downward. After filling the burrow nearly flush with the surface she began breaking in the rim of the entrance with the mandibles and possibly pushing this sand into the tunnel with the head; at least the head was placed inside the burrow. At 1556 she raked in the sand surrounding the entrance with the forelegs, at times passing the sand to the mid- and hindlegs. At 1559 the female new off, without fully levelling the tumulus or cleaning herself.

The circular tumulus was 20 mm d., with the entrance, 4 mm d., positioned off-center. The burrow entered the sand obliquely, was 23 mm long, including cell length, and terminated in a horizontal cell, 20 mm beneath the surface, including cell height. The cell was 5 mm d. and 8 mm long; its walls were extremely smooth. The spider was placed in the cell dorsal side upward and head toward the entrance. The wasp’s egg, 1.5 mm long, was attached medially to the venter of the abdomen, near its base.

DISCUSSION

The time of day at which females of Calicurgus hyalinatus provision their nests varies widely. Evans and Yoshimoto (1962) noted a female with prey in Kansas at ca 0830 hr, whereas one of us (FEK) has collected this species transporting a spider in Pennsylvania at 1745. The manner of prey transport in C. hyalinatus is related to the sizes of the wasp and spider. We observed females with prey weighing 5 and 6 times the weight of the wasp moving slowly forward on the ground, whereas wasps with prey of their own size make long sustained flights (Kurczewski and Kurczewski 1968b). Ferton (1897) first noted that the prey is grasped near the junction of the cephalothorax and abdomen, and Evans and
Yoshimoto (1962) recorded the wasp grasping the spider by the bases of its hindlegs, as we observed. This grasp is retained by the wasp throughout prey transport (whether by ground or in flight) and during prey cachement and prey entry into the nest (Ferton 1897, Soyer 1946, Evans and Yoshimoto 1962). We observed the spider being released once on the sand prior to nest entry and Wahis (1949) noted a female which released her spider momentarily before taking it into the nest. Ferton (1897), Soyer (1946), and Evans and Yoshimoto (1962) reported no such release prior to nest entry.

Evans and Yoshimoto (1962) and we have observed females of C. hyalinatus malaxating the abdomen of the spider prior to suspending it via silken threads from a plant. This malaxation evidently aids in the release of silk from the spider's spinnerets. In addition we noted one wasp manipulating the silken threads with its fore- and midlegs. The taut suspension of the prey undoubtedly serves to keep it away from predators such as ants. This behavior would be particularly valuable in the tropics where ants are abundant and species of Calicurgus are numerous. Likewise, the suspension of the spider from dead rather than living branches should lessen the chances of predation since ants and other predators frequent the living parts of trees in search of exudates, honeydew, and similar secretions. The numerous examinations of the prey by C. hyalinatus may also be related to lessening predation.

The mechanics of burrow construction in C. hyalinatus are similar to those reported for many other species of Pompilidae (see e.g., Pompilus michiganensis (Dreisbach) [Kurczewski and Snyder 1964]). Some details of burrow construction in C. hyalinatus have been presented by Evans and Yoshimoto (1962). In Pompilidae the manner of burrow construction is often dictated by the structure of the foretarsus (Evans 1950, 1951 a, b).

The details of the closure of the nest are similar to those reported by Evans and Yoshimoto (1962) for this species, except that one of our females filled the burrow by working both up- and downward in it. In addition she appeared to either push sand downward with the front of the head or, at least, place the head inside the burrow to examine the amount of fill. The latter needs confirmation from additional observations on this species.

The dimensions of the nest and architecture of the burrow and cell that we observed are similar to those noted by Ferton (1897) in France and Bouwman (1917) in Holland. The nest excavated by Evans and Yoshimoto (1962) in Kansas was about twice as long and deep as the one we examined. The walls of the cell in the nest we dug were smoothened, as if deliberately made so by the wasp. Because the female spent 30 min in constructing a burrow and cell only 23 mm long, we suspect that perhaps \( \frac{1}{2} \) or so of this time was spent in smoothing the cell walls. Ferton (1897), likewise, noted the cell walls of C. hyalinatus as "carefully smoothed."

The placement of the spider in the cell and the position of the egg upon the spider are similar to those noted by Maneval (1939), Soyer (1946) and Evans and Yoshimoto (1962), i.e., spider dorsum upward and head outward in a horizontal cell with the egg attached near the base of the ventral side of the abdomen. Ferton (1897) reported the spider to be positioned in the cell "vertically" with the egg "laid on the right side of the base of the abdomen."

All prey records for C. hyalinatus are for Araneidae (Ferton 1897; Bouwman 1917; Minkiewicz 1934; Maneval 1939; Soyer 1946; Wahis 1949, 1955; Townes 1957; Krombein 1958 a, b, 1961; Evans and Yoshimoto 1962; Kurczewski and Kurczewski 1968 a, b, 1972). Although early collecting records indicate a preference for the genus Araneus (Evans and Yoshimoto 1962), several genera of orb-weaving spiders are used as prey depending upon the ecological setting (Kurczewski and Kurczewski 1968 a, b, 1972).

ACKNOWLEDGMENT

We thank R. A. Norton, CESF, for identifying the prey Araneidae.
LITERATURE CITED


RECORD OF MICHIGAN MOSQUITO SPECIES (DIPTERA: CULICIDAE) COLLECTED IN A NATURAL FOCUS OF JAMESTOWN CANYON VIRUS IN 19841

Paul R. Grimstad and Michael J. Mandracchia2

ABSTRACT

Data are presented on the seasonal succession of 22 species of mosquitoes collected at the Houghton Lake Wildlife Research Area, Missaukee County, in northcentral Michigan during a three-month period in 1984. Nine species represent new county records.

Jamestown Canyon (JC) virus, a subtype of Melao virus of the California serogroup, is widely distributed throughout temperate North America (Grimstad 1983). The natural vertebrate host is the white-tailed deer, Odocoileus virginianus (Zimmerman); however, domestic bovine, caprine, and equine hosts in the Midwest also apparently become infected and develop circulating antibody. This human encephalitogenic virus (Grimstad et al. 1982) has been repeatedly isolated from numerous mosquito species; it has also been isolated from three tabanid species (DeFoliart et al. 1969, Sudia et al. 1971, Grimstad 1983). While no one hematophagous dipteran species has been shown conclusively to be the primary vector, JC virus is very probably a mosquito-borne arbovirus.

Transmission of JC virus to humans and deer is not uncommon in the upper Midwest. A recent serologic survey of adult Michigan residents (conducted by the senior author utilizing premarital blood samples obtained through the courtesy of the Michigan Department of Public Health) indicated that antibody prevalence to JC virus averaged 20% in residents of the Lower Peninsula (Grimstad et. al., in press). Some of the highest antibody prevalence rates detected in that survey (33%) occurred in residents of northcentral Michigan, including the area around Missaukee County where this study was conducted. Every adult deer from Missaukee County that was tested for neutralizing antibody to JC virus was positive.

This report enumerates the 1984 mosquito species collections at our study site, the Houghton Lake Wildlife Research Area (HLWRA), a Michigan Department of Natural Resources property located in eastern Missaukee County. This collection was made as part of a long-term study of the ecology of vectors of JC virus and the epidemiology of virus transmission. Our eventual goal is to associate one or more mosquito species with the transmission of JC virus to deer and humans in northcentral Michigan.

METHODS

Adult mosquitoes were collected by means of two standard 6-volt DC CDC miniature light traps (Hausherr’s Machine Works, Toms River, NJ), a tent trap (Sears nylon-polyester screenhouse with a 3 by 3.7 m base), a clear cellulose plastic DeFoliart-Morris trap (DeFoliart & Morris 1967), and a 12-volt DC battery-powered aspirator (Nasci 1981) that was used to sweep ground-level vegetation. The light, tent, and DeFoliart-Morris traps were all CO2-baited (dry ice). Small chunks of dry ice (< .45 kg) were also placed

1Supported in part by National Institutes of Health Grant AI-19679.
2Laboratory for Arbovirus Research and Surveillance, Department of Biology, University of Notre Dame, Notre Dame, IN 46556. Address requests for reprints to PRG.
along deer trails to attract mosquitoes to the vicinity; shortly after, a collector carrying the aspirator passed up and down the trails, vacuuming the nearby foliage. Aspirator sweeps were made in the afternoon, evening, and early the morning following each of the collection dates. Traps were set up by 1500 hr EST each collection date and left overnight; contents of the traps were always removed by 0700 hr EST the following morning. All mosquitoes were frozen with dry ice at the collection site, transported to the laboratory, sorted to species on a chill table, and pooled for virus isolation.

RESULTS AND DISCUSSION

Our survey was conducted from 14 May through 14 August 1984, the time period during which all virus transmission to deer occurred at HLWRA. No adult mosquitoes were collected in traps or attempted to bite collectors on 14-15 May; adult emergence apparently occurred between that date and 23 May. On several occasions in early June and July we were unable to collect mosquitoes due to high winds and (or) steady rainfall.

Table 1 lists the different species of mosquitoes collected each of the dates; sex and new county records are indicated on that table. A total of 22 species representing five genera were collected, with a peak collection during the third week in June. Nine species represent new county distribution records (Table 1); our collection of Anopheles walkeri

Table 1. Record of mosquito species collected on six different dates at Houghton Lake Wildlife Research Area, Missaukee County, Michigan in 1984.

<table>
<thead>
<tr>
<th>mosquito species</th>
<th>May 23-24</th>
<th>June 12-13</th>
<th>June 19-20</th>
<th>June 25-26</th>
<th>July 16-17</th>
<th>August 13-14</th>
<th>Total Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aedes abserratus (Felt &amp; Young)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>228/14</td>
</tr>
<tr>
<td>-punctor (Kirby)</td>
<td>20/1 a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>auriifer (Coquillett)</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>7/1</td>
<td></td>
<td>37/1</td>
</tr>
<tr>
<td>canadensis (Theobald)</td>
<td>.-</td>
<td>30/1</td>
<td>.-</td>
<td>2/1</td>
<td>.-</td>
<td></td>
<td>1060/29</td>
</tr>
<tr>
<td>cinereus Meigan</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>937/221</td>
<td>352/12</td>
<td></td>
<td>2574/310</td>
</tr>
<tr>
<td>communis (DeGeer) group</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
</tr>
<tr>
<td>exsicians (Walker)</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>7/1</td>
<td></td>
<td>8/-</td>
</tr>
<tr>
<td>fitchii (Felt &amp; Young)</td>
<td>1/-</td>
<td>6/9</td>
<td>1/7</td>
<td>4/-</td>
<td>4/-</td>
<td>1/-</td>
<td>33/16</td>
</tr>
<tr>
<td>impictus (Vockeroth)</td>
<td>.-</td>
<td>2/-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>2/-</td>
</tr>
<tr>
<td>intrudens Dyar</td>
<td>4/-</td>
<td>9/1</td>
<td>8/4</td>
<td>9/-</td>
<td>4/1</td>
<td>6/-</td>
<td>40/6</td>
</tr>
<tr>
<td>provocans Walker</td>
<td>6/-</td>
<td>24/-</td>
<td>11/-</td>
<td>13/-</td>
<td>4/-</td>
<td>.-</td>
<td>58/-</td>
</tr>
<tr>
<td>triserius (Say)</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>1/-</td>
<td></td>
<td>1/-</td>
</tr>
<tr>
<td>trivittatus (Coquillett)</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>1/-</td>
<td>.-</td>
<td></td>
<td>1/-</td>
</tr>
<tr>
<td>vexans (Meigen)</td>
<td>.-</td>
<td>33/4</td>
<td>19/22</td>
<td>20/-</td>
<td>101/-</td>
<td>115/1</td>
<td>288/27</td>
</tr>
<tr>
<td>species</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
</tr>
<tr>
<td>Anopheles quadrimaculatus Say</td>
<td>.-</td>
<td>2/-</td>
<td>.-</td>
<td>7/-</td>
<td>11/-</td>
<td></td>
<td>21/-</td>
</tr>
<tr>
<td>walkeri Theobald</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>1/-</td>
<td>.-</td>
<td></td>
<td>8/-</td>
</tr>
<tr>
<td>Mansonia perturbans (Walker)</td>
<td>.-</td>
<td>50/3</td>
<td>325/19</td>
<td>282/11</td>
<td>844/2</td>
<td>302/1</td>
<td>1803/36</td>
</tr>
<tr>
<td>Culex pipiens L. restoams Theobald</td>
<td>.-</td>
<td>15/1</td>
<td>5/4</td>
<td>1/-</td>
<td>28/-</td>
<td>2/3</td>
<td>51/8</td>
</tr>
<tr>
<td>territans Walker</td>
<td>.-</td>
<td>1/-</td>
<td>4/4</td>
<td>.-</td>
<td>3/7</td>
<td></td>
<td>8/12</td>
</tr>
<tr>
<td>Culiseta imparsi (Walker)</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td></td>
<td>1/-</td>
</tr>
<tr>
<td>minnesota Barr</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>.-</td>
<td>6/-</td>
<td></td>
<td>6/-</td>
</tr>
<tr>
<td>morosis (Theobald)</td>
<td>.-</td>
<td>2/-</td>
<td>5/2</td>
<td>5/-</td>
<td>47/-</td>
<td>8/3</td>
<td>67/5</td>
</tr>
<tr>
<td>Totals for each sex</td>
<td>31/2</td>
<td>1114/101</td>
<td>1621/306</td>
<td>1211/37</td>
<td>1700/5</td>
<td>695/17</td>
<td>6372/467</td>
</tr>
<tr>
<td>Species totals</td>
<td>33</td>
<td>1215</td>
<td>1927</td>
<td>1248</td>
<td>1705</td>
<td>712</td>
<td>6389</td>
</tr>
</tbody>
</table>

aFemale/male collection totals. A - denotes no specimen of that sex was collected.
bNew county collection record for that species.
Table 2. Record of mosquito species collected in four different trap types at Houghton Lake Wildlife Research Area, Missaukee County, Michigan in 1984.

<table>
<thead>
<tr>
<th>Trap type</th>
<th>DeFoliart-Morris</th>
<th>Morris</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aedes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>abserratus-punctor</td>
<td>71/1, 109/13</td>
<td>44/1</td>
<td>228/14</td>
</tr>
<tr>
<td>aurifer</td>
<td>6/1, 30/1</td>
<td>1/-</td>
<td>37/1</td>
</tr>
<tr>
<td>canadensis</td>
<td>439/1, 482/29</td>
<td>99/-</td>
<td>1060/29</td>
</tr>
<tr>
<td>cinereus</td>
<td>549/4, 1811/305</td>
<td>120/1</td>
<td>2574/310</td>
</tr>
<tr>
<td>communis group</td>
<td>-/-, -/-, -/-, -/-</td>
<td>-/-</td>
<td>-/-, -/-, -/-, -/-</td>
</tr>
<tr>
<td>excrucians</td>
<td>7/-, 1/-, -/-, -/-</td>
<td>-/-</td>
<td>8/-</td>
</tr>
<tr>
<td>fitchii</td>
<td>11/-, 22/16</td>
<td>-/-</td>
<td>33/16</td>
</tr>
<tr>
<td>implicatus</td>
<td>2/-, -/-</td>
<td>-/-</td>
<td>2/-</td>
</tr>
<tr>
<td>intrudens</td>
<td>16/-, 18/6</td>
<td>6/-</td>
<td>40/6</td>
</tr>
<tr>
<td>provocans</td>
<td>20/-, 25/-</td>
<td>13/-</td>
<td>58/-</td>
</tr>
<tr>
<td>triseriatus</td>
<td>-/-, -/-, -/-, -/-</td>
<td>-/-</td>
<td>-/-</td>
</tr>
<tr>
<td>trivittatus</td>
<td>-/-, 1/-, -/-, -/-</td>
<td>-/-</td>
<td>-/-</td>
</tr>
<tr>
<td>vexans</td>
<td>116/-, 90/27</td>
<td>79/-</td>
<td>288/27</td>
</tr>
<tr>
<td>species</td>
<td>2/-, -/-</td>
<td>-/-</td>
<td>-/-, -/-</td>
</tr>
<tr>
<td><strong>Anopheles</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>punctipennis</td>
<td>16/-, -/-</td>
<td>5/-</td>
<td>21/-</td>
</tr>
<tr>
<td>quadrimaculatus</td>
<td>4/-, 1/-</td>
<td>3/-</td>
<td>8/-</td>
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<tr>
<td>walkeri</td>
<td>14/-, 3/-</td>
<td>57/-</td>
<td>75/-</td>
</tr>
<tr>
<td><strong>Mansonia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>perturbans</td>
<td>281/3, 358/21</td>
<td>1158/12</td>
<td>1803/36</td>
</tr>
<tr>
<td><strong>Culex</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pipiens-restuans</td>
<td>20/1, 9/7</td>
<td>22/-</td>
<td>51/8</td>
</tr>
<tr>
<td>territans</td>
<td>1/1, 7/10</td>
<td>-/-</td>
<td>8/12</td>
</tr>
<tr>
<td><strong>Culiseta</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>impatiens</td>
<td>1/-, -/-, -/-, -/-</td>
<td>-/-</td>
<td>-/-</td>
</tr>
<tr>
<td>minnesotae</td>
<td>-/-, -/-, 6/-, -/-</td>
<td>-/-</td>
<td>-/-</td>
</tr>
<tr>
<td>morstians</td>
<td>8/-, -/-, 59/2, -/-</td>
<td>-/-</td>
<td>67/5</td>
</tr>
</tbody>
</table>

| Totals for each sex | 1584/9, 2967/441 | 1673/17, 148/- | 6372/467 |
| Species totals     | 1593, 3408      | 1690, 148     | 6389     |

*Female/male collection totals. A - denotes no specimen of that sex was collected.

constitutes the first collection record of adults of that species from Missaukee County.

Table 2 lists the different species of mosquitoes collected by the four different trapping methods. The CO₂-baited tent trap was the most successful in attracting a diversity of mosquito species, 19 of the 22 total species collected. It also attracted numerous species of tabanids and blackflies. Aspirator collections yielded 17 of the 22 species taken by all methods. This was an efficient tool for collecting a diversity of species; of the 14 species collected by all means on 19-20 June, 13 were collected with the aspirator. It was also efficient in collecting newly emerged females not yet seeking a host. In addition, 94% of all male mosquitoes were collected with the aspirator (Table 2). Specimens representing 16 species were collected by the light traps. However, Mansonia perturbans composed 69% of the total light trap collections.

Light traps also appeared to be the best method for collecting Anopheles and Culiseta...
species. We found that the DeFoliart-Morris trap was surprisingly inefficient in comparison to the tent and light traps in collecting mosquitoes despite our relocating it several times within a 15.2-m radius. Only six of the 22 species collected were attracted to and entered this trap. This was unexpected in light of the reportedly successful use of this trap in a Wisconsin arbovirus survey (DeFoliart et al. 1967). The senior author has had extensive prior experience with this trap in Wisconsin; the trap we constructed and used at the HL WRA was virtually identical to that used in the Wisconsin studies. On average 5% of a daily collection would typically be collected with this trap compared to 24% with the light, 41% with the aspirator, and 29% with the tent traps.

Observations at the site showed that this northcentral Michigan area was very dry in 1984 especially from mid-spring (due to a minimal snow cover, melt, and less than average rainfall) throughout much of the summer. Areas normally wet or even partially flooded into late June were dry by late May of 1984. These factors may have resulted in collections that reflected reduced population size and reduced diversity of mosquito species collected. Thus, the density and diversity of mosquito species were probably less than what might be expected in future years. Of the 16 species reported earlier from Missaukee County (Cassani & Newson 1980), four were not collected this year, including *Aedes stimulans* (Walker) from which JC virus has been isolated in northern Indiana and elsewhere (DeFoliart et al. 1969), *Aedes sticticus* Meigen, *Anopheles earlei* Vargas, and *Uranotaenia sapphirina* (Osten Sacken). This first season’s collections in Missaukee County did show an overall diversity similar to that reported from Isabella County to the south (Cassani & Bland 1978). We intend to continue this survey in future years.

ACKNOWLEDGMENTS

The authors thank the Michigan Department of Natural Resources and especially J. Nellist, property manager of the Houghton Lake Wildlife Research Area, for permitting us to conduct studies at that site; and D. G. Williams and J. Meara for their dedicated assistance in making field collections.

LITERATURE CITED

SEWAGE SLUDGE APPLICATION LINKED TO INCREASE IN EASTERN TENT CATERPILLAR POPULATIONS (LEPIDOPTERA: LASIOCAMPIDAE)

Louis F. Wilson, John H. Cooley, and William J. Mattson

ABSTRACT

Numbers of Malacosoma americanum caterpillar tents were positively correlated with average numbers and biomass of cherry trees as well as with amount of sludge applied. The enhancing effect of sewage sludge on amounts of black cherry biomass and foliar nitrogen may have been the principal factors leading to higher tent caterpillar populations on fertilized plots.

A growing body of evidence supports the hypothesis that herbivore population dynamics are linked to the quantity and quality of the population's food resources (Haukioja 1980; Meyers 1980, 1981; Zucker 1982). Such evidence is still mostly circumstantial and piecemeal because unequivocal, substantive evidence is hard to obtain in natural ecosystems. Other factors such as natural enemies, uncontrolled weather, and competitors interact with food resources to confound the main effects of each on the population dynamics of herbivore populations. In this paper we present evidence that eastern tent caterpillar, Malacosoma americanum (Fabricius), populations were locally enhanced by the fertilizing effect of anerobically digested municipal waste sludge applied to a recently disturbed natural forest ecosystem.

METHODS

In 1975, a 5-year-old 7.5-ha aspen stand near Wellston, Michigan (T21W R12W S16), was roller chopped in the fall to simulate clear cutting. In that stand, we randomly selected 53 circular plots (32 m. d.) for the following sludge treatments: 7.5 metric tons / ha (5 plots), 11.5 mt / ha (8 plots), 15.0 mt / ha (5 plots), 23.0 mt / ha (17 plots), 46.0 mt / ha (12 plots), and controls or 0.0 mt / ha (6 plots). Fifteen plots were treated in fall 1975 and the rest were treated in early spring 1976. Municipal wastewater sludge is a semi-solid or liquid containing various inorganic nutrients (e.g., N, P, K, as well as other elements) that are removed from wastewater by municipal treatment plants. Such waste products are being tested as sources of supplemental nutrients for forest ecosystems.

In 1977 we first noticed that populations of the eastern tent caterpillar had invaded the abundant black cherry, Prunus serotina Ehrh., reproduction (from seed and stump sprouts) that emerged as a result of the treatments. This natural, fortuitous event offered us an opportunity to compare caterpillar density with respect to host tree density and sludge loading (i.e., amount applied). So, in June 1978 we counted all tent caterpillar colonies (i.e., tents) on each of the 45 main plots. We also counted all cherry stems taller than 30 cm, and then measured their diameters on four randomly placed circular subplots (4 m^2 each) within each main plot.

Twenty-seven cherry trees representing the full range of sizes on the plots were cut and weighed. Composite subsamples of aboveground parts were oven-dried for 48 h at 85°C to determine moisture content. A log-log regression relating total dry weight (foliage and

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1USDA Forest Service, North Central Forest Experiment Station, 1407 S. Harrison Rd., East Lansing, MI 48823.
wood) of these trees to their basal stem diameter was used to calculate dry weight in metric tons / ha from the stem counts. We also measured the foliar Kjeldahl N content (using a Technicon Autoanalyzer system US-EPA 1979) of cherry leaves collected on 30 of the 45 plots between 19 and 23 September 1977.

Data were analyzed using both multiple regression and analysis of covariance. Insect tent counts (Y) were transformed using a power transformation \( z = y^{3.7} \) to stabilize variances.

**RESULTS AND DISCUSSION**

The number of caterpillar tents per treatment plot (804 m²) ranged from none to 49 (Table 1). Tent counts were linearly, positively correlated \( (P \approx 0.05) \) with total numbers \( (r = 0.48) \), total biomass \( (r = 0.50) \), and mean dry weight \( (r = 0.33) \) of cherry trees in addition to sludge loading \( (r = 0.51) \) (Fig. 1) per plot, which also had a significant, non-linear quadratic effect.

A multiple regression of loading \( (\text{load}, \text{load}^2) \) with cherry tree variables in all possible combinations revealed that after accounting for loading, cherry tree biomass / plot made the highest added contribution to variation in tent counts \( (R^2 = 0.51) \), followed by stem numbers / plot \( (R^2 = 0.48) \), and finally mean tree size \( (R^2 = 0.45) \). This bivariate pattern was not unexpected because the various plant variables per plot were intercorrelated. For example, biomass / plot was strongly associated \( (P \leq 0.01) \) with both mean tree size \( (r^2 = 0.82) \) and numbers of stems / plot \( (r^2 = 0.40) \). On the other hand, loading rate was significantly associated only with numbers of stems / plot \( (r^2 = 0.38) \), not amount of cherry tree biomass or average stem size. Total biomass / plot, which included all vegetation (of which cherry trees averaged about 56%), was significantly correlated with loading rate \( (r = 0.41) \).

The regression equations imply that both sludge loading and amount of cherry trees per plot somehow affected the numbers of eggs laid per plot. Tent counts usually directly reflect eggs because each tent represents the entire egg load from one female, except under high densities where larvae from more than one egg mass join to form one tent. We would expect that as the amount of cherry trees / plot increases, so would the number of potential oviposition sites and total food. If we assume that tent caterpillar moths distribute their eggs at or near random among cherry trees, then numbers of tents should increase as observed along with amount of cherry trees. Sludge applications may have increased the number of eggs laid per sludge plot by somehow enhancing the plant cues (other than size) that stimulate gravid moths to stop and oviposit. Such cues might be volatile chemicals or color. For example, leaf color and chlorophyll content are both highly correlated with leaf N content (Tsay et al. 1982). On the other hand, the sludge

<table>
<thead>
<tr>
<th>Sludge Load (mt/ha)</th>
<th>Plots</th>
<th>Tents</th>
<th>Stems</th>
<th>Tree size (kg)</th>
<th>Cherry biomass (kg)</th>
<th>TKN foliar %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6</td>
<td>3.2</td>
<td>38.5</td>
<td>1.8</td>
<td>71.8</td>
<td>2.19</td>
</tr>
<tr>
<td>7.5</td>
<td>5</td>
<td>9.0</td>
<td>41.2</td>
<td>2.8</td>
<td>112.3</td>
<td>—</td>
</tr>
<tr>
<td>11.5</td>
<td>8</td>
<td>16.1</td>
<td>46.6</td>
<td>2.5</td>
<td>96.2</td>
<td>2.6</td>
</tr>
<tr>
<td>15.0</td>
<td>5</td>
<td>13.6</td>
<td>68.0</td>
<td>4.3</td>
<td>274.8</td>
<td>—</td>
</tr>
<tr>
<td>23.0</td>
<td>17</td>
<td>18.8</td>
<td>53.8</td>
<td>3.7</td>
<td>193.5</td>
<td>3.2</td>
</tr>
<tr>
<td>46.0</td>
<td>12</td>
<td>22.7</td>
<td>68.4</td>
<td>2.7</td>
<td>173.0</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Table 1. Mean values for insect and cherry tree variables per plot (804m²) by sludge treatment classes.
may have enhanced the survival and fecundity of insects through its effect on foliar nutrients and (or) allelochemics. If offspring from the early colonizing females tended to remain on or near their "mother" tree for oviposition, then the build-up of tent caterpillars on fertilized plots could be self-reinforcing.

One factor that may have contributed to such a build-up on sludge plots is the higher foliar N of these trees. On control plots, foliar N concentrations averaged 2.18% dwt; on the plots with highest sludge loading, they averaged 3.67%. Percent foliar N concentration (N) was a curvilinear function of sludge loading (SL): \( N = 2.16 + 0.06(SL) - 0.0005(SL^2), R^2 = 0.71 \). According to Auchmoody (1982), black cherry foliar N levels of \( \leq 2.5\% \) indicate an N deficiency. Hence, the trees on check plots (2.18% N) were probably suffering from an N deficiency. Regressing tent counts (T) on foliar N (N) revealed a significant, curvilinear relationship: \( T = -9.02 + 6.91(N) - 0.98(N^2), R^2 = 0.49 \). Furthermore, a multiple regression of N (N, N\(^2\)) and the cherry tree variables and loading in all possible combinations revealed that none of the added variables accounted for any additional variation beyond that explained by N alone.

This study suggests that sludge treatments somehow enhanced the invasion and buildup of tent caterpillar populations on treated plots. Even after accounting for variations among plots that were due to amount and size of cherry trees, there were still significant treatment effects. However, after accounting for plot to plot variations in foliar N levels, the effects of all other variables inexplicably became nonsignificant. This result implies that N was either mainly responsible or very intimately linked to the various other factors responsible for the variation in tent counts among plots. The linkage could be direct through more available protein, a better balance of amino acids, or better protein / energy ratios in the diet (Schroeder and Malmer 1980, Mattson 1980, Shaw et al. 1978). Or, it could be indirect through so many possible pathways that we shall enumerate only a few main ones. Foliar N content was significantly positively correlated with every measured plant variable per plot, so it may have acted to increase cherry tree biomass, which in turn caused more eggs to be deposited in treated plots. Undoubtedly it changed leaf color, which may have enhanced female propensity to oviposit if one flew into the treated plots. On the other hand, higher N levels typically cause leaves to remain in the growth mode longer and to have higher levels of leaf water and lower levels of non-nutritional compounds such as cellulose, lignin, and allelochemics. The effects of these may have
enhanced larval survival and growth (Mattson 1980, McClure 1979). Moreover, it's possible that some other elements in the sludge correlated with N were incorporated into the plants and these enhanced tent caterpillars.

These data provide additional circumstantial evidence to support the hypothesis that the structure and quality of the plant community can have a significant effect on the population dynamics of herbivores that occupy it. Unfortunately, we did not monitor the insect population beyond the first year, 1978, so we cannot address the issue of long-term effects. Nevertheless, we suspect that eventually the herbivores, in turn, change the system by altering the competitive abilities of plants, nutrient cycling, and other subtle relationships in the system (Schowalter 1981, Mattson and Addy 1975).

LITERATURE CITED

EFFECT OF ARTIFICIAL DEFOLIATION ON BROCCOLI YIELD

W. S. Cranshaw and R. J. Default

ABSTRACT

Broccoli plants were artificially defoliated at varying plant growth stages and defoliation intensities to determine bases for control decisions with lepidopterous defoliators. Low levels of defoliation (≤ 25%) did not significantly depress head weight at any treatment date. Higher levels of defoliation severity (50%) depressed head weight when inflicted following the development of small (< 2 cm) heads. Only complete defoliation (100%) consistently affected head weights. Because of the great ability of broccoli plants to compensate for leaf loss, most preheading insecticide applications should be able to be eliminated in Minnesota without yield losses.

Cole crops grown in Minnesota are subject to attack by numerous insect pests. Insecticides are used routinely to control species which defoliate the crop and injure the marketable head, primarily imported cabbageworm, Artogeia rapae (L.), cabbage looper, Trichoplusia ni (Hubner), and diamond back moth, Plutella xylostella (L.). Efforts to reduce the number of insecticide applications have usually involved the development of "action thresholds" based on counts of the number of larvae per plant (Wyman and Oatman 1977, Chalfant et al. 1979). These thresholds are based on an understanding of how yields are affected by insect damage and how developing problems can be detected and corrected.

Work on broccoli (Brassica oleracea var. italica) in California suggests yields of broccoli were not reduced with preheading pest numbers of nine larvae/plant (Wyman and Oatman 1977). Similar results also occurred with cabbage (Chalfant et al. 1979). Protection of cole crops during head stages, however, is important to prevent damage to and contamination of the marketed product. In cabbage, use of visual thresholds was found to be an effective and rapid means of detecting these problems, although threshold based treatments did suffer from reduced effectiveness during periods of heavy pest pressure (Workman et al. 1980). To determine the response of broccoli to defoliation and to establish levels of defoliation which could be used as conservative treatment guidelines, experiments were conducted during 1982.

METHODS AND MATERIALS

Six-week-old transplants of 'Premium Crop' broccoli were planted to plots 15 June at the University of Minnesota, St. Paul Campus. 'Southern Comet' broccoli was transplanted 18 June at the Rosemount Agricultural Experiment Station, Rosemount, Minnesota. At both locations plants were spaced 30 cm within row and 90 cm between rows. Insecticidal sprays of cypermethrin and carbaryl were applied, as needed, to prevent naturally occurring insect defoliation. Plots consisted of eight plants, separated by border plants, and were arranged in a randomized complete block design with five replications.

Plants were defoliated at three intervals after transplanting with the final defoliation, 2–3 August, coinciding with the development of small (2 cm) heads. Foliage was removed by excising an average of 25, 50, or 100% of the leaf tissue from each leaf in a

1Department of Entomology, Colorado State University, Fort Collins, CO 80523.
2Texas A & M University, 2415 East Highway 83, Weslaco, TX 78596.
uniform pattern. The central six plants from each plot were harvested when the untreated check plants were judged to be of marketable size (12–13 August, Rosemount; 17 August, St. Paul).

RESULTS AND DISCUSSION

Low levels of defoliation (25%) did not cause a reduction of yield in either experiment (Tables 1, 2). At the St. Paul location, weight of broccoli heads was not significantly reduced following any treatment date except when plants were completely stripped of leaves. At Rosemount, there was a significant depression of yield when plants were defoliated 50%, 45 days following transplanting, coinciding with formation of small central heads.

The sensitivity of broccoli to defoliation during head formation is similar to that noted with cabbage (Chalfant et al. 1979). Only 100% defoliation prior to heading had an effect on yield in our experiments. These data, however, appear to conflict with those of Straka (1979) who reported evident economic damage (> 3%) when cabbage and cauliflower was defoliated 7.8–16.9% during the vegetative period.

From the results of our study, it appears that 25% defoliation can be safely tolerated by broccoli prior to the period when insecticidal sprays are needed to protect the head. Defoliation of this magnitude is extremely rare in Minnesota and thus there could be almost complete elimination of early season insecticide treatments if these guidelines were employed. These thresholds would, of course, have to be modified, if substantial levels of black rot, *Pseudomonas campestris*, are present in the field since this disease may increase in severity if there is an increase in leaf wounding by insects (Smith 1898).

LITERATURE CITED


Table 1. Influence of partial or complete leaf defoliation on central head formation in 'Premium Crop' broccoli, St. Paul, MN, 1982.

<table>
<thead>
<tr>
<th>Defoliation treatment</th>
<th>Defoliation date</th>
<th>Central head weight (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 days post planting</td>
<td>25% 8 July</td>
<td>732 A</td>
</tr>
<tr>
<td>20 days post planting</td>
<td>50% 8 July</td>
<td>661 A</td>
</tr>
<tr>
<td>20 days post planting</td>
<td>100% 8 July</td>
<td>42  B</td>
</tr>
<tr>
<td>31 days post planting</td>
<td>25% 19 July</td>
<td>621  A</td>
</tr>
<tr>
<td>31 days post planting</td>
<td>50% 19 July</td>
<td>701  A</td>
</tr>
<tr>
<td>31 days post planting</td>
<td>100% 19 July</td>
<td>106  B</td>
</tr>
<tr>
<td>45 days post planting</td>
<td>25% 2 Aug.</td>
<td>594  A</td>
</tr>
<tr>
<td>45 days post planting</td>
<td>50% 2 Aug.</td>
<td>622  A</td>
</tr>
<tr>
<td>45 days post planting</td>
<td>100% 2 Aug.</td>
<td>75   B</td>
</tr>
<tr>
<td>Untreated Check</td>
<td></td>
<td>623  A</td>
</tr>
</tbody>
</table>

*Means followed by the same letter are not significantly different by Duncan's MRT at 0.05 level.*
Table 2. Influence of partial or complete leaf defoliation on central head formation in 'Southern Comet' broccoli, Rosemount, MN, 1982.

<table>
<thead>
<tr>
<th>Defoliation treatment</th>
<th>Defoliation date</th>
<th>Central head weight (grams)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 days post planting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25%</td>
<td>8 July</td>
<td>426 A</td>
</tr>
<tr>
<td>50%</td>
<td>8 July</td>
<td>433 A</td>
</tr>
<tr>
<td>100%</td>
<td>8 July</td>
<td>34 C</td>
</tr>
<tr>
<td>31 days post planting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25%</td>
<td>19 July</td>
<td>451 A</td>
</tr>
<tr>
<td>50%</td>
<td>19 July</td>
<td>369 AB</td>
</tr>
<tr>
<td>100%</td>
<td>19 July</td>
<td>43 C</td>
</tr>
<tr>
<td>45 days post planting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25%</td>
<td>2 Aug.</td>
<td>424 A</td>
</tr>
<tr>
<td>50%</td>
<td>2 Aug.</td>
<td>279 B</td>
</tr>
<tr>
<td>100%</td>
<td>2 Aug.</td>
<td>70 C</td>
</tr>
<tr>
<td>Untreated Check</td>
<td></td>
<td>410 A</td>
</tr>
</tbody>
</table>

$^a$Means followed by the same letter are not significantly different by Duncan’s MRT at 0.05 level.

Smith, E. F. 1898. The spread of plant diseases—a consideration of some of the ways in which parasitic organisms are disseminated. Trans. Massachusetts Hortic. Soc. 1:117–133.

Straka, F. 1979. [The level of economic damage caused by leaf gnawing pests during the first half of the vegetation period of cabbage and cauliflower]. Gradinska; Lozarska Navka 16:84–92. (Bulgarian)


A Technique for Estimating the Number of Shoots on Pole-Sized Red Pine: The Relationship of Selected Tree Parameters to Number of Shoots in Central Wisconsin Sand Plains Plantations

J. H. Hainze and D. M. Benjamin

Abstract

Diameter at breast height (dbh), of ten tree parameters tested, was most highly correlated with the number of shoots per tree in six red pine plantations in the central Wisconsin sand plains. Tree height, frequently used as an estimator of shoot number in young conifers, was not highly correlated with shoot number. A strong, nonlinear correlation existed between branch diameter and number of shoots per branch. Multiple regressions using several tree parameters yielded the highest \( R^2 \) values, however, dbh was judged the simplest and most practical estimator of shoot number for central Wisconsin red pine plantations.

Red pine shoot moth, *Dioryctria resinosella* Mutuura, larvae infest and destroy the shoots and cones of mainly 20-40-year-old red pine, *Pinus resinosa* Ait. Feeding in the terminal and lateral shoots causes reductions in height and radial growth and poorly formed crowns. Height growth losses ranged from 38 to 65% over a 10-year period during a recent outbreak in central Wisconsin (Hainze and Benjamin 1984). The population dynamics of this insect currently are being studied in central Wisconsin through the construction of life tables to examine the effect of shoot moth mortality factors. These studies require absolute estimates of population density so that they reflect only changes in insect numbers and not changes in the insect’s habitat (Morris 1955). This usually entails estimating the number of insects present per unit area as opposed to presence per habitat unit. In forest situations, this involves converting the number of insects per tree to numbers per hectare, based upon the number of stems per hectare. Since the red pine shoot moth primarily attacks pole-sized and larger trees, it is impractical to observe directly the number of insects per tree. Alternatively, each tree can be sampled and the percentage of shoots infested may then be converted to numbers per tree if the number of shoots on the tree is known. Therefore, a critical step in these estimations was the calculation of the total number of shoots on a tree from certain readily measured tree parameters. The objective of the research presented here was to determine such a method for pole-sized red pine in central Wisconsin.

Tree height frequently has been used successfully to estimate the number of shoots on young conifers. It has been used as an estimator of numbers of shoots or branches in studies of young white spruce, *Picea glauca* (Monench) Voss, (Houseweart et al. 1974), young through mature lodgepole pine, *Pinus contorta* Dougl. ex Loud., (Graham and Shepard 1951) and young red pine (Miller 1965). In nine-year-old *Pinus contorta* and eight-year-old *Picea stichensis* (Bong.) Carr., the number of lateral shoots and the length of branches were related to leader growth (Cannell 1974). Miller (1965) evaluated the predictive value of nine tree parameters, the best of which were total height through the previous year, current year’s total height, and stem diameter 1 ft (ca. .3 m) above ground level. The number of current shoots was shown to be closely related to tree diameter in balsam fir, *Abies balsamea* L. Mill., with mean diameters varying from 3.6 to 21.3 cm.

1Department of Entomology, University of Wisconsin, Madison, WI 53706.
It is questionable if tree height is a valid estimator in older, closed canopy stands and particularly in stands damaged by the red pine shoot moth. We investigated the relationship of a range of tree parameters to the number of shoots per tree.

**MATERIALS AND METHODS**

Studies were conducted in six even-aged red pine plantations in the central Wisconsin sand plains. Two stands were located in Marquette County, one each in Jackson and Richland counties, and two in Sauk County. Plantations ranged in age from about 20 to 40 years and each was infested by the red pine shoot moth. Stands were chosen for their similarity to the study sites used in our work on shoot moth population dynamics. Six trees, felled along the edge of each plantation, were selected to provide a representative sample of the variation in diameter at breast height (dbh), crown length, and total height. The dbh of the sample trees from all plantations ranged from 13.7 to 28.5 cm and was relatively evenly distributed. Parameters measured on each sample tree included total number of live branch whorls, live crown length, previous year's live crown length, total tree height, crown height through the previous year, basal branch length (longest branch in the lower 2/3 of the crown), number of shoots on each branch, total number of branches, diameter of all branches in the living crown (measured at the base), length of all branches in the living crown, and dbh.

Overall tree parameter data were pooled and plotted against total number of shoots per tree, and branch parameters were plotted against the number of shoots per branch. Linear correlations were obtained and regression analyses were performed individually and pairwise on the total number of branch whorls, crown length (present and previous year's), tree height (present and previous year's), basal branch length, the number of branches, largest branch diameter, the sum of the proximal 48 branch diameters and dbh versus the total number of shoots on each tree. The same analyses were performed on branch length, branch diameter and whorl age versus number of shoots on each branch. A stepwise regression procedure was used to determine the "best" multiple regression from the parameters relating to the total number of shoots on each tree.

**RESULTS AND DISCUSSION**

The highest correlation coefficients for the total number of shoots per tree were obtained with (1) dbh and (2) the sum of the branch diameters of the lowest live 48 branches (Table 1). Crown length and the total number of branches showed the weakest correlations; however, all correlations were significant at the 0.05 level. The stepwise regression procedure yielded best regressions using five parameters with the boundary $F$-value set for removal and entry at 2, using four parameters with the $F$-value set at 3 and using two parameters with the $F$-value set at 4 (Table 2).

Our findings for pole-sized red pine, $r^2$ values of 0.42 and 0.43 for the previous year's height and current year's height respectively, differed from those reported for young red pine in which previous year's height and current year's height were the two best individual estimators at $r^2 = 0.90$ and 0.83 respectively (Miller 1965). One of the differences between the younger range of tree ages and the older age range we measured was that the crown in the younger trees probably extended to ground level, while in our study they covered a variable length of the main stem. For this reason, we measured crown length as a potential predictor. Neither current year's nor previous year's crown length were well correlated with shoot number (Table 1). Another major difference between the young red pines and the trees in our study, was the damage to the crown caused by the red pine shoot moth. Shoot feeding by the moth can result in pruning or bushing, a reduction or an increase, respectively, in the number of branches at the injured node. The younger red pines had not been subject to physical or biotic damage that would influence shoot number. Despite these differences our use of dbh as a predictor compared favorably with the results for the younger trees using stem diameter 1 ft (ca. 0.3 m) above ground level.
Table 1: $r^2$ and $r$ values for selected tree parameters versus total number of shoots on red pine.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$r^2$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>diameter at breast height</td>
<td>0.78</td>
<td>0.88</td>
</tr>
<tr>
<td>sum of proximal 48 branch diameters</td>
<td>0.74</td>
<td>0.87</td>
</tr>
<tr>
<td>largest branch diameter</td>
<td>0.53</td>
<td>0.73</td>
</tr>
<tr>
<td>number of whorls in live crown</td>
<td>0.46</td>
<td>0.68</td>
</tr>
<tr>
<td>basal branch length</td>
<td>0.45</td>
<td>0.67</td>
</tr>
<tr>
<td>current year’s total tree height</td>
<td>0.43</td>
<td>0.66</td>
</tr>
<tr>
<td>previous year’s total tree height</td>
<td>0.42</td>
<td>0.65</td>
</tr>
<tr>
<td>previous year’s crown length</td>
<td>0.34</td>
<td>0.58</td>
</tr>
<tr>
<td>current year’s crown length</td>
<td>0.33</td>
<td>0.58</td>
</tr>
<tr>
<td>number of live branches</td>
<td>0.30</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 2: $R^2$ values for best multiple regressions of parameters on number of shoots per red pine.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>dbh × sum of 48 branch diameters</td>
<td>0.83</td>
</tr>
<tr>
<td>dbh × sum of 48 branch diameters × number of branches × largest branch diameter × tree height</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Both studies found a linear relationship between stem diameter and the number of shoots; our equation was $Y = -1379 + 152X$ (Fig. 1). Even though our data set contains a great deal of variation in total tree height, crown length, dbh and numbers of shoots per tree, we obtained an $r^2$ value of 0.78 using dbh (Table 1), a value very close to the $r^2$ value of 0.80 obtained using stem diameter for younger red pines (Miller 1965). The variability of our data, involving trees of a variety of ages, crown shapes, sizes, and injury levels, and its correspondence with the data for younger, uninjured trees, suggests a consistent relationship between stem diameter and the total number of shoots on a tree. This relationship also is suggested by a demonstrated relationship between the destruction of shoots by the red pine shoot moth and reduction of radial growth (Hainze and Benjamin 1984).

We also found a strong nonlinear relationship between branch diameter and the number of shoots per branch (Fig. 2) that was best fit by a log-log model, $\log Y = -4.08 + 2.13(\log X)$. The $r^2$ value for this model was 0.87. This result, involving a relationship between number of shoots and diameter increment, would seem to be analogous to that obtained with dbh and number of shoots per tree.

We have selected the single parameter, dbh, as an estimator of the total number of shoots per tree in our studies of shoot moth population dynamics. Although improvements in fit can be made by including additional measured parameters, we concluded that the degree of improvement attained did not warrant the additional time, cost and effort involved in obtaining those measurements. Diameter at breast height is easily and quickly measured and thus allows valid estimates to be made for total shoot number of a large number of trees.
Fig. 1 The relationship of total number of shoots per tree and dbh in trees from six even-aged red pine plantations in central Wisconsin.

$logY = -13.7W + 152X
R^2 = 0.70$

Fig. 2. The relationship of total number of shoots on a branch and branch diameter in trees from six even-aged red pine plantations in central Wisconsin; curve is derived from 2254 data points.

$logY = -4.28 + 2.13\log X
R^2 = 0.87$

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LITERATURE CITED


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